National Rural Infrastructure Development Agency
Ministry of Rural Development
Government of India

सत्यमेव जयते

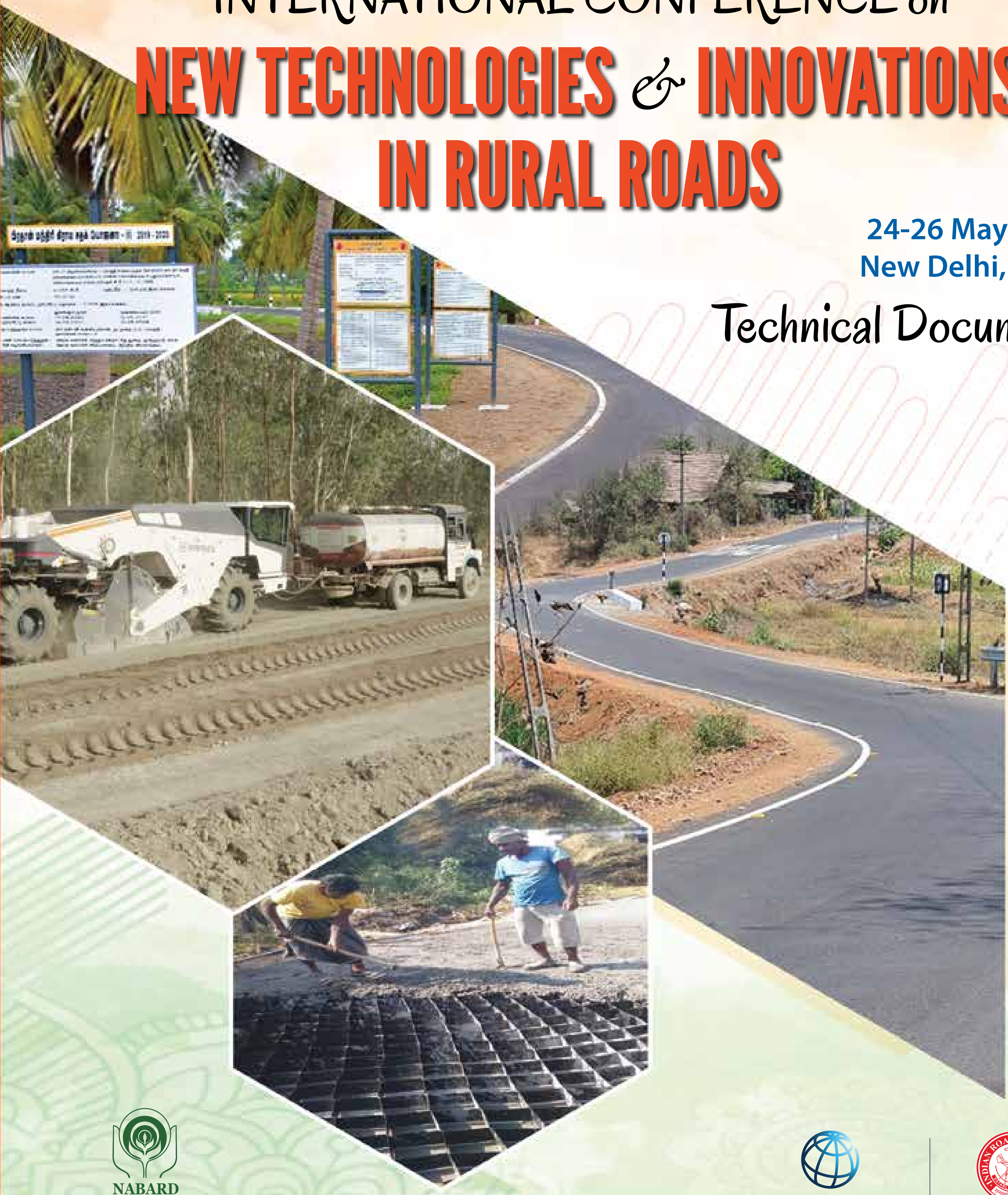
Azadi Ka Amrit Mahotsav

Pradhan Mantri Gram Sadak Yojana

INTERNATIONAL CONFERENCE on NEW TECHNOLOGIES & INNOVATIONS IN RURAL ROADS

24-26 May 2022
New Delhi, India

Technical Document



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Azadi Ka Amrit Mahotsav

India's 1st Technology Development Board, Department of Science & Technology, Government of India funded Venture in Road Sector

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  - (1) RS1, RS2, SS1, SS2, Ideal for Tack Coat Applications, Fog Seal etc .
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**Ref to TERI Report on "Life Cycle Assessment of Hot Mix and Cold Mix Technologies for Construction and Maintenance of Rural Roads prepared for NRRDA, 2016"*

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गिरिराज सिंह
GIRIRAJ SINGH

ग्रामीण विकास तथा पंचायती राज मंत्री
भारत सरकार
कृषि भवन, नई दिल्ली
MINISTER OF
RURAL DEVELOPMENT AND PANCHAYATI RAJ
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI

MESSAGE

I receive great pleasure in learning that under the inspiration of our Hon'ble Prime Minister Shri Narendra Modi, the Ministry of Rural Development, Government of India, is organizing an international conference on "New Technologies and Innovations in Rural Roads" from 24 - 26 May 2022, at Pragati Maidan, New Delhi. The conference will be of value to engineers, research scholars, engineering students, field implementers, construction agencies, academicians, administrators, consultants, and other stakeholders involved in the design and construction of rural roads across the globe. The conference provides an ideal opportunity for intensive interaction and deliberation on the various themes, such as Resilient & Sustainable Rural Roads Infrastructure - Lowering Carbon Footprint, Transforming Rural Economy through Access - Enhancing Integration & Inclusivity, and Management & Maintenance of Rural Roads - Effective Governance Framework. It is hoped that the papers, discussions, and interactions during the conference will help shed light on a diverse set of viewpoints and issues related to the successful adoption of new technologies and innovations in rural roads.

My warmest wishes to all conference attendees for making the most of this opportunity and for the conference to be a huge success.

Shri Giriraj Singh
Union Minister
Rural Development & Panchayati Raj

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साध्वी निरंजन ज्योति
SADHVI NIRANJAN JYOTI

उपभोक्ता मामले,
खाद्य और सार्वजनिक वितरण एवं
ग्रामीण विकास राज्य मंत्री
भारत सरकार
MINISTER OF STATE FOR
CONSUMER AFFAIRS, FOOD AND PUBLIC DISTRIBUTION &
RURAL DEVELOPMENT
GOVERNMENT OF INDIA

MESSAGE

It gives me immense pleasure to note that the experts from academia, field functionaries, technology providers and policy makers are on a common platform for detailed deliberations in the International Conference on "New Technologies and Innovations in Rural Roads" being held during 24th – 26th May, 2022. The Conference draws the inspiration from the fact that we are moving at a very fast pace in this changing economy and our practices need to keep up with the demands of this changing economy. The main goal of this conference is to innovate and 'break through the impossible' in the field of rural road construction. It is pertinent to state that PMGSY has been a pioneer in the adoption of new and green technologies in construction of rural roads. It is a matter of great satisfaction that Ministry of Rural Development has so far completed more than 70,000 km of roads using new and green technologies under PMGSY which is in fact a remarkable achievement. Major such technologies being used are waste plastics, cold mix, stabilization using chemical or commercial stabilizers, full depth reclamation of existing pavements, cell-filled concrete, panelled cement concrete, etc. The objective is to achieve economy and speed in construction of roads, reduce carbon emission and environment degradation, and provide sustainable roads with reduced maintenance cost.

I hope the conference shall be a useful forum of exchange of knowledge and practices related to new technologies and fruitful amongst participants from India and abroad.

Sadhvi Niranjan Jyoti
Union Minister of State
Rural Development, Consumer Affairs and Food &
Public Distribution

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फग्गन सिंह कुलस्ते
FAGGAN SINGH KULASTE

इस्पात एवं
ग्रामीण विकास राज्य मंत्री
भारत सरकार
उद्योग भवन, नई दिल्ली-110011
MINISTER OF STATE FOR STEEL
AND RURAL DEVELOPMENT
GOVERNMENT OF INDIA
UDYOG BHAWAN, NEW DELHI-110011

MESSAGE

Road infrastructure has a huge multiplier effect in the economy. Along with ease of travel, it also improves ease of doing business. This also gives impetus to the productivity across all sectors. PMGSY has created huge rural infrastructure over the last 20 years and maintenance of such a huge infrastructure is a humongous task to ensure sustainability of the road assets created under the programme. PMGSY has introduced new technologies not only in construction process but also in maintenance of rural roads. I am glad to know that an International Conference on "New Technologies and Innovations in Rural Roads" is being held at Pragati Maidan during 24th – 26th May, 2022 to deliberate adoption of different new and green technologies in construction of rural roads where academicians, experts, government officials, contractors, technology providers from India and abroad are participating. I hope the output of deliberations in the conference will be fruitful and beneficial for the rural roads sector.

My best wishes for smooth and productive deliberations and success of the conference.

Shri Faggan Singh Kulaste
Union Minister of State
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नागेन्द्र नाथ सिन्हा, आई.ए.एस.
सचिव

NAGENDRA NATH SINHA, IAS
Secretary

सत्यमेव जयते

आज़ादी का अमृत महोत्सव

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ग्रामीण विकास विभाग
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May 19, 2022

Message

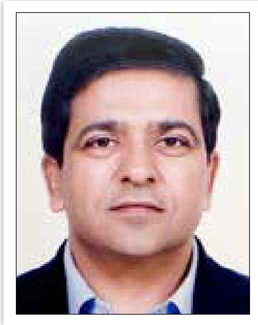
It is my great pleasure to welcome you to the International Conference on "New Technologies and Innovations in Rural Roads" being held at New Delhi. Pradhan Mantri Gram Sadak Yojana (PMGSY) has been a pioneer in the adoption of new and green technologies in construction of rural roads. The Ministry of Rural Development had issued New Technology initiatives Guidelines in 2013 in order to use new/green technologies and locally/marginally available/non-conventional materials in road construction. In this regard, Ministry had mandated that the states should adopt new technologies in at least 15% of the total proposal (10% using IRC mainstreaming technologies and 5% IRC accredited technologies). The objective was to achieve economy and speed in construction of roads, reduce carbon emission and environment degradation, and provide sustainable roads with reduced maintenance cost. Recently, full depth recycling is being adopted in a major way to achieve cost economy and reduction in environmental footprint and conservation of natural resources. Ministry of Rural Development has revised the existing guidelines and has come out with New Technology Vision 2022, to enhance the adoption of new/green technologies in construction of roads being taken up under PMGSY on a large scale.

More than 100,000 Km road length has already been approved for construction using new and green technologies, against which approximately 70,000 km has already been completed as on 31st March 2022. During the last year alone, a total of 19,000 km road length was approved under new and green technologies, which is more than 40% of the total road length approved in the year.

The Ministry of Rural Development is releasing document on "New Technology Vision 2022" with an objective of enhancing the adoption of new technologies in rural road construction on a large scale. This will help in addressing the issues relating to excessive use of natural resources, rapid depletion of aggregates, insufficient durability, poor riding quality and excessive pollution. The International Conference will provide a platform to showcase the latest technologies, new materials, road construction and maintenance machinery and asset management practices. The deliberations that will be held during the conference will be useful to engineers, field implementers, construction agencies, academicians, administrators, consultants and other stakeholders engaged in construction and management of rural roads.

My best wishes to you for illuminating and productive deliberations!

(Nagendra Nath Sinha)



Dr. Ashish Kumar Goel, IAS
Additional Secretary,
Ministry of Rural Development
& Director General, NRIDA
Government of India

FOREWORD

Rural Connectivity is one of the key components in rural development and contributes crucially towards alleviation of poverty. A wide variety of employment and self-employment opportunities arise from the creation and continued existence of good quality all-weather roads. Such roads provide access to economic and social goods and services, thereby generating additional agricultural incomes and productive employment. Improved access to health, education, nutrition and other services and facilities are most cost-effectively delivered by developing good quality transport access through all-weather roads.

With the objective of providing rural connectivity, the Government of India had launched Pradhan Mantri Gram Sadak Yojana (PMGSY) (referred as PMGSY-I) on 25th December 2000 to provide all-weather access to eligible unconnected habitations with a population 500 persons and above (as per the 2001 census) in plain areas and 250 and above in hills and other special areas. The Scheme had also an element of upgradation of existing rural roads in districts where all the eligible habitations of the designated population size have been saturated with all-weather road connectivity, though this objective was not central to the Programme. In the year 2013, the Government decided to also cover unconnected habitations with population of 100 persons and above in Left Wing Extremism (LWE) affected block (identified in consultation with Ministry of Home Affairs) under the scheme.

All the projects under PMGSY-I have been sanctioned. In 250+ and 500+ population category, 99.23% eligible and feasible habitations have already been connected. In the 100-249 population category in LWE areas, 95% habitations have already been connected. A total of 6,45,590 km road works and 7,515 bridges have been sanctioned under PMGSY-I, against which 6,16,337 km road length and 6,100 bridges stand completed and 14,140 km road length and 1,415 bridges are presently under execution. The scheme is slated for completion in September, 2022.

The Government subsequently widened the ambit of the programme and in the year 2013, a new intervention namely PMGSY-II was started with a target to upgrade 50,000 km of the existing rural road network to improve its overall efficiency as a provider of transportation services for people, goods and services. All the sanctions under PMGSY-II have already been given to the states/UTs. In all, 49,885 km of road length and 765 bridges have been sanctioned under PMGSY-II, of which 47,314 km road length and 612 bridges stand completed and balance 2,091 km road length and 153 bridges are under execution. The sunset date for PMGSY-II is September, 2022.

Subsequently, the Government as part of its multi-pronged strategy to address the LWE problem in an effective manner, launched Road Connectivity Project for Left Wing Extremism Affected Areas (RCPLWEA) in the year 2016 as a separate vertical under PMGSY, to improve the road connectivity in 44 districts in the 9 States to ensure socio-economic development of the area. A total of 11,303 km road works and 593 bridges have been sanctioned under this vertical, of which 6,000 km road length and 166 bridges stand completed. The scheme has sunset date of March, 2023.

The implementation of the ongoing PMGSY-I, as also the new connectivity schemes by the states under their own programmes has helped immensely in improving rural connectivity. The Government in order to improve the connectivity status further to facilitate easy and faster movement to and from various services and facilities, approved PMGSY-III in the year 2019, for consolidation of 1,25,000 km Through Routes and Major Rural Links connecting habitations to Rural Agricultural Markets, Higher Secondary Schools, Hospitals and other socio-economic services.

The prioritization of roads to be covered under the scheme was a humongous task, as 1,25,000 km of road length was to be selected out of India's 4 million km rural road network which best meet policy objectives of access to schools, hospitals and markets. For this process, over 2.5 million km of road length and 1 million habitations were mapped and digitized on GIS through inhouse efforts of NRIDA/Ministry. This GIS database has been released in public domain in February, 2022. This unique dataset is a public good of national importance and can revolutionize travel & commerce, increase innovation and research, and can bridge the gap between urban and rural India and will help in boosting the rural economy based on recent data sharing policy of the Government of India. This has potential to create new services for businesses and citizens and give a boost to the rural economy. The dataset will also be helpful in achieving objectives determined under Prime Minister's Gati Shakti project. The respective state governments can also utilize this data for formulating schemes related to rural development.

Under PMGS-III, against allocated target of 1,25,000 km, 83,867 km road length has been sanctioned to 17 states, out of which 37,244 km stands completed. The implementation period of PMGSY-III is upto March, 2025.

The PMGSY has been pioneer in use of new and green technologies in construction of rural roads. The Government in the year 2013 mandated construction of minimum 15% road length using new technologies and locally available materials. The objective was to achieve economy in construction of roads, reduce carbon emissions, provide sustainable roads with reduced maintenance cost and to accelerate the progress of works. More than 1,11,000 km road length has been sanctioned under the scheme for construction using new and green technologies, against which approximately 70,000 km road length has already been completed. During the year 2021-22, a total of 28,257 km road length has been sanctioned, out of which 15,924 km road length has been sanctioned under new and green technology, which is more than 50% of the total road length sanctioned.

In order to implement the research outcomes on new and green technology in construction of rural roads under the scheme, the Ministry is releasing New Technology Vision 2022, wherein it is proposed to enhance the adoption of new/ green technology in construction of rural roads substantially.

The scheme places high emphasis on quality. There is a well-structured three tier Quality Assurance Mechanism for ensuring construction of quality road works and durability of road assets. The first two tiers of the structure are the responsibility of the respective State Governments and under the third tier, independent National Quality Monitors (NQMs) are deployed for random inspections of road works under the programme to monitor quality and also to provide guidance to the field functionaries. The Government has been introducing innovative measures to enhance the quality of road construction. As a result of various innovative measures taken, the proportion of satisfactory works is increasing over the last few years; it was 91.47% in 2019-20, 93.55% in 2020-21 and 95.41% in 2021-22.

The maintenance of roads constructed under the programme is the responsibility of the State Governments. All road works are covered by initial five year maintenance contracts to be entered into along with the construction contract, with the same contractor. The maintenance funds to service the contract are required to be budgeted by the State Governments and placed at the disposal of the Nodal Executing Agency. As a measure of enhancing the focus on maintenance of roads during the defect liability period (five years from the date of completion of road) and streamlining the delivery of routine maintenance of PMGSY roads on the basis of performance based maintenance contract, Electronic Maintenance of PMGSY roads (eMARG) has been implemented in all the states, which is an online platform, used by all the states, that monitors maintenance of PMGSY works for five years from the date of completion.

All the states are on board eMARG, and a total amount of Rs. 1,396.25 crore has been released as maintenance-related payments through eMARG over the last three financial years. As a result of increased focus on maintenance, the maintenance expenditure by the states during defect liability period is increasing since 2019-20. It was Rs. 824.70 crore in 2019-20, Rs. 967.70 crore in 2020-21 and Rs. 1,015.75 crore in 2021-22.

A number of evaluation studies have been carried out by independent agencies, including ILO and World Bank focusing on various aspects of PMGSY and their impact. All these studies have concluded that the scheme has impacted agriculture, health, education, urbanization and employment generation sector in a big way. The World Bank in its report of 2018 concluded, inter-alia, that PMGSY roads yielded 8% increase in share of crops transported to markets for sale. Farmers selling food grains travelled 7.2 to 9.8 km farther after the PMGSY roads were built, for higher price of crops. As a consequence of PMGSY roads, rate of primary employment in non-farm sector increased by about 13%. Share of people with primary employment outside their habitation increased by 8%. Share of babies delivered at home decreased by 30% in connected habitations.

The NITI Aayog in its report for the period 2015-16 to 2018-19, submitted to Government in 2020 concluded inter-alia, that PMGSY is well aligned with India's international priorities and is seen to contribute to Sustainable Development Goals 1, 2 & 9 as it address the issues of poverty, hunger and infrastructure for growth.

The International Conference on 'New Technologies and Innovations in Rural Roads' has been organized to deliberate on ways to strengthen and adopt emerging new technologies, new materials, and adoption of established technologies, though beneficial but yet not prevalent in the Indian context. I am hopeful that all the stakeholders and participants will benefit from deliberations.

I acknowledge the contributions and suggestions of Shri Deepak Ashish Kaul, Director (F&A), Shri B.C. Pradhan, Consultant Director (Technical), Dr. I.K. Pateriya, Director P-III, Shri Pradeep Agrawal, Director P-I, Shri Devinder Kumar, Director (P-II), Shri P. Mohansundram, Joint Director (P-II), Shri Satyendra Prasad, Joint Director (Technical), Shri Ashish Srivastava, Joint Director (Technical), Shri Sunil Kumar, Joint Director (P-III), Shri Navneet Kumar, Joint Director (P-I), Dr. Pradeep Kumar, Deputy Director (F&A), Shri Kailash Bisht, Deputy Director (F&A), Shri Rakesh Kumar, Deputy Director (P-III), all Assistant Directors of NRIDA and all Young Civil Engineers, for this International Conference.

I acknowledge the immense contribution made by Dr. A. Veeraragavan, Professor, IIT Madras, Dr. Sudhakar Reddy, Professor, IIT Kharagpur, Dr. Praveen Kumar, Professor, IIT Roorkee, Dr. U.C. Sahoo, Professor, IIT Bhubaneshwar, Dr. B. Krishna Prapoorna, Professor, IIT Tirupati, Shri Guru Vittal, Chief Scientist, CRRI in organizing this Conference.

I acknowledge the continuous and sincere efforts of Indian Road Congress in organizing this Conference successfully. The contribution of our knowledge partners, IIT Madras, IIT Kharagpur, IIT Bhubaneshwar, IIT, Roorkee, IIT BHU, IIT Hyderabad, IIT Tirupati, NIT Warangal and SVNIT, Surat every stage of the conference is also highly acknowledged.

I am thankful to the World Bank and especially Dr. Reenu Aneja for extending whole hearted support including financial assistance for organization of this Conference. The World Bank has been instrumental in providing technical support and they have been our long standing partner in PMGSY.

The financial assistance received from Research and Development fund of National Bank for Agriculture and Rural Development (NABARD) towards publication of journal/printing of proceedings of the conference is gratefully acknowledged.

Finally, I am grateful to Hon'ble Minister, Rural Development, Shri Giriraj Singh for his tremendous encouragement and mentorship for adoption of new technologies in PMGSY. I am thankful to Hon'ble Ministers of State, Rural Development Sadhvi Niranjan Jyoti and Shri Faggan Singh Kulaste for their constant guidance. I am indebted to Shri Nagendra Nath Sinha, Secretary, Ministry of Rural Development for his invaluable support in developing a vision and strategy for adoption of new technologies and innovative approaches in PMGSY and overall guidance in organizing this Conference.

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5	Shri Anand Kapur, AD	NRIDA	Member
6	Shri D. Sam Singh, DS(A)	IRC	Member
7	Shri Ajay Kumar, SO (Admn.)	IRC	Member
8	Shri Rajneesh Katoch, ASO	IRC	Member

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5	Shri Jitender Jha AD	NRIDA	Member
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7	Shri Mukesh Dubey, SO (Cash)	IRC	Member
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Use of Alternate Technologies and Materials in the Construction of Low Volume Rural Roads

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Abstract

Worldwide, many millions of kilometers of rural unpaved road and earth tracks require upgrading to a low volume road paved standard to afford the communities in these areas good all-weather accessibility for minimal road user costs. However, using traditional pavement design technologies that were mostly developed for conventional higher volume roads is neither cost-effective nor environmentally sustainable. This paper discusses a simple alternative pavement design technology that makes optimum use of locally available materials and means of improving such materials when they are of inadequate quality. The use of by-product materials and their benefits and problems is also briefly discussed.

1. Introduction

Worldwide, many countries have substantial rural road networks consisting of earth or graveled roads. These are often poorly designed and maintained, subjected to extreme weather conditions and heavily trafficked, resulting in impassable conditions and poor access during inclement weather. This leads to unacceptable social conditions (e.g., loss of access to schools and health facilities), loss of income and access to markets and reduced economic development opportunities.

However, the cost of upgrading these roads to a paved standard using conventional designs generally makes improvement of the roads untenable. As a result, a simplified design method for rural low volume roads has been developed that maximizes the use of locally available materials, minimizes the use of imported materials and promotes sustainability with the added inclusion of optimizing climate resilience. As the pavement designs are not overly conservative, more attention to their inputs and analysis is required than for the generally more conservative traditional designs and a good understanding of the process, materials and construction and maintenance is required from the design engineer.

This brief paper summarizes some of the fundamental concepts involved and identifies areas where significant savings may be derived.

2. Background

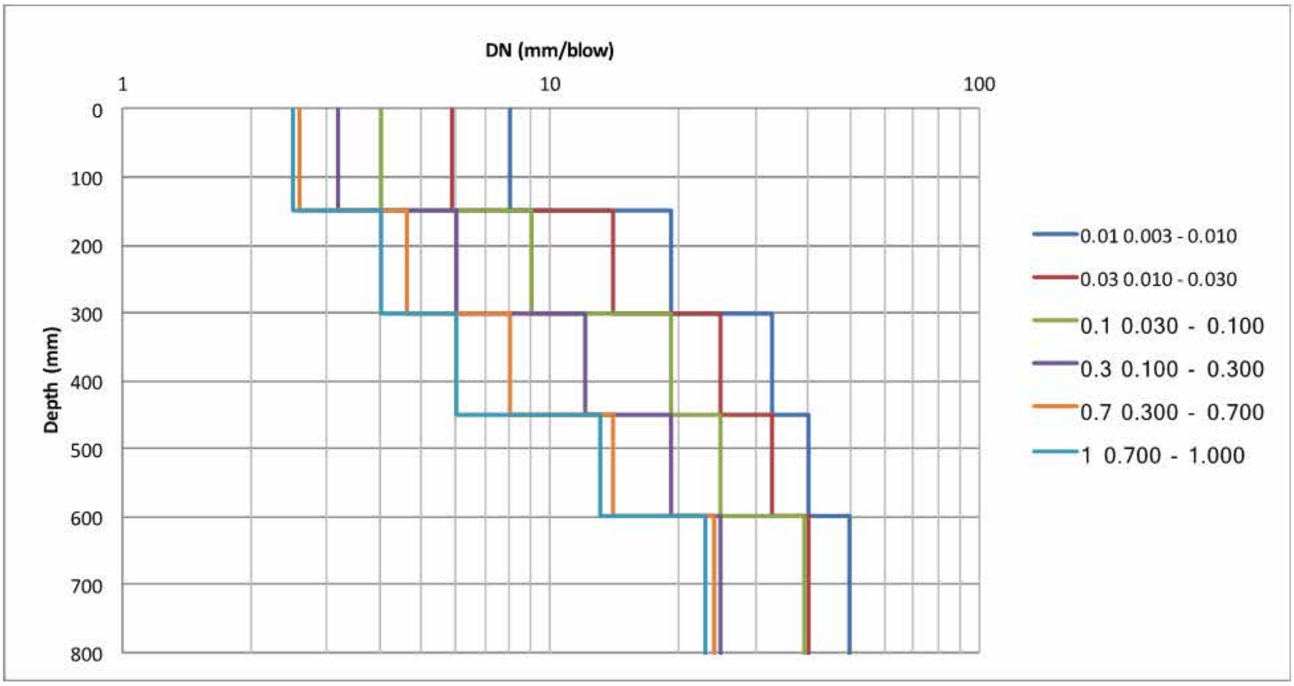
The design philosophy discussed in this paper follows ongoing research and investigations covering more than four decades in southern Africa and is based on accepted scientific principles and full-scale and accelerated pavement monitoring as fully discussed in Paige-Green and van Zyl (2019).

The design method uses the Dynamic Cone Penetrometer (DCP) which is a good proxy for measuring the in-situ shear strength of materials at the test point, typically to a depth of at least 800 mm. The number of

DCP blows required to achieve this depth is the DCP structural number (DSN_{800}). The measured strength is at the in-situ moisture and density conditions, and these need to be taken into account in the design process. DCP testing allows many tests to be carried out quickly with minimal disturbance of the actual road surface. From this data, sections with similar characteristics can easily be identified and the road under investigation can be subdivided into uniform sections. The fundamental concept of an Environmentally Optimized Design (EOD) is an integral component of the design method.

Each section can then be designed according to the required structural needs. These have been developed for various traffic categories in the form of layer strength diagrams (LSD) which show a plot of the required DCP strength or DN (mm/blow) with depth for different traffic (standard axle) categories (Figure 1). Each diagram has been derived to provide a well-balanced deep pavement structure (Paige-Green and van Zyl, 2019) and is developed on the basis of the DCP structural number (DSN_{800}).

Figure 1: Standard Layer strength diagrams



In addition to using the DCP as a basis for design, the test is also used for material characterization in the laboratory as discussed briefly below, and in more detail in another presentation at this Conference (Pinard, 2022), as well as for construction quality control.

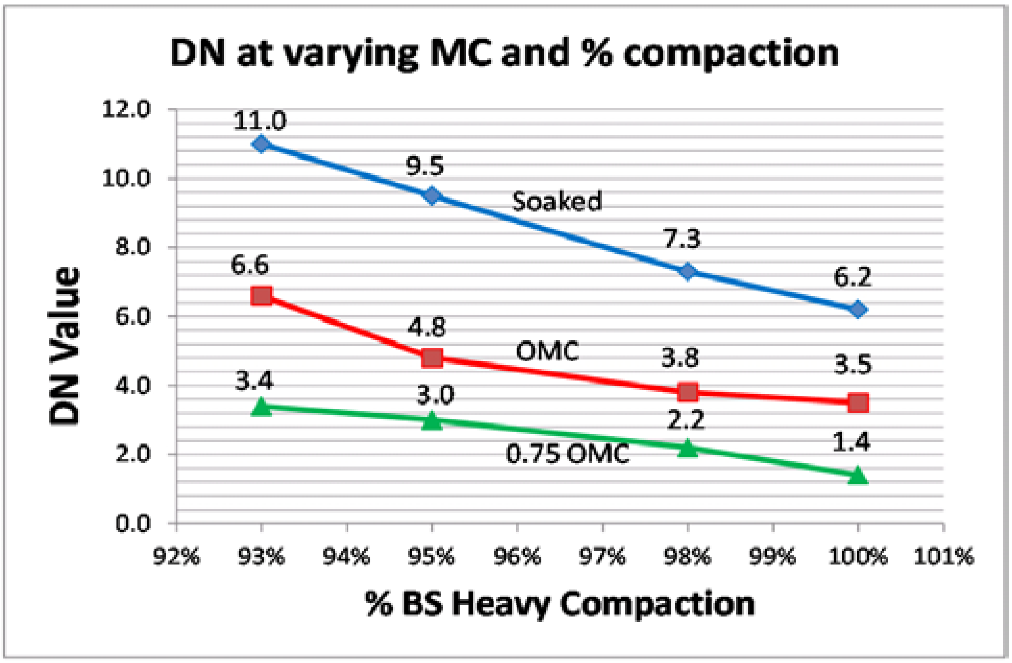
3. Alternative Technologies

Although some basic testing of the in situ and potential borrow materials is required (Pinard et. al, 2021), this is only to ensure that the materials in the existing road are fundamentally suitable for use. The entire pavement design is conducted using the DCP test results. Based on the preliminary routine tests, problem materials such as expansive or soft clays, dispersive, saline or collapsible soils need to be identified and avoided.

The DCP survey is then carried out with tests being conducted at regular intervals depending on the variability of the in-situ materials. Where the materials are unform over a long distance, tests need only be conducted every 250 or 500 meters. However, where conditions are variable, testing may be required at 100 m intervals or even less where highly variable conditions occur. The main objective of the testing is to obtain at least 10 complete (to a depth of 800 mm) tests in each uniform section to ensure an adequate statistical validity of the analysis. The main benefit of using the DCP over the conventional California Bearing Ratio (CBR) test procedure is that significantly less laboratory testing is necessary and the strength profile over the entire 800 mm depth is obtained as opposed to the normal single CBR test result over a limited depth or, even more disconcerting, using a composite material sample that is not representative of any particular pavement depth.

Once uniform sections are identified, it is still necessary to obtain representative samples of the materials that will be used in each potential pavement layer for laboratory testing and analysis. It is also necessary to determine the prevailing moisture contents in the materials at the time of DCP testing. Laboratory testing includes a series of DCP tests in conventionally compacted CBR molds at various moisture and density combinations to allow an understanding of the moisture - density-strength relationships (Figure 2). This figure shows both the strength variation with moisture and density changes as well as being indicative of the grading and plasticity of the material. The wider the spread of the curves on the vertical axis, the more moisture sensitive the material is (a function mostly of the plasticity), while the degree of flatness of the curves with a change in compaction effort indicates density sensitivity (a function mainly of the particle size distribution).

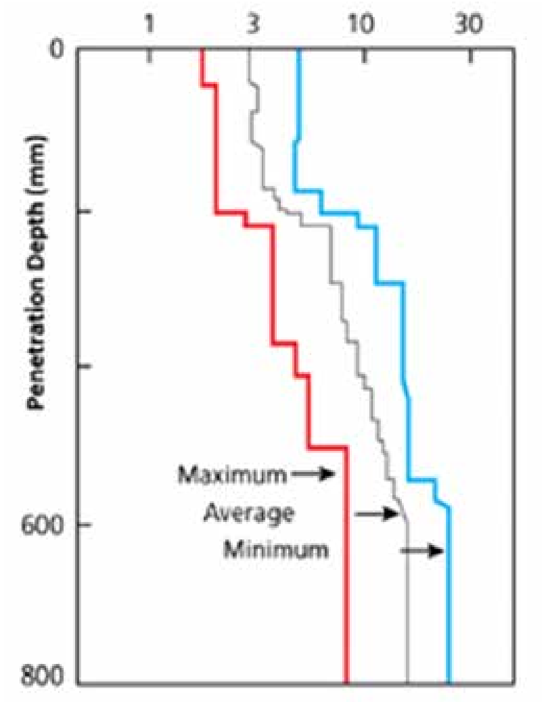
Figure 2: Moisture-density strength relationship



The use of the DCP penetration rate (DN in mm/blow) is preferred to the conventional CBR strength due to the poor repeatability and reproducibility of the CBR test (Rallings, 2014) and to avoid converting the DCP penetration rate to CBR. Research has clearly shown that this relationship is strongly material dependent (Livneh, 2007), and the inaccuracies due to this lack of correlation (for any specific material) can be avoided.

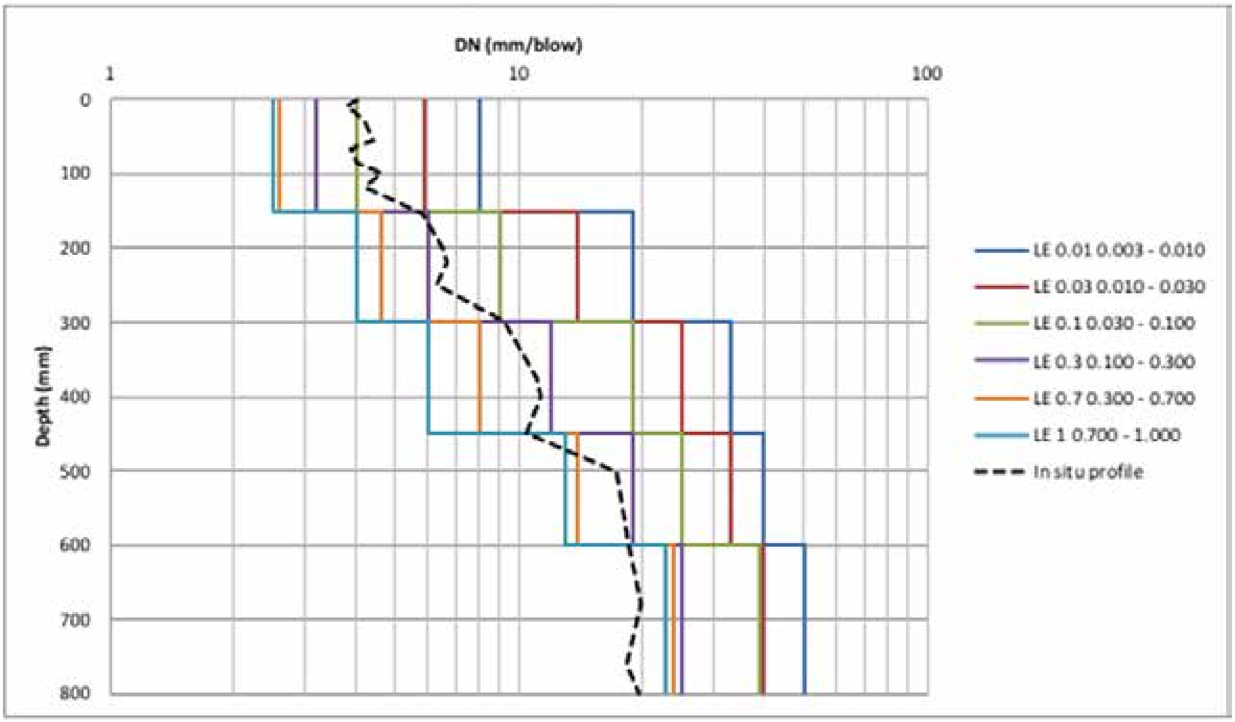
The average plot of the DCP profile for each uniform section will typically appear as shown as the gray trace in Figure 3. The maximum (red trace), minimum (blue trace) or any selected percentile can also be derived.

Figure 3: Typical DCP profile for a uniform section



The design method involves comparing the selected DCP profile for each uniform section with the required layer strength diagram (Paige-Green and van Zyl, 2019), as shown in Figure 4.

Figure 4: Overlay of in situ profile and Layer strength diagrams



It can be seen that where the in situ DCP profile lies to the right of the selected "design curve", the material has insufficient strength and where it is to the left of the design curve, it has adequate strength at the in-situ moisture content. However, moisture contents in the pavement structure may vary with time, and the material would weaken if the moisture content increases. This is handled by the use of Figure 2, where the impact of the operating moisture environment on the material strength can be assessed. It is also required that compaction of any layers accessible during construction be carried out to refusal, without damaging material particles.

Field investigations (Emery, 1981) have shown that the moisture content in pavement layers seldom rise above optimum. moisture content (OMC). An essential part of the DCP design method is stabilizing the moisture regime by incorporating an adequate and effective drainage regime. This includes:

- Higher than normal crossfalls on the carriageway (preferably 3 to 4%) and shoulders (> 5%)
- A minimum height between the crown of the road and the bottom (invert) of the side-drains (depending on climate, terrain, drain lining and traffic but usually about 750 mm),
- Effective movement of water from the side drains away from the road (good smooth grade and effective miter drains (or turnouts)), and
- Regular and effective maintenance of the road surfacing and drainage systems.

Effective maintenance is essential to ensure climate resilience, but in addition, the capacity of all drains must be such that the expected increase in extreme storm events in the future (higher and more intense rainfall due to climate change) is adequately catered for.

All of the calculations and identification of the pavement design and strengthening needs can be simply calculated using the AfCAP DCP design software (Pinard and Hongve, 2020), freely available for download (https://dcp-dn.csir.co.za).

In order to optimize the design and construction costs, appropriate and cost-effective bituminous surfacings should be used. Many of the low volume road pavement structures may be quite flexible and have higher deflections than conventional pavements. The flexibility of the surfacing to absorb and tolerate these deflections is an important consideration. Surfacing options are discussed in a separate paper at this conference (van Zyl, 2020).

There are, of course, some limitations to this design method. It is obviously most suitable where an existing unpaved road will be upgraded to paved standard following mostly the existing alignment and grade. If the road is to be re-aligned significantly or raised on a high embankment (often a necessity in terms of climate resilience adaptation), the method is not totally suitable although aspects of it can be used in the design. These include subgrade evaluation and strength assessment of the proposed materials such that they can comply with the required layer strength diagrams, which are still applicable and appropriate for the upper pavement structure.

The method has been fully detailed in a document specifically for India by the World Bank (World Bank, 2018).

4. Alternative Materials

As discussed above, not all economically available materials are suitable for the pavement layers, particularly the more important structural subbase and base. In such cases, the need for improving these materials arises.

Material improvement can be achieved in several ways, the most appropriate being mechanical or chemical stabilization. It is important to differentiate between modification and stabilization. The former improves the material properties without any marked cementation (i.e., the material remains in a granular state), whilst the latter causes cementation and the development of tensile strength.

4.1. Mechanical stabilization

Mechanical stabilization is a standard construction practice that includes blending of different materials, removal or break-down of oversize material and, obviously, densification. Modern equipment such as bucket-crushers and screeners which attach to conventional excavators allow on site breaking down and screening of materials.

4.2. Chemical stabilization

Chemical stabilization involves adding a product to the material such that bonding between individual particles within the material may occur. This could involve direct bonding (such as with bitumen) or the creation of new bonding products as is the case with lime or cement. The bonding products (cement, lime, bitumen) are well established and not covered in this presentation but is discussed elsewhere at this conference.

There are also numerous modern proprietary soil improvers on the market. Each of these has a particular mechanism of "reaction" and needs to be tested on the proposed material to be treated to ensure that the required material properties are achieved (usually an end-product specification" in terms of strength or stiffness.

In addition, there are numerous materials/chemicals that are combined with cement, lime or bitumen that are being increasingly used for soil improvement. These include nano-polymers in bitumen, which in particular is showing significant success (Jordaan and Steyn, 2021).

4.3. Use of by-product materials

Most countries are littered with the residues from mining, industrial, manufacturing or construction processes. These are all potentially useful construction materials and include (Bandyopadhyay, 2018):

- Crushed concrete
- Aluminum industry wastes
- Construction and demolition waste
- Tires
- Foundry sand
- Cement kiln dust
- Glass
- Pulverized fuel ash (PFA or fly ash)
- Blast-furnace slag
- Steel slag
- Other metallurgical slags
- Mine and stone processing waste
- Spent oil shale
- Reclaimed bituminous material (RA)
- Phosphogypsum
- Used rail ballast

Whilst significant research has been carried out on some of these materials, such as blast furnace slag and construction and demolition waste, many of these products still require additional research. The general behavior of a lot of the materials is similar to conventional aggregates. However, certain materials may have specific problems (e.g., un-hydrated magnesium oxides in blast-furnace slags and soluble salts in mine wastes). Bandyopadhyay (2018) identifies possible uses and some of the potential problems and special requirements of each material. Research is recommended into other materials, where little experience has been gained.

The use of such by-product materials comes with many advantages, including less environmental degradation, release of land used for storage of these materials, reduced processing costs, reduced haulage costs and conservation of existing non-renewable material resources that are becoming more costly and difficult to obtain.

5. Conclusions

In order to reduce the backlog of unpaved roads requiring upgrading to paved standards, innovations and new technologies are essential. This paper discusses a simple design method for low volume roads based on the use of a Dynamic Cone Penetrometer (DCP) survey. A simple comparison of the in-situ soil profile with the structure required to carry the design traffic allows specific pavement designs for each uniform section along the road. The application of this procedure, together with innovative soil improvement techniques and the use of local and/or available by-product materials, can result in highly cost-effective and sustainable road provision. Climate resilience and environmental issues are also briefly introduced.

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उत्तर प्रदेश बन रहा है एक्सप्रेसवे प्रदेश

नये एक्सप्रेसवे के निर्माण से उत्तर प्रदेश तेजी से बढ़ रहा है प्रगति की नई राह पर...

पूर्वांचल एक्सप्रेसवे

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बुन्देलखण्ड एक्सप्रेसवे

14849.09 करोड़ की लागत से 296.07 कि.मी. लम्बे 4 लेन चौड़े बुन्देलखण्ड एक्सप्रेसवे का निर्माण अन्तिम चरण में जिसका लोकार्पण जून 2022 में किया जाना प्रस्तावित।

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New Materials and Technologies for Rural Roads

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Abstract

The total length of roads to be built and maintained to provide connectivity to all the villages in any country is generally very large compared to the network of high volume roads. Hence, any innovation made in the use of materials, layer combinations, construction methods and maintenance and rehabilitation approaches can bring substantial benefits in terms of reduced material usage, longer pavement lives and less frequent maintenance requirements and associated costs. The general frame-work of design of new pavement and overlays in which innovative practices are adopted, is discussed in this note with particular reference to low volume roads constructed using cement concrete. This note covers some broad common issues related to the design and maintenance of low volume roads constructed using short-panel concrete pavements, cell-filled concrete pavement and pre-cast block pavement.

1. Introduction

The pavements of roads, whether expressways/freeways, high traffic volume national highways or village roads carrying low commercial traffic volumes, must be built to satisfy the functional requirements of comfort, safety and economy. While travelling on roads, different parts of the vehicles, drivers and passengers are subjected to three dimensional displacements, velocities and accelerations. This, combined with the interaction of the tyre and road surface, produce wear and tear in tyres and different mechanical components of vehicles. On the other hand, vertical acceleration of the abdominal cavity has been identified (ref) as one of the critical parameters affecting the comfort of persons travelling in vehicles. Discomfort is the highest at or near a frequency of 5 cycles/s. As the vehicles travel along a road, variation in the surface profile (levels) along the paths of the wheels affect the comfort (which is inverse of roughness, a parameter commonly used to quantify the surface condition of the roads).

While the road profile variation and texture of the road surface affect comfort and safety respectively, it is not easy to directly correlate the strengths of the materials used and the layer thicknesses provided with comfort or safety. However, pavement designers attempt to select materials and layers thicknesses and their combinations in such a way that there will not be excessive cracking or permanent deformation in any of the pavements. Formation of cracks or plastic deformations can lead to formation of potholes and/or depressions, uneven deformation leading to variation in surface profile and roughness. Excessive cracks and plastic deformation in different layers can be caused by heavy loads, repetitions of wheel loads, climatic parameters such as temperature and moisture and deterioration of material strength with time. To ensure adequate structural soundness of different pavement layers during the service life of the pavement, it is essential that the wheel loads applied at the surface of the pavement (vertical or horizontal) are distributed through successive layers so that the resulting stress/strain levels in each of the pavement layers are small enough not to cause excess cracking or plastic deformation. For some of the pavement layers/materials such as cement concrete and cement treated base (CTB) layers, fracture is the main issue; for some (subgrade soil and granular layers) it is only the plastic deformation which is the mode of failure. Some of the other layers are susceptible to fracture as well as plastic deformation (bituminous layers, CTB layers after they are fractured).

Innovations in materials, construction, maintenance and rehabilitation techniques generally aim at improving the materials or the composition of pavement structure so that either the stresses/strains in different layers are reduced because of improved mechanical properties of individual layers or improvement in the load spreading mechanism or by controlling the reduction in the strength of materials with time or when subjected to high moisture levels. Innovations are also being made to make the construction or rehabilitation or maintenance faster or more convenient.

2. Innovations in Low-Volume Road Technologies

Over the last one decade, highway agencies in India and other countries have been embracing newer technologies for making the task of building and maintaining low-volume roads economical and more sustainable. A variety of technologies were adopted in the roads being built under the Pradhan Mantri Gram Sadak Yojana (PMGSY). These include: technologies which reduce the moisture susceptibility of different layers materials (so that the strength does not reduce significantly under severe post monsoon condition); chemical stabilization of subgrade and granular layers; use of geo-synthetic materials to improve drainage and strength of granular layers and subgrade; use of improved bituminous surface layers (use of modified binders, waste plastic in dry process, etc); use of cold mixes and adopting different forms of concrete pavement (cell-filled concrete, short-panel concrete pavement, pre-cast concrete block pavement. Compared to conventional method of construction of low-volume roads consisting of subgrade, granular subbase and base surfaced with a thin bituminous layer or a concrete slab, innovative pavements generally improve performance, reduce consumption of materials (especially aggregates) making the projects sustainable.

The following are the key considerations while using new technologies

- Availability of tools for analysis of new forms of pavements
- Identification of critical forms of failures and the layers which fail or contribute to these failures
- Availability of materials
- Ease of construction
- Durability of materials
- Recyclability of materials
- Ease of maintenance and rehabilitation

For the purpose of this presentation, different forms of cement concrete pavement, which can be considered for low volume roads, are discussed briefly. Although these pavements cannot anymore be considered as innovative in the strictest sense, these are pavement types that can be used beneficially for low volume roads. It is necessary to understand the issues critical to the performance of pavements and adequate care should be taken during design, construction and maintenance stage. Failure to appreciate the importance of these critical design and construction considerations may prove to be counter-productive.

3. Cement Concrete Pavements for Low-Volume Roads

Conventional type low volume roads consisting of soil subgrade, granular subbases and base layers and a thin bituminous surfacing and designed as per IRC:SP-72 (2015), generally fail due to excessive plastic deformation in subgrade and/or granular layers. The thin bituminous surfacing does not contribute significantly to the structural strength of the pavement. A poorly constructed bituminous surfacing may undergo durability related distresses such as age hardening of bitumen and the associated brittle cracking. The cracking of bituminous layers is often preceded by plastic deformation (depression) of the underlying layers. Besides traffic loading, variation of moisture in embankment, subgrade and granular layers significantly affect their strength and in turn affect the performance of the pavements. Moisture also severely affects thin recipe bituminous layers which usually have less thickness of bitumen film. Ground water and the surface water ingressing into the pavement layers can cause damage to conventional flexible pavements. Owing to the paucity of funds and other practical difficulties, it is often not possible to provide complete internal and external drainage arrangements in terms of raising the subgrade above high flood level/water level, extending the drainage layer (granular subbase) to full width (daylighting), etc.

It is well known that cement concrete is less susceptible to damage due to moisture compared to the other materials used in pavements. Thus, it is advisable to use cement concrete for the main structural layer in the pavement for project sites with difficult drainage conditions and even for regular climatic conditions. IRC:SP-62 (2014) provides guidelines for design of cement concrete pavements for low volume roads. A contraction joint spacing of 2.5 m to 4.0 m is recommended. It may be noted that the typical transverse and longitudinal joint spacings for high traffic volume concrete pavements considered in IRC:58 (2015) are 4.5 m and 3.5 m respectively. If full depth cracks develop below the contraction joint grooves (cut to one third to one fourth depth of the thickness of the slab), the size of the individual slab is governed by the longitudinal and transverse contraction joint spacing.

For a given size of the slab, as the thickness reduces, the bending stresses increase. Reducing the thickness to low values is not feasible even for low volume traffic conditions. The general experience with designing concrete pavements for village roads is that the thickness of the slab is usually in the range of 170 to 200 mm depending on the design traffic, temperature differential and the foundation provided. Such large slab thicknesses make the concrete pavements compare unfavorably with flexible pavements in terms of initial cost, even though it is known that the life cycle cost of concrete pavement is expected to be less. It is possible to design and build thinner slabs by reducing the size of the slab. As the slab size reduces gradually, the mode of distribution of wheel load by the slab changes from flexural to compressive. For smaller slabs, flexural stresses in the slab will be reduced and the compressive stress on the foundation layers will increase. Similarly, the flexural stresses associated with the temperature gradient within the slab also reduce with reduction in the size of the slab. Thus, reducing the size of the concrete slab is an important for making concrete pavements a more acceptable choice for low volume roads on account of the reduced slab thickness. It is however, to be noted that the total length of joint to be constructed and maintained increases as the slab size is reduced.

Since the main objective of the main structural layer of the pavement (such as the concrete layer) is to distribute the stresses in such a way that the underlying and foundation layers are protected. Since discrete slabs are created in jointed (formed by cutting grooves) concrete pavement due to the cracking of the slab below the groves, the participation of multiple adjacent slabs in sharing the load applied on a slab influences the stress produced in the slab. Since no dowel bars are used in the shorter concrete slab pavements for low volume roads, the transfer of load to adjacent slabs depends on the degree of aggregate interlocking along the cracks which develop at joints below the grooves. Thus, the load transfer across the joints becomes a key design element in jointed pavements, especially when no dowel bars are provided.

Some critical issues related to three different short slab concrete pavements are discussed in the following sections.

3.1. Short-panel concrete pavements

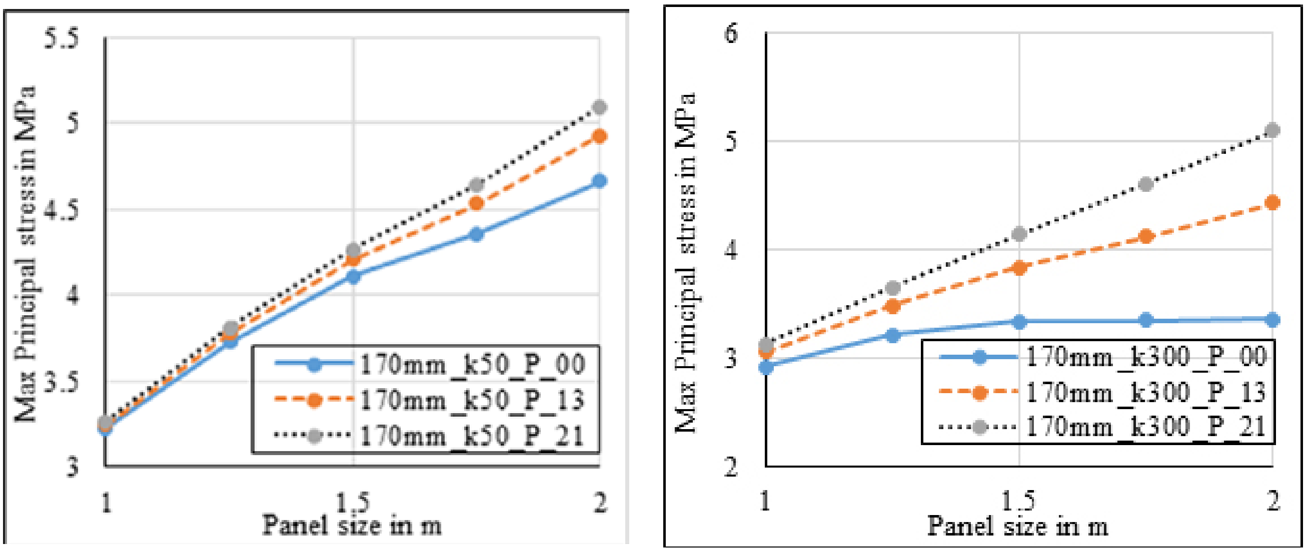
The essential design features of short-panel concrete pavement are noted below. Figure 1 shows a short-panel concrete pavement on a national highway.

- Contraction joint spacing of 1.0 m to 2.0 m.
- Because of the reduced slab size, wheel load bending stress and curling stress (due to temperature differential in the slab) are reduced.
- The critical positions of the axle load on the panel for top-down and bottom-up cracking depend on panel size, carriageway width, axle type and day time and night time.
- Figure 2 shows the variation of edge flexural stress with slab size, foundation strength (k of 50 and 300 MPa/m) and positive (day time) temperature differential (0, 13 and 21°C) in a 170 mm thick slab for 160 kN single axle load. Multi-panel finite element analysis was carried out.
- The magnitude of stress increases with increasing panel size and with increasing temperature differential for the two critical load positions of edge and corner.
- The load transfer efficiency at the joints keeps varying with season as the joints open and close with change in temperature.
- Curling stresses are smaller for smaller panel sizes.

Figure 1: Short-panel concrete pavement on NH-18

The issue that needs special consideration in this type of pavement is that the joint cutting operation must be carefully planned since the total length of joints to be cut is significantly longer than that required for typical highway pavements with longer spacing. Joint sawing must be completed within the joint sawing window of 10-16 hours (from the time the mix is prepared), to avoid random cracking due to shrinkage stresses. If cracks do not form below every joint grove the resulting panel size will be much larger than designed. This may lead to cracking at irregular locations.

Figure 2(a) and (b): Variation of edge flexural stress with the panel size (for a 160 kN single axle load; k = 50 and 300 MPa/; positive temperature differentials of 0, 13 and 21 °C)



3.2. Cell-filled concrete pavement

The cell-filled concrete pavement technology was developed by late Prof BB Pandey and was transferred to different agencies, finally to NRRDA. The development of this technology, illustrated in Figure 3, was based on various laboratory and on-site trials including accelerated testing of cell-filled concrete pavements and subsequently demonstrated through various field sections. The motivation for this technology is to provide thinner concrete pavements by reducing the joint spacing to as small as 150 mm, thereby creating slabs (or blocks) of small size. The reduction in the size of the slab helps in transforming the mode of load transfer to flexure to more of compression resulting in reduced wheel load and curling flexural stresses in concrete. The small joint spacing is created by using a formwork of plastic cells into which concrete is placed. This pavement is, in fact, a cast-in-situ interlocking concrete block pavement.

Figure 3: Cell-filled concrete block pavement

As is the case with short-panel concrete pavement, it is important that the load placed on one block or a set of blocks is shared by some additional adjacent blocks so that the stresses on the underlying layer are reduced. The area of foundation over which the load is distributed in a cell-filled concrete block pavement depends on the interlocking created between adjacent blocks. Blocks with vertical faces do not have any interlocking and hence there will be no transfer between blocks. Hence, it is most crucial for the success of the cell-filled concrete pavements, to create interlocking between the blocks. This is done by selecting the stiffness of the plastic sheet used to prepare the plastic cell formwork within a suitable range so that the walls do not collapse while placing the concrete but bend enough to form irregular vertical faces and thereby generate aggregate interlocking. If too stiff plastic sheet is used and the blocks form with vertical faces, there will not be any significant load distribution of the cell-filled concrete layer.

The main mode of failure of this type of pavement will be the permanent deformation of the foundation. The structural design of the pavement can be done by considering the rutting performance criteria used in the Indian Roads Congress guidelines for flexible pavements (IRC:37, 2018) with an appropriate reliability level. An effective elastic modulus of 2000 MPa is recommended for the cell-filled concrete layer.

3.3. Interlocking concrete block pavements

Interlocking concrete block pavements (ICBP) have been used in India and other countries for several decades. Its design and construction is covered by IRC:SP-63 (2018). The only issue that needs to be highlighted, which is relevant to the current discussion is the layer of blocks should be capable of distributing the load over wider area so that the stresses over the foundation layers are reduced to acceptable levels. Hence, it is necessary that there has to be some interlocking mechanism between adjacent blocks of the ICBP layer. The interlocking in a properly designed and constructed is mobilised by the dilating action of the jointing sand placed in the joint gaps between blocks. The sand particles dilate when subjected to shear resulting in application of lateral force on the faces of the blocks. Optimal mobilisation of the interlocking mechanism of interlocking can be achieved by strictly adhering to the joint gap, gradation of jointing sand and the gradation of the bedding sand specified by IRC:SP-63 (2018).

4. Concluding Remarks

This note covered some broad issues to be considered while adopting innovative materials and technologies for low volume rural roads and highlighted the special precautions to be taken for the successful implementation of three technologies which can be beneficially used for low volume roads.

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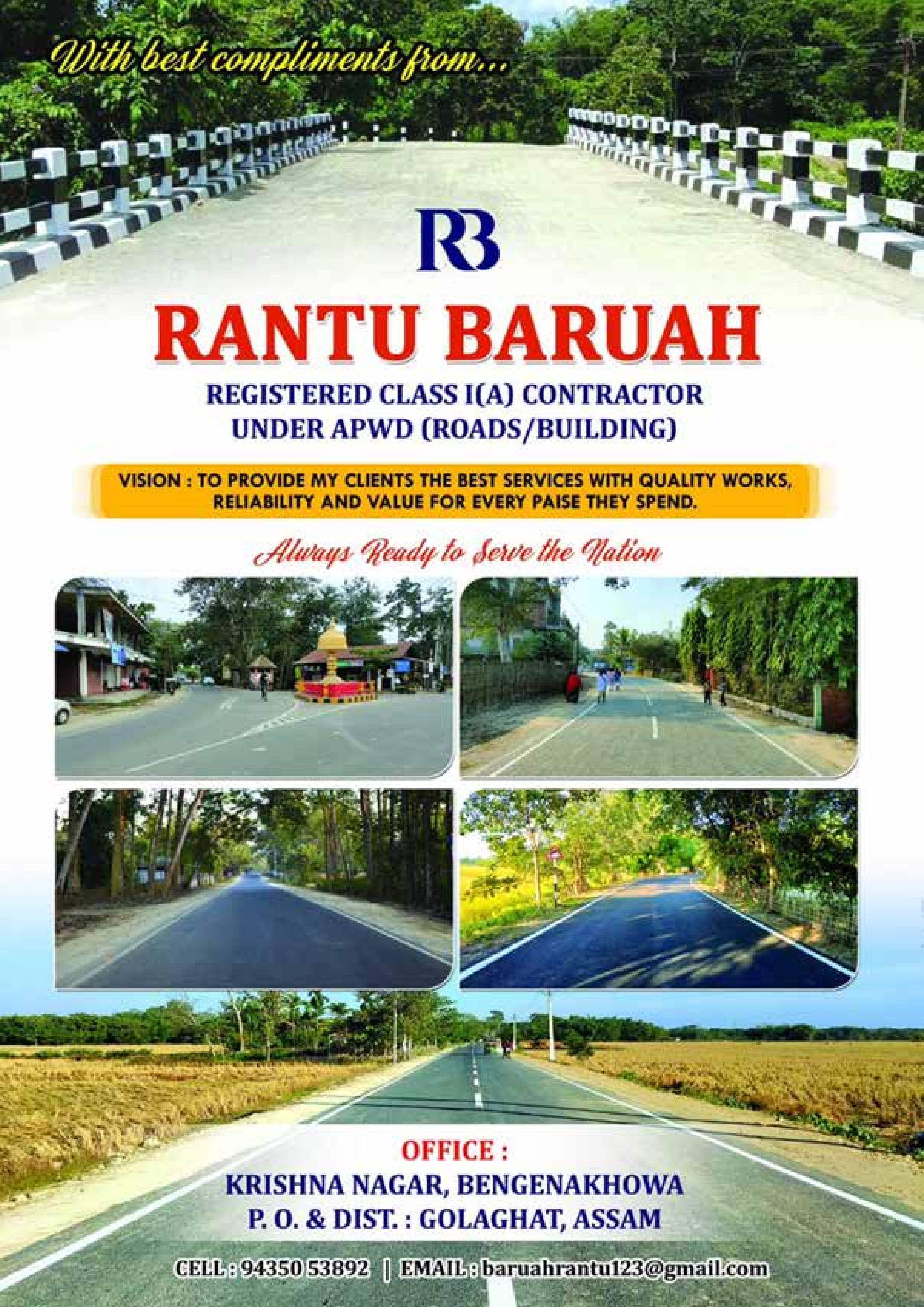
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Cement Treated Bases for Development of Cost-Effective Rural Roads

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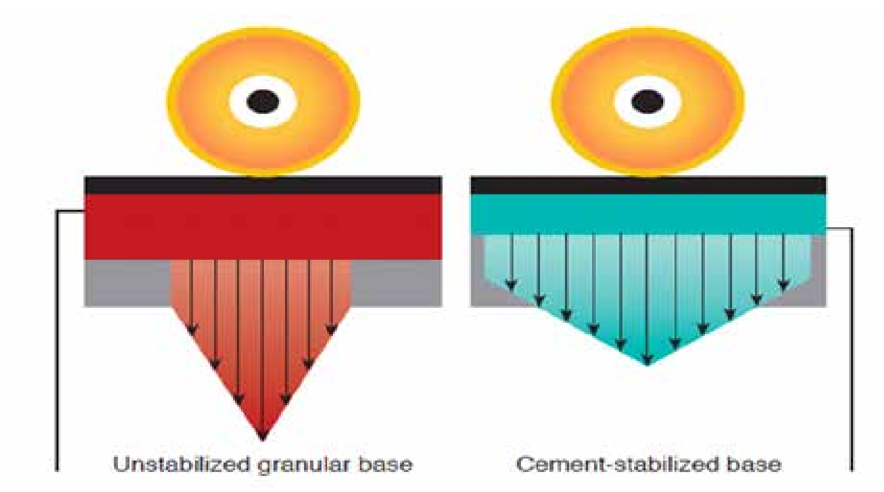
Abstract

To address the scarcity of good quality crushed stones, use of cement treated bases (CTB) are increasing as a sustainable measure. Chemical stabilizers such as cement, lime and other commercial stabilizers are being successfully used to stabilize different soils and marginal aggregates to result in enhanced strength, stiffness and durability characteristics making the material suitable for use in pavement structure. Proper mix design targeting the strength and durability requirements should be done before construction. Construction of CTB layers using mechanised methods are preferred for better performance. Quality control and quality assurance of the CTB construction is equally important for satisfactory performance of such layers.

1. Introduction

Figure 1: Stress Distribution in Pavements with CTB



Huge network of roads are presently being developed in India under different highway development projects including the most ambitious rural connectivity programme PMGSY. However, the non-availability of good quality stone aggregates within a reasonable distance is creating hindrance in sustainable development of road infrastructure in the country. In addition to the scarcity of aggregates, strict environmental regulations have also restricted further expansion of existing stone quarries in developing countries. This has necessitated the use of marginal materials in pavement structural layers through suitable stabilization technique for construction of cement stabilized base or CTB layer. The CTB layer provides better load dispersing behaviour than the unbound granular layer as shown in Figure 1. Chemical stabilizers such as cement, lime, and various commercial stabilizers have been successfully used to stabilize different soils and marginal aggregates that resulted in enhanced strength, stiffness, durability and workability characteristics, making the material suitable for use in pavement structure.

CTB is in use for a long time in many developed countries like USA, China, Australia, Brazil and South Africa. Further, in some countries like South Africa, it is one of the most preferred option, taking into account the benefits of its performance throughout the life of pavements.

2. Materials for CTB Layer

Soil-cement is a generic term that is used to represent cement-treated base, cement-stabilized soil, and cement-stabilized aggregate base are alternative terms used to represent soil-cement (PCA, 1995). However, regardless of the terminology, the principle of working remains the same. The soil material in soil-cement can be almost any combination of sand, silt, clay, and gravel or crushed stone. Local granular materials (such as moorum, kankar and gravel etc.) plus a wide variety of waste materials (such as fly ash, slag and quarry waste etc.) can be used to make soil-cement. In soil-cement, the soil material is mixed with desired amount of Portland cement/cementitious material, water, additives (if any) and compacted to high density. As the cement hydrates, the mixture becomes a hard and durable paving material. Also, old granular-base roads, with or without their bituminous surfaces, can be recycled to make a good soil-cement layer, which is known as full depth recycling (FDR).

3. Strength and Stiffness of CTB

Stabilized materials or bound materials are usually characterized by their ability to sustain tensile stresses as these materials fail under tension. Tensile strength can be assessed using direct tensile strength, indirect tensile strength (IDT) or flexural strength (FS) tests to characterize the stabilized soils. Four point bending test is the preferred test method to determine the modulus of the materials as the test conditions better simulate the stress or strain gradients developed in a bound layer of a pavement (Wen et al., 2014; Austroads, 2012). However, due to simplicity of the test procedure, UCS is widely used as a criterion for examining the suitability of bound material in pavements. The default value of modulus of rupture (MOR) for CTB is taken as 0.69 MPa, which corresponds to a minimum 28 days UCS value of 5.17 MPa (NCHRP, 2004). IRC:SP:72 (2015) recommends a minimum UCS of 1.76 MPa for subbase and 3.0 MPa for base layer for application in rural roads.

Elastic modulus of stabilized materials is an important parameter required for layered elastic analysis of pavements and determination of stresses and strains at critical locations. As the laboratory determination of elastic modulus is a tedious process, generally UCS of stabilized materials is used to predict the moduli values of cemented materials. The elastic modulus (in MPa) has been found to be 1000 to 1250 times the UCS value (in MPa) after 28 days of curing (Austroads, 2012; NCHRP, 2004). IRC: 37 (2018) recommends to use 1000 as the multiplying factor for estimating the modulus of cement treated base layers.

4. Durability of CTB Layer

Durability can be defined as the ability of any material to retain stability and integrity over a number of years of exposure to the action of weathering. Though, UCS is one of the most important parameters used to assess the suitability of CTB layers, most importantly, their performance depends the durability properties (Paige-Green, 1998). The standard durability test specifications used in USA, Australia and India are wetting-drying (W-D) or freezing-thawing (F-T) brushing test, which was proposed by Portland Cement Association (PCA, 1971). Wetting-drying has been found to have a more detrimental impact on the strength of the road base material than freezing-thawing (F-T). The W-D brushing test consist of 12 cycles of wetting, drying and brushing of the samples. Mass loss after 12 cycles of W-D test is used as a design criteria for stabilized materials towards durability consideration. It also takes into account the carbonation durability. Table 1 presents the allowable mass loss for different types of soils to be used for CTB construction.

Though W-D test is one of the widely used durability tests, the main disadvantage associated with this test is that it takes more than a month to complete the test. Due to this reason, many researchers tried to establish a minimum UCS value that ensures durability of stabilized materials. In a study by Portland Cement Association (PCA, 1995), 20% of the cement stabilized samples with a compressive strength 300 psi (2.07 MPa) passed the freezing and thawing test and 70% of samples with compressive strength of 500 psi (3.45 MPa) passed the same test requirement. Zhang and Tao (2008) studied the durability of silty clay soil and reported that a minimum 7 day UCS of 2.2 MPa satisfies the durability requirement as per PCA (1995) criteria.

Table 1: Permissible mass loss in W-D durability test (PCA, 1971)

AASHTO Soil Group	Unified Soil Group	Allowable Mass Loss (%)
A-1	GW, GP, GM, SW, SP, SM	14
A-2	GP, GM, SC, SM	14
A-3	SP	14
A-4	CL, ML	10
A-5	ML, MH, CH	10
A-6	CL, CH	7
A-7	OH, MH, CH	7

5. Construction of CTB Layer

Construction of CTB layer may be dome using the mix prepared at a plant or with the help of mix-in-place method. In-situ stabilization process is usually preferred, which involves several steps such as preparation of the ground, spreading of stabilizer, pulverisation and mixing, compaction and curing etc. Spreading the stabilizing agent at the required dosage may be done manually or using a spreading machine. Pulverisation and mixing (Figure 2) should be done using a stabilizing equipment or a rotavator. Uniformity of the mix should be ensured before compaction, which is carried out in two stages, i.e. initial compaction using a spread foot roller and final compaction using a vibratory roller. Finally, curing of the compacted layer should be done for a minimum period of 7 days.

Figure 2: Mixing during construction of CTB layer

As the CTB layer is prone to shrinkage or fatigue cracking, it is advised to provide a stress relief layer usually in the form of an unbound aggregate interlayer, SAMI (Stress Absorbent Membrane Interlayer) or a geotextile fabric between the CTB and surfacing layer to control the reflection cracking.

6. Quality Control and Evaluation of CTB Layer

Field Testing for quality control during construction should include checks for pulverization, uniformity in mixing, cement content, water content and density. After the layer is constructed, its stiffness and strength may be evaluated using different non-destructive and partially destructive methods. For stiffness evaluation, equipment such as Falling Weight Deflectometer (FWD), Light Weight Deflectometer (LWD) and Soil Stiffness Gauge (SSG) etc. may be used, whereas for strength, cores should be taken out from the layer for testing.

7. Conclusions

For sustainable development of road infrastructure, there is a need to save the limited natural resources. Stabilization of the soil and/or aggregates using cementitious materials for replacing the granular layers is a common ecofriendly practice in most of the countries to save the natural resources. Almost all types of soils/ materials can be stabilized, however a proper mix design is essential. Quality control tests at regular interval are also equally important for successful implementation of the technology. Properly executed pavements with CTB layers usually result in lower life cycle cost and help in construction of cost-effective rural roads using marginal materials.

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Full Depth Reclamation Using Portland Cement

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Abstract

Full depth recycling or Full depth reclamation (FDR) has been successfully adopted as a road rehabilitation technique in many countries. FDR process is employed for constructing economical and long lasting new pavements by recycling highly distressed flexible pavements. FDR can be defined as "a pavement rehabilitation and up-gradation technique where in bituminous and underlying granular pavement layers of predetermined thickness are excavated, pulverised and blended with a binder and compacted; to act as a bound or hardened base course of the new pavement". Even though different pavement layers of existing pavement are recycled, they are mixed well along with binder and recycled to lay a single new base layer of stabilised material. This paper highlights salient aspects of FDR process by using Portland cement, as applicable to rural roads.

1. Introduction

When a road pavement has completed its service life and has become highly distressed, three options would be available for its rehabilitation. They are (a) Providing thick bituminous overlay (b) Removal and replacement of the existing pavement (c) Full depth reclamation. Among these three options, 'Full Depth Reclamation (FDR)' is the least cost alternative. In FDR technique, old bituminous pavement and pre-determined portion of underlying layers are recycled to construct new pavement layer. FDR process begins by using a road reclaimer machine to pulversie existing bituminous and granular pavement layers. Pulversied material is then blended with a stabiliser which can be either bituminous emulsion or foam bitumen or Portland cement and compacted using heavy rollers. The result is a stiff, hardened base that is ready for a new wearing course. FDR using Portland cement is preferable rather than the bituminous binder based FDR because of cost considerations. FDR uses nil or minimum quantity of new materials, largely making use of in-situ materials, and hence, it is considered as a sustainable technology. By limiting the effort involved in removing and disposing the existing material and for hauling and placing new material, FDR saves time and money.

Full-depth reclamation with cement increases the structural capacity of the new roadway by providing a stronger and more consistent base. The pulversied, stabilised, and compacted pavement and subsurface layers become a new roadway base with a vastly improved resilient modulus. With a cement-stabilised FDR base, the thickness of the new surface course can be decreased. Strong uniform support provided by cement admixed FDR layer, results in reduced stresses due to wheel loading. Subgrade failures, potholes, and road roughness are thus minimised. Slab like characteristics and beam strength of cement admixed FDR bases are unmatched by granular bases, which can fail when aggregate interlock is lost. PMGSY-III road works mainly comprise of strengthening (and widening) of existing road pavements, which are past their service life. Hence, FDR is an ideal technology for adoption in PMGSY-III works, to save natural aggregates and to re-use the existing old road pavement.

2. Limitations of FDR

If there are any areas having drainage problems such as saturated subgrade or inadequate drainage systems to divert water away from the pavement structure, FDR alone will not rectify such issues. The project should then include measures to mitigate drainage issues prior to FDR process. Full-depth reclamation can be adopted after drainage issues have been addressed. In case poor quality soil has been used for subgrade construction, FDR cannot be used to rectify this situation. Also, FDR being essentially a cement stabilisation process, reflection cracks may appear in the bituminous pavement, if crack relief layer is not provided. In spite of these limitations, for pavements with adequate subgrade support, and distressed base/surface layers, FDR is justified when increased structural capacity is needed to meet higher loading conditions.

3. Mix Design for FDR

FDR being basically a cement stabilisation process, it involves determination of optimum percentage of cement required for gaining specified compressive strength. For mix design, first step would be to excavate representative pavement layer samples, pulverise them manually and determine the gradation. Gradation shown in Table 1 can be adopted for pulverised pavement material which can be used for FDR process in field or for laboratory samples. Addition of suitable quantity of fresh aggregates may be necessary in some cases if the pulverised pavement does not meet the gradation given in Table 1.

Table 1: Suggested Gradation for Pulversied Pavement in FDR

IS Sieve	Per cent Passing (Max)
75 mm	100
53 mm	65
4.75 mm	55
75 Micron	25

After ensuring that the pulverised pavement meets the gradation given in Table 1, moisture-density relationship for FDR material should be determined through Proctor Compaction Test. Since, heavy vibratory roller and pad-foot roller are used for compacting FDR layer, 'Modified Proctor Compaction Test' can be adopted instead of standard Proctor compaction test. The next step would be 'Compressive Strength test' on FDR material admixed with different percentages of cement. From the compressive strength test results, requisite (or optimum) cement percentage for achieving 7 days compressive strength of 4.50 MPa can be determined. Conducting durability tests as per IRC SP:89 on FDR material admixed with optimum percentage of cement would be the final step in mix design. Preparation of cylindrical moulds of 150 mm diameter and 300 mm height may be difficult, and hence 150 mm side cubical moulds can be prepared for compressive strength test and durability test.

4. Pavement Design Using FDR

IRC SP:72 provides design templates for rural roads having cement stabilised sub-base and base courses. While taking up FDR operations, both sub-base and base course layers can be recycled, thereby substantially increasing the sub-base strength. IRC SP:72 stipulates provision of crack relief granular layer over stabilised base when design traffic is more than 3,00,000 equivalent single axle load. A suitable type of granular crack relief layer can be adopted so that it has adequate strength for use in base course (CBR value more than 80 per cent) and functions as an effective drainage layer.

5. Construction and Quality Control

FDR construction requires use of many different road construction machineries, such as (a) Road Reclaimer (b) Motor Grader (c) Water tanker (d) Different types of rollers such as Pad-foot roller, single drum and tandem vibratory rollers. Road reclaimer is an essential equipment for FDR process. Reclaimer should be capable of excavating up to 300 mm thick flexible pavement and simultaneously crushing it and mixing with requisite quantity of water to bring the mix to optimum moisture content. During excavation process itself reclaimer can mix cement and water with pulverised pavement, so that it becomes a single pass operation. However, if mixing or pulverisation are not done efficiently in single pass, reclaimer can be used for two-pass operation also. In that case, during first pass, reclaimer will excavate and pulverise the pavement and during the second pass, it will mix water and cement with already pulverised pavement. Water tanker is usually coupled with reclaimer since there is a need to continuously feed water to reclaimer. Motor grader would be required for spreading the mixed material to correct camber, and rollers (pad-foot roller followed by single drum and tandem vibratory rollers) for compaction. Compaction operations should be completed within four hours after mixing water and cement to pulverised pavement. Curing of the compacted cement stabilised FDR layer should be carried out by using wet hessian for a period of at least 7 days.

Quality control operations comprise of tests to be carried out before construction and also during construction. Tests given at Sl no (i), (ii) and (iii) below should be performed while preparing DPR. They may be re-checked before starting the works. Tests/checks mentioned at (iv) would be required before starting the work. Quality tests to be conducted during construction are given in Table 2.

(i) Existing Pavement Subgrade - Gradation, Plasticity, in-situ density and in-situ moisture content – 3 Samples per km; CBR at in-situ density – One set of tests (3 CBR moulds) for each type of soil.

(ii) Other Pavement Layers - Samples of other pavement layers to be collected (at least one sample per km) and tested for gradation and plasticity.

(iii) Mix design to be adopted – For determination of percentage of water and cement to be added as well as density for which mix is to be compacted during FDR Process – Modified Proctor Compaction test, Compressive strength test and durability test on pulverised pavement sample admixed with cement.

(iv) Cement, Water and other additives if any – As per IS Standards.

Table 2: Quality Tests/Checks During Construction

Type of Test	Frequency
Pulverisation of pavement layer IS 2720 (Part 4) or IS 2386 (Part 1)	At least 3 tests daily, sample to be collected by operating reclaimer to excavate and pulverise the pavement, but without mixing cement or water.
Placement Moisture Content (IS:2720 Part 2)	At least 3 tests daily, well spread over the day's work, sample to be collected after reclaimer has mixed cement and water with excavated pavement
Quantity of cement spread on pavement	At random (at least 3 tests daily), well spread over the day's work, sample to be collected before reclaimer operates on the existing pavement
Uniformity of Cement Mixing	At random (at least 6 tests daily), Visual inspection for uniformity of colour of mixed material (proper mixing) or presence of streaks (insufficient mixing) After mixing cement using reclaimer, holes or trenches should be made up to full depth of mixed material which has been laid for compaction. Uniform texture and colour represent proper mixing, while a streaked appearance indicates that mixing is insufficient
In-situ Density measurements (IS:2720 Part 28)	At least 3 tests daily, well spread over the day's work i) Average of 3 test results shall not be less than the specified degree of compaction. ii) Individual test values of the degree of compaction attained shall not be less than 1 per cent of the specified degree of compaction.
Thickness of compacted layer	At random (at least 6 tests daily), well spread over the day's work
Compressive Strength of the field mix laid for compaction*	At least 6 cube samples to be prepared daily from material laid for compaction. Material for each cube shall be from different location in the stretch under construction. Cured in moist chamber for 7 days before strength testing i) Average of 6 test results (compressive strength) shall not be less than the 4.5 MPa. ii) Individual test compressive strength value of the sample shall not be less than 3 MPa.
Compressive Strength of field compacted FDR layer after 7 days	At least 3 cores (150 mm diameter) to be extracted for each day's work. Locations of core extraction shall be well distributed. i) Average of 3 test results (compressive strength) shall not be less than the 4.5 MPa. ii) Individual test compressive strength value of the sample shall not be less than 3 MPa.

* Notes

While preparing cube moulds using pulverised pavement admixed with cement and water, aggregate particles more than 37.5 mm size should be removed from the mix that is being compacted in the moulds. This may affect the gradation and strength properties. Hence, either aggregate particles having gradation between 4.75 mm to 37.5 mm size are to be added to the mix on equal weight basis or Engineer can decide about field mix strength properties, based on cores extracted from the in-situ pavement.

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ERA of Adoption of New Technology: Full Depth Reclamation (FDR) in the State of Uttar Pradesh

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1. Rural Roads Infrastructure in the State of Uttar Pradesh

Uttar Pradesh Rural Road Development Agency (UPRRDA) has constructed Rural Roads of length 49,427 km to provide Connectivity to habitations of 500+ under Pradhan Mantri Gram Sadak Yojana-I (PMGSY-I) and has upgraded Rural Roads of length 7,508 km under PMGSY-II. Under PMGSY-III, the target is to upgrade and strengthen 18,770 km of rural roads during 2019–2024. As on date under PMGSY-III, length of 3,761 km strengthening and up-gradation of rural roads has been completed and balance is under progress/award.

2. Background of Introduction of Full Depth Reclamation (FDR) Technology

The Government of Uttar Pradesh submitted proposals of 1215 roads in Batch-I of Year 2020-21 under PMGSY-III, to Ministry of Rural Development (MoRD), Government of India for sanctions. MoRD observed that per km cost of the proposals of up-gradation of 5.50 meter carriageway width is to the tune of Rs. 135.98 lacs, which is quiet high, therefore UPRRDA was asked to think about means for reduction of cost by adoption of new materials and new technology or both. Further, MoRD advised State to consider FDR Technology and submit DPRs of 299 higher cost roads (2416 km) for appraisal.

Table 1: Comparison of cost per kilometer of road upgradation work in different States under PMGSY-III

S. No.	State (Road of 5.5 meters width)	Per kilo meter cost in Rs. Lakh
1	Madhya Pradesh	76.73
2	Rajasthan	59.45
3	Chhattisgarh	71.28
4	Andhra Pradesh	69.10
5	Tamil Nadu	68.24
6	Karnataka	89.58
7	Telangana	73.27
8	Kerala	101.83
9	Uttar Pradesh	135.98

UPRRDA took the initiative and appointed a Consultant-Consortium of Translink Infrastructure Consultants, Trans – Asian Techno Pvt Ltd and MK soil testing Lab, and set up a PMU to prepare the DPRs of 299 roads (2416 kms) and to monitor, execution, coordination and assist the UPRRDA and PIUs in quality control and quality checks of FDR works. Simultaneously, few visits were organised for technocrats of Public Works Department (PWD), Rural Engineering Department (RED) and Uttar Pradesh Rural Roads Development Agency (UPRRDA) to Vijayawada, Andhra Pradesh to study and gain knowledge & technical knowhow of the FDR works, where few roads (1. Road No. 25-Construction of R/F Kathipudi-Pamarru R&B Road to Seethanapalli via Vadarlapadu., Kailkaluru Mandal, Krishna District Total Length – 3.10 km; 2. Road No. 28 Construction of R/F Yadavalli to kondangi via Pallipalem. Kalidindi Mandal, Krishna District Total Length – 3.30 km and others) on FDR Technology were constructed.

Figure 1: Chief Minister, GoUP meeting on 06.02.2021 regarding FDR Technology

Road construction, especially Low volume rural roads in India, under PMGSY-III, has been a state-of-the-art affair now, with the focus on recycling, reclamation of existing crust and the materials, with due consideration of Cost, Quality, reduction of carbon footprint and the environmental conservation. Uttar Pradesh Rural Road Development Agency, GoUP has been the pioneer in adopting and implementing the global construction methodology and technique of FDR in India especially for rural roads.

With the conventional methods and technology, the state of Uttar Pradesh has been struggling in project appraisal from Government of India due to high cost of DPRs due to larger lead of transportation of aggregate as well as scarcity of mining material. Construction of sustainable, long life of flexible pavement rural roads due to high cost is major concern for the State. In fact the cost of construction per kilometer appeared to be the highest among all the states in India due to several factors, which contributes to the higher cost, the important among them are:

i. Very high usage of fresh aggregates and other construction materials & scarcity.

ii. Long hauls for the aggregates and materials contributing to higher transportation cost.

iii. Low life of the pavement, contributing to frequent repairs and re-construction.

The PMGSY-III has been framed for strengthening/widening and upgradation of the rural roads, therefore, design, cost of construction and life of the pavement were the prime and prominent triggers for State to think about new alternative technology, methods of construction and the materials for a sustainable, long life perpetual flexible pavement in the state.

While State had conceived the idea for adoption of New Technology of FDR and started discussions with various stake holders and the agencies. There were reservations and reluctance, due to non-availability of approved Schedule of Rate (SoR), past experience of failures of stabilized roads, non-availability of equipments needed for the purpose, lack of experience of working with FDR in contractors. In joint efforts from all the stake holders, including the able guidance and support from NRIDA, GoI, UPRRDA started exploring the possibilities of implementing FDR-Full depth reclamation technology for the rural roads in the State. In due course, the presentations from various national and international agencies from the countries like Japan, Germany, and South Africa on the technology strengthened the resolve and confidence in officers of UPRRDA and PIUs for working with this new technology of FDR.

The technology of FDR is in use worldwide since 1930's and being improved continuously in the countries like USA, UK, Japan, Germany, Switzerland, Australia, South Africa. The Technology of FDR was introduced in India as well way back in 2010. But for the rural roads (Now onwards, we shall call that as The Rural Highways) FDR Technology is being implemented for the first time in India at this scale to create a benchmark.

3. Implementation of Pilot Projects

Another important decision, UPRRDA took was to run pilot projects before entering into the large scale tendering of works based on FDR technology. The State selected 09 roads of different terrain/region (District - Prayagraj-2 roads, Chitrakoot-1 road, Agra-1 road, Mainpuri-1 road, Hathras-1 road, Hamirpur-2, Jhansi-1 road) from sanctioned roads in conventional technology of Batch-I, Year 2020-21 under PMGSY-III to construct by FDR Technology as Pilot project to have real-time experience, hurdles in implementation/ execution, correct method of statement for construction, quality control, third party testing and short term behaviour of FDR crust etc. Details of sanctioned Pilot Projects are shown in Table 2.

Table 2: Pilot Project under Full Depth Reclamation FY 2020-21

Traffic Category	5.50 Meters Carriageway					
	No. of Roads	Length (kms)	Pavement Amount (Lakh)	Avg. Pavement Cost (Lakh/km)	Sanctioned Cost (Lakh)	Avg. Total Cost (Lakh/km)
T7	1	9.50	914.66	96.28	1032.37	108.67
T9	8	100.68	9585.32	95.21	11371.58	112.95
Grand Total	**9**	**110.18**	**10499.98**	**95.30**	**12403.95**	**112.58**

The State also implemented some pilots in Zila Panchayat roads in Azamgarh and Jaunpur districts. The pilot projects helped us like laboratory of learning for understanding the crucial and critical aspects of the new technology, educating all the stake holders and also checking possible errors and hindrance effectively, based on which subsequently several processes were put in place for guiding the process and stringent quality checks for achieving the desired results.

Premier institutions like IITs, CRRI, NITs are associated for mix design/third party test/performance evaluation of roads are being constructed/to be constructed on FDR technology.

4. Brief of Process, Execution and Testing of Pilot Projects

Sampling and Testing: 50 cm x 50 cm Square Pit is dug on the pavement and representative sample is taken to the full depth of pavement crust (GSB, WBM Grade-2, WBM Grade-3 & Black Top Layer) for mix design of FDR base. Quantity of materials taken of sample is as per IRC: 2015. At least 100-150 kg of representative material per test pit (at least 1 pit for each km of road) is collected. Material collected from all pits mixed thoroughly for mix design of FDR base. It is observed that samples contain base/sub-base course material having stone aggregate size upto 75 mm and considerable amount of material final then 4.75 mm. Gradation of representative samples is performed subject to sieve analysis as per IS:2386 (Part-I) and IS:2720 (Part-4). Atterberg limits (Liquid Limit and Plastic Limit) for particles passing 425 micron sieve conducted as per IS:2720 (Part-5). Liquid Limit for pulverize pavement sample should be less than 45% and Plasticity Index should be less than 20, otherwise suitable percentage of lime (about 3-4%) can be added to bring down the plasticity limits. The PH value of the soil is also tested for FDR and should not be acidic in nature. Sub-grade strength of fair CBR (5-6) has been achieved in pilot project roads.

Mix Design for FDR base: (i) The job mix design is an important factor for FDR. This varies with soil type/nature and gradation of aggregate available in the existing pavement crust. The main objective of mix design is to establish the most economical and practical combination of reclaimed pavement materials (RPM) in conjunction with cement and additive/CCS to suit the road construction employing Full Depth Reclamation technology. *(Portland cement, bituminous emulsion, fly ash, lime, calcium chloride and commercial chemical stabilizer are used in FDR process).*

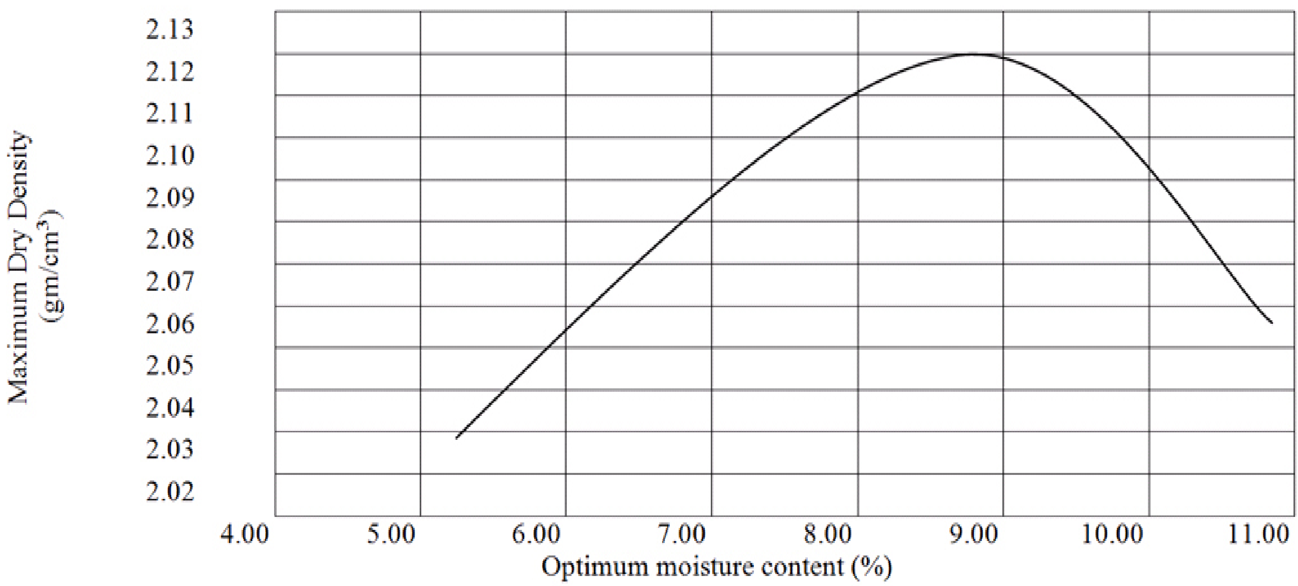
For T05 Archha Barethi Kamasin Road (District-Chitrakoot), Mix Design was prepared by Indian Institute of Technology, Roorkee. Design Mix has been established in accordance with IRC: 89 (Part-II), 2018 and gradation of RPM was carried out keeping the requirements of grading as specified in Table 400-4 of MoRTH. Gradation of existing crust materials for T05 Archha Barethi Kamasin Road (District-Chitrakoot) is shown in Table 3.

Table 3: Combined gradation of existing crust materials for T05 Archha Barethi Kamasin Road

(District-Chitrakoot)			
Sieve Size (mm)	**Percentage passing %**	***Specified Limits as per IRC:SP:89 & MoRTH**	**Mean**
53	97.07	100	100
37.5	92.15	95-100	100
19	81.35	45-100	72.5

(District-Chitrakoot)			
Sieve Size (mm)	Percentage passing %	*Specified Limits as per IRC:SP:89 & MoRTH	Mean
9.5	69.91	35-100	67.5
4.75	54.81	25-100	62.5
0.6	36.29	8-65	36.5
0.3	31.75	5-40	22.5
0.075	3.88	0-10	10

Figure 2: Proctor compaction curve of existing crust materials for T05 Archha Barethi Kamasin Road (District-Chitrakoot)



Modified proctor compaction test on existing crust materials was carried out in accordance with IS: 2720 (Part-8) and the compaction curve is shown in Figure 2. The optimum moisture content is 9.20% and corresponding maximum dry density is 2.120g/cc.

Unconfined Compressive Strength (UCS) Test: The unconfined compressive strength (UCS) test on existing crust materials samples were carried out in accordance with IRC:SP:89 (Part-II)-2018 and IS:4322 (Part-5). In order to assess the gain in compressive strength characteristic due to stabilization, nine cubes specimens of size 150 mm x 150 mm x 150 mm were prepared mixed with cement (binder) + additive/CCS stabilizer by compacting 97% of MDD at its corresponding OMC. Test specimens were cured under moist conditions covered with wet gunny bags for 7 days and 28 days. The average UCS value of stabilized existing crust materials are 4.77 MPa satisfying the IRC specified range for UCS (4.5 to 7 MPa in 7/28 days curing period in the case of cementitious bases.

Table 4: UCS Results of 7 days & 28 days for T05 Archha Barethi Kamasin Road (District-Chitrakoot)

Cube Number	Date of casting	Date of Testing	Age (Days)	UCS (MPa)
1	25.12.2021	31.12.2022	7	4.56
2	25.12.2021	31.12.2022	7	4.70
3	25.12.2021	31.12.2022	7	5.05
Averaged 7 days UCS = 4.77 MPa				
4	25.12.2021	22.01.2022	28	5.35
5	25.12.2021	22.01.2022	28	5.20
6	25.12.2021	22.01.2022	28	5.36
7	25.12.2021	22.01.2022	28	5.23
8	25.12.2021	22.01.2022	28	5.26
9	25.12.2021	22.01.2022	28	5.26
Averaged 28 days UCS = 5.276 MPa				

Existing pavement crust materials stabilized with Terrasil & Zycobond stabilizer (cement 5.0% Terrasil: 0.85 kg/cum & Zycobond: 0.85 kg/cum) produced averaged UCS value of 4.77 MPa which is well within the IRC specified range (4.5 to 7 MPa in 7/28 days) for cementitious bases. Hence, the aforesaid dosages for stabilizers have been recommended by IIT Roorkee for the construction of CTB layer. It was strongly recommended to validate the same in the field trial section prior taking to the main work areas. The laboratory strength value is considered 1.1 times the minimum field UCS value stipulated in contract.

The approximate quantity of cement, additive, water for 1 m^3 of RPM materials are as follows:

(a) Weight of RPM = 2120 kg.

(b) Cement (OPC-43 grade) @ 5.0% by weight of existing RPM = 106 kg.

(c) Terrasil @ 0.85 kg/m^3 [(2120 x 0.85 x 1000)/2120] = 850 gm.

(d) Zycobond @ 0.85 kg/m^3 [(2120 x 0.85 x 1000)/2120] = 850 gm. Total weight = 2227.7 kg.

(e) Quantity of water to be added = 204.95 kg.

Adjustment in quantity of water has been done to produce cohesive RPM mixture which depend upon the prevailing weather condition.

Similarly for other pilot projects road, mix design has been prepared by the approved institute/organization. Details of the Mix Design of Pilot Projects has been shown in Table 5.

Table 5: Mix Design Details of the Pilot projects

Project Name/ District	Average MDD (kg/cum)	OMC (%)	Cement (%)	Additive (%) by weight	Mix Design Prepared by/used additive	Average UCS (MPa)
T02 T01 (km 413) to Charkhari (Hamirpur)	2000	8.66	5	2% of cement	Terrastab/TIMAB NLBB, Netherlands (Additive-Geocrete)	5.15 (7 days) 8.77 (28 days)
L060 Nouranga - Bakrai - Khota to Tooka (Hamirpur)	2000	9.73	5	1.5% of cement	Terrastab/TIMAB NLBB, Netherlands (Additive-Geocrete)	5.66 (7 days) 8.65 (28 days)
MRL06 – T01 to Gobara (Jhansi)	2000	5.30	5	1.5% of cement	Terrastab/TIMAB NLBB, Netherlands (Additive-Geocrete)	5.41 (7 days) 8.62 (28 days)
Archha Barethi Kamasin Road (Chitrakoot)	2120	9.20	5	Terrasil: 0.85 kg/cum of RPM & Zycobond: 0.85 kg/cum of RPM	IIT Roorke (Additive-Terrasil & Zycobond)	4.77 (7 days) 5.26 (28 days)
T04 - Etmadpur to Barhan (Agra)	2352	6.50	4	3.5% of cement	IIT Roorke (Additive-Geopave)	5.26 (28 days)

The contractor executing the FDR Project, if does not have its own additive, is required to have an agreement with the additive company. The Additive Company should have ample experience in the field of road construction using New Technology "*Full Depth Reclamation (FDR) in-situ stabilization with cement stabilization and additives*", either in India or Outside India. The Additive Company will have to support for mix design, execution and supervision of the soil stabilized layer. Further, it has been made mandatory the accreditation of additive/commercial chemical stabilizer (CCS) from the IRC or any other similar organization of the other country. The stabilizer/Additive/Commercial Chemical Stabilizer's acceptability is examined in light of the provisions in MoRTH circular dated 14.12.2020 and IRC SP-89 (Part-II)-2018.

The train of equipments used in FDR: The specific equipment usage is must for success of FDR technology. The important equipment are: (a) Computer-controlled Binder Spreader–Water Tanker truck–Additive Truck–Recycler (working width 2.4 meters, of Engine Horsepower 440 KW)–Pad Foot Roller (20 Ton) + Single Drum Soil Compactor (10 to 12 Ton)–Motor Grader (Blade width 3.35/3.70/4.30 m)–Vibratory Tandem Roller (8 to 10 Ton)–Pneumatic Tyre Roller (14 Ton).

Execution of FDR base of trial length/stretch: (i) It is essential to witness the results of mix design of laboratory into actual construction site, therefore, trial stretch in the length of 100–300 meters mechanized construction as per drawings of full carriageway width, has been made mandatory to execute before execution of entire stretch of road. Stabilization of in-situ (existing pavement crust) or soil or otherwise sub base/base course up to the required depth by cold in-situ recycling using cement and chemical additives/ otherwise: Providing pulverizing, spreading, milling and mixing of chemical additives at the appropriate rate as per job mix design in accordance with IRC-SP-72-2015, IRC-37-2012 & 2018 and IRC SP 89 (part II) 2018. Ordinary Portland Cement Grade 43 confirming to IS:8182 as binder and CCS/CS additive as per job mix design, is spread on the existing pavement using a mobile truck mounted containerized cement/additive spreader with micro processor controlled weighing and spreading system. The in-situ stabilization process is carried out by a mobile and self propelled stabilizer/reclaimer of working width of 2.4 m and with minimum engine horse power of 440 kw with a variable working depth up to 50 cm. The resultant stabilized mix is then profiled to the required grade, level and thickness using motor grader and the mix would be compacted using 20 ton pad foot roller in combination with smooth wheel compacted and PTR to achieve desired proctor density as per IRC 37-2012 & 2018 curing with water of minimum 7 days or as required including all materials, labour and machinery etc. The entire in-situ process is carried out in single pass with milling and pulverizing of damaged asphalt pavement/soil/aggregates/soil-aggregate mixture to the desired depth and with simultaneous addition of additives and water with machine integrated spray bars fitted on the wheeled self-propelled and vibratory pad foot roller to achieve the desired proctor density in all respects. The minimum unconfined compressive strength (UCS) of stabilized sub base/base satisfied 4.5 to 7 MPa after 7/28 days as per IRC-SP-72-2015, IRC-37-2012 & 2018. Durability aspects (wet-dry cycles) of stabilized base satisfied as per IRC 37-2012 & 2018 and IRC SP 89 (part II) 2018. There is a provision of crack relief Stress Absorbing Membrane Layer (SAMI) over FDR base before laying of Bituminous Concrete (BC).

Figure 3: T05 Archha Barethi Kamasin Road (District-Chitrakoot) Length – 17.90 km, width 5.5 meter

Spreading of Cement and Additive

Recycling of existing crust

Grading of FDR material

Compaction by Padfoot Roller

Compaction by compactor and PTR

Water curing of FDR Base

Test result of trial length of FDR pilot projects is shown in Table 6 which are under permissible limits as per code provisions.

Table 6: Test Results of Trial length of FDR Pilot Projects

Project Name	Average UCS at 7 days (MPa)	Average UCS at 28 days (MPa)	Flexural Strength test (MPa)	Residual Strength (MPa)	Durability Test (Wetting & drying 12 cycles)
T02 T01 (km 413) to Charkhari (District-Hamirpur)	4.62	5.76	-	3.11	9.84%
Archha Barethi Kamasin Road (District Chitrakoot)	3.26	5.38	-	3.66	5.89%
T04 - Etmadpur to Barhan (District Agra)	4.45	7.08	6.04	2.09	7.75%

Pilot projects are under progress and performance evaluation of FDR roads has been planned to conduct in due course for vetting of performance criteria in all weather conditions.

Figure 4: Secretary, MoRD, GoI & Additional Secretary, MoRD/DG, NRIDA review meeting at Prayagraj and site visit of FDR road: Archha Barethi Kamasin Road (District-Chitrakoot) on Date 02.04.2022

5. Conclusions

On vetting of test results of ongoing FDR pilot projects by IITs/AMU and NABL accredited laboratories which are under permissible limits and full fill the design criteria as defined in the IRC codes/Guidelines, further UPRRDA took decision to adopt FDR technology of high cost roads and obtained sanction from the MoRD, Government of India for 5353 kms rural roads under PMGSY-III in the State.

Pavement design catalogue for cement treated Bases and Sub-Bases (Figure 6) as per IRC: SP:72-2015: guidelines for Design of flexible pavement for low volume rural roads has been considered in preparation of DPRs of FDR Technology which is shown in Table 7.

Table 7: Traffic Category-wise Provisions of FDR Road in DPR

Traffic Categories	Existing Width (meters)	Widening Width (meters)	FDR thickness Compacted (mm)	SAMI Layer	BC thickness (mm)
T3	3.0/3.75	5.8/5.65	200	Geo Fabric	30
T4	3.0/3.75	5.8/5.65	210	Geo Fabric	30
T5	3.0/3.75	5.8/5.65	225	Geo Fabric	30
T6	3.0/3.75	5.8/5.65	250	Geo Fabric	30
T7	3.0/3.75	5.8/5.65	250	Geo Fabric	30
T8	3.0/3.75	5.8/5.65	250	Geo Fabric	40
T9	3.0/3.75	5.8/5.65	250	Geo Fabric	40

Average of sanction works under PMGSY-III, Financial Year – 2021-22 for 3.75 meter carriageway and 5.5 meter carriageway, details is shown in Table 8.

Table 8: Full Depth Reclamation Sanctions under FY 2021-22

3.75 Meter Carriageway				
Traffic Category	**No. of Roads**	**Length (kms)**	**Average Pavement Cost (Lacs/km)**	**Average Total Cost (Lacs/km)**
T3	12	70.86	57.19	70.79
T4	136	854.09	62.47	74.75
T5	73	494.37	64.10	75.09
T6	23	165.42	68.78	81.75
T7	9	73.68	71.72	87.19
Grand Total	253	1658.41	63.77	**75.93**
5.5 Meter carriageway				
Traffic Category	**No. of Roads**	**Length (kms)**	**Average Pavement Cost (Lacs/km)**	**Average Total Cost (Lacs/km)**
T4	11	82.81	86.47	97.14
T5	90	690.18	95.23	105.57
T6	106	907.51	100.07	113.69
T7	24	187.27	95.06	105.01
T9	204	1827.46	99.57	114.34
Grand Total	435	3695.23	98.36	**111.69**

36 packages, length 1061 km on FDR Technology has been awarded, commencing for execution at site in the month of May/June 2022.

It has been observed that the benefits of implementing the New Technology - FDR and the alternative materials have been multi-fold which have seen as visible results during sanction and implementation of pilot projects as under:

1. FDR Technology is economical compared to conventional technology.
2. In PMGSY, design life of conventional technology road considered 10 years, the same has been opted in FDR Technology but it is presumed that FDR Technology road having long life of pavement which may be more than 10 years. Besides above, maintenance cost of FDR roads will be lesser in comparison to conventional technology road in long run.
3. FDR Technology is environment friendly, minimal air quality problems during construction; conservation of national resources as course aggregate/fine aggregate and improving the carbon footprints.
4. Positive impact on socio-economic development.
5. FDR Technology is effective in the most distress pavement constructed on conventional technology along with improved riding quality, improved pavement crust, reuse of existing material of crust, very speedy construction (300 to 700 meters single lane carriageway per day), lesser hindrance to traffic/public and improved performance of low volume roads.
6. It is observed that there is an approximate saving of 2500-2700 cum aggregate per km in sub base and base layer of pavement if we construct 5.5 meter carriageway T8/T9 traffic category rural road on FDR technology in place of conventional technology.
7. On adoption of FDR Technology, there is need to analyze the carbon foot print elements as well in due course of time.

Further, UPRRDA is now imparting new set of experience and skill to other Rural Road Development Agencies by taking up activities like seminar, in Patna (25-26 April, 2022) organised by Bihar Rural Roads Development Agency, engaging all the stake holders, the technology partners, and concerned officials. Similarly, workshop and site visit on FDR Technology was organized by UPRRDA on 28.04.2022 & 29.04.2022 for Tripura Rural Roads Development Agency for hand holding, transfer of technology and to promote FDR Technology and new materials on low volume roads.

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Application of Cold Recycling for Rural Roads

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Introduction

Increased connectivity and improved road infrastructure developed in the country in the recent past has resulted in significant increase in the growth of traffic in terms of both number of vehicles and axle loads. However, the increased construction activities have resulted in an increased demand of materials and thereby allowing depletion of naturally occurring materials like stone aggregates. This has made the concerned to explore the alternate methods including re-use of materials from existing pavements. The largest portion of pavement in terms of mass and volume are aggregates. The unit price of the aggregates is comparatively low with relatively low environmental impact on production. Correspondingly, because aggregate is exercised in large quantities, is non-renewable, and is incapable to mine near its point of use, it can play a big role in pavement sustainability. Also, there is a problem of the scarcity of aggregates, which forces truck delivery of materials from long distance. The use of diesel for running these trucks contributes to emission of pollutants such as particulate matter, nitrogen oxides, carbon dioxides and sulphur dioxides. Many of the diesel engine emissions have been identified as carcinogenic, and harmful to the human health, even at occupational and environmental levels of exposure.

The construction of a 4 lanes highway requires approx. 12000 tons aggregates per km which leads to approximate 500 truckloads, a large share of this amount, i.e. approximately 80% is used in unbound layers like Granular Sub Base (GSB) and Wet Mix Macadam (WMM). As the unbound layers consume 80% of the total requirement of fresh aggregates, the focus of highway industry is shifting to minimize the use of aggregates in these layers of pavement. The conventional method of pavement construction requires significant amount of materials and energy. Therefore, in order to reduce consumption of fuel and aggregates, technologies like recycling and stabilization of pavements should be adopted for Indian roads.

Recycling of existing pavement materials to produce new pavement materials will result in considerable savings of material, money and energy. Because of the reuse of existing material, pavement geometrics and thickness can also be maintained during construction. In a time when highway professionals determine pavement rehabilitation techniques based on cost, performance, and environmental sustainability, in-situ recycling processes offer the best alternative to optimize these benefits. With strict attention paid to pre-engineering, mix design formulation, construction, and quality control, pavements constructed using these techniques offer the ability to decrease life-cycle costs and the environmental impact.

Based on the process adopted in recycling the asphalt mix, it can be broadly classified as central plant recycling and in-situ recycling. If the RAP (recycled asphalt pavement) is modified at a plant, away from construction site then the process is known as central plant recycling. In-situ recycling process the RAP modified in place, where from it is available. In case of cold mix recycling, old materials are conditioned using recycling agent (like, low viscosity emulsion or foamed bitumen) without application of heat.

CSIR-Central Road Research Institute (CSIR-CRRI) has recommended recycling of pavement in several projects of maintenance, rehabilitation and up gradation of roads. This article presents a case study of rehabilitation and up grading of NH-31, using cold in place recycling (CIPR).

NH-31 Rehabilitation Program

National Highway 31 (NH 31) starts from Unnao in Uttar Pradesh passes through Bihar and terminates at its crossing with State Highway 10 (West Bengal). The project road is in the state of Bihar, about 60 km in length. It was heavily deteriorated showing signs of distress and failure, especially in the form of cracks and deformation. Photo 1 shows the condition of the distressed pavement.

Photo 1: Pavement condition before rehabilitation

With the aim of recycling the existing pavement layers and at the same time strengthening the aged and distressed pavement, Cold in situ recycling using foamed bitumen approach was considered. Based on field and laboratory test results of the sub-grade and the planned traffic design, if the pavement had to be reconstructed, the existing bituminous layer would not have been put on effective use and the pavement design of the whole pavement is shown in Table 1.

Table1: Conventional Pavement Design

Layer Specification	Thickness, mm, for design traffic of 150 MSA
Granular Sub Base (GSB)+ Granular Base (WBM)	450
Existing Bituminous Crust	230
Dense Bituminous Macadam (DBM)	135
Bituminous Concrete (BC)	50

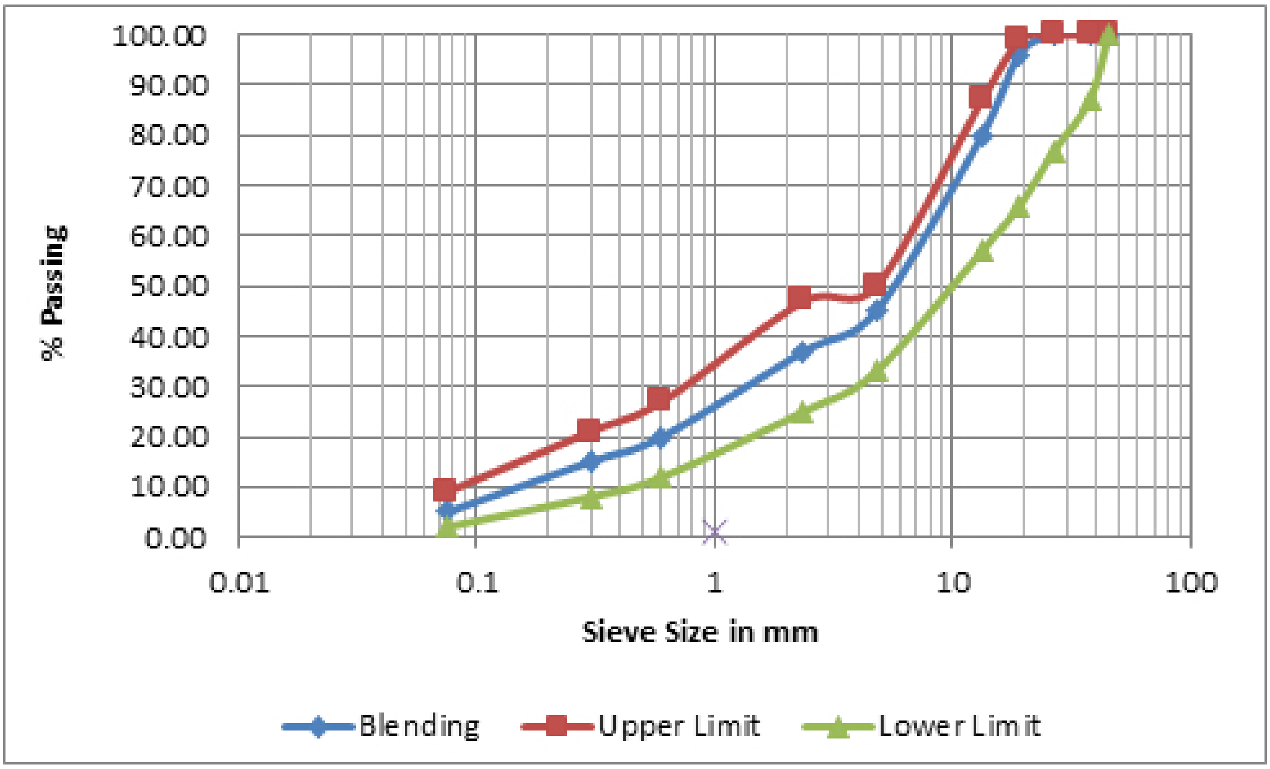
RAP Mix Design Using Foam Bitumen

Refinery produced VG-30 grade bitumen was used for foaming purpose. Injection of cold water and air with varying pressure into hot bitumen produces foamed bitumen. The optimum water addition is chosen as an average of two water contents required to meet minimum criteria of Expansion Ratio (ER) more than 8 and half life (HL) more than 6 second (as specified by TG-2, 2009; Wirtgen, 2012). Foaming experiment is conducted at two different asphalt temperatures and four different water contents. Best foam with an ER of 10 and HL 12s was observed at temperature of 180°C and the foaming water content of 8 percent. This combination for foaming was selected for the VG-30 binder in mix design.

Preparation of Foam Mix

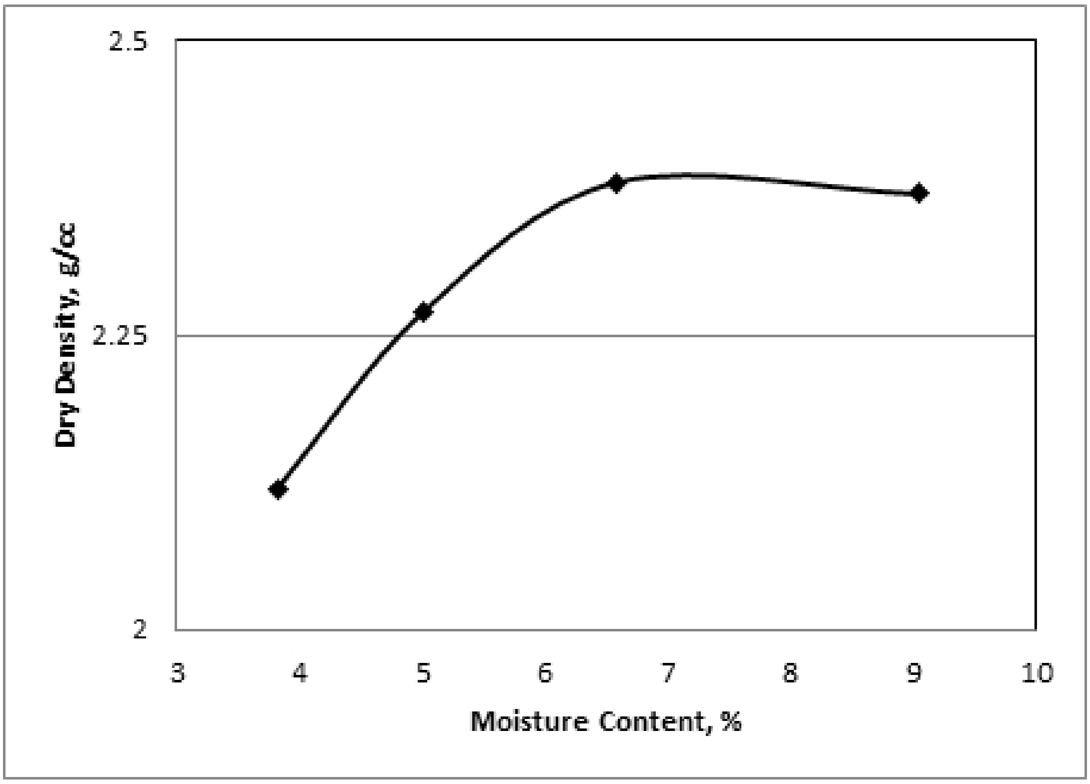
Materials like blended recycled and fresh aggregate, foamed bitumen with VG-30, and filler as cement of about one percent is used. The average binder content in this processed RAP material was found to be 2.00% by weight of total mix according to ASTM D6307 test procedure. The aggregates obtained after binder extraction process were washed and dried in oven for 24 hours. This was followed by sieve analysis to find the particle size distribution. 80 percent of RAP material, 19 percent of stone dust and 1 percent cement was blended to meet the gradation requirement as given in IRC 37: 2012 (Figure 1).

Figure 1: Gradation of Blended Material as per IRC 37



The Optimum Moisture Content (OMC) of the untreated blended materials was determined using the moisture-density relationship according to AASHTO T180 (2010) as shown in Figure 2. It was 6.5 percent. This pre-wetting water content is added to get better dispersion of foam in the mix. The sample of 8 kg of material was prepared and mixed at particular Foamed Binder Content in Wirtgen WLM 10 pug mill mixer. The different batches by varying the foam bitumen content from 2.0% to 3% in increment of 0.5% by weight of aggregate were prepared. Upon mixing, samples were prepared using Marshal compactor. Compacted mix was then cured for 72 hrs at 40°C in an oven. Moisture resistance of foam mix was evaluated as per ASTM: D6931-12.

Figure 2: Optimum Moisture Content



Indirect Tensile Strength: Dry & Wet

Indirect tensile strength test is useful to evaluate resistance of compacted bituminous mixture to cracking. Marshal specimens were tested for their tensile strength at 25°C. The failure load was recorded and the indirect tensile strength (St) was calculated using following Equation (1)

$$S_t \frac{2p}{\pi DT} \tag{1}$$

Where, P is the load (kg), d is the diameter in cm of the specimen; t is the thickness of the specimen in cm.

To identify the susceptibility of binder coating to moisture damage, indirect tensile strength of water conditioned specimens is determined. Unconditioned specimens are maintained at room temperature and then adjusted to 25°C. The conditioned specimens are placed in a water bath maintained at 25°C for 24 hours and then placed in an environmental chamber maintained at 25°C for two hours. The minimum requirement of Dry ITS and Wet ITS is 225 and 100 kPa respectively. The maximum strength both in wet and dry conditions was found to be at 2.5% of binder content.

The resilient modulus test was also carried out to analyze the pavement response for the repeated traffic loading, MR was evaluated by measuring the indirect tensile strength modulus according to ASTM D7369 (2011). Table 2 shows the Resilient Modulus at 25°C and 35°C for different binder content. The maximum MR values are obtained at 2.5% foamed binder content at both the temperatures.

Table 2: Resilient Modulus Values

Foam Binder Content	2.0%		2.5%		3.0%	
Testing Temperature	25°C	35°C	25°C	35°C	25°C	35°C
Resilient Modulus, MPa (Average of 3 tests)	1302	1034	2129	1550	1875	1429

The final recommendation for RAP mix design was for 2.5% foam bitumen and 6.5% optimum moisture content. The optimum foaming characteristics were achieved at temperature of 180°C and foaming water content of 8%. This combination for foaming was selected for the VG-30 asphalt binder in mix design. 1% cement OPC 43 grade was added to improve the stability and better dispersion of foamed bitumen in fine particles of the mix. The RAP content recommended to be used was 80%, stone dust 19% and 1% cement. The pavement was designed as per IRC 37:2012 for 150 msa and CBR 8%, with 90% reliability performance. The existing bituminous crust was 200-230 mm, out of which 180 mm was recycled.

The new crust composition is given in Table 3.

Table 3: Crust composition with recycled (BSM) layer

Layer Specification	Thickness, mm, for design traffic of 150 msa
Granular Sub Base (GSB) + Granular Base (WBM)	450
Foam Bitumen Stabilized Base (BSM) (recycled layer)	200
DBM	90
Bituminous Concrete (BC)	50

Field Construction

The existing bituminous crust was recycled using foam bitumen. Photo 2 (i-v) shows the recycling process carried out at NH 31 section. Fresh crusher dust was spread (as per the gradation requirement) before spreading of the cement.

Photo 2: Cold in place recycling carried out at NH 31

(i)

(ii)

(iii)

(iv)

(v)

WR240 machine was used for recycling at NH31 project. The recycled surface is cured for 48-72 hours by sprinkling of water at an interval of 6-7 hours. Photo 6 shows the surface after overlay.

Photo 6: Recycled surface after overlay

Conclusion

The recycling process resulted in construction time saving, minimal use of virgin aggregates, less transportation of materials and several other environmental benefits. Huge reduction in carbon emissions can be achieved with the use of RAP technology. However, in India the adoption of this sustainable road construction technology is at snail's pace. While there are still challenges to overcome related to predicting mixture performance, the user guidelines and specifications have been evolved based on research and the industry's desire to innovate. The first step to take toward advancement and wider implementation of RAP usage is to adopt the practical guidance related to mix design, materials characterization, and virgin binder grade selection.

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Intelligent Compaction for Improved Performance of Rural Roads

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Abstract

The cost of rural road pavement construction is close to one crore. However, the process control and acceptance are still based on traditional spot testing without complete mapping. The **I**ntelligent **C**ompaction **(IC)** is a continuous compaction monitoring system that provides real-time feedback and information on compaction quality. This paper presents an overview of the IC technique to construct better-performing roads. The components of IC, working principles, and advantages during process control are described. The existing IC quality assurance protocols and implementation challenges are also presented. The benefits of IC utilization include time and cost savings and reduced energy consumption with lower greenhouse gas emissions.

1. Introduction

The compaction of pavement layers is an important construction activity that transforms the pavement structural design in the field. The uniformity in compaction quality enables the pavement layer to sustain the traffic loading under varying climatic conditions. The traditional methods of evaluating the compaction quality in terms of density or modulus based on spot test results pose significant challenges in benchmarking the compaction quality. Also, the spot testing methods could not provide feedback, complete coverage, and identify the rework area in real-time. IC technique help to overcome these issues (Mooney, 2010). An instrumented IC roller, spot testing device, and complete mapping concept are shown in Figure 1.

Figure 1: (a) Instrumented IC roller, (b) LWD testing, & (c) Mapping

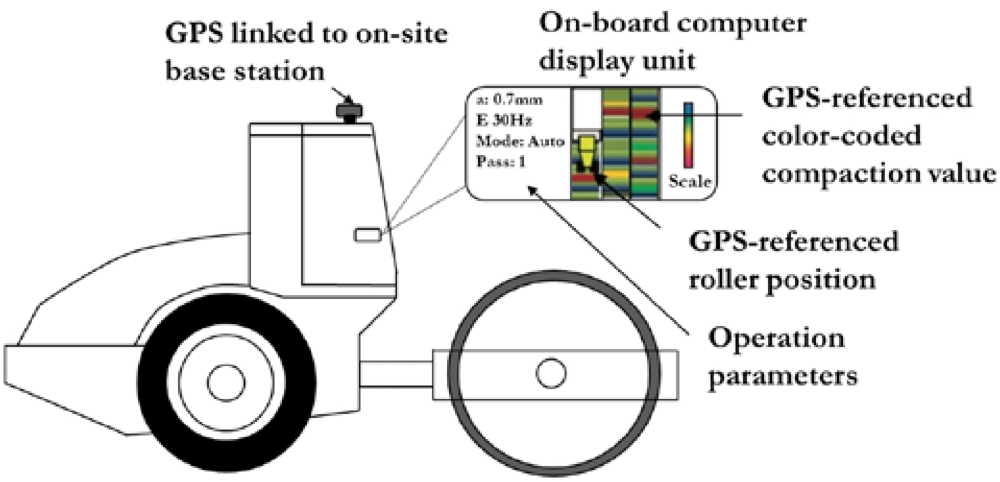
(a) IC Roller	(b) Deflection testing	(c) Mapping

2. Components of Intelligent Compaction

The intelligent compaction monitoring system consists of an instrumented vibratory roller with the following accessories.

- **Accelerometer:** to monitor the response of pavement layer to roller vibration forces
- **High precision Global Positioning System (GPS):** to record the roller drum spatial position and map the roller coverage
- **Infrared temperature sensor:** to record the temperature profile during compaction of bituminous mixes
- **Data acquisition system:** to collect, analyze, transform and document the data
- **Feedback monitor:** onboard display to provide real-time feedback to the roller operator.

Figure 2: Components of IC



3. Working Principle

The IC system utilizes the interaction of material responses to compaction forces exerted by the vibratory drum to compute the Intelligent Compaction Measurement Value (ICMV), as shown in Figure 2a (Kumar et al., 2016). The ICMVs are calculated using either force-displacement relation or spectral analysis of the accelerometer data (Mooney, 2010). The various forms of ICMV values by different agencies are listed in Table 1.

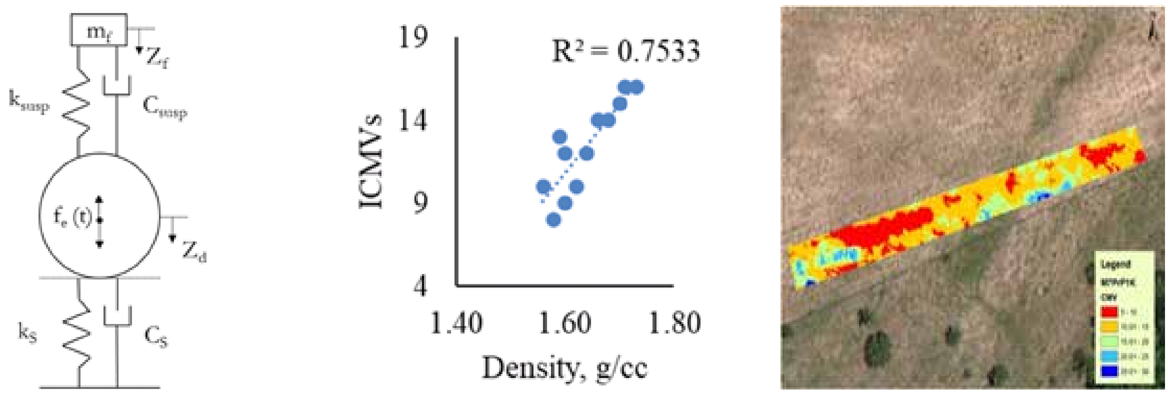
Table 1: Summary of different intelligent compaction measurement values

Measurement Value	Manufactures	Relations Used
Compaction Meter Value (CMV)	Dynapac, Caterpillar, Hamm, Volvo	$CMV = c\frac{A_2\Omega}{A\Omega}$
Compaction Control Value (CCV)	Sakai	$CCV = \left[\frac{A_1 + A_3 + A_4 + A_5 + A_6}{A_2 + A_2}\right]$

Measurement Value	Manufactures	Relations Used
Stiffness, K_s	Ammann	$k_s = \Omega^2 \left[m_d + \frac{m_o e_o \cos(\phi)}{z_d} \right]$
Vibration Modulus, E_{vib}	Bomag	$z_d = \frac{2 \times (1 - v^2)}{\pi \times E_{vib}} \times \frac{F_s}{L} \times \left(1.8864 + \ln \frac{L}{b} \right)$
Machine Drive Power (MDP)	Caterpillar	$MDP = P_g - WV \left[\sin\theta + \frac{a}{g} \right] - (mV + b)$

Through continuous assessment of mechanistic pavement materials (e.g., stiffness, modulus) from roller vibration monitoring, the onboard display provides information for on-the-fly modification of vibration amplitude and frequency based on the target ICMVs. The target ICMVs are obtained from a control section by developing relations with spot test results (Figure 2b). The display is color-coded based on the target ICMV to identify the area with poor compaction properties, material variability, or ground support conditions. Further, the integrated global positioning system provides a complete geographic information system–based record of the worksite. The number of passes and coverage area is mapped with GPS information. IC mapping the construction process help to optimize the compaction with reduced risk of over or under compaction. In addition, to improve the pavement performance, the optimized compaction process will help minimize roller usage.

Figure 2: (a) ICMV mechanism, (b) Target ICMV, (c) Colour coded Feedback



(a) IC Mechanism (b) Target ICMV (c) Variation in ICMVs

4. Advantages of IC

Compared to the conventional compaction monitoring system, the advantages of IC are graphically illustrated in Figure 3. The proportionate cost benefits are shown in Figure 3a, and technological benefits are illustrated in Figure 3b. The main benefits of IC include complete geo-tagged information of compaction, capturing the stochastic nature of the material response, identifying weak or rework areas, and on-fly compaction parameters modification to achieve uniform compaction. In addition, the use of IC avoids over or under compaction, and the roller maintenance operation cost is much lesser than conventional rollers (Savan et al., 2016). Further studies have shown that the life cycle cost of pavement reduces with the use of IC with reduced environmental pollution (Mazari et al., 2021).

Figure 3: Summary of IC benefits (a) & (b)

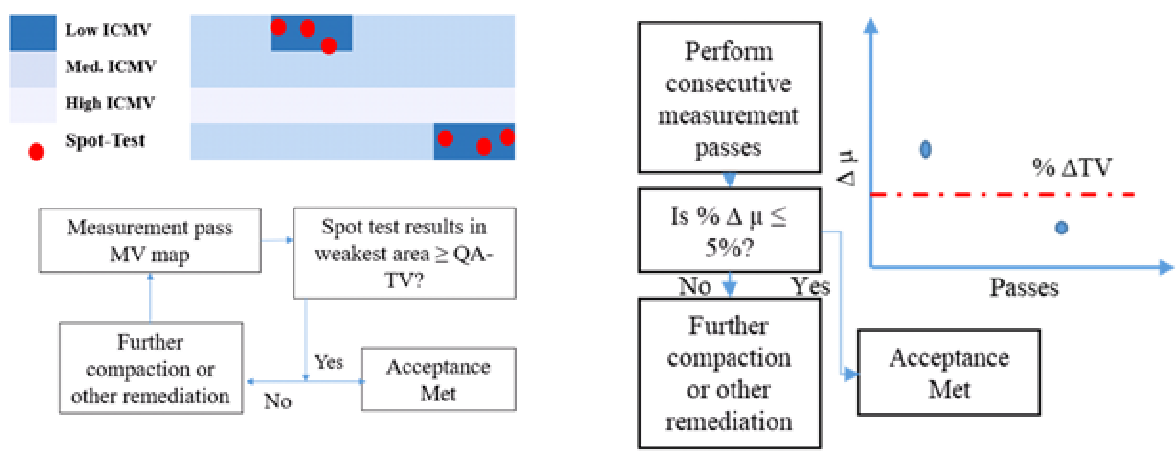
(a) Cost proportionate (b) Technological benefits

5. Quality Assurance and Challenges

Various agencies worldwide have come up with different quality assurance options with IC. The options depend on the association between the ICMVs and the target quality characteristics such as density or modulus. Figure 4a illustrates the basic QA options where the spot tests (density or modulus) are carried on the areas mapped with low ICMVs. Accepting the section will depend on the spot test results meeting the agency requirement. Likewise, another option (Figure 4b) accepts the section if the percent difference between the successive passes ICMVs are lesser than the target value (agency-specific).

Even though the IC aims to improve the compaction quality, the challenges in implementation include understanding the complex interaction between the roller drum forces and material responses, variations in data collection frequencies, and the association between spot tests and ICMV due to depth of influence and testing mechanism.

Figure 4: Typical quality assurance options (a) & (b)

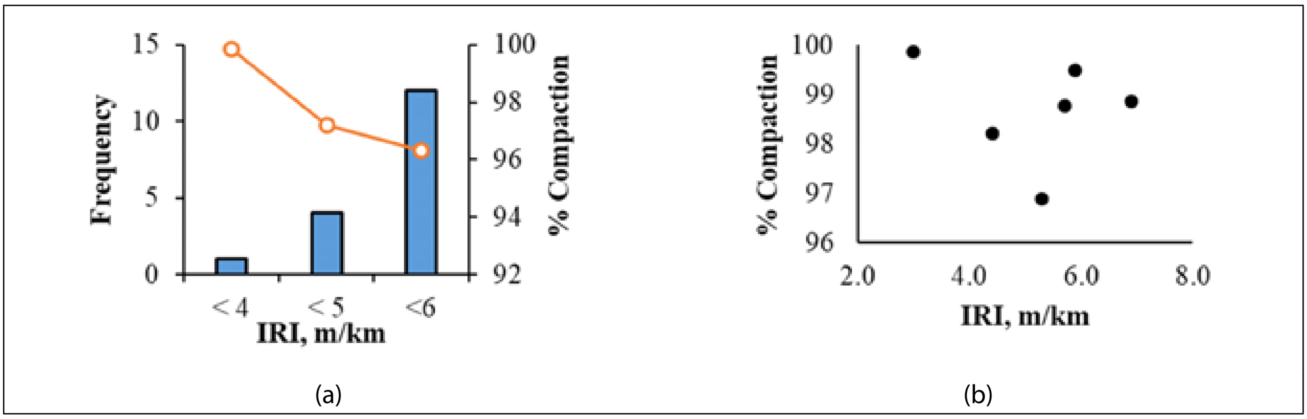


(a) Option II (b) Option II

5. IC Potential for Rural Roads

Rural roads are typically composed of soil subgrade, granular layers, and bituminous surface treatment. Hence rural road performance and longevity are directly linked to the compaction quality of soil and granular layers. The importance of compaction quality on the performance of rural roads in terms of riding quality is illustrated in Figure 5. It can be seen from Figure 5a that riding quality reduces with a reduction in % compaction. Further 5b represents the case where % compaction may not be sufficient to ensure performance. Hence compaction quality should be an integration of the degree of compaction and uniformity of compaction. The main potential of IC in achieving uniform compaction and mechanical properties of rural road pavement layers helps to construct long-lasting rural roads.

Figure 5: Variation of Road Performance with Compaction



6. Conclusions

IC has emerged as an important and timely technique to achieve good compaction quality. Monitoring the complete area will help improve construction quality, identify the weak area, and timely rectification. With the low traffic volume and loading, emphasizing more stringent compaction quality measures of pavement layers improves the performance and brings substantial savings in maintaining a rural road network. The spatial information available with the IC system will help identify the possible reasons for pavement distress, maintenance, and fine-tune design and construction considerations for rural roads. Also, utilization of the IC technique in rural road construction benefits time and compaction cost savings, reducing energy consumption and greenhouse gas emissions. Hence, it could be emphasized that IC is a sustainable technique that should be utilized to compact pavement materials and improve the service life of rural roads.

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Design of Short Panelled Concrete Pavements for Low Volume Roads

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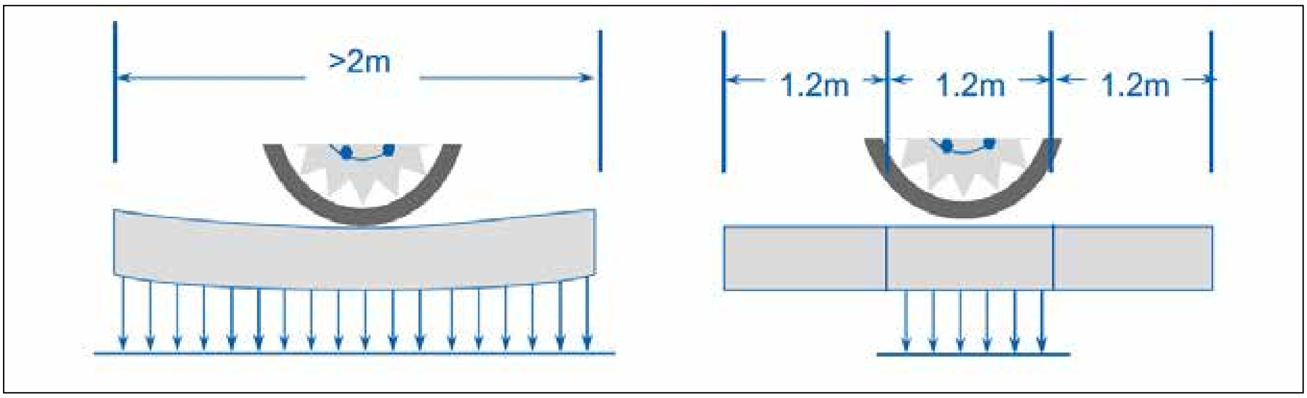
1. Introduction

Concrete pavements are becoming popular because of maintenance requirement is less over years as compared to bituminous pavements but the initial cost associated with these pavements is high. IRC: SP:62-2014 guidelines for concrete pavements for low volume roads adopts transverse joint spacing of 2.5- 4.0 m respectively with thickness of concrete slab varies from 210 to 240 mm for 150 `CVPD. Adopting transverse joint at closure intervals i.e 1.0 to 2.0 m size, it is quite possible to reduce thickness of concrete slabs for the same thickness and this is possible through Short Panelled Concrete Pavements (SPCP) with dimension of slab in the order of 1.0 x 1.0 m to 2.0 x 2.0 m. Panels are formed by introducing early entry saw-cut of 3 to 4 mm width and to a depth of 1/4th to 1/3rd of thickness of the slab within 16 to 20 hours of placement of concrete. The purpose of saw-cut is to reduce the constraint for drying shrinkage and produce 4 controlled full depth cracks, which can be maintained periodically. After partial isolation of slabs (panels), load transfer in SPCP is ensured by aggregate interlock and hence SPCP does not require any load transfer devices (Pradena & Houben 2018) such as dowel bars unlike JPCP making it an economical solution as well.

2. Short Panelled Concrete Pavements

Short Paneled Concrete Pavement (SPCP) is a new type of pavements which is evolving slowly and not much literature is available regarding design and performance of these pavements. SPCP is gaining popularity owing to the satisfactory performance of thin white toppings (WT) worldwide. The load distribution over a smaller panel size can be seen from the figure below where the concrete slab is bending when the span is more than 2 m and the panel (<1.2 m) is merely taking the compressive force and transferring the load to base through punching.

Figure 1: The slab action and short panel action of concrete overlay



WT (smaller panel size concrete slab over existing bituminous pavement) of thickness 100–150 mm (or even lesser for ultra-thin white toppings-UTWT) are successfully implemented for rehabilitation of existing bituminous pavements is provided over the existing bituminous pavement and performance of these pavements are very well without any need for maintenance for a long time as the CC panels distribute the load on wider area before transferring it onto the bituminous (base) layer. IRC: SP 76. (2015) provides guidelines for conventional and thin Whitetopping.

Successful implementation of WT attracted the attention of highway community to adopt SPCP on high volume roads where in concrete slab is placed on existing thick bituminous pavement as well as DLC, CTSB and subgrade. SPCP test section of panels of sizes 1 m X 1 m, 1.5 m X 1.5 m and 2.0 x 2.0 m were designed with a thickness of concrete slabs as 180 mm, 200 and 220 mm was constructed on DLC, CTSB and subgrade of NH-18 (old NH-33) of Baharagora - Mahulia section on high traffic corridor as a part on NHAI posnored project on SPCP for high volume roads. The performance of the test section was evaluated and found satisfactory. Figure 2 shows the view of SPCP on NH-18 (old NH-33) constructed in the year 2017.

Figure 2: A view of Short Panel concrete pavement (SPCP) on NH-18 (old NH-33) (Year 2017)

(Technical Report-VI, 2019)

By reducing the slab sizes, the curling stresses gets reduced which is a function of the temperature gradient prevailing in the slab. The type of distress observed in the pavement depends more on the slab size rather than the thickness of the pavement.

3. Review of Literature on SPCP

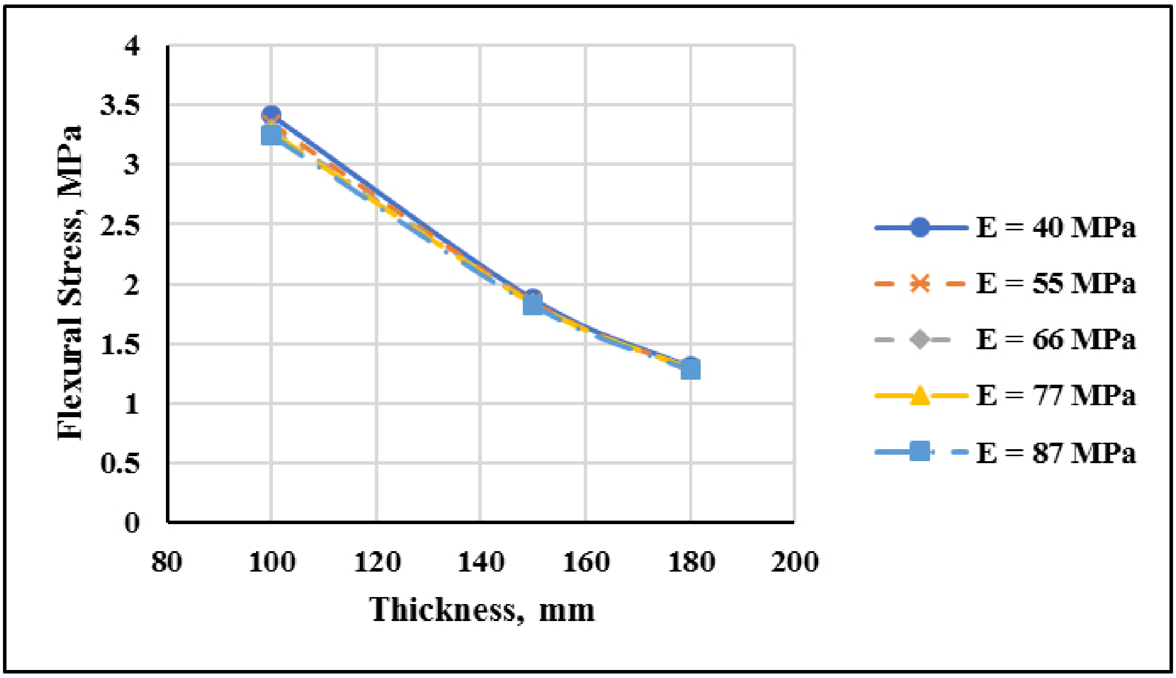
As SPCP are successfully designed and used on high volume roads, similar type of pavement can also be adopted for low volume roads with similar base and subbase course used in conventional concrete pavement (IRC: SP-62: 2014). However, solution for these panel sizes is not available for new road construction. It was observed from the literature available that the pavement performance is more affected by the slab size compared to the thickness. Smaller size slabs would undergo lesser curling stresses compared to larger size slabs. The distress observed in short slabs is corner cracking and longitudinal cracking. Bhattacharya et al. (2019) summed up the critical type of cracking observed on interstate highways for square slabs with variable joint spacing. An interesting fact is that the square short slabs (0.6 to 1.2 m of side) are prone to corner cracking; medium-sized square slabs (1.5 to 2.4 m of side) experience longitudinal cracking and large square slabs (3.0 to 3.6 m of side) witness transverse cracking. The square slabs are typically being adopted for low-to-high volume roads by various agencies in the USA, Chile, and India. The Chile field sections (Salsilli et al., 2013; Salsilli et al., 2015) with 80 mm thick slab and 0.88 m, 1.20 m, 1.75 m, and 3.5 m of square slabs have been observed to perform poorly whereas the thicker slabs (150 mm) performed better. The observed predominant distresses are in the order of longitudinal, transverse, and corner cracking alarming the low degree of load transfer. It is to be noted that these sections have been built over granular subbase (CBR ranges about 85 to 90%) and subgrade (CBR of 15 to 70%).

For very short panels sizes where the wheel paths coincide with the corners of the pavement, corner cracking is observed and in slabs approximately half the lane width, longitudinal cracking is observed. The critical tensile stresses are reduced in smaller slabs as not more than one set of wheels are placed on the slab at a given time. As curling stresses are also reduced in short concrete pavements, thickness of slab would be reduced compared with conventional concrete pavements.

4. Design of Short Panelled Concrete Pavements

In order to design SPCP, critical load positions were arrived first for different slab sizes and then analysis was carried out for different loading and temperature gradients based on single slab analysis and stress charts were developed. Finite element modelling by ABAQUS tool with elastic solid foundation was employed for this purpose and three critical loading positions were considered – corner, edge and longitudinal cracking. The stresses due to wheel loads and temperature differential were calculated for a single slab resting over (i) CTB layer, and (ii) WMM layer for LVR. Three different thicknesses of PQC and WMM were considered for the analysis. The thickness of the slab was varied and the stresses were computed corresponding to critical load positions. The stress chart for PQC resting over 100 mm CTB for a loading of 120 kN placed at the longitudinal edge of the pavement with positive temperature gradient of 17.3^{0}C is shown in Figure 3.

Figure 3: Stress due to load of 120 kN at the longitudinal edge with ΔT = 17.3˚C



(Pandey, 2022)

Similar charts were developed for different loading conditions (40 kN to 160 kN) and slab sizes for given modulus of subgrade reaction (k) values. From the analysis, it was found that the critical stresses due to loads with positive temperature gradient are found to be higher as compared to the loads with negative temperature gradients. Further stresses in the PQC slab are lesser when the slab is placed over the CTB layer as compared to WMM layer. This can be attributed to the fact that CTB is much stiffer as compared to WMM layer. However, there were exceptions to this trend depending on the load positions.

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Overview of Low-Volume Roads in Europe

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1. The Importance of Low-Volume Roads in Europe

Although the Public Administrations often focus their resources on main roads and motorways, it must be noticed that low-volume roads represent the vast majority in Europe (Figure 1).

Figure 1: Types of roads in Europe [Source: European Road Federation]

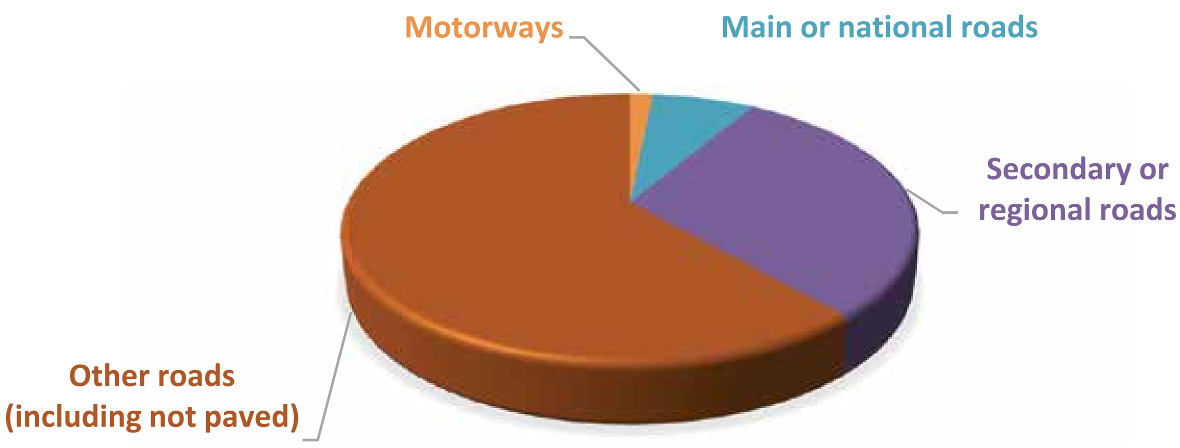


Table 1: Example of road type distribution in France

	km	% Length	% Traffic
Highways	> 11.466	1,0%	22,0%
National roads	> 8.979	0,9%	17,0%
Departmental roads	> 378.000	38,1%	36,0%
Local roads	> 630.000	60,0%	26,0%

These roads usually connect rural communities and businesses (e.g. farms) with the densely-populated urban areas, allowing a flow of goods and people necessary to achieve important development goals, such as public health and education. Hence, they play a crucial role in many countries' economies.

These roads tend to be particularly vulnerable to factors, such as soil conditions and surface water drainage, which can quickly degrade their usability, cause structural failures and result in adverse impacts on the local environment, water quality and aquatic life. However, precisely due to their location, the availability of high-quality materials and construction equipment can be challenging.

2. Good Practices in Europe

Good rural road design and construction practices are cost effective in the long run by preventing failures, eliminating repair needs, and reducing maintenance.

Different countries have achieved this through different strategies and design methods. Hence, each country has different national specifications for national roads. Although low-volume roads are normally included in such specifications, these are normally competence of the Local/Regional Authorities, which are free to set their own design criteria.

For this presentation, 3 case-studies are presented:

1. **Spain:** placed in the South of Europe, Spain has one of the most similar climates to the warm Indian regions. In addition, the design guides are very pragmatic, providing a simple catalogue of road pavement sections to be selected depending on subgrade and traffic conditions.
2. **UK:** the specifications in UK have a more empirical approach that can be used to explore or assess new design options. In addition, they are in English, which makes them more accessible internationally.
3. **Norway:** with one of the coldest climates in Europe, Norwegian specifications offer some interesting particularities for pavements exposed to low temperatures.

3. Low Volume Roads In Spain

The pavement design is given by a catalogue of sections depending on the subgrade (Table 2) and the daily traffic intensity of heavy vehicles (IMDp) [1]. Heavy vehicles are considered:

- Trucks with a payload greater than 3 t, with more than 4 wheels and without a trailer
- Trucks with one or more trailers
- Articulated vehicles and special vehicles
- Vehicles dedicated to the transport of people with more than 9 seats.

Table 2: Types of subgrade according to the Spanish national specification

Subgrade class	E1	E2	E3
Ev_2 (MPa)	≥ 60	≥ 120	≥ 300

* E_{v2} is the compressibility modulus at second load cycle according to plate load test (Standard NLT-357)

Table 3: Types of traffic according to the Spanish national specification

Traffic class	T00	T0	T1	T2	T31	T32	T41	T42
Number of heavy vehicles per day	≥4.000	2.000-4.000	800-2.000	200-800	100-200	50-100	25-50	< 25

Figure 2: Pavement sections in the Spanish specification depending on traffic and subgrade

MB: Asphalt mixtures. **ZA:** Granular material with continuous gradation, totally or partially composed of crushed particles, used as a pavement layer. **SC:** Homogeneous mixture of granular materials (gravel, granular soil or inert waste products), cement, water and possibly additives made in central, which conveniently compacted is used as a structural layer in road surfaces. **HF:** Concrete

The types of bitumen normally used for the asphalt mixtures in these sections 50/70 and 70/100, which allows certain flexibility to adapt to the deformations of the granular materials underneath. In addition, the Spanish specification also allows the use of crumb rubber modified bitumen, which can help to improve the cracking resistance in these cases.

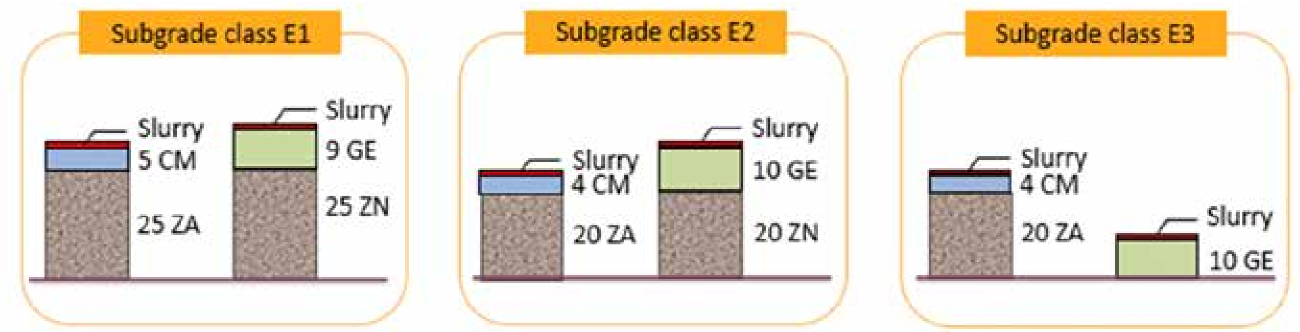
The Spanish specification also allows up to 60% of reclaimed asphalt (RA) content. Even higher is allowed but for these cases the express authorization of the General Directorate of Roads will be mandatory.

Although mixes containing RA are only allowed in general for binder and base courses, they may be also used in surface courses for low heavy-traffic categories (T2 to T4), when it comes to manufacturing dense or semi-dense mixes, with RA from aged surface courses.

Another important aspect, especially in the countries of the centre-south of Europe (e.g. France and Spain) is the use of cold asphalt mixtures. These have environmental benefits, since their manufacture does not require prior heating of the components, reducing energy consumption and emissions of gases and fumes into the atmosphere. They are storable mixtures, which can help to increase transport distances and reach secondary roads placed far from asphalt manufacturing plants. Spreading and compaction will be carried out at room temperature environment.

They present disadvantages, such as higher air voids content, lower stiffness (prone to permanent deformations), or the need of curing time to evaporate water, which make them not suitable for many high-traffic applications. However, in low-volume roads, the greater flexibility allows them to adapt, without breaking, to the permanent deformations of the lower layers, especially when the subgrades are of poor quality. Furthermore, traffic disruptions during curing are usually not a big inconvenient in low-volume roads.

Figure 3: Examples of sections with Cold Mix Asphalt used in low-volume roads



CM: Cold Mix. **GB:** Grave-emulsion. **ZA:** Granular material with continuous gradation, totally or partially composed of crushed particles. **ZN:** Granular material with continuous gradation, containing natural particles. Slurry dosing for all these sections = 8-11 kg/m^2

4. Low Volume Roads in UK

The national design guidance documents in UK [2] provide empirical charts and formulas to calculate the thickness of each layer for 2 types of pavements: (1) flexible pavements with asphalt base and (2) flexible pavements with asphalt layer on a hydraulically bound granular material. This depends on the number of axel loads expected in the 40-years service life.

Basically, anything below 6 msa (for a 40 year design life) in asphalt must be minimum 200 mm thick for flexible pavements with asphalt base. In the worst-case scenario (foundation class 1) the asphalt thickness would be a minimum of 200 mm for high-modulus mixes and 240 mm for asphalt concrete.

For pavements with bases of hydraulically bound granular materials, up to 3 msa, the asphalt thickness is 100 mm and the HBGM base, depending on the HBGM category, between 150 and 180 mm.

Nowadays, alternative pavement designs are allowed not following pervious considerations. For this, analytical methods to model the stresses and strains and assumed material properties to determine design thicknesses are used. All alternative designs shall require 'departure from standard' approval by the Overseeing Organisation.

Still, the foundation shall be designed in accordance with the guidance for new carriageways and will consider a design life of 40 years. In addition, the minimum design traffic for new roads shall be 1 msa.

5. Low Volume Roads in Norway

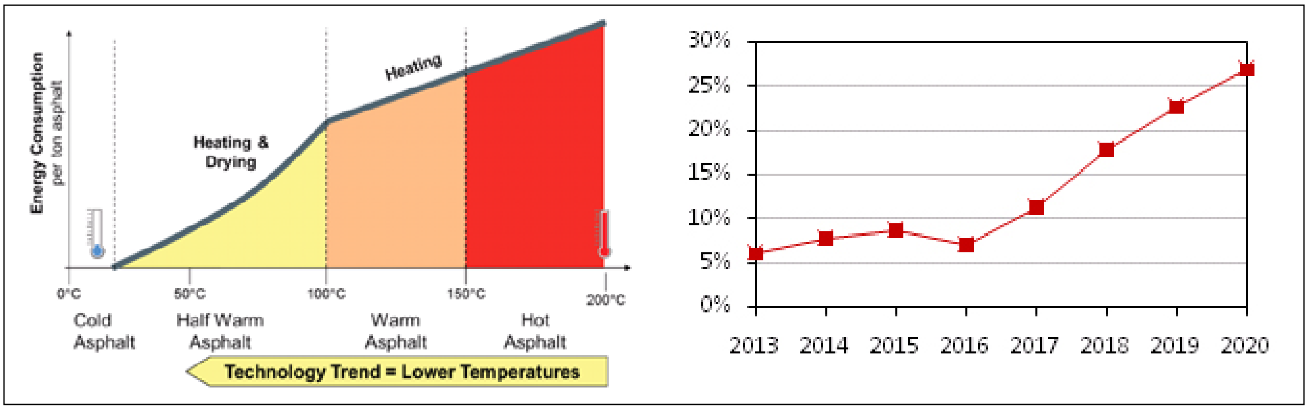
Damage caused by frost action is a critical problem for roads in Northern Europe. The damages are caused by frost heave during the winter and reduced bearing capacity in the spring thaw period. Different solutions to prevent the frost from penetrating down into frost susceptible subsoil have been used during the last decades. The easiest and most common solution may be to replace the in-situ soil with sufficient amount of non-frost susceptible soil. This solution may sometimes not be the technically or economically optimal solution. Different products that have thermal insulating effects have been used with varying degree of success. Some examples used since the 60's-70's are bark and extruded polystyrene boards (XPS). Nevertheless, lightweight clay and foam glass aggregates are commonly used today.

All requirements, including the thickness of frost protection layers, are described in the Road Administration handbook N200 [3] or the case of low volume roads (defined as ADT<1500) the need for frost protection shall be assessed on sections where problems can be expected (the specifications do not stablish a minimum protection).

In general, such roads have a service life of 13-20 years and are just paved with either 100 kg/m² Soft Asphalt or Asphalt Concrete.

Another important aspect is that Norway has tremendously increased the use of Warm Mix Asphalt technologies over the last years (Figure 4). This is due to the Green Public Procurement systems that benefit proposals with this kind of sustainable technologies. Nevertheless, besides environmental advantages, other benefits were achieved, such as a reduced exposure to fumes and odours, cooler work conditions or a better workability of the mix, which allows the extension of the paving season and delivery distance from the asphalt plant, the earlier opening of the road and a reduced binder ageing during production.

Figure 4: Energy consumption of Warm Mix Asphalt compared to other mixes (left) and percentage of total asphalt production done with Warm Mix Asphalt technologies in Norway over the last years (right)



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Waste Plastic in Bituminous Mixes for Low Volume Roads – Indian Experience

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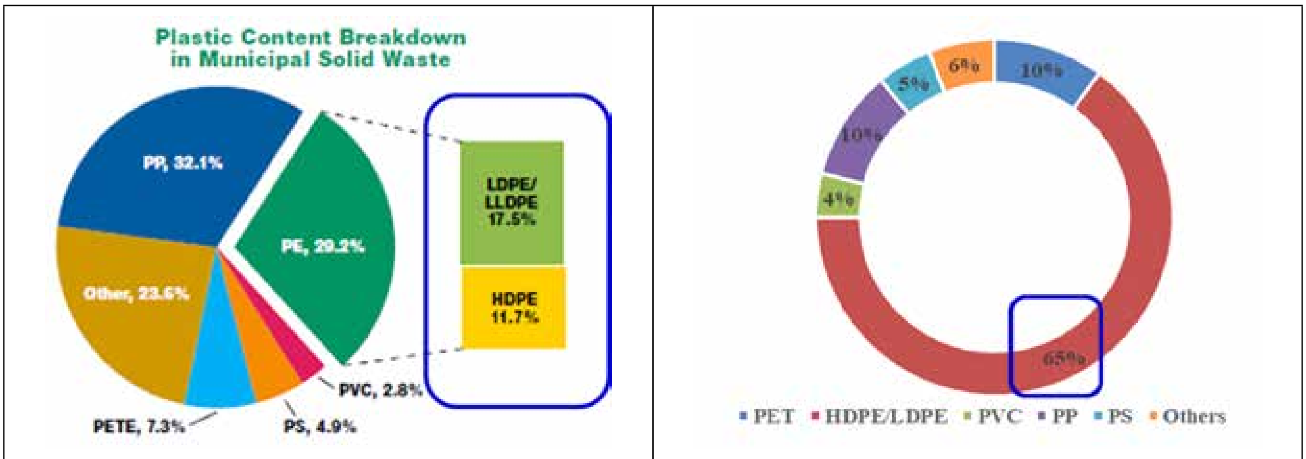
Abstract

This short communication presents some basic insight into the use of waste plastic for the production of hot mix asphalt (HMA). Summary of research in this area is highlighted using data from available literature. Further, brief findings from a field investigation carried out by National Rural Infrastructure Development Agency (NRIDA) is also discussed.

1. Background

More than 200 million tons of plastic is consumed globally and the annual increase is approximately 5%. In India, approximately 40-115 kg of plastic is generated per metric ton of solid waste. Cities like Lucknow produces 1200 MT/day of MSW per day while Delhi produces 6800 MT/day. Approximately 5.0 million tons per annum (TPA) plastic waste is generated in the country, which amounts to 15342 tons per day (TPD). Most commonly, the plastics are manufactured as packaging materials. The type and amount of plastic generated can be location specific. For example, Figure 1 compares the data presented by National Asphalt Pavement Association (NAPA) [1], and Central Pollution Control Board (CPCB) [2], India. It can be seen that in India almost 65% of the plastic waste produced is HDPE/LDPE, in contrast to the data by NAPA, which indicates only 29.2% share of HDPE/LDPE. Recyclability issue and un-organized disposal, associated with these materials, imposes ecological concern [3]. Therefore, avenues of re-using the end of life or post-consumer plastic products are being continuously researched.

Figure 1: Plastic content breakdown in MSW a) NAPA, 2020 b) CPCB, 2015



(a) (b)

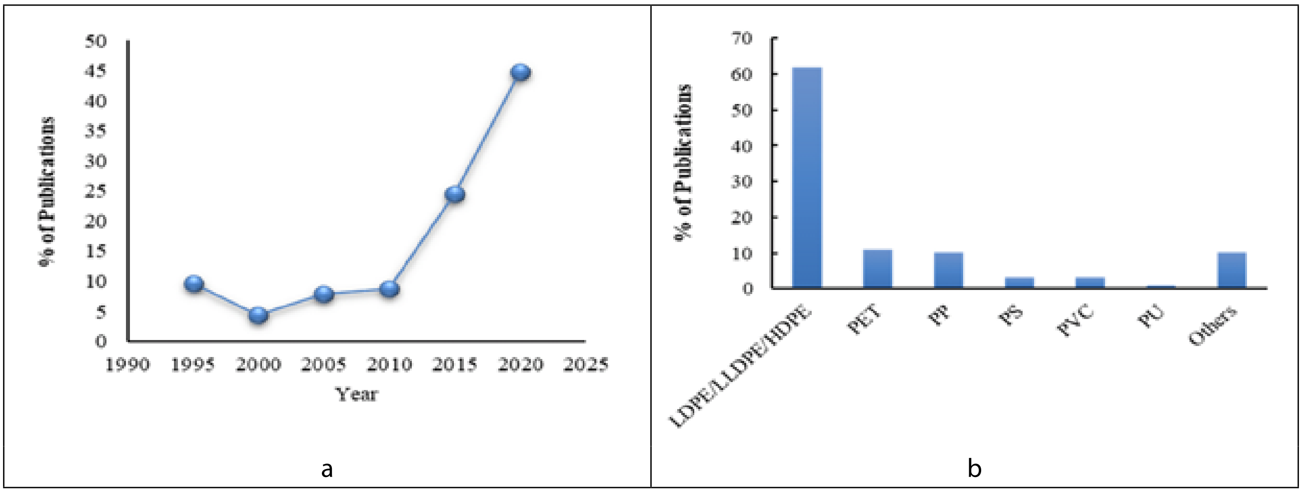
Depending on the country, on an average, more than 80% of the roads constructed are flexible pavement types. The flexible pavement structure comprises of granular and asphalt layers resting on a compacted subgrade. The surface layer of a flexible pavement is hot mix asphalt (HMA), which is a mixture of graded mineral aggregates and asphalt binder [4]. Asphalt binder, in an asphalt mix, provide cohesion, keeping the graded mineral aggregates glued in a dense mass. It imparts complicated viscoelastic property to the mix, making it a distinct and unusual engineering material [5]. Asphalt binder, with enhanced rheological properties, can significantly increase the resistance of the asphalt pavement to various distresses. Out of various improvement techniques, modification of asphalt binder, with virgin and waste polymers, has been found to be promising [6]. Polymers, when mixed with virgin asphalt binder (at high temperature and shear rate), forms a swelled polymeric network, which improves the rheological response of the asphalt binder. Polymer modified asphalt binder, depending on the type of polymer, increases the stiffness of the binder at higher temperature (thereby improving the rutting performance) and imparts flexibility at intermediate temperature (thereby improving fatigue performance). Waste polymers from commonly manufactured polymeric materials can help in reduction of environmental burden and will provide a sustainable solution for asphalt binder modification [7]. Use of waste plastic, for modification of asphalt binder and/or asphalt mixture, has been long considered as a suitable candidate in this direction.

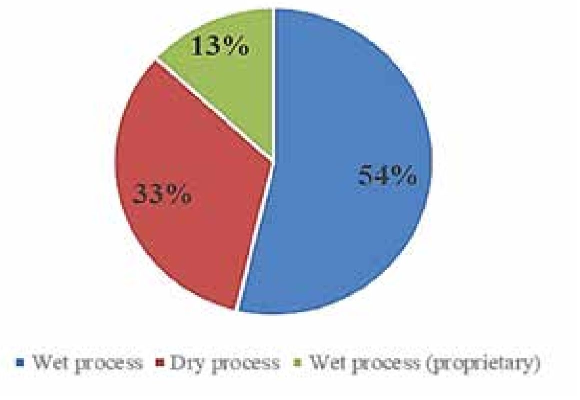
Studies on use of waste plastic in HMA has grown rapidly over a period of time [8,9]. Out of the various types of plastic, use of LDPE, LLDPE and HDPE is more popular. This is attributed to the lower melting point of these plastic waste which facilitates easy dispersion in the asphalt binder [10]. Figure 2 (a-d) shows some statistical data extracted from the available literatures. Waste plastic can be added in two forms in HMA:

(a) Wet process, in which waste plastic (typically, 2-8% by weight of the binder) is mixed with the asphalt binder and this modified binder is used for the production of HMA.

(b) Dry process, in which shredded waste plastic (0.2-1% by weight of aggregates) is mixed with hot mineral aggregates to form a melted plastic coat over aggregate surface. Further asphalt binder is mixed with the graded aggregates for the production of HMA.

Figure 2: Facts on use of waste plastics in HMA a) % publication upto 2020, b) Type of waste plastic being researched, c) distribution of wet and dry process, d) melting point ranges of different plastic types





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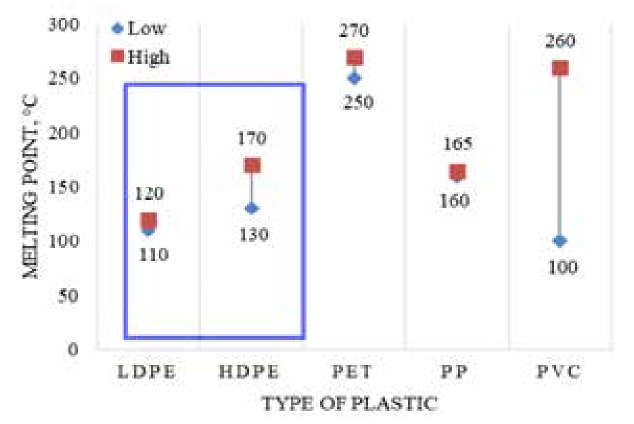
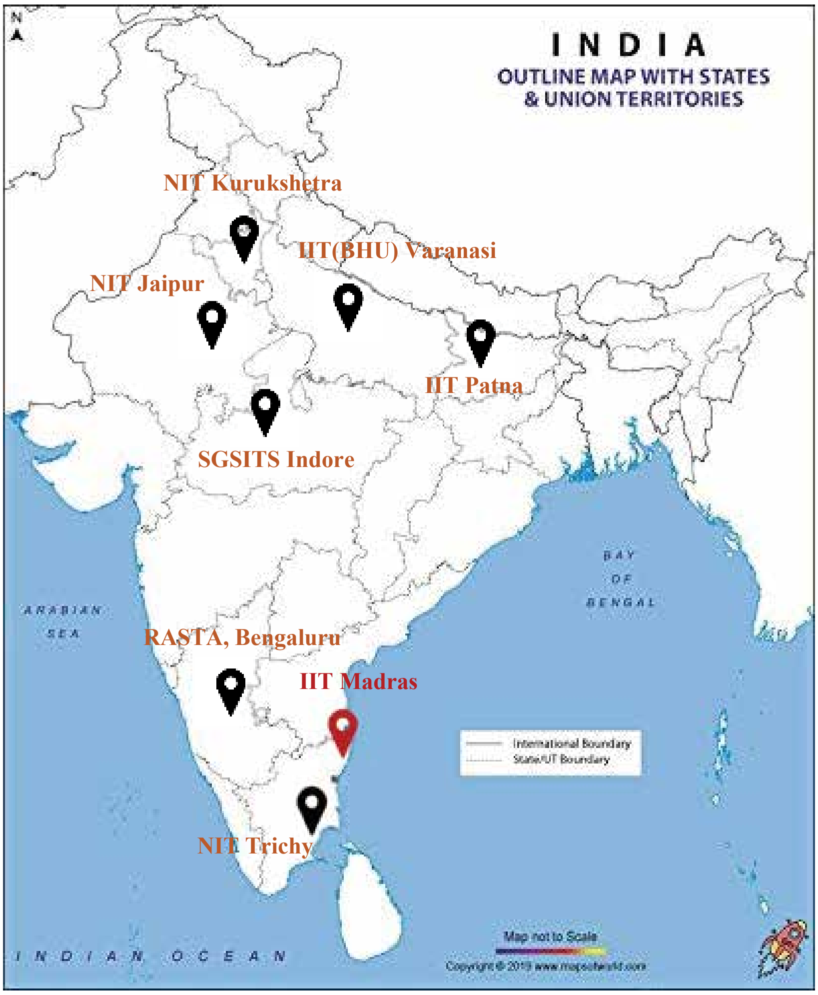


d

In India, IRC SP 98-2020 [11] provides the guidelines for use of waste plastic in HMA wearing course. This guideline is based on dry process, wherein only the use of LDPE and HDPE are recommended. Waste plastic, 8% by weight of bitumen, can be used to satisfy a set of Marshall mix design properties. Under the umbrella of Pradhan Mantri Gram Sadak Yojna (PMGSY), about 13,139 km length of rural roads have been constructed using waste plastic in India [12]. In order to promote the technology and appreciate the recycling strategy of using waste plastics in bituminous pavements, PMGSY undertook a 2 year field research study in the year 2019. Different states in the country where waste plastic technology was implemented were selected. Various research institutes (IIT Madras being the monitoring institute), as shown in Figure 3, were identified to carry out the field investigations. The main aim of the study was to carry out performance assessment of rural roads constructed using waste plastics and compare its performance the conventional HMA wearing course. The scope of the study included carrying out pavement condition survey (as per IRC 82-2015 [13]) for calculation of pavement condition index (PCI), field and laboratory testing of materials from different pavement layers, and to estimate the net present value (NPV) based on cost of construction and maintenance. The following section highlights some of the key findings from the research study.

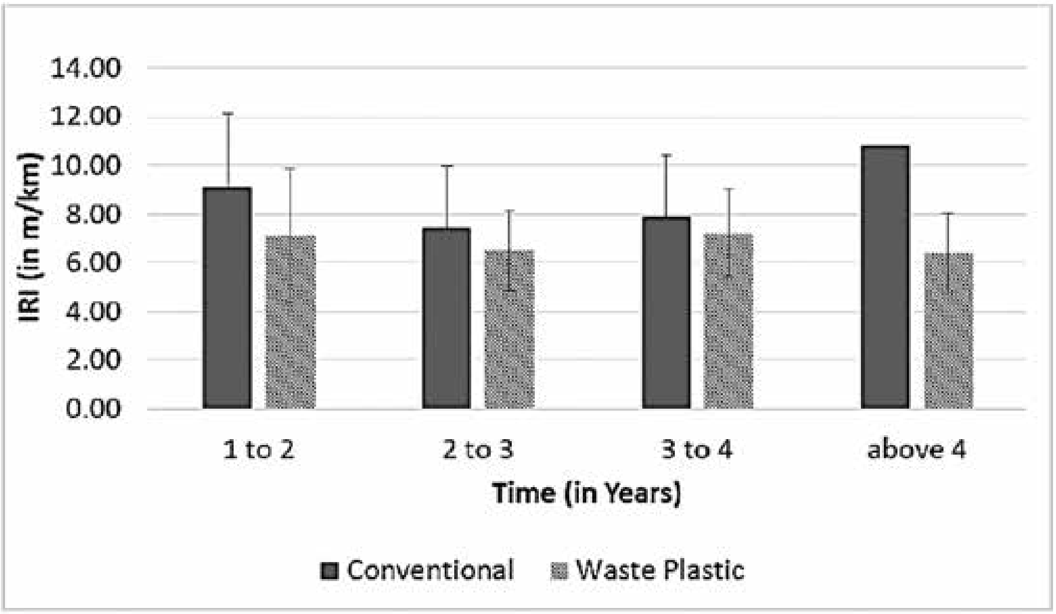
Figure 3: Partner institutes involved in the project



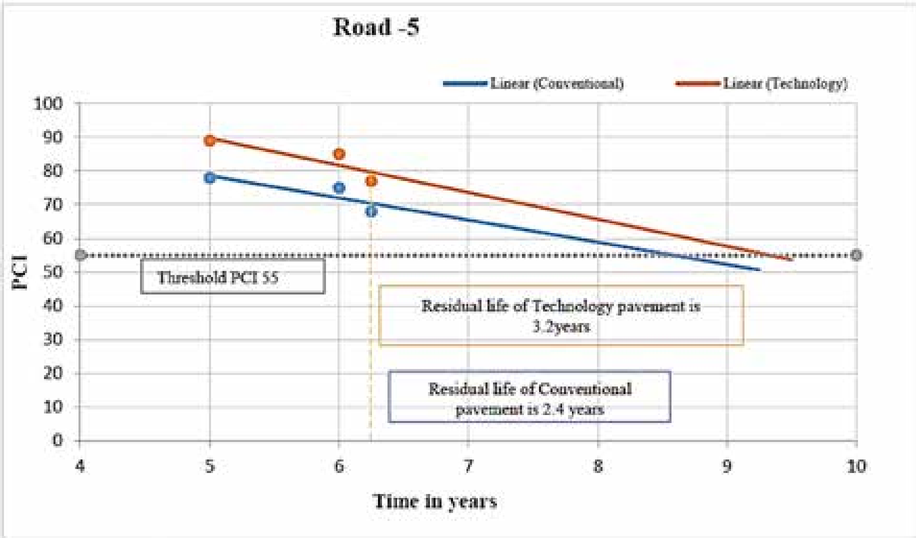
2. Key Findings from Field and Laboratory Investigation

Field investigation, laboratory study, and subsequent analysis carried out by different institutions were found to be in favor of using waste plastic for rural road construction. Some of the key findings are as follows:

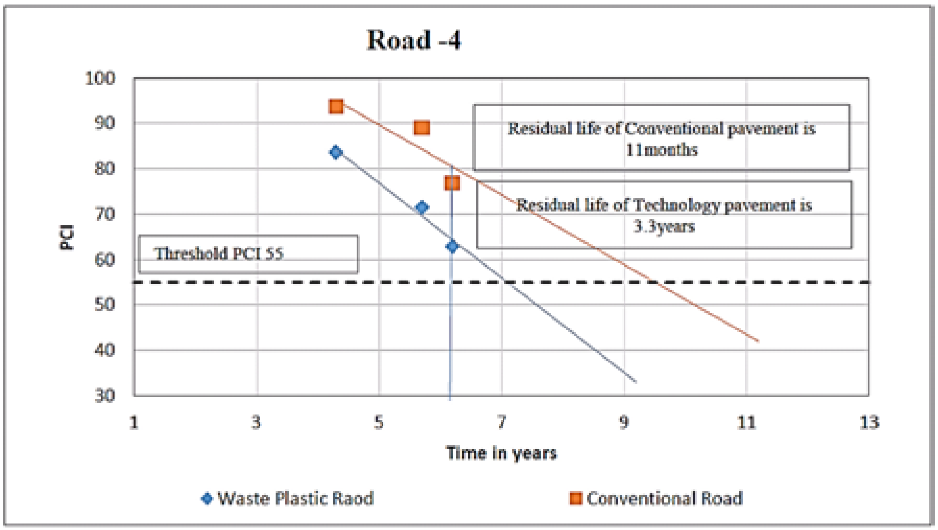
- Quantitative presence of waste plastics in HMA was not reported by most of the Institute. Due to difficulty in analysis of waste plastic modified asphalt mixtures, other advanced technologies are required. Based on IR spectroscopy results, RASTA Bengaluru concluded presence of 1.3% to 6.4% plastic content which is less than the desired value (8%).
- IRI values of waste plastic roads were found to be lower than the conventional roads in most of the test sections. This indicates that the rate of deterioration of waste plastic roads in lower than the roads constructed using conventional technology. Analysis obtained by IIT Patna is shown in Figure 4a.
- Data from Bihar indicated that material and transportation cost is lower for waste plastic roads. Additionally, total embodied energy (MJ/km) and embodied carbon (kgCO_2/km) is lower for waste plastic roads.
- Benkelman beam study carried out on sections in Rajasthan indicated similar to lower values of deflection in waste plastic road sections in comparison to conventional roads. Analysis based on IRI values were inconclusive.
- Comparison of road roughness data (MERLIN) from two cycles indicated that the percentage increase in roughness in conventional road is higher than for waste plastic roads. This indicates that waste plastic roads are more durable in comparison to roads constructed using conventional hot mix bituminous mixtures.
- Two out of three road sections in Bengaluru showed higher remaining life (based on a terminal PCI of 55) for waste plastic road sections in comparison to conventional roads. These variations are shown through Figure 4b to 4d.



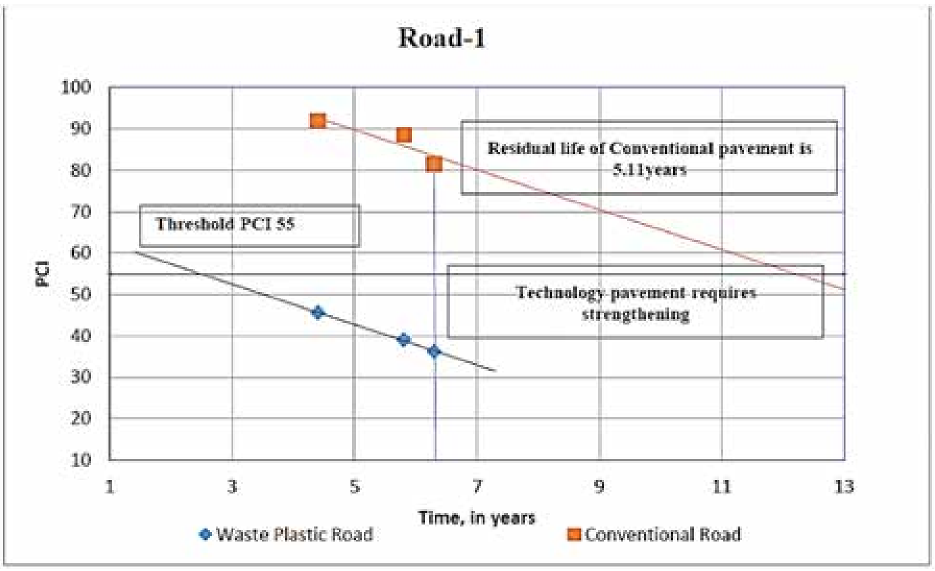
a


Road -5
Linear (Conventional)
Linear (Technology)
100
90
80
70
60
50
40
30
20
10
0
PCI
Threshold PCI 55
Residual life of Technology pavement is 3.2years
Residual life of Conventional pavement is 2.4 years
4
5
6
7
8
9
10
Time in years

b


Road -4
100
90
80
70
60
50
40
30
PCI
Residual life of Conventional pavement is 11months
Residual life of Technology pavement is 3.3years
Threshold PCI 55
1
3
5
7
9
11
13
Time in years
Waste Plastic Raod
Conventional Road

c


Road-1
100
90
80
70
60
50
40
30
20
10
PCI
Residual life of Conventional pavement is 5.11years
Threshold PCI 55
Technology pavement requires strengthening
1
3
5
7
9
11
13
Time, in years
Waste Plastic Road
Conventional Road

d

3. Conclusions

Based on literature review, present status of incorporating waste plastics in road construction, and investigations down by NRIDA, following conclusions can be drawn from the study:

a. Literature indicates success on use of wet modification technique for use of waste plastic in HMA. India presently used dry process which has more variability in terms of manufacturing and performance. Research is required in understanding and developing best practices for use of wet process in asphalt binder modification using waste plastics

b. More study is required to quantify the amount of waste plastic used during the construction of HMA with waste plastic.

c. Field study carried out by NRIDA indicates improvement in IRI, PCI and durability of pavement surface constructed using waste plastic. Therefore, use of waste plastic in HMA should be promoted, but through an engineered process. This will ensure optimization of cost and performance.

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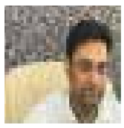

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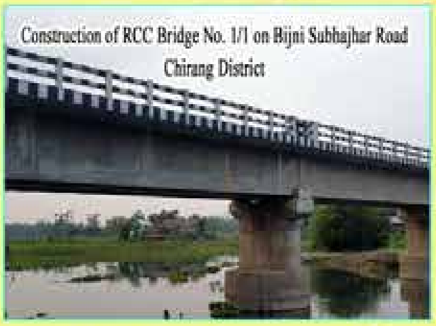
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Kalgachia

Side View of Polytechnic Institute Building
Barpeta

Experience on use of Coir in Rural Roads

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Abstract

Subgrade properties of flexible pavements could be improved by embedding a flexible member like geotextile as reinforcement on construction sites with soft ground. Coir has the highest tearing strength of any natural fibre, even when wet. As a result, the efficacy of coir geotextile in improving the functional performance of the pavement and increasing the modulus of the subgrade soil has been determined in this paper by conducting tests such as visual examination, Benkelman Beam Deflection (BBD) test, Geogauge, Dynamic Cone Penetration, Field CBR and static plate load tests on field-constructed test sections. In the current study, two types of coir geotextiles with varying mass per unit area (700 gsm and 400 gsm) are used to compare the mechanical behavior between the test tracks constructed. According to the findings, the geotextile with a larger apparent opening size is less effective than the geotextile with a finer mesh. The possibility of reducing the thickness of the pavement layer is investigated using the IITPAVE software suite. According to the study, using coir geotextile as reinforcement results in a significant reduction in aggregate layer thickness. Thus, the use of coir geotextiles as pavement reinforcement can help to reduce the demand for and consumption of rapidly depleting natural resources.

1. Coir Geotextile Reinforced Roads

To meet the needs of India's low-volume rural roadways, the road network must occasionally be oriented through areas where the subgrade soil is unsuitable for road building. The inherent potential for volume change in the presence of water, which impacts road performance, has made construction and maintenance of roads along unsuitable soils difficult. The subgrade must be treated adequately throughout the construction phase. Otherwise, due to the poor pavement performance, road user and maintenance expenses may increase drastically. Geotextile reinforcement is one approach to remedy subgrade. Coir geotextile, in particular, is being recognized as an appropriate material capable of providing an environmentally benign and ecologically sustainable solution. Coir geotextiles are appropriate for low-cost applications since coir is abundant and inexpensive when compared to other synthetic geotextiles. This research looks at how the coir geotextile interacts with the subgrade and granular subbase layer. This will aid in determining the strength properties of pavement sections with and without coir geotextile, as well as the design of a cost-effective section for a specific geotextile.

This paper proposes a practical implementation of coir geotextile improvement of weak subgrade soil. Eighteen roads (a total length of 37.88 km) have been built with coir geotextile reinforcement as part of Bharat Nirman Phase III. Various in-situ tests were carried out on such coir geotextile reinforced roads in order to evaluate the performance of coir reinforced pavements with varying thicknesses and coir geotextile types.

1.1. Coir geotextiles

Coir geotextiles, also known as "Coir Bhoovastra" in India, are a type of geosynthetic manufactured from coconut fibre derived from the husk of the coconut fruit. Coir geotextiles, like their polymeric counterparts, can be synthesised for specialised uses in geotechnical engineering. Due to its prime properties of reasonable durability, strength, and hairy surface, coir geotextile is clearly more favourable than jute or any other form of natural fiber-based geotextile, according to studies conducted on geotextiles (Beena, 2010). The natural features of coir geotextiles, such as resistance to rot, moulds, and dampness, make it a better choice than other natural fibres. As a result, coir geotextiles do not require any particular chemical treatment. Mesh matting with various standards can be found under the quality code numbers H_2M_1 through H_2M_{10}. India produces more than two-thirds of the world's coir and coir-related products. Kerala is the birthplace of the Indian coir industry, especially white fibre, accounting for 61% of coconut production and over 85% of coir products. The high lignin content of coir is said to contribute to an overall life of more than 2–3 years (Rao and Dutta 2005) and a long-term infield service life of 4–10 years in geotechnical applications (Rao and Dutta 2005). (Hejazi et al. 2012). It has uses in the mitigation of reflective cracking in asphalt overlays, stabilisation of road bases and soft subgrades, and lateral drainage because it accomplishes the tasks of separation, filtration, reinforcement, and drainage (Zornberg 2017).

1.2. Functions of coir geotextiles

Coir geotextile has been found to improve the load bearing capacity of subgrade soil by performing the simultaneous functions of separation, filtration, drainage, and initial reinforcement during one or two season cycles when applied at the interface of sub-grade and subbase.

1.2.1. Separation

When laid beneath the aggregate layer of an unpaved road, coir geotextile serves this purpose. A geotextile's separation role maintains the subgrade soils and aggregate layer intact, allowing the aggregate layer to maintain its intended thickness for the life of the road. The coir geotextile causes the entire layer to operate together like a flexible beam, spreading the weight across a greater region. This separation and confinement, as well as the additional strength generated by frictional interlock between the aggregate and coir geotextile, help to keep stress on the subgrade low and thus boost the structural section's load bearing capability.

1.2.2. Reinforcement

The coir geotextile's two main mechanisms are to restrict and restrain movement of the granular, structural layer, and to generate a vertical tension upward through the so-called membrane effect, which occurs when a fabric achieves high tensile strength under load. This helps the granular layer support vehicular loads while lowering the degree of stress on the sub-grade. The use of a coir geotextile at this level will prevent intermixing and maintain the pavement's effective depth.

1.2.3. Filtration and drainage

In the presence of moist or saturated soils, the coir geotextile will also serve as a filtration and drainage medium. High pore pressure causes soil slurry to push upward against the fabric during dynamic loading. The coir geotextile functions as a filter, preventing particles from polluting the aggregate layer while enabling water to readily drain through the aggregate or the coir geotextile plain. As a result, the subgrade consolidates more quickly.

1.2.4. Sealing

When impregnated with asphalt or other polymeric mixtures, a nonwoven geotextile accomplishes this function, making it comparatively impervious to both cross-plane and in-plane flow. Paved road repair is the most common application of a geotextile as a liquid barrier.

1.3. Specifications of coir geotextiles used

Table 1: Properties of Coir Geotextiles Used in the Low Volume Roads

Sl. No	Property	Grade	
		I	II
1.	Mass per unit area, g/m^2, *Min*	400	700
2.	Width, cm, *Min*	100.0 or as required	100.0 or as required
3.	Length, m	50 or as required	50 or as required
4.	Thickness at 2 kPa, mm, *Min*	6.5	6.5
5.	Ends (warp), runnage	180	150
6.	Picks (weft), runnage	160	160
7.	Break load, dry (kN/m), *Min* a) Machine direction b) Cross machine direction	 7.0 4.0	 8.5 8.0
8.	Break load, wet (kN/m), *Min* a) Machine direction b) Cross machine direction	 3.0 2.0	 7.0 4.5
9.	Peak load, dry (kN/m), *Min* a) Machine direction b) Cross machine direction	 7.5 4.0	 9.0 8.0
10.	Peak load, wet (kN/m), *Min* a) Machine direction b) Cross machine direction	 3.0 2.0	 8.5 5.5
11.	Trapezoidal tearing strength (kN) at 25 mm gauge length, Min a) Machine Direction b) Cross Machine Direction	 0.18 0.15	 0.35 0.30
12.	Mesh size, mm, *Min*	20.0 × 16.75	7.50 × 7.30

1.4 Installation of coir geotextile

According to Clause 7 of IS 15871, the following order was followed while installing Coir geotextiles in the rural roads:

1. Excavated the subgrade to the required level, removed all extraneous materials, and compact to the required density.

2. The subgrade was cambered and profiled according to the specifications.
3. Next the coir geotextile was laid over the subgrade. By pushing the roll in the direction of the reinforcement run, the roll was unwound. The exposed base end of the reinforcement was folded and attached to the formation by pinning it. The free end of the reinforcement was manually tightened by pinning once the roll has been entirely unwound.
4. The first layer of material in the subbase or base course with grading as per relevant MORD specifications was then spread over the geotextile.

Figure 1: Construction of coir geotextile reinforced road

(a) Preparation of subgrade

(b) Stiffness determination

(c) Field density determination

(d) Laying of coir geotextile

(e) Pinning the edges of coir geotextiles

(f) Laying & compaction of GSB

(g) Laying & compaction of base layer

(h) Laying of premix concrete

(i) Finished road

1.5. Tests conducted on coir geotextile reinforced roads

Figure 2 shows the various tests conducted on the subgrade of the coir geotextile reinforced and unreinforced pavement subgrades. To reveal the subgrade layer, the asphalt concrete layer, base layer and subgrade layers were sliced to a diameter of 50 cm and the tests were carried out on the exposed layer after it has been leveled.

Figure 2: Various tests conducted on the coir geotextile reinforced pavement

1.6. Test Results

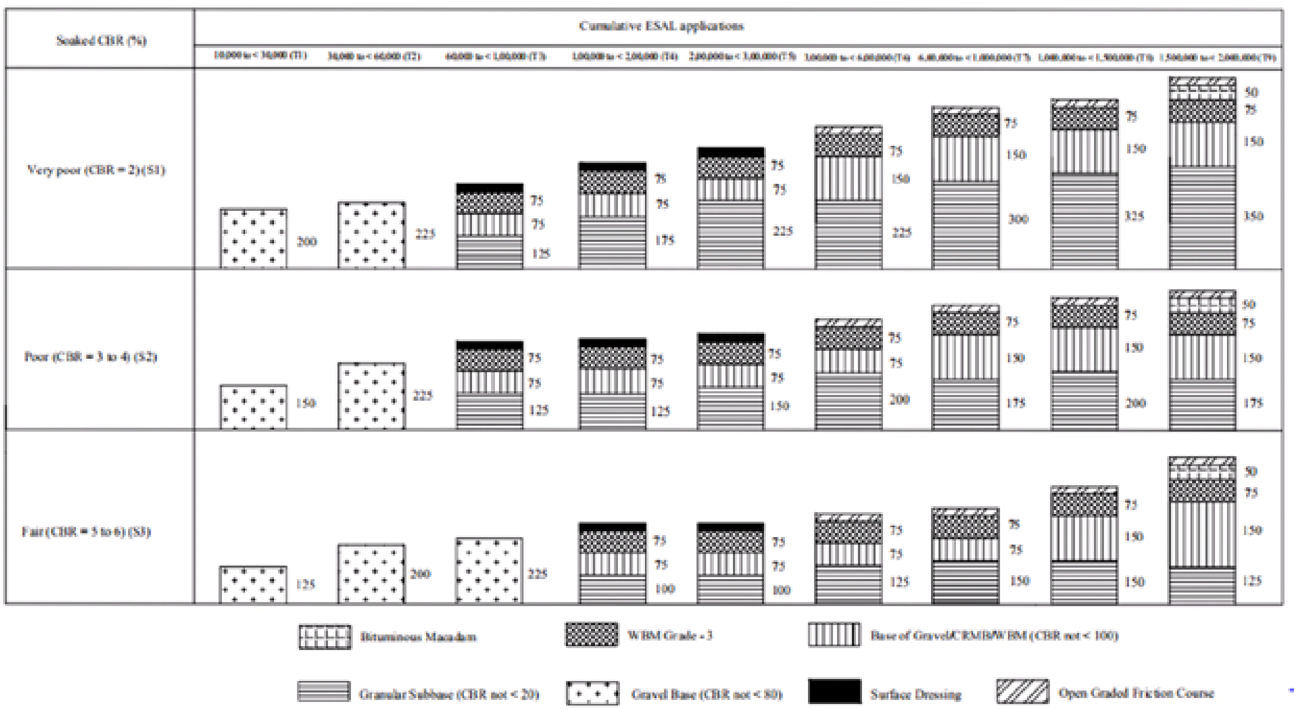
Table 2: Elastic modulus values obtained from various tests

Test Section		Subgrade Elastic Modulus E (MPa)		
		Geogauge	Plate load test	DCP
Control section		48.5	46.9	49.9
Subgrade reinforced with	700 gsm	68.5	69.8	106.0
	700 gsm	71.8	66.0	100.5
	400 gsm	59.0	61.5	85.0
	400 gsm	61.0	58.7	74.9

As per Geogauge test results, MIF = 1.41-1.48 (700 gsm); 1.22-1.26 (400 gsm)
As per Plate load test results, MIF = 1.41-1.49 (700 gsm); 1.25-1.31 (400 gsm)
As per DCP results, MIF = 2.0-2.12 (700 gsm); 1.5-1.7 (400 gsm)

The software suite IITPAVE was used to determine the extent to which the thickness of the subbase layer may be reduced. The safe section was determined by comparing the maximum vertical compressive strain on the coir geotextile reinforced subgrade to the maximum vertical compressive strain value of the unreinforced road section prescribed in IRC SP 72 (2015). Figure 3 shows a design template that has been created in this manner.

Figure 3: Sample design chart developed using IITPAVE



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A Framework for Road Asset Management

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Abstract

The effective management of roads requires a holistic approach that addresses all contributory factors. The Road Preservation Pyramid provides a framework for governments and road agencies to assess their performance in road management and monitor changes over time. It also provides a framework for governments to compare the performance of road agencies within the county and identify weak areas in asset management that can be addressed through policy and institutional reform, training and technical support. The performance of the road agency under each building block of the Pyramid is assessed through a series of questions which have a "yes" or "no" answer. The results for each building block can be weighted according to the importance of the building block in the asset management. The results are presented graphically to highlight areas of strength and weakness. The pyramid concept can be used to analyse performance in other aspects of road provision, as well as the management of other infrastructure assets.

1. Introduction

The sustainable provision of road infrastructure in developing countries is essential for economic and social development. Roads carry transport services which allow the rural population to reach markets, basic services and employment opportunities. Despite the importance of the road network, rural roads agencies in developing countries often have low management capacity and are provided with limited funds. A large proportion of the rural road network remains in poor condition. When funds are available for rural roads, they are often used to reconstruct roads in poor condition rather than for maintenance of the existing network.

Governments need to break the cycle of build-deteriorate-rebuild and instead implement efficient long term maintenance of road assets. Ongoing maintenance requires a commitment to regular funding, but the economic benefits are high. Governments need to adopt a new and holistic approach which considers all factors contributing to road asset management. The Road Preservation Pyramid provides a framework for this alternative approach.

2. Road Preservation Pyramid

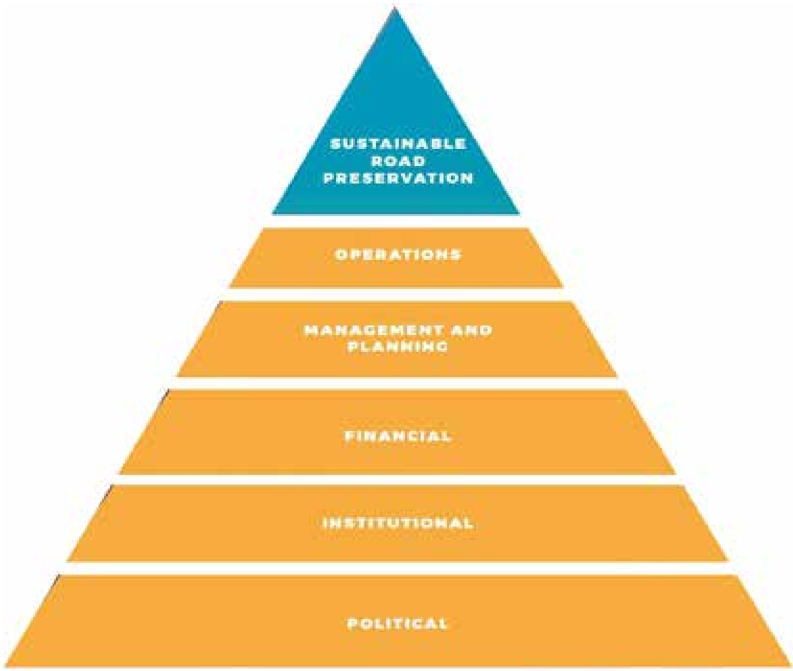
2.1. Pyramid Concept

"Pyramid Power" is the belief that the ancient Egyptian pyramids and objects of similar shape can confer great benefits. It is believed that the Great Pyramid of Giza can collect and concentrate electromagnetic energy in its chambers and at its base. There have been claims that small models of pyramids can preserve food and maintain the sharpness of razor blades[1].

[1] Source: Wikipedia.

The pyramid concept was adopted by the World Road Association (PIARC) to support its call for greater focus on road maintenance. The "Road Maintenance Pyramid" (Figure 1) appears in the PIARC publication 'Preserve your Country's Roads to Drive Development' of 2016. PIARC recognised that the maintenance challenge is "multi-dimensional" and is influenced by "a number of inter-related factors that can be viewed as a hierarchical pyramid". Government policy and political support for road maintenance provide the foundation for the pyramid. Effective institutional arrangements supported by a predictable and reliable flow of funds provides the basis for planning and managing successful delivery.

Figure 1: PIARC Road Maintenance Pyramid



2.2. Economic Growth through Effective Road Asset Management (GEM)

Between 2014 and 2020 the United Kingdom (UK) Department for International Development (DFID) supported a research programme for the rural transport sector in Africa and Asia known as the "Research for Community Access Partnership" (ReCAP). The programme was active in 12 countries in Africa and five countries in Asia. ReCAP was a continuation of the Africa Community Access Programme (AfCAP), which funded research in seven African countries between 2008 and 2014.

The focus of AfCAP and ReCAP was on strengthening the evidence base for more cost effective and reliable low volume roads and transport services, thereby influencing policy and practice in the participating countries[2]. One of the projects funded by ReCAP concerned "Economic Growth through Effective Road Asset Management" (GEM). The GEM project promoted new approaches to rural road asset management, with field work carried out in Sierra Leone, Uganda, Zambia, Tanzania and the Western Cape Province of South Africa.

The GEM project developed a framework for measuring the performance of roads agencies in road asset management based on the PIARC pyramid concept. The "technical" building block was added, and the pyramid was renamed as the "Road Preservation Pyramid" (Figure 2).

[2] Outputs of ReCAP can be found at https://www.research4cap.org/index.php/resources/rural-access-library

Figure 2: The Road Preservation Pyramid (GEM)

The Road Preservation Pyramid identifies the requirements for effective road asset management. Good performance is required by government and road agencies under all of the six building blocks to achieve the goal of sustainable road preservation. Good performance is not guaranteed, for example, by installing a bespoke asset management system in a road agency, or through the procurement of equipment for force account maintenance operations. Effective asset management requires proactive alignment of asset management policy, organisational strategy, asset management plans and implementation.

The monitoring framework developed by the GEM project enables road agencies to assess their overall performance. Agencies can compare their performance with a minimum benchmark of expected performance and with the performance of other agencies in the same country or region. Road agencies can use the framework to monitor changes in their performance over time and to identify weak areas in their road asset management.

2.3. Building Blocks

The base of the pyramid is the "**External**" building block. This includes high-level political support and related government policy upon which the attainment of all the other factors depends. A conducive external environment including a national policy supporting road preservation is a prerequisite for sustainable road asset management. Performance under this building block is typically assessed by considering the following issues:

- Does the government have a rural road asset management policy which is supported by senior decision makers and adopted at the highest level in government?
- Does the road agency carry out informed consultation and open communications with road users and other stakeholders to understand their needs and expectations?

Performance under the "**Institutional**" building block is assessed by considering a range of issues contributing to the performance of the agency. These include whether:

- the agency has a corporate vision and mission statement which considers stakeholder needs and expectations;

- the basic levels of service for roads have been defined and agreed with stakeholders;
- emergency response plans are in place and understood by key members of staff;
- the agency's organisational structure identifies roles, responsibilities and competencies of key staff and is aligned with its AM policy, strategies, objectives and plans;
- the agency provides training opportunities for staff; and
- road agency staff salaries are comparable with private sector positions.

The "**Financial**" building block is often the weakest component of the pyramid, with inadequate resources provided for roads. Performance is assessed by considering:

- Is there a stable, adequate and sustainable source of funding for road maintenance?
- Is an annual valuation carried out of road infrastructure assets?
- Is a costing framework in place for determining unit costs of works?
- Is a budgeting and programming processes in place for a prioritised maintenance and investment plan?
- Are robust financial accounting and auditing procedures in place?

Performance under the "**Planning and Management**" building block is assessed by considering:

- the existence of an appropriate asset management system that contains network definition (road and bridge inventory information) and network condition data;
- asset utilization estimates and forecasts, including the existence of bottlenecks on the network; and
- regular updating of the database including traffic counts and visual condition assessment surveys for the preparation of prioritised annual, medium and long-term maintenance and development plans.

Assessment of performance under the "**Technical**" building block typically includes whether the government or road agency's design standards for roads are:

- clearly defined;
- appropriate to local conditions and the needs of road users;
- affordable; and
- sustainable.

The "**Technical**" building block can also consider the technical aspects of road asset management, for example road referencing systems, condition monitoring methodology, roughness progression curves and gravel loss equations.

The "**Operational**" building block concerns the planning and scheduling of maintenance, procurement of service providers and technical compliance. Performance under this building block is typically assessed by considering:

- Is an appropriate form of contract used for road maintenance?
- Does the agency have an appropriate balance between in-house (force account) operations and outsourced maintenance works?
- Are non-core activities outsourced by the agency?
- Is the scheduling of maintenance works aligned with the financial year and the rains?
- Does the agency carry out independent technical auditing of works?

2.4. Performance assessment

The GEM project used a questionnaire to assess the performance of the participating road agencies. The questionnaire included four sub-questions under each topic of the six building blocks. Each building block typically included seven topics. The average of the scores for each topic gave a score (out of four) for each building block.

In discussions with the participating agencies, it was realised that the building blocks contributed to different extents to achieving satisfactory asset management performance. The External building block was given the highest weighting as it was regarded as the most important determinant of performance. The Institutional, Financial, Planning and Management, Technical and Operational blocks were given progressively smaller weightings. The weightings were converted to coefficients by dividing the weighting by the sum of all of the weightings. The coefficients were then multiplied by the self-assessment questionnaire score for each building block to yield a score for each block. The sum of these results gives the "Road Sector Sustainability Assessment Score", with a maximum value of 4. This score is divided by four to give the Road Sector Sustainability Index (RSSI) applicable to the road agency.

The derivation of the RSSI for one of the rural roads agencies that participated in GEM is shown in Figure 3. The weighted average of the scores under each building block gives a "Road Sector Sustainability Assessment Score" of 1.8, which is rated as "fair" under the assessment criteria. The RSSI was 0.46.

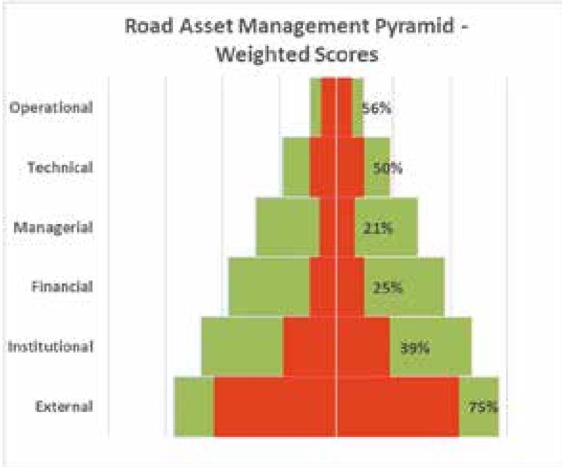
Figure 3: Derivation of the Road Sector Sustainability Index

Weighting Ranking	Building Block	Max. Possible Score	Agency score	Weighting
1	External	4	3.0	0.29
2	Institutional	4	1.6	0.24
3	Financial	4	1.0	0.19
4	Managerial	4	0.9	0.14
5	Technical	4	2.0	0.10
6	Operational	4	2.3	0.05
Road Sector Sustainability Assessment Score			1.8	1.00
Road Sector Sustainability Rating			Fair	
Road Sector Sustainability Index (RSSI)			0.46	(Scale: 0 - 1)

Assessment Scoring Criteria:	
< 0	Very Poor
0-1	Poor
1-2	Fair
2-3	Good
3-4	Very Good

The outcome of the performance assessment can be presented graphically as shown in Figure 4. This particular agency showed good performance under the "External" building block but poor performance under "Financial" and "Technical". Using this method a road agency can monitor its performance over a period of time, with the objective of increasing the area within the line on the radar diagram. Governments can use this method to compare the performance of the different agencies responsible for roads in the country. Under the GEM project the analysis of the questionnaire scores enabled each participating road agency to identify specific actions required to address shortcomings in their road asset management. Actions might include policy and institutional reform in the rural road sector, or technical assistance and training to support improved planning and operations.

Figure 4: Outcome of the GEM performance assessment



3. Other Applications of the Pyramid Concept

The pyramid concept is not only useful for the assessment of performance in the management of roads. It can be used to assess performance in other aspects of road provision, for example axle load control, and the management of other infrastructure assets such as buildings, water supplies and electricity generation, transmission and distribution. In his paper entitled "A View of Maintenance Around the World", S. Bradley Peterson of SAMI Corporation refers to the "Asset Healthcare Triangle", which "helps people see where they have gone wrong in the past" in the maintenance of plant and equipment. Peterson states that "many times too much emphasis is placed on higher level activities without having the enabling base of the triangle in place".

4. Conclusion

The economic benefits of effective road maintenance are high because effective maintenance avoids the high cost of rehabilitation or reconstruction. However, ongoing maintenance requires a commitment to regular funding from the government and road users and an enabling policy and institutional environment. It is not sufficient to install road asset management systems in road agencies and expect this to result in effective road maintenance. A holistic approach is required which addresses all six building blocks of the Road Preservation Pyramid.

The Road Preservation Pyramid provides a useful framework for governments and road agencies to assess their performance in road management and monitor changes over time. It facilitates the identification of weak areas in road asset management that can be addressed through policy and institutional reform. Improved performance in road asset management will lead to the sustainable provision of road infrastructure, which is necessary for economic and social development.

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Preventive Maintenance and Performance Based Maintenance Contracts for Asset Management of Rural Roads

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Abstract

Huge investments are made for the creation of rural road infrastructure in the country. It is essential that the rural roads that are constructed over the decades under the Pradhan Manti Gram Sadak Yojana are preserved with timely and appropriate maintenance during the design life of the pavement. The maintenance of the rural road infrastructure warrants selection of appropriate preventive maintenance and preservation techniques and also creation of a data base to develop appropriate pavement asset management pogram. The benefits of preventive maintenance treatment techniques are discussed. A performance based maintenance contract technique is presented.

1. Background

Pradhan Mantri Gram Sadak Yojana was launched in December 2020 to provide all-weather connectivity to rural habitations and is fully funded by the Government of India. Maintenance of these roads is a subject of the State Governments. An efficient road infrastructure is very important for economic and social development of any country. The benefits from the investment in rural road sector are indirect and long term and, not immediately visible and the societal benefits are very high. Creation of road assets is important. However if timely preservation and maintenance of these road infrastructure is not carried out, the society has to pay heavily for an inefficient and ill preserved road network.

The task of maintaining the road network in the country which now totals about 6.3 million km which consists of over 6.0 million km of other roads including rural roads, is an issue of concern. It requires not only adequate resources but also proper planning and innovative way of maintenance. Road maintenance managers recognize the value of timely preventive maintenance. However, because the benefits of maintenance of rural roads are often poorly defined, preventive maintenance programs are in many cases, not able to compete with other programs, which are reactive and costly. More effort is needed to inform decision makers of the benefits and cost effectiveness of preventive maintenance for pavements in particular. There is a need to bring a long term performance based contract for the maintenance of the rural roads, so that assets created with huge investments last long and serve their intended purpose of providing all-weather connectivity to the rural habitations and offer the required performance and level of service to the rural India.

2. Importance of a Rural Pavement Asset Management System

Pavement asset management system is emerged as an important tool to aid in the identification and prioritization for maintenance and rehabilitation treatments on low-volume roads. A rural pavement management system is composed of:

- A database for storing pavement performance condition and inventory information
- Performance models to predict the pavement deterioration rates during the design life
- Treatment rules to trigger timely maintenance and rehabilitation activities, and
- Analytical routines to evaluate the information so that improvement programs can be developed.

The success of a pavement program is based on selecting the right treatment for the right pavement at the right time. The real challenge lies in selecting the right pavement section for the maintenance, assess the structural and functional condition, select the appropriate maintenance treatment and predict the optimal timing to apply the appropriate treatment to the project road. Time is the element by which cost-effectiveness is defined. To determine the optimal timing, performance standards and indices for various treatment types need to be established through research and the collection of performance data.

One of the preservation approaches that has seen an increased attention over the last few years is the implementation of a pavement preventive maintenance program, which is defined by the AASHTO Standing Committee on Highways as follows:

'Preventive maintenance is the planned strategy of cost effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system [without increasing the structural capacity].

3. What is Pavement Preservation?

As a component of system management, pavement preservation is aimed at preserving the investment in our highway system, extending pavement life, and meeting the needs of the road users in terms of ride quality and safety. It is the timely application of carefully selected surface treatments to maintain or extend a pavement's effective service life. Pavement preservation does not include new or reconstructed pavements or any activity that significantly increases the structural capacity of the existing pavement. An effective pavement preservation program encompasses a full rage of preventive maintenance techniques and strategies, such as fog seals, slurry seals, surface dressing, micro-surfacing, thin overlays, crack sealing etc. A traditional rehabilitative approach allows the original pavements section to deteriorate to a fair to poor condition in terms of both ride quality and structural condition. At this point, structural damage has occurred, the objective of the rehabilitation treatment is to repair that damage and restore the pavement. Thus, the traditional approach is reactive and can be costly and time-consuming process.

4. Implementing the Pavement Preservation Philosophy

A major hurdle in establishing a pavement preservation program is dedicated funding. In many highway agencies budgets, maintenance activities have traditionally received "bottom of the barrel" funding. So, from where will these dedicated funds come? That funding is the responsibility of lawmakers, budgetary planners, and upper level management. However, these individuals along with the public, need to be convinced that every rupee spent now on pavement preservation can save upto six rupees in future. Therein lies the importance of a comprehensive training program jn conjunction with the champions who are committed to fostering the success of pavement preservation programs and techniques.

Preventive maintenance programs have been shown to be cost-effective because they slow the rate of pavement deterioration, essentially delaying the need for major rehabilitation activities by several years. The delay in rehabilitation needs is more than offset by the fairly low cost of preventive maintenance treatments, resulting in dramatic cost savings for preserving the road network. The deferred need for rehabilitation is reflected in the modified performance curve due to the application of a preventive maintenance treatment. Other benefits can be realized through the use of a pavement preventive maintenance program. Some of the benefits documented in the literature are:

- Higher customer satisfaction with the road network
- Ability to make better, more informed decisions on an objective basis
- More appropriate use of maintenance techniques
- Improved pavement conditions over time
- Increased safety and
- Reduced overall costs for maintaining the road network.

5. The Road Ahead

An issue that is of emergence is the performance related specifications (PRS) and associated performance level warrantees. In the future, pavement contractors may be required to guarantee the performance of a pavement for a specified service life after the initial build and maintenance period. To ensure the desired level of performance, the contractor will be responsible for performing maintenance or preservation activities on a selective basis. It is critical that the concepts and techniques of pavement preservation are passed on to the contractor to ensure that maintenance is preventive rather than reactive. Therefore, pavement contractors must be part of the target audience.

6. Performance Specified Road Maintenance Contracts

The traditional way of contracting road maintenance is based on a schedule of unit prices and estimates of quantities. The works to be performed are specified in the contract and payments are based on executed measured works. By contrast, a Performance Specified Road Maintenance Contract defines the minimum conditions of road, bridge, and traffic assets that have to be met by the contractor. Payments are based on how well the contractor manages to comply with the performance standards defined in the contract, and not based on the amount of works executed. The nature of the contract allocates responsibility for work selection, design and delivery solely to the contractor. Hence, the choice and application of technology and the pursuit of innovation in materials, processes and management is all up to the contractor. This allocates higher risk to the contractor compared to the traditional contract arrangement, but on the other hand may increase the contractor's margin where improved efficiency and effectiveness of technology, process, design or management reduces the cost of achieving the specified standards. To define these standards is rather a challenging task. The aim is to minimize total systems cost, including the long-term cost of preserving the roads as well as the cost to the road user. To avoid ambiguity, performance standards have to be clearly defined and objectively measurable. Typical performance standards includes maintenance of the rural roads at minimum or desired Pavement Condition Index (PCI), ride quality in terms of roughness or in terms of maximum permissible values of rutting, cracking, number of potholes, patch area, shoulder condition etc.

7. Advantages of Contract Performance Based Maintenance

The principal advantage of contracting out road maintenance based on performance standards is its potential for reducing road maintenance costs and improving road conditions, especially in India, where mega rural road development program has been implemented. Another important advantage of this new contracting scheme is that the users know exactly the road conditions they can expect and demand. Unfortunately, improper implementation of this scheme could backfire and produce adverse effects.

8. Preparation of Bidding Documents and Bidding Process

Prior to the preparation of the bidding documents a number of steps have to be taken to define the road network to be contracted out, to make an inventory of the assets involved and to determine its condition, to select and define the performance indicators, select and define the methods of measuring those indicators, to define the likely maintenance and possibly rehabilitation works, and to prepare preliminary cost estimates. The data on the inventory and the conditions of the assets are given to the potential contractor as reference only. It is the responsibility of the contractor to make sure that the information is correct, since the agency has to assume responsibility for meeting the performance criteria.

9. Summary

1. A rural pavement management system requires creation of a database on pavement condition and also road inventory information periodically. Performance prediction models are to be developed for low volume roads duly considering subgrade soil type, traffic level, climate and environmental conditions and also the construction quality, so that timely and effective pavement preservation programmes can be developed.
2. An issue that is of emergence in maintenance of the rural road infrastructure is the performance related specifications (PRS) and associated performance level warrantees, penalties for deferred maintenance and also rewards for maintenance above the threshold levels of performance requirements. A suitable second step could consist of four to five year contracts for a network of roads in a district at different ages and traffic levels.
3. The key to the success of a rural road asset management programme is the dedicated funds for the maintenance. Even though the maintenance of the rural road infrastructure assets is the responsibility of the state governments, efforts should be taken to create dedicated funds for the maintenance as well as the mechanism of the management of the funds through the stakeholders and through the use of innovative tools based on artificial intelligence and machine learning techniques.

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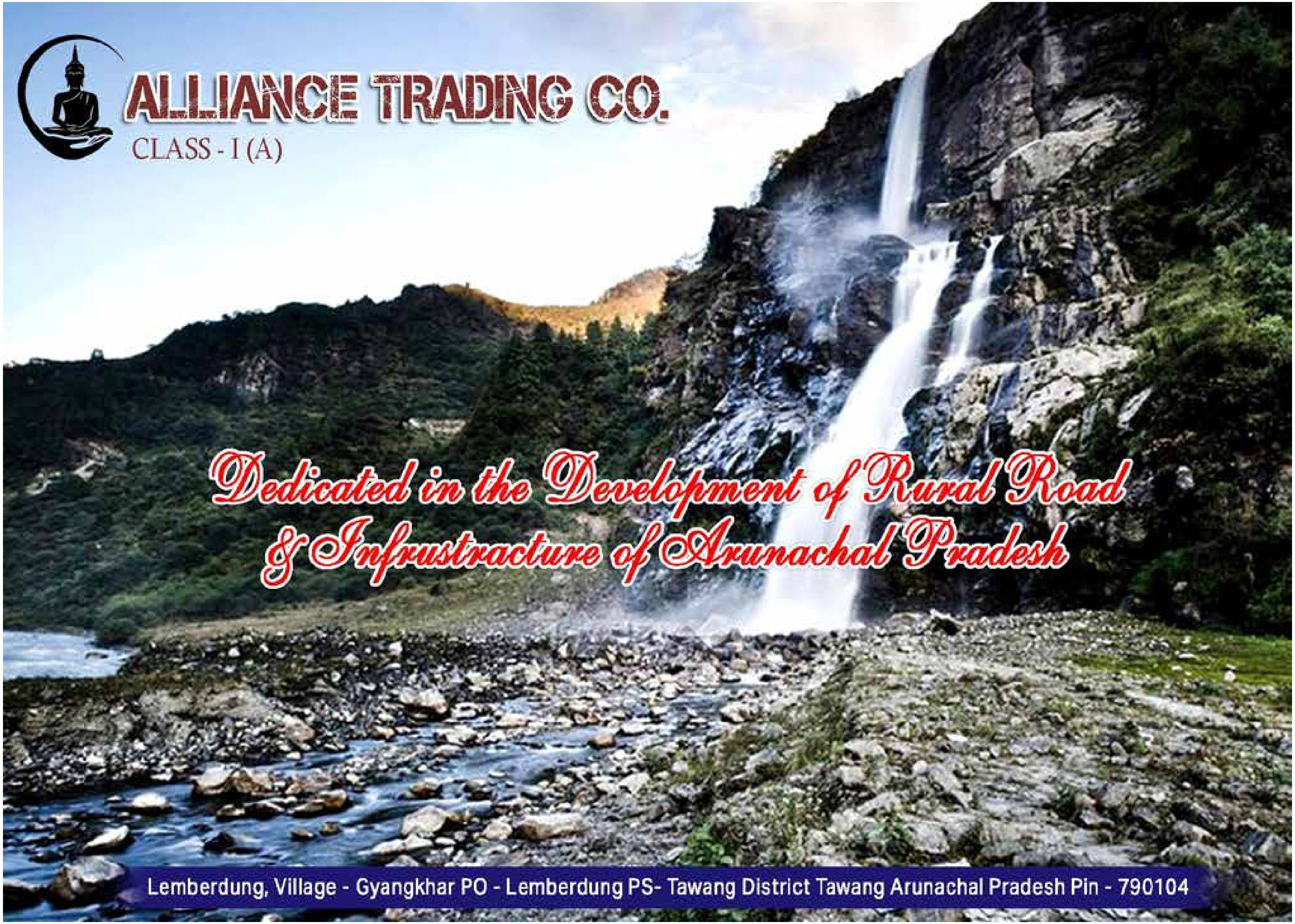
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International Best Practices in the Provision of Low Volume Roads

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Abstract

The traditional approaches to providing low volume roads (LVRs) in many tropical and sub-tropical countries are generally based on technology and research in temperate climates. While these "standard" approaches might still be appropriate for much of the relatively heavily-trafficked primary road network, they remain conservative, inappropriate, and too costly for application on much of the relatively lightly trafficked LVR networks in Asia and Africa. Thus, more appropriate approaches need to be considered in facing the challenges of improving and cost-effectively expanding LVR networks. This paper presents some examples of relatively recent developments in LVR provision based on research that has been carried out during the past several decades in many Asian and African countries.

1. Introduction

The sustainable provision of road infrastructure to rural communities in any country is essential for their livelihoods. It may be viewed as a universal human right to facilitate poverty reduction, food security, access to markets, healthcare, education and social and economic opportunities. In many developing countries, almost the entire rural road network is unsurfaced, and the cost of maintaining it to provide all-year passability has generally proved to be insurmountable. The resulting poor road conditions have impacted the welfare of rural communities by reducing their growth opportunities and negating the benefits in other sectors designed to improve their livelihoods.

While there are potentially significant life-cycle benefits from upgrading unsurfaced rural roads to a paved standard, the cost of following traditional standards and specifications can be prohibitive. This is because these approaches tend to be overly conservative and ill-matched to the requirements of the local road environment. As a result, they are generally far too costly for application to most rural road networks in developing countries. Fortunately, extensive research and investigations have been carried out into the performance of LVRs in the Asian and African regions in the past thirty years (Gourley and Greening, 1999; Paige-green, 1999; Rolt et al., 2017). This has identified many anomalies in our pervious understanding of the performance mechanisms of such roads and has also questioned many of the accepted paradigms associated with their design. These findings have prompted a need to re-think many aspects of the provision of LVRs in developing countries.

This paper aims to engender a greater awareness of relatively recent developments in LVR provision that allow such roads to be provided more affordably and sustainably than hitherto.

2. Characteristics of Low Volume Roads

There following specific characteristics of LVRs affect the manner of their provision and need to be fully appreciated:

- Traffic on most LVRs is relatively low, typically below 300 motorized vehicles per day.
- They are constructed mainly from naturally occurring, often "non-standard", moisture-sensitive materials.
- Pavement deterioration is driven primarily by environmental factors, particularly moisture, with traffic loading being a relatively lesser influential factor and drainage being of paramount importance.
- The alignment may not necessarily need to be fully "engineered", especially at very low traffic levels, with most sections following the existing alignment.
- There is a need to cater to a significant amount of non-motorized traffic, especially in urban/peri-urban areas, coupled with a focus on adopting a range of low-cost road safety measures.
- Variable traveling speeds will seldom exceed 80 km/h, as dictated by local topography.

An appreciation that conventional economic analysis often cannot justify the investment of public funds in the provision of such roads due to the difficulty of quantifying the many intangible socio-economic and environmental benefits.

As described above, the unique characteristics of LVRs challenge conventional engineering practice in several aspects, including materials and pavement design, geometric design, drainage, road safety, and maintenance.

3. Design Philosophy

The approach to the design of a LVR follows the general principles of any good road design. However, there are several differences from the traditional methods adopted for high volume roads (HVRs) that need to be appreciated by the designer to provide designs that will meet the multiple social, economic, and environmental requirements of road users in rural areas. Accordingly, optimizing a LVR design requires a multi-dimensional understanding of all of the project elements, and in this respect, all design elements become context-specific. Therefore, the designer needs to be able to work outside his/her normal areas of expertise and understand the implications of his/her recommendations or decisions on all other elements of the design.

Given the above, the successful design of LVR will rely on:

- A complete understanding by the design engineer of the local environment.
- An ability to work within the local environment's demands and turn these to a design advantage.
- Innovative and flexible thinking by applying appropriate engineering solutions rather than following traditional thinking related to road design.
- A client who is open and responsive to innovation.
- Assured routine and periodic maintenance.
- Recognition and management of risk.

4. Lessons Learned from Research

The outcome of several investigations into the performance of many LVRs in the Sub-Saharan Africa region has produced many significant findings relevant to the design approach for LVRs. These findings may be summarized, as follows:

- The Structural Numbers (SNs) (bearing capacity) of the good-performing roads are below the design SNs obtained using most traditional design manuals.
- Most of the pavement failures were caused by failures of the surfacings (high pothole and crack intensities) but are non-structural.
- No structural failures have been observed in the bases, sub-bases, or subgrade except in situations where water ingress into the base occurred after the surfacing had been breached.
- There is almost no correlation between the measured CBR and the traditional soil indicator properties such as Grading Modulus and Plasticity Index (PI).
- There was no significant difference between the Plasticity Modulus (PM) (Plasticity Index x % passing CBRE sieve) of the bases of sections performing well and those performing poorly.
- The ranges of particle size distributions of the base and sub-base materials differed widely (both much finer and much coarser) than the traditional specification envelopes; these envelopes can be widened to allow the use of a broader range of materials.
- In general, sections with low crown heights tended to perform worse than sections with higher crowns (except where coarse or sandy materials were used in the pavement layers).
- Drainage is a significant performance factor and is influenced by the crown height, type of shoulders (sealed/unsealed), and whether or not a permeability inversion in the structure exists.
- Given adequate drainage, and based on the micro-climate in the project area, the moisture content in the subgrade tends to equilibrate at or just above optimum moisture content (OMC), and in the pavement layers to below OMC.

The above findings provide valuable insight into the key factors that affect the performance of LVRs, particularly regarding the manner of selecting materials for use in the pavement structure.

5. New Approaches

5.1. Geometric Design

Conventional highway geometric design relates to increasing standards to increasing speed, the volume of traffic, and user comfort and convenience, which has led to relatively high-cost solutions. The application of these standards on LVRs cannot be justified since the costs would far exceed the commensurate benefits. Thus, a more holistic approach needs to be taken in which the over-riding criterion of acceptability is the achievement of an appropriate level of all-year access to communities at "least cost" (in terms of total life-cycle costs), while at the same time ensuring the LVRs are "fit for purpose" in terms of user requirements and road safety (Pinard and Hongve, 2016). To this end, the main challenge of the engineer is:

- To design a road that is "fit for purpose" by fitting the road into the physical environment at least cost allowing ***the existing alignment to fix the travel speed*** and ***variable cross section width to accommodate the prevailing traffic***.

- To address potential "black spots" with properly engineered solutions such as appropriate traffic calming or road widening and lane segregation at blind crest curves.

The adoption of these design principles will require good engineering judgment to be exercised by the design engineer, hence the need for highway engineers to be re-oriented towards sound LVR engineering practices to design the road to be **fit for purpose** and **at least cost.**

5.2. Cross Section

Until relatively recently, the provision of sealed shoulders on LVRs would have been considered to be both expensive and unnecessary. However, there is a structural benefit from maintaining a drier environment under the running surface. The resulting high strength derived from the relatively dry condition results in a stronger pavement. It also allows weaker materials to be used in the upper pavement layers

Of particular importance to LVRs is catering simultaneously to the requirements of motorized and non-motorized traffic (NMT). It is necessary to consider cost-effective ways of segregating these various types of road users within an appropriately designed cross section in some circumstances. For example, relatively wide shoulders might need to be considered in some mixed traffic situations.

5.3. Pavement Design

The general approach to designing a LVR pavement is a challenging task that differs in many important respects from that of HVRs. For example, conventional HVR pavements are generally designed to low risk levels and relatively high levels of serviceability, requiring numerous layers of selected or processed materials. However, such standards can hardly be justified for LVRs. Significant reductions in pavement costs can be achieved by reducing the number of pavement layers and/or thicknesses and making optimum use of in situ materials, albeit at higher, though manageable, risk levels and lower serviceability levels.

There is now a much better understanding of the relative influences of road deterioration factors for LVRs. Rather than traffic loading, the environment has been shown to play a relatively more dominant role in pavement performance up to about 0.5 million equivalent standard axles.

The Dynamic Cone Penetrometer (DCP) has been shown to provide a simple but robust and cost-effective method for the design of LVRs (Paige-Green and van Zyl, 2019; Pinard et al., 2019). The increasing use of this method of design, coupled with its use for material selection and quality control, has injected a degree of quality assurance in the design of LVRs not easily possible with the use of the more traditional and less reliable CBR method of testing and design.

5.4. Materials

The traditional approach for selecting materials for use in a pavement layer has typically been based on strength (CBR), grading, and plasticity criteria. However, the lack of correlation between these parameters and performance [5,6] has often presented uncertainty as to the extent to which some deviation from the specified values can be tolerated. This has prompted a move away from this approach to one in which the suitability of the material is assessed based on its DN value at a particular moisture and density on the premise that in-service performance indirectly takes account of the actual grading and plasticity of the material which do not need to be separately specified for LVRs (Pinard and Hongve, 2020).

In the DCP-DN approach, the moisture and density dependence of the materials to be used in the imported upper/base layers of the new road must be evaluated so that a full understanding is obtained of the potential performance of the material under the possible moisture conditions that may occur in service.

5.5. Surfacing

For many years, the standard seal used for LVRs has traditionally been a double bituminous surface treatment (surface dressing). However, a wide range of surface treatments is available for LVRs, such as Cold Mix Asphalt and the Ota Seal (Van Zyl, 2022). They offer a range of attributes that need to be matched to expected traffic levels and loading, locally available materials and skills, construction and maintenance regimes, road safety concerns, and the environment. Therefore, careful consideration should be given to all of these factors to make an informed choice of surfacing to provide satisfactory performance and minimize life-cycle costs.

5.6. Construction Methods and Compaction

In many design manuals, the level of compaction or density to be achieved during construction is set as a proportion of the maximum dry density in standard laboratory tests. However, maximizing the strength potential of a subgrade or pavement material can be achieved, not necessarily by compacting to a pre-determined relative compaction level, as is traditionally done but, rather, *by compacting to the highest uniform level of density possible ("compaction to near refusal") without significant crushing of the particles.* In so doing, there is a significant, beneficial gain in density, strength and stiffness, and reduction in permeability, the benefits of which generally outweigh the costs of the additional passes of the roller. Because the whole-life performance of a road pavement is very dependent on the pavement stiffness, in many circumstances, considerable long-term benefits can be achieved using the method described above for a relatively small additional cost during construction (SADC, 2003).

5.7. Drainage

Effective drainage of the road pavement remains the most critical factor affecting the performance of LVRs. This can be achieved by ensuring that the road is raised above the level of existing ground such that the crown height of the road (i.e., the vertical distance from the bottom of the side drain to the finished road level at the center line) is maintained at a minimum height (h_{min}) of about 0.75 m. This will ensure that, even in the rainy season, the moisture content in the subgrade tends to equilibrate at or just above OMC, and in the pavement layers to below OMC.

5.8. Maintenance

LVRs are particularly vulnerable to inadequate or deferred maintenance due to the extensive use of local, often moisture-sensitive materials for pavement construction. This vulnerability is further exacerbated by the projected climate changes in the coming decades. Thus, the highest priority should be given to timely and adequate maintenance of LVRs to avoid their premature deterioration. In this regard, appropriate policies should be developed that promote optimal and efficient funding, allocation and application of resources for fully maintaining LVRs.

5.9. Risk Factors

The departure from well-established, conservative material quality specifications may carry an increased risk of failure for an LVR. However, such a risk should be a calculated one and not a gamble and must consider not just materials but the whole pavement and its environment. Thus, it is necessary to be aware of the principal risk factors and adopt mitigating measures to minimize them. These factors include:

- Quality of the materials (strength and moisture susceptibility)
- Construction control (primarily compaction standard and layer thicknesses)

- Environment (particularly drainage)
- Maintenance standards (drainage, surfacing and shoulders)
- Vehicle loads (overloading)

The risk of premature failure will depend on the extent to which the above factors are negative – the greater the number of unsatisfactory factors, the greater the risk of failure.

6. Summary

There is an urgent need to improve rural access in Asian and African countries to further economic and social development and reduce poverty. However, the attainment of this goal through the application of traditional methods of LVR provision, including the use of conventional standards and specifications, would be prohibitively expensive. Fortunately, there is a wealth of invaluable research information now available that has provided practitioners with a better understanding of the performance mechanisms of LVRs. Flexibility in geometric design, low-cost improvements to drainage, sealed shoulders, compaction to refusal, use of "non-standard" materials in the pavement structure, and alternative surfacing techniques have all been identified as potentially cost-effective measures that should be considered in the construction of LVRs. Thus, the message is for the engineer to be more flexible in his approach to providing LVRs based on valuable investigations and research undertaken in several Asian and African countries in the past several decades.

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Promoting Sustainable and Climate Resilience Materials for Rural Roads

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Abstract

Increasing amount of damages to build environment and infrastructure assets has been associated with the more frequent occurrence of extreme weather. The damage is more severe on evolved and less well maintained (and thus less resilient) roads, such as rural roads, when they are subjected to extreme weather, coupled with increased traffic volumes and axle weights and the age of the network. Materials innovations have been promoted and considered as attempts to improve climate resilience and sustainability of the infrastructure assets. These include recycling end of life materials and waste from construction works as well as low energy construction techniques. These processes reduce disposal costs and carbon emissions. They can also help complying with environmental legislation and restrictions on what can be sent to landfill, improve circularity, and support the UK Government net zero target by 2050. This short paper presents a narrative of some UK experience in promoting sustainable and climate resilience materials for rural roads; more details can be found in the main presentation (powerpoint) file.

1. Introduction

The UK Department for Transport classifies rural roads as major roads and minor roads outside urban areas (but excluding motorways) and having a population of less than 10 thousand. According to the 2020 statistics, there were 247,500 miles of roads in Great Britain, where the majority was rural. These rural roads account for 76% of 'A' roads, 81% of 'B' roads, and 58% of the combined 'C' and 'U' roads (https://www.gov.uk/government/statistics/road-lengths-in-great-britain-2020). Motorways, 'A', 'B' and 'C' roads are classified roads, and 'U' roads are unclassified. 'U' roads are typically residential streets or rural lanes.

Geographical distributions of rural roads encompass three distinct categories: main roads, villages, and country lanes. Consequently, the requirements for design and maintenance of rural roads vary significantly. As an example, a country lane can be a very narrow single carriageway made of thin pavement with surface dressing which often prone to damage from severe weather and/or traffic loading, whilst a main road can be dual carriageways sealed with a thicker bituminous or composite pavement making it more resistance to climate and traffic loading.

We have been witnessing climate change triggered more extreme weather, causing damages to environment and infrastructure assets. The recently published ALARM survey 2022 reported a 2% increase in deteriorations on the UK road network, with 4%, 5% and 15% of the principal, non-principal and unclassified road network were classed as in poor state, respectively. The more frequent occurrences of extreme weather, particularly wetter winters with more intense downpours and storms, and hotter-drier summers, coupled with increased traffic volumes and axle weights and the age of the network have been blamed for accelerating road damages and premature failures. The impact is more severe on evolved and less well maintained (and thus less resilient) roads, where water can penetrate existing cracks or defects, leading to the formation of potholes and, in time, undermining the entire structure of the road. In this context, around 78% of road user in England and Wales have claimed damages related to potholes during 2021. In anticipation, around 80% of local authorities in England and Wales have declared a climate emergency (www.climateemergency.uk/) and these authorities have started taking measures to promote innovations to improve climate resilience of their infrastructure assets.

On the other hand, infrastructure improvements, new industrial site developments and construction works are on the increase. The main dilemma is that substantial amount of carbon, greenhouse gas (GHG) emission, have been spent during the life cycle of a material: from production, installation, to the end of life, until ending to a landfill. The UK Building Council has warned the need to reduce carbon emission from construction related works (www.ukbc.org). Road construction contributes 70% global GHG emission, 30% of global material consumption and waste generation as reported by World Bank (2018) and EU Commission (2019). The good news is that having good process and material selection can save up to 85% GHG emission, and 60% cost (Oristic.net). On 4th December 2020, the UK Prime Minister (2020) announced a new target to cut the UK's emissions by at least 68% in the next 10 years, compared to 1990 levels.

2. Low Energy Construction

European countries are using technologies that appear to allow a reduction in the temperatures at which asphalt mixes are produced and placed. These technologies have been known as Low Temperature Asphalts (LTAs), which comprise warm mix asphalt (WMA), half-warm mix asphalt (HWMA) and cold mix asphalt (CMA). The European Asphalt Paving Association (EAPA, 2009) defines WMA as material manufactured using special techniques that have a mixing temperature in the range 100-140 °C. This compares with HMA at 120-190 °C and HWMA at 70-100 °C. In the UK, CMAs are defined as cold road materials where the aggregates are mixed at ambient temperature, although other constituents such as foamed bitumen or bituminous emulsions may be well above ambient immediately before adding to the mixer. During the last 5 years, there has been a significant increase in use of WMA in roadworks in the UK. Materials produced using this WMA technology has now become the preferred choice of road paving materials.

The immediate benefit to producing LTAs is the reduction in energy consumption required by burning fuels to heat conventional asphalt mixture to temperatures in excess of 160° C at the production plant. These high production temperatures are needed to allow the bituminous binder to become viscous enough to completely coat the aggregate in the asphalt mixture, have good workability during laying and compaction, and durability during traffic exposure. The decreased production temperature brings the additional benefit of reduced emissions from burning fuels, fumes, and odours generated at the plant and the paving site; Widyatmoko (2016) refers.

3. Promoting Sustainability with Higher Recycle Contents

Widyatmoko and Cossale (2012) reported many benefits associated with recycling end-of-life materials and waste from this construction work. These end-of-life materials and waste products can be used in several ways, such as: binder modifier, mixture additive, aggregate replacement and artificial (processed) aggregate. Examples of papers and technical reports on the use of these materials can be downloaded from https://www.researchgate.net/profile/Daru-Widyatmoko.

Recycling reduces waste costs and carbon emissions. It also helps comply with environmental laws and what restrictions can be sent to landfill. It is expected that reliable recycling methods in the future should efficiently use comprehensive catalogues and material databases currently used in construction. Furthermore, there has been increased usage of innovative "green" materials, which include non-bituminous, non-mineral and waste-derived products, in pavement construction. However, the impact from application of these materials on the pavement durability is not well understood. The main unknowns when dealing with non-conventional materials are:

- Their track records – what are the risks?
- Durability – is there any issue?
- Comparison against standards and specifications – any issue with safety and compliance?

Widyatmoko (2016) and Thom and Dawson (2019) proposed additional processes that will be required when dealing with non-conventional materials, and those derived from waste and end-of-life materials. These extra processes will add more layers for analysis and design. An inclusive process to assess and manage impacts to support all stakeholders at the various stages of technology development is required:

- What processes are required to assess new paving material components, including those which have been derived from waste or as by-products of other industries?
- How to support sustainable innovation and efficient use of paving materials and their constituents?
- How to establish if any proposed material is suitable for use in pavements?

To answer the above questions, Lacalle et al (2021) presented a Filtering Protocol which has been developed from a collaborative research project between National Highways, Mineral Products Association (MPA), Eurobitume UK and AECOM. The Protocol is designed to support the assessment of any innovative material proposed for use as a paving material. A paving material could be anything from additives, modifiers, fillers, binders, natural or manufactured aggregates, hydraulically bound mixtures, asphalt mixtures and concrete, to all types of admixtures or any other constituent used in a mixture proposed to be incorporated in the structure of a pavement.

The Filtering Protocol applies to all innovative materials, independent of source (primary, by-product, manufactured, recycled and waste stream); however, some of the requirements are specific for by-products or materials originated from a waste stream and do not apply to materials coming from a primary source. Figure 1 illustrates the Filtering Protocol; a full report presenting more details on the Protocol can be downloaded from https://tinyurl.com/7e2ytner.

Nonetheless it is recognized that use of innovative materials can bring new risks, and these risks must be managed. For highway asset, Hakim and Widyatmoko (2018) reported that the risks can be managed and evaluated by using the guide to Technology Readiness Levels. This process comprises 9 readiness levels, where the risk and responsibility will be gradually shift from the innovator or material supplier to the asset owner:

- Levels 1–3 are mostly owned by the innovator or supplier to promote and make case for their innovative materials.
- Levels 4–6 comprise engagement between the innovator and the client (asset owner).
- Levels 7–9 are where the client may take over the process for possible construction project or scheme implementation.

A case study example reported by Widyatmoko et al (2018) suggested that an allowance should be made for at least 5 years, for a new innovative material to go through the above sequence of readiness levels; Figure 2 refers.

Figure 1: Filtering protocol to deal with innovative paving materials, including waste derived materials

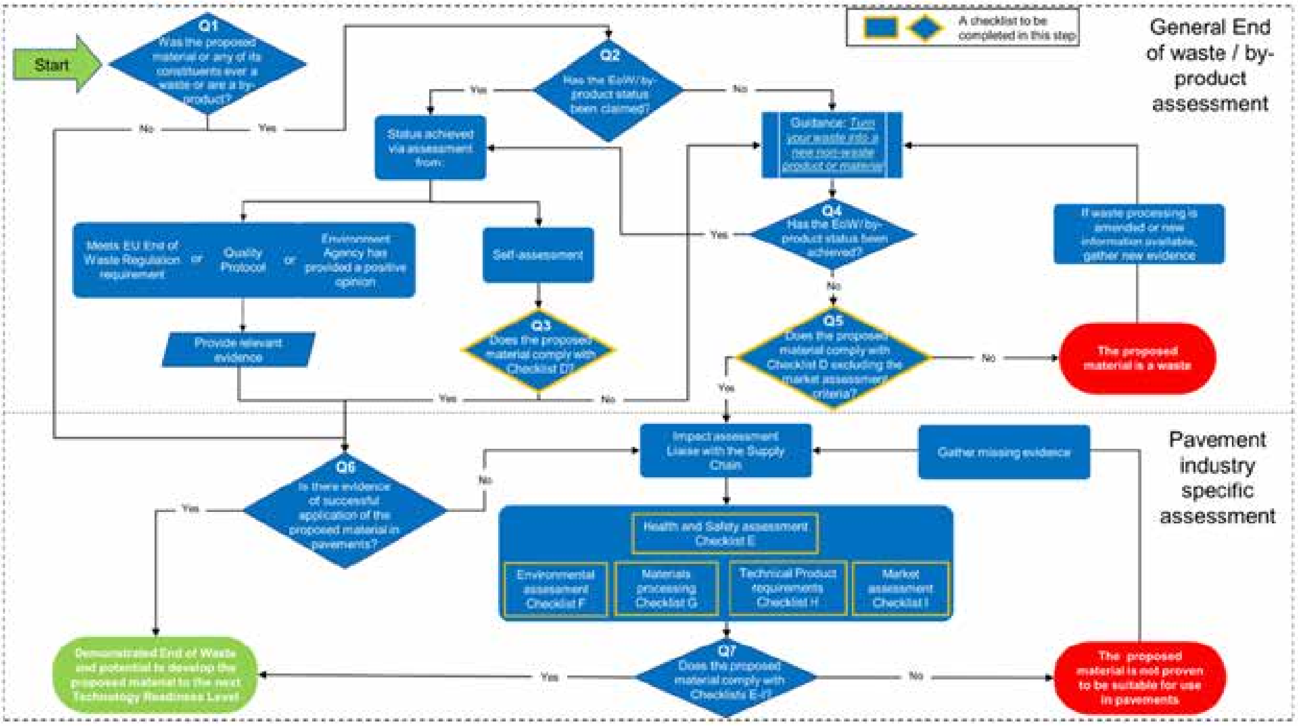

Figure 2: Process and timeline to go through stages of Technology Readiness Level

4. Case Studies

Several case studies are presented, encompassing the use of reclaimed and waste derived materials in roadworks in the UK, such as:

- Use of ground tyre rubber in combination with reclaimed materials in warm mix asphalt.
- Use of high recycle contents in warm mix asphalt.

- Some developments in the use of plastic waste as asphalt mixture modifier.
- New British Standards: BS 9227 (BSI 2019) and BS 9228 (BSI 2021) for in situ and ex situ recycling.

Case studies presented a substantial (40%) reduction in energy consumption to produce road paving materials, 40% reduction in GHG emission and preventing the waste materials from being sent to landfill. Nonetheless, it is very important that these materials should be designed to offer at least comparable performance and mechanical properties to those using primary materials. Therefore, they can be expected to provide good resilience against variations in traffic loading and weather conditions. Ultimately, these activities will contribute to the UK Government's climate target, in achieving net zero carbon by 2050.

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Road Asset Management for Rural Roads

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Abstract

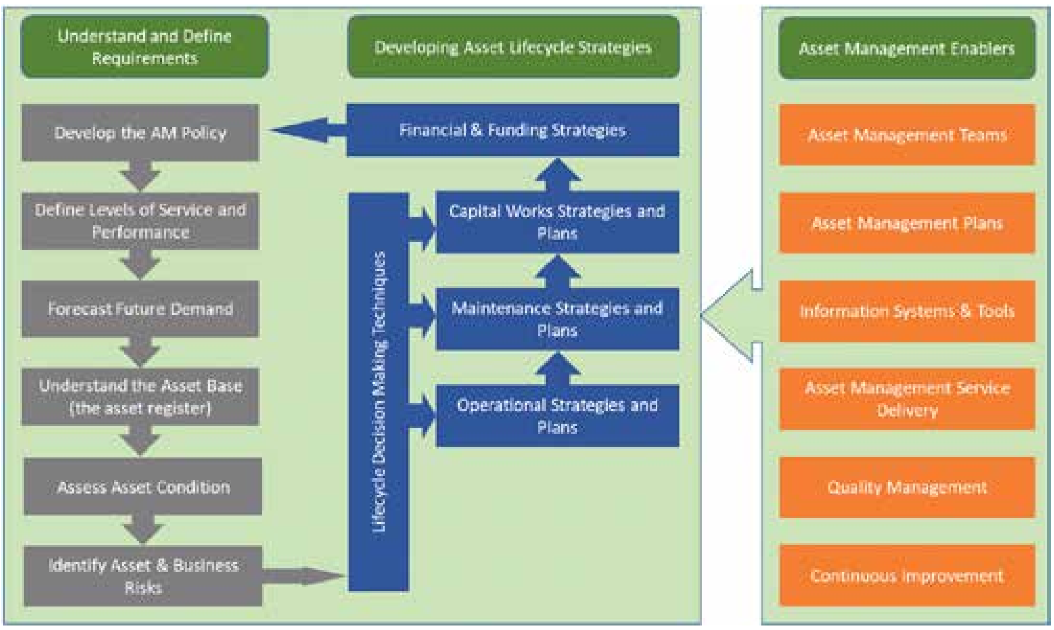
While the concept of maintenance management is well understood across road authorities, Road Asset Management (RAM) has often been left to those road authorities managing higher classes of roads (national highways or state highways) with lower classes of roads such as rural roads and village roads often been neglected from a holistic RAM approach. In other cases the implementation of an Asset Management Information System (AMIS) has been confused with the adoption of RAM itself.

RAM is equally applicable across all road hierarchies, and indeed across all asset types, it is just the level of detail that goes into the RAM process that changes. For instance while it is entirely appropriate to collect high quality and high frequency surface condition data on a national highway network, for a low volume road a simple visual inspection once every 2-3 years may suffice.

1. What is Road Asset Management

RAM is a holistic approach to the management of all assets used in the delivery of services to the road user. By definition it is a strategic and systematic process of planning, operating, maintaining, upgrading and expanding road assets throughout their life cycle. RAM is an approach that is outcome-based and aims to achieve the defined service levels for the least cost over the long term. While there are a number of well-regarded RAM processes in use around the world, for simplicity here let us consider that presented in Figure 1.

Figure 1: RAM Process



Source: International Infrastructure Management Manual, NAMS NZ (2011)

There are various points of note that are obvious from the figure:

- The typical RAM initiatives that road authorities start with of collecting data ('Understand the Asset Base' and 'Assess Asset Condition' in the figure), along with implementing an AMIS ('Information Systems & Tools') are but two components out of a much larger process.
- RAM starts from high level policy, and goes through all the data collection, funding optimization, and on to consideration of how to deliver the physical works.
- Quality assurance of RAM (as distinct from QA of physical works) and implanting an Improvement Plan are all part of RAM.

The other notable aspect of the process is that it doesn't specify how to do any given component. That is because the 'how' will vary between road classes, and likely also between road authorities. For instance, a road network that is experiencing significant congestion pressures will naturally require the road authority to place greater attention on the 'Forecast Future Demand' step of the process, than will a low volume rural road network. While the former may require complex multi-stage land use and traffic modelling to appropriately deliver on the Future Demand step of the process, for the latter network it may be sufficient to undertake sporadic traffic counts once every 5-10 years to simply confirm the level of excess capacity that remains in the traffic system.

2. RAM in the Indian Rural Roads Context

India has around 4.6 million km of roads, the third largest road network in the world, with rural roads making up 82% of the network. Extensive road development programs are in place at both at National and State Levels, including a national level rural roads program (PMGSY) which has added around 700,000 km of paved rural roads over the past two decades. While providing benefits to the rural communities served, these investments place long term financial liabilities on the State road authorities who must then maintain and renew these assets going forward. Furthermore, despite a significant increase in investment in the last 10-20 years, the Government of India's 12th Five Year Plan identifies that.

> *"the road network remains grossly inadequate in various respects. It is unable to handle high traffic density and high speeds at many places and has poor riding quality .... Many State roads suffer from low investment, inadequate width of carriageway, weak pavement and bridges, poor safety features ...", etc.*

There are many other challenges. The funding for Rural Roads comes from numerous sources with different standards and objectives meaning that network-wide prioritization and planning is difficult. Road authorities themselves are often restricted in terms of human capability and capacity when it comes to implement AM approaches. There is a culture of 'build and re-build' with little attention to the 'whole of life' costs of the assets and often very limited State funding to maintain the roads built through central government funds. This may well be leading to excess and unnecessary use of limited physical resources – gravel resources in many States are scarce and there is increasing reliance on imported resources.

All of these issues are compounded by the limited rural roads network level data on asset performance which constrains the ability to effectively justify the required level of funding and leads to often subjective and reactive approaches to decision making.

These issues are well recognized at both a Central and State government level, with initiatives such as implementation of Performance Based Maintenance Contracts (PBMCs) and the development of Asset Management Information Systems (AMIS) being gradually rolled out to redress some of these issues.

State Road agencies are under increased pressure by both the government and their communities to improve efficiency, transparency and accountability in the management of the road network.

The Financial Case for Asset Management in India

Various reports on the impact of not managing and maintaining a road cite that every Rs. 1 not invested by the road agency at the right time will result in an additional Rs. 3-4 costs to the country as a whole. This cost is partly incurred by road agencies due to premature road network deterioration but also falls on road users in terms of higher vehicle operating costs (vehicle damage), slower travel speeds while navigating roads in poor condition and a decrease in the safety of the road network. While there may be short term costs associated with doing the right thing at the right time – the benefits of such activity typically far outweigh any other form of road investment.

MORD estimate that the average rate of depreciation of the rural road network in India is 5%, while internationally the comparable figure is around 2.5%. At 5% the Rs. 20,000 crore annual investment in building new rural roads is less than the annual depreciation of Rs. 21,700 crore, resulting in a net loss of road asset owing to current practices, not the significant gain in value intended by the major road programmes.

Following good asset management practices and achieving outcomes similar to the international community would be the equivalent of increasing the annual investment by Rs. 10,000 crore. This effective saving could then be used to connect even more of the rural communities that the rural road network serves – thereby producing and securing 50% more benefits, for no long-term increase in costs.

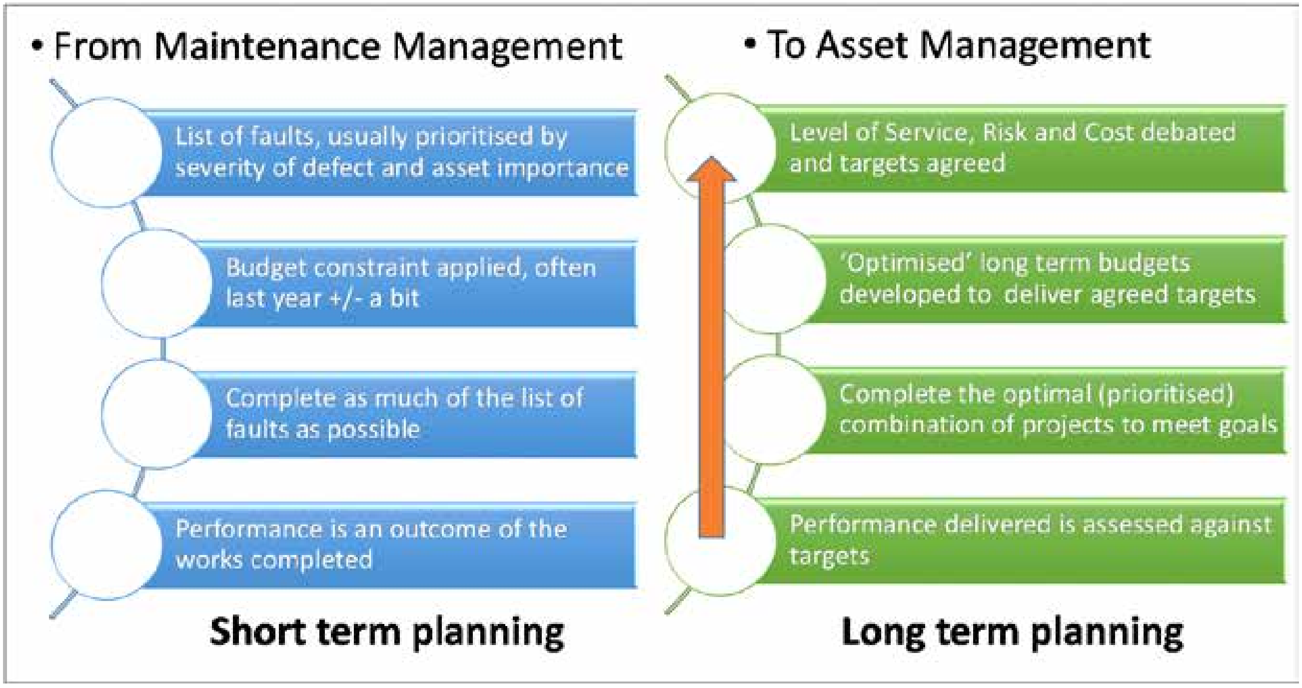
Source: Asset Management Guidelines for Indian State Road Agencies, World Bank (2017)

3. Addressing the Challenges through Better RAM

3.1. Transforming from Maintenance Management to Lifecycle Asset Management

The challenges identified in the previous section are not unique to India. Globally there has been a move towards RAM as a way of better managing the huge investment in infrastructure around the world. Figure 2 illustrates the characteristics of historical road management practices (a facilities or maintenance management approach), typical of many Indian State Road agencies, compared with the RAM practices common in many leading road agencies both within India and internationally.

Figure 2: Transforming from Maintenance Management to Asset Management



Source: Asset Management Guidelines for Indian State Road Agencies, World Bank (2017)

3.2. The Benefits That RAM Can Provide

RAM is an approach which focuses on two key concepts – it is **outcome-based** and aims to achieve those outcomes for the **least cost over the long term**. RAM uses better and more transparent decision-making using quality information and defined objectives (levels of service) to ensure asset expenditure is optimized.

RAM helps to assess what funds are required to deliver required road outcomes (levels of service) and the implications of reduced or increased funding options. In other words, an effective RAM Framework can help road managers to respond to a number of key questions:

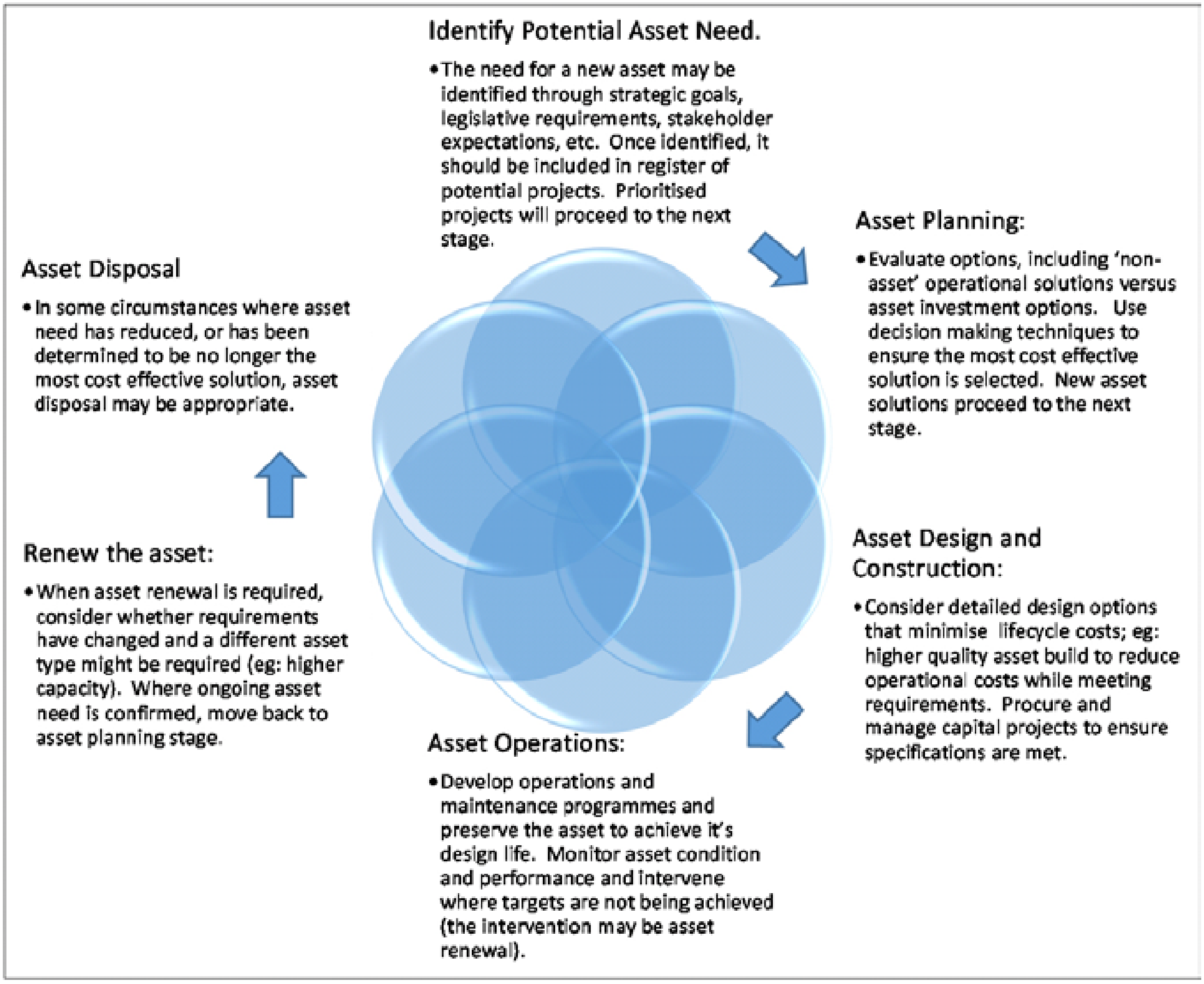
1. ***What are the required outcomes from my road network?*** *This can be expressed as levels of service such as 'The road network effectively connects communities', measured through standards such as "% of communities connected by an all-weather road.*
2. ***What is the current state (condition and performance) of my road network?*** *Is it capable of delivering the outcomes defined above? What information do I need to report on the current state?*
3. ***What are my best strategies for managing the road network?*** *Strategies may include operational and capital investment strategies and making sure that funds are being allocated to the activities to ensure a minimal lifecycle cost. For example, is it better to re-surface more frequently to extend the life of the road pavement?*
4. ***How much will maintaining the road network cost over the long term?*** *Long term financial forecasts will enable road managers to ensure that are not investing in assets that are unaffordable in the long term, ie, where there is a significant gap between what is required to maintain the assets and the ability to secure that level of funding.*

In summary, the application of RAM can reduce lifecycle costs, ensure funding is allocated where it will provide most benefit, provide transparency in decision making and reduce financial and operational risks.

3.3. The Lifecycle Asset Management Framework

At each stage of the asset lifecycle, consideration needs to be given to making decisions that provide the best solution across all lifecycle stages – with the aim of achieving required levels of service for the lowest lifecycle cost. Considerations are summarised in Figure 3.

Figure 3: Asset Lifecycle Considerations



Source: Asset Management Guidelines for Indian State Road Agencies, World Bank (2017)

4. Learnings from International Asset Management Practices

Internationally, the application of AM principles to road networks is well understood and these guidelines draw on the development of global best practice road AM and the learnings that have occurred as AM has evolved as a discipline over the last 2-3 decades.

4.1. Common 'Road Blocks' for Asset Managers

Experience has shown a number of issues that have hindered organizations in establishing an effective RAM Framework. Possibly the top two challenges for public sector organizations are institutional inertia (a reluctance or inability to change, possibly highly constrained by bureaucracies) and organizational silos. RAM involves a wide sector of the organization – planning, construction, maintenance, information systems, finance, etc. Without effective interaction and organisational agreement on approach the RAM Framework is unlikely to succeed.

Other obstacles that are frequently faced include poorly scoped information systems (too much data can be as problematic as too little), inadequate staffing (both capacity and capability) inadequate funding, and a culture that prizes building new assets over the 'poor cousin' of maintenance.

4.2. Characteristics of Effective Asset Management Organisations

Characteristics of effective AM organizations include:

- AM is part of the culture of the organization – it is 'the way we do business' not a task done by one or two people. AM is visibly led at the highest levels, everyone in the organization understands what AM is and their role in the AM Framework.
- Road users and stakeholders are recognized and treated as important 'customers' – the road assets are only there to provide a service to those customers and a robust performance reporting framework demonstrates the level of service that is provided.
- The road is recognized as a valuable asset that needs to be maintained with consideration of lowest lifecycle costs. This may mean higher construction costs or more frequent re-sealing to achieve longer lifecycles.
- Priority is given to funding maintenance and renewal of existing networks before any funds are allocated to new or upgraded assets.
- Prioritisation and decision frameworks ensure the organization achieves best value for money.
- The full 'cost of service' over the road network lifecycle is assessed and funded each year, including consideration of the level of service and cost trade-offs. The full cost of service includes the loss of service potential (depreciation) of the road assets.
- The organization recognizes the value of information, and a robust asset inventory is maintained with condition and performance information available for objective decision making to achieve lowest lifecycle costs.

5. The Indian Rural Roads Asset Management Framework

In 2017 the World Bank released the first version of the Asset Management Guidelines for Indian State Road Agencies. Developed based on international best practice for the management of rural roads, the guidelines provide a sound framework for the management of the vast Indian rural road network.

The RAM Framework comprises a detailed guidance document covering every step of the RAM process, along with templates for the production of the AMP, generation of a long-term financial plan and the like. Developed by leading international proponents of RAM, in conjunction with Indian experts, and piloted in two Indian states, the RAM Framework is fully customised to the terminology and institutional set up in India.

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Cement Grouted Bituminous Mix for Longevity of Flexible Pavements

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Cement Grouted Bituminous Mixes (CGBM) technology is an attempt to overcome the primary failure modes of bituminous pavements through moisture induces damages. The CGBM layer is normally described as a porous bituminous layer which is filled with a cementitious grout. Mainly open graded aggregates are used for these mixes which normally produce higher air void content. The cementitious grout is generally composed of cement, sand, fly ash, micro silica, superplasticizer and water. Most of the void spaces in the bituminous mix are occupied with cement grout by the gravity force.

1. Introduction and Objectives

In an attempt to overcome the primary failure modes of bituminous pavements, the idea of **Cement Grouted Bituminous Mixes (CGBM)** was taken up at CRRI. The practise of grouting the high void bituminous layers with cementitious materials was mainly to reduce the damage caused to bituminous pavements due to moisture induced damages in the pavement.

The CGBM layer is normally described as a high void (around 25 percent) bituminous mixture (binder content around 3 percent) which is filled with a cementitious grout. Mainly open graded aggregates are used for these mixes which normally produce higher air void content. Compaction of the high void bituminous mixes was done using Marshall compaction method. It is essential that the high void bituminous mix be designed properly to have sufficient air voids with proper inter-connectivity in them and to select a grout which could penetrate into the voids. The cement grout is generally composed of cement, sand, fly ash, micro silica, superplasticizer and water. Most of the void spaces in the bituminous mix are occupied with cement grout by the gravity force. The newly grouted surface may be broomed to increase the skid resistance.

The study was taken up to evaluate different issues related to aggregate gradation, compaction effect, selection of bitumen content and degree of grout penetration. Micro-CT analysis was carried out to check the air voids in CGBM sample. Two Trial sections of about100 mts. were laid in Surat City, Gujarat for the field performance and validation study.

2. Methodology and Tests Performed for the Study

To accomplish the above main objectives of the project, it was envisaged to have a clear comparative assessment of the cement grouted bituminous mixtures in comparison to the conventional bituminous mixes. In this endeavour, the following main issues were thoroughly examined.

(a) Evaluation of mechanistic properties of CGBM and its performance study.

(b) Evaluation of grout material properties with respect to water content and curing period such as grout workability (flowability) and grout strength parameters.

(c) Field performance of CGBM mix with seasonal evaluation and performance verification as per different aspects such as skid resistance, pavement structural strength evaluation using Falling

Weight Deflectometer method, cross verification of actual air voids in the laid section by using X-Ray Micro-Computed Tomography technique (Micro CT), etc.

(d) Comparison of the performance of CGBM with that of conventional BC mix. Different comparative studies are done for the technical assessment of CGBM to check its suitability as per the requirements of better performing surface course material.

3. Laboratory Based Development of CGBM

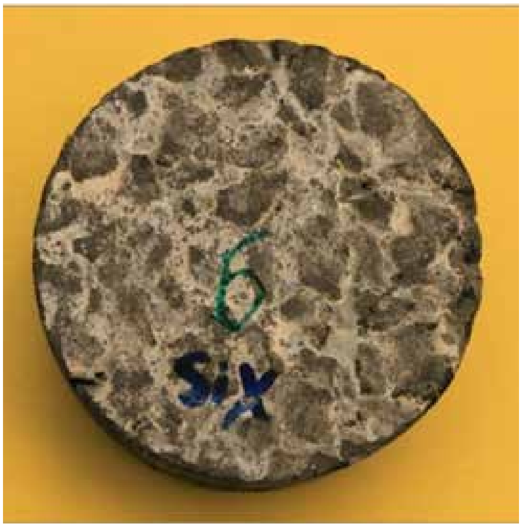
Bituminous Skeleton
(Laboratory Prepared)

1. Bituminous Mix Design
   - Selection of Aggregate Gradation
   - Designing Binder Content
   - Optimising Compaction of Mix

Flowability Check for Grout

2. Optimisation of Grout
   - Optimising water content in grout slurry to have desired flowability with sufficient strength

3. Preparing Composite Material
   - Grouting the compacted Marshal Samples having high voids



4. Laboratory based evaluation of the composite material
   - Check for Rutting Criterion
   - Check for Fatigue Life
   - Check for Moisture Susceptibility
   - Check for resistant to Oil Induced Damages

Raw materials and equipment for field implementation

- Aggregates as per design gradation and VG-30/VG-40 bitumen, for high void mix.
- Cementitious material for grouting over the high void bituminous layer.
- Split moulds of height 63.5 mm and 101.2 mm diameter for preparation of bituminous mix to check full depth penetration of Grout in CGBM.
- Cube moulds of 75 mm x 75 mm x 75 mm to check the compressive strength of grout.
- Marsh flow cone to check the flow of grout.
- Conventional construction equipment's can be used for construction of CGBM.

Environmental and Social benefits

- Moisture induced damages post monsoon will be minimised in CGBM which is one of dominant advantages of CGBM.
- Less Consumption of bitumen, which in-turn will make this an environmental friendly.
- Low maintenance cost.
- Environmental, cost economy and societal benefit results in sustainability in Road construction**.**

Deployment plan

- CSIR-CRRI has laid two trial sections of 100 m each at S.D Jain road and TP road in Surat, which was provided by Surat Municipal Corporation on trial basis. The trail sections laid of CGBM are being monitored and performance evaluation is being done at regular interval.

Paved High Voids bituminous layer at site (Stage 1)

Grouting in bituminous layer (Stage 2)

Finished surface of CGBM (Stage 3) in June 2017

CGBM section after 5 monsoon Sept 2022

4. Findings & Outcomes of the Study

The following are the outcomes of the study:

- Grouted mixes had significantly smaller rutting, nearly 1/10 times as compared to the BC mix.
- CGBM having TSR value 96% indicates significantly better resistance to moisture induced damage in comparison to BC mix having TSR value 80%.
- CGBM mix shows approximately 3, 7 and 10 times higher value of resilient modulus corresponding at test temperatures of 25°C, 35°C and 45°C, when compared to BC mix. This trend shows lower temperature susceptibility of CGBM in terms of Resilient Modulus, when compared to BC mix. Similar trend is observed for the Indirect Tensile Strength of the CGBM with near about 2.5 times higher values than BC mix.
- In terms of compressive strength and stability; CGBM shows approximately 6.5 times and 2.75 times correspondingly higher value in comparison to BC mix.
- CGBM mix was found to be more resistant to damaging effect of oil spillage than BC mix. The retained ITS value for CGBM mix immersed in diesel for 24 h was 92 percent against 78 percent for BC mixes.
- Dynamic moduli of CGBM specimens are substantially higher than those of BC mixes, at all temperatures and frequencies.
- IDT fatigue test results show that CGBM is marginally less fatigue resistant when compared with the control BC mixture.
- Full depth grouting was observed in the both laboratory and field samples. No distress either rutting, fatigue cracking or pot hole was observed in the field trial section even after 5 monsoon seasons.

5. Technology Highlights

- No sign of distress either rutting, fatigue cracking or pot hole was observed in the field trial section in surat city road even after 5 monsoon seasons.
- CGBM wearing surface had significantly no rutting, lower temperature susceptibility, hard and durable surface. CGBM is long lasting pavement and retard moisture induced damage for roads in areas where water logging takes place.
- This CGBM can be used for new Construction or for Maintenance of distressed pavement.

CSIR-CRRI in association with IRC has developed IRC Guidelines ie IRC:SP:125 -2019 Cement Grouted Bituminous Mix for Urban Roads.

Sustainable Practises of Cold Recycling of Roads Leads to Sustainable Performance

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Abstract

Cold recycling has globally lifted foamed bitumen and emulsion stabilisation technology to unprecedented levels. From humble beginnings five decades ago, where bitumen stabilisation provided sustainable solutions for road rehabilitation under light to moderate traffic, cold recycling has evolved into a technology that addresses the demands of heavily trafficked highways with a high percentage of recycled asphalt. The key to the success of road recycling is reliable pavement performance evaluation (including durability) of recycled materials through the identification of the critical parameters, their tests defined by well-defined protocols, a reliable structural design function to estimate their service life as well as sound specification limits to measure against. This paper uses RAP (Reclaimed Asphalt Pavement) as an increasingly important component of cold recycling to highlight the technological advances that have taken place in the last two decades. The development and standardization of mix and structural design processes for bitumen stabilised materials has enabled optimisation and reliable application of the technology.

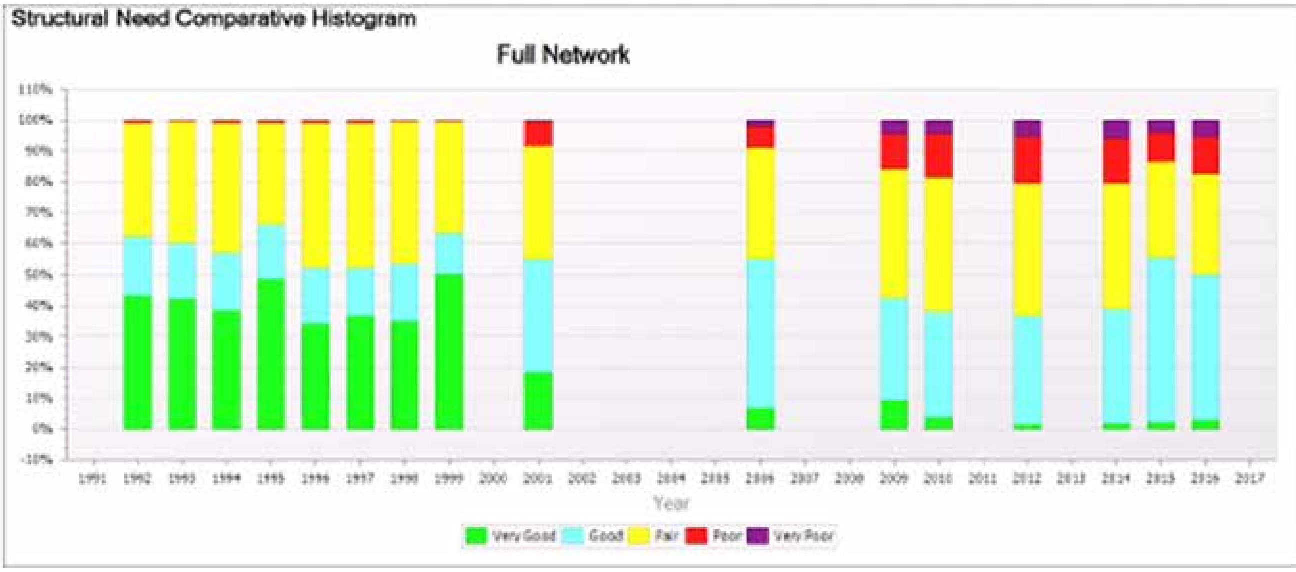
1. Introduction

Asset Management has become a common term in a pavement engineer's vocabulary. It is not surprising as road infrastructure often holds pride of place in the ranking of countries' asset values. The extent of the current global road network is approximately 65 million kilometres, of which an estimated 20 million kilometres of roads are surfaced (Jenkins *et al.*, 2019).

With prominence comes responsibility. In the case of roads, the upkeep is prohibitive with routine maintenance (clearing drainage and vegetation, crack filling, etc), periodic maintenance (asphalt overlays in a periodic cyclic) and structural rehabilitation. Using an example of surfaced roads in the global network having a structural design life of 20 years, implies that every year planet earth requires 1 million km's of its roads to receive structural rehabilitation in order to retain asset value. If that were occurring, the trend of cumulative structural distress in a pavement network, shown in Figure 1, would not be a reality. Unfortunately, this trend is all too common and prevails in both developing and developed nations, providing a bleak outlook in countries' economies.

Fortunately, there is hope where new, effective rehabilitation measures are embraced and implemented. From humble beginnings five decades ago, the cold recycling process including bitumen stabilization has provided sustainable solutions for rehabilitation of roads carrying light to moderate traffic. In recent decades, cold recycling has evolved into a technology that addresses the demands of heavily trafficked highways with a high percentage of recycled asphalt.

Figure 1: Evolution of Visual Condition Index of a southern African Road Network



During the last three decades, pavement structures that were carrying heavier loads and higher traffic volumes were identified for rehabilitation using cold recycling. This has challenged pavement designers, researchers and practitioners to meet the roads industry needs by addressing:

- Appropriate material characterization: the pavement layers in an existing structure that is distressed, require key performance indicators to be analysed. If the base or subbase layers are likely to be recycled, their suitability for bitumen stabilization with either foamed bitumen or emulsion, needs to be reliably evaluated (Jenkins *et al*., 2019).
- Reliable test methods, linked to performance: Indicator tests such as the Indirect Tensile Test, is adequate for light pavements but does not have a sufficiently strong link to performance as a critical parameter for heavily trafficked pavements. Triaxial testing, for example, is a more reliable performance-based test (Ebels, 2007) and (Jenkins *et al*., 2009).
- Failure mechanisms of Bitumen Stabilized Materials: Initially design functions for asphalt were adopted and adapted for design of Bitumen Stabilized Materials thus using fatigue as the damage mechanism. Research subsequently revealed that for mixes with 2 to 2.5% residual bitumen and 1% active filler, permanent deformation is the appropriate damage mechanism (Jenkins *et al*., 2008) and (Bierman *et al*., 2019).

2. Characterisation of Materials for Bitumen Stabilization

Bitumen stabilisation is typically used in the rehabilitation of existing granular base layers using either foamed bitumen or bitumen emulsion. The granular material is treated with small amounts of bitumen, i.e. less than 3%. A small amount of active filler, typically 1%, is used in the mix to improve the bitumen adhesion to the aggregate. The resulting material is a non-continuously bound material that differs from hot mix asphalt (HMA) and cement stabilised material.

Cold recycling technology that produces BSMs offers a unique solution to the challenging infrastructure demands through sustainable, environmental and economic solutions and benefits. This technology is constantly being optimised and refined, requiring periodic update of the guidelines available for implementing BSM technology.

Ironically, in the modern era BSM technology remains a relatively new technology in some countries. In such circumstances, best practice procedures are necessary to provide guidance for the road authorities, designers and contractors to implement the technology reliably and successfully.

In order to gain perspective, it is important to have oversight of the systematic development of cold recycling through the decades. The use of binding agents dates back millennia, with Mesopotamians using bitumen and Romans using pozzolanic binders. Early in the twentieth century bitumen emulsions were developed and approximately 50 years ago foamed bitumen technology was developed.

Cold recycling technology, however, gained momentum when plant and equipment that could create mixtures of reliable composition and quality construction, emerged. This was in the 1980s. It was also in this period that the publication of best practice guidelines began to burgeon. Several countries have a track record of taking the initiative to continually update the technology developments and guidelines. This assists in addressing the road industry's needs and concerns.

3. Summary

Cold recycling technology has made significant strides in the past two decades. There is a strong link between theory and practice that is encouraging this progress to take place. Research findings with potential are being implemented in material compositions, test methods in the laboratory, advances in recycling plant and application methodology all play a role.

In particular, developments in sustainable technology across the spectrum of durability and performance for pavement structures:

- Material characterisation: Evaluation of aggregate and RA behavioural characteristics, sampling of distressed pavements, blending ratios of materials, compaction methods in the laboratory and the field and curing methods assist in successful mix design.
- Reliable BSM test methods: Although ITS tests are an indicator of BSM behaviour, they do not provide a reliable link to in-service performance, even though a special ITS test procedure is included in many standards. Triaxial testing is needed to ensure reliable mix designs.
- Structural design: One decade ago, highly empirical design methods have been used for layer thickness evaluation, leading to conservate designs. Subsequently, heuristic as well as mechanistic-empirical models have been developed for designing with BSMs, providing more reliable pavement structures.
- Implementation: Advances in recycling machines have led to the advent of down-milling recyclers that can generate reliable, continuous gradings and can provide high production rates. In addition, cold recycling carried out in the past 2 decades have provided insights into project selection for in place versus in plant recycling. Many factors require consideration to select the appropriate technology.

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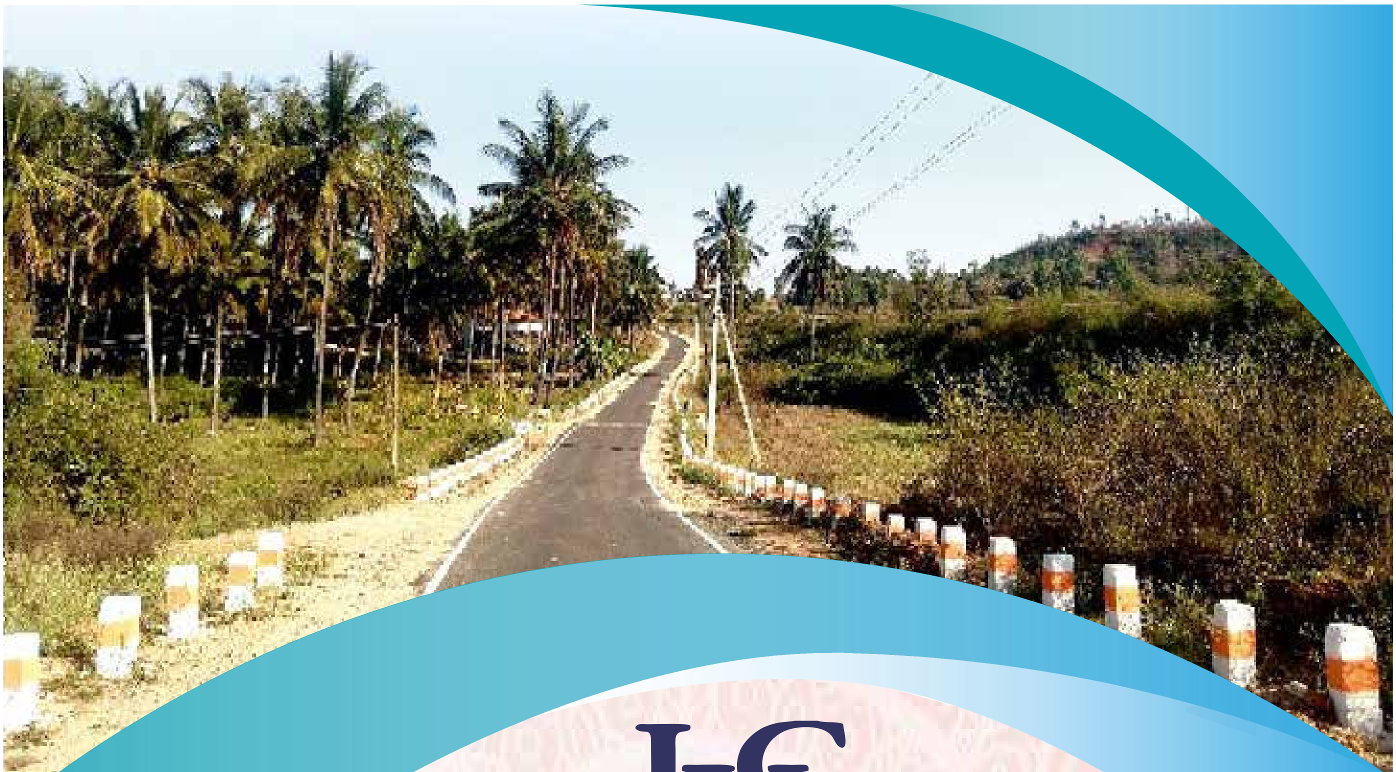

Pervious Concrete Pavement Systems for Low-Volume Road Applications

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Abstract

Pervious concrete pavement (PCP) systems are engineered roadway technologies that are known to mitigate stormwater runoff attributed to their high porosity. Though significant advancements have been made at the global level, research and innovation pertinent to PCPs is still emerging in India. Therefore, the objective of this document was to present the actual case studies on PCP technology undertaken in India. The details pertinent to mix design and characterization, field construction and monitoring, and development of innovative PCP products were discussed. Test results indicated that PCPs are suitable for applications in walkways, parking lots, and low-volume roads. Though paver blocks offer superior quality product than conventional PCP, they suffer from low strength. Therefore, recent research focused on developing pervious All-Road class All-weather Multilayered paver (PARAMpave) products, whose flexural strength and infiltration rates were higher than 4.8 MPa and 0.77 cm/s, respectively making them suitable for applications in all-road-all-weather conditions. Further, PARAMpave consume lower energy and generate fewer emissions during production. In future, additional research must focus on constructing test sections by utilizing pervious concrete paver blocks and PARAMpave products to identify their performance during the entire design life.

1. Introduction

In recent times, climate change has emerged as one the major causes for deterioration of pavement infrastructure across the globe. The urban dwellers are exposed to an all-time high risk of flooding, harsh weather conditions, and urban heat islands, which not only affect the quality of life but also result in premature failure of pavements (Chandrappa and Biligiri 2016; Singh et al. 2022b). Therefore, there is an urgent need to identify and develop resilient pavement systems that address the threats posed by climate change. One such strategy is the design and construction of pervious concrete pavement (PCP) systems, which typically comprise a pervious base/sub-base layer (void content 20-40%) designated as reservoir layer overlying a compacted subgrade and underlying a pervious concrete (PC) surface wearing course (void content 15-30%) (ACI 522 2010; Singh et al. 2020; Tennis et al. 2004). PC overlays are primarily designed with coarse aggregates, cement, and water to create an interconnected porous network that allows infiltration of stormwater to the underlying layers. Though multiple efforts have been made at the global level to characterize PC material and further construct the PCP systems, only a few attempts have been made at the national level.

Some recent studies conducted at the Indian Institute of Technology Kharagpur (IITKGP) and the Indian Institute of Technology Tirupati (IITT) have focused on designing the PC mixtures, investigating their performance characteristics, field implementation, performance monitoring, and developing new generation PC paver blocks (Chandrappa et al. 2018; Singh et al. 2019; Vaddy et al. 2020). However, there is still limited awareness at the national level pertaining to the implementation and use-phase benefits offered by the sustainable PCP systems. Therefore, the objective of this presentation/document was to discuss and present the information pertinent to the construction of PCP technologies in India. It is envisioned that the present research will certainly build confidence amongst the implementation agencies to construct these resilient pavement systems in suitable locations such as low-volume roads in order to develop sustainable urban habitats.

2. Materials and Methods

2.1 Pervious concrete mix design

The research on development and characterization of PCP mixtures began at IITKGP (2014-17), where 18 mixtures were designed and tested for different characteristics. The structural characteristics included compressive strength, flexural strength, and fatigue, while the functional characteristics included permeability and pore structure properties (Chandrappa and Biligiri 2018). In a more recent study at IITT (2018-21), a full factorial PC mix design was performed where 18 control and 18 sand modified mixtures were designed and tested for their fundamental characteristics using two single-sized aggregate (6.7 and 4.75 mm) particles, three levels each of water-to-cement (0.27, 0.30, and 0.33) and cement-to-aggregate (1:3.75, 1:4.00, and 1:4.25) ratios (Singh 2021; Singh et al. 2022a).

2.2 Pervious concrete pavement systems

The first PCP test section that comprised 18 PC slabs (each measuring $3 \times 2 \times 0.15$ m) was designed from the laboratory studies and constructed with six different mixtures on-campus IITKGP using labor based on-site mixing. This test section served as a walkway and two-wheeler parking lot (Chandrappa et al. 2018). Later, two additional PCP parking lots were installed at the premises of Municipal Corporation of Tirupati (MCT) that was 125 m long and 4 m wide using the on-site mixing method and in the IITT campus (50 m long and 5 m wide) using ready-mixed PC (Singh et al. 2019; Vaddy et al. 2020). Further, field cores were extracted to ascertain the porosity, density, and compressive strength immediately after construction. Additionally, the hydrological performance was monitored for a period of over three years by performing in-situ infiltration rate tests (Singh et al. 2021).

2.1.1 On-site mixing method

The steps utilized to construct the PCP roadway were as follows:

1. Marking of the pavement area by extending stringlines.
2. Soil excavation up to the required depth to achieve the desired pavement level.
3. Compaction with a 10-metric-ton static steel wheel roller.
4. Placement of sub-base material, and compaction with a static steel wheel roller.
5. Fastening the steel formwork to mark the boundary of PCP slabs.
6. Construction of alternative PCP slabs, and providing isolation joints across the full pavement depth. Placement of rubber mastic pads (full width) between the joint spaces.
7. Batching and mixing the constituent materials in an in-situ drum type mixer for 180s.
8. Laying and spreading the fresh PC mixture manually over the area of formwork. Note that the PC material was stroked off approximately 25 mm above the surface.

9. Sprinkling water over the PC surface to control the loss of luster and workability prior to compaction.
10. Compaction and finishing by slowly moving a plate vibratory roller (60-90 s per pass) over a rigid and flat sheet made of aluminum to prevent the direct exposure between fresh PC and the base of the vibrator.
11. Curing the consolidated PC slabs by covering with plastic sheets and wet gunny bags for 7 days.

2.1.2 Ready-mix concrete

The steps (1-6) were similar as that for the on-site mixing, except that the fresh PC constituents were batched and mixed in a ready-mix facility that were brought to the site in transit mixer trucks. The laying, spreading, compaction, finishing, and curing were similar to steps (8-11) for the on-site mixing method. Note that a plywood sheet of 12 mm thickness was placed between any two adjacent PC slabs in the transverse direction. Mastic pads were supported over these plywood sheets to create isolation joints. Fresh PC mixture was poured directly over the area of formwork on either side of the plywood sheet extending outwards on one of the sides, and spread manually to achieve an approximately leveled surface before applying vibratory effort using a surface plate vibrator for compaction.

2.2 Pervious concrete paver blocks

With recent advancements in technology, the concept of PC paver blocks has emerged as a suitable alternative for conventional PCP systems. Though PC paver blocks provide better quality control and address the on-site complexities associated with construction of traditional PCPs, they still suffer from low strength. In this direction, researchers at the IITT developed Pervious All-Road class All-weather Multilayered paver (PARAMpave) blocks that have a bottom structural layer of M40 and an upper water-draining PC wearing surface course (Singh 2021; Singh et al. 2022b). Two holes of 25.4 mm diameter were made across the full depth of PARAMpave to allow the infiltration of stormwater through the product. PARAMpave were tested for their structural and hydrological properties.

3. Results and Discussions

3.1 Pervious concrete mix design

The results for different properties of PC mixtures prepared at the IITKGP and IITT are presented in Table 1.

Table 1: Properties of pervious concrete mixtures

Property	IITKGP	IITT
Porosity (%)	12-38	19-32
Density (kg/m^3)	1850-2250	1704-2031
Permeability (cm/s)	0.1-5	0.22-1.11
Compressive strength (MPa)	5-28	8-33
Flexural strength (MPa)	1.2-2.8	-

These results indicated that PC material has high potential to mitigate the stormwater flooding and is suitable for applications in parking lots, medians, and low-volume roads.

3.2 Pervious concrete pavement systems

The results for different properties of PCP systems immediately after construction and over three years are presented in Table 2.

Table 2: Infiltration rate of PCP systems immediately after construction and 3 years

Property	After construction			After 3 years		
	IITKGP	MCT	IITT	IITKGP	MCT	IITT
Porosity (%)		24.56	31.61	-	-	-
Compressive strength (MPa)		21.28	8.85	-	-	-
Infiltration rate (cm/s)		0.51	1.43	-	0.01	1.35

The reduction in infiltration rate was substantial at the MCT majorly attributed to the deposition of sediments in the pores from the adjacent areas. Further, no reduction in the infiltration rate at IITT was noted ascribed to the fact that PCP was subjected only to the rainwater and stormwater from adjacent surfaces did not flow over the pavement. Therefore, appropriate maintenance strategies must be devised for PCPs constructed in areas subjected to heavy discharge of pollutants from stormwater, while regular brooming (once in two weeks) will be sufficient for PCPs exposed to only rainwater. Further, the major structural distresses were joint/edge deterioration, and raveling of aggregates from PCP.

3.3 Pervious All-Road class All-weather Multilayered paver blocks

The properties of the PARAMpave products are provided in Table 3. Test results indicated that the PARAMpave products were superior to traditional PCP designs in terms of structural as well as hydrological performance characteristics. PARAMpave weighed around 17 kg, which was about 10% lighter than a cement concrete paver block of similar configurations. Further, the PARAMpave products were about 10% cheaper than PCC paver blocks of similar configurations. Additionally, PARAMpave products consumed 8% lower energy during manufacturing and emitted 8% lower emissions compared to concrete paver block of similar dimensions.

Table 3: Properties of Pervious All-Road class All-weather Multilayered paver blocks

Property	IITKGP
Porosity (%)	17-24
Permeability (cm/s)	0.77-1.33
Flexural strength (MPa)	4.83-6.13

4. Conclusions

This presentation discussed the current status pertinent to implementation of PCP technology in India. The construction steps involved with in-situ and ready-mix were presented. Further, to address the issues of on-site quality control and inherent low strength of PCP, novel PARAMpave products were developed. However, sections must be built to ascertain the performance and sustainability credits of PCP, which will help develop guidelines.

5. Acknowledgments

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Rural Transport Services

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Abstract

Rural roads are vital for access to markets, clinics, education and livelihood opportunities but transport services are also needed. Rural transport services generally operate with hub-and-spoke patterns, with larger vehicles (buses) based in towns. Apart from some commuter bus services, most rural transport depends on small-scale, informal sector entrepreneurs with limited capital. Minibuses, jeep and pickups tend to be old, overcrowded and carry passengers and freight. Motorcycle numbers are growing rapidly. Three-wheelers may operate rural route-based services. Transport services regulatory bodies concentrate on urban and inter-urban transport services. There is weak enforcement by police on rural roads. Rural adoption of electric vehicles and technologies will be slow, but ride-hailing apps will increase. It is easy to collect simple outcome indicators relating to transport services (tariffs, frequencies, modes). These indicators should be included in road databases to facilitate planning and evaluation. Low-cost motorcycle trails and trail bridges can connect small off-road communities.

1. Access, Infrastructure and Rural Transport Services

Rural connectivity, as provided by PMGSY, is vital for socio-economic development. Rural road provision, maintenance and transport services allow men, women and children to access markets, clinics, education and livelihood opportunities (Starkey and Hine, 2016). Despite increasing numbers of motorcycles, most rural people in low-and-middle-income countries (LMIC) do not own motorised transport. They depend on transport services for their mobility, access to services and earning potential. Rural roads are generally constructed and maintained through government-funded contracts and are subsidised assets. In high-income countries, rural transport services depend on subsidies. In LMICs, provision of transport services is generally left to the private sector and market forces, although parastatal bus companies operate some rural routes. Richer people may own cars or motorcycles, but most people depend on walking, bicycles and transport services. Road authorities seldom have much knowledge or understanding of rural transport services. Yet, to ensure road investments are providing optimal benefits, it is important to understand whether the transport services are sufficient and appropriate to all residents. It is proposed that datasets of simple indicators relating to transport services are maintained within roads databases. These indicators can be reviewed when evaluating roads and planning new investments.

2. Demand for Rural Transport Services

Rural residents are diverse, and include women, men, children, older persons and people with disability. People have different travel needs. Vulnerable people are particularly dependent on transport services. The main rural transport demands are:

- Transport of people with goods to and from the nearby market
- Transport to and from a nearby town for employment (commuter transport)

- Transport to and from schools, notably secondary schools
- Transport to and from clinics and hospitals
- Transport to and from the national long-distance transport network for family, business and other visits
- Rural people want predictable and reliable transport services
- Rural people want affordable, timely, safe and easily accessible transport services.

Based on people's choices between different transport services, timeliness and affordability are often more important criteria than safety, although women are more concerned with safety and security and may be prepared to pay more for safer, secure transport (Starkey et al. 2021).

3. Supply of Rural Transport Services

Private sector rural transport operators may provide large vehicles (notably buses) to meet the peaks of transport demand, and some parastatal bus companies address this demand. Rural transport peak demands include twice-daily commuter transport to town/cities, twice-daily school runs (on weekdays) and market day transport (where weekly rural markets are important). Large buses carrying many passengers offer the lowest fares but they need large passenger numbers to be profitable. Without subsidies or regulatory requirements, rural bus services seldom operate throughout the day, being uneconomical outside peak demand. People seeing buses operating along inter-urban roads mistakenly think that rural transport services are adequate. However, even if some buses start in villages, they only meet commuter needs. Other rural people need daytime transport after the bus has left. Women need to make multipurpose daytime journeys to visit clinics and shops. These require smaller transport services (minibuses, jeeps, communal taxis, three-wheelers and motorcycles). The pricing and timeliness of rural transport services is affected by vehicle size, market demand, competition and (sometimes) by regulation. Smaller vehicles charge higher tariffs per passenger-km than buses. Three-wheelers and motorcycle taxis charge two to five times the tariffs of buses.

Figure 1: Examples of rural buses in India and Nepal and a passenger truck in Myanmar

4. Characteristics of Rural Transport Services

In South Asia, large buses mainly operate on urban and inter-city routes, and smaller vehicles serve the smaller villages. Minibuses, jeeps, communal taxis, passenger trucks, three-wheelers and motorcycles all have different advantages, disadvantages and pricing (Starkey, 2016). Most rural transport services operate along specific routes within hub-and-spoke systems centred on small town hubs. In urban areas, autorickshaws operate point-to-point private hire services, but in rural areas three-wheelers may operate route-based services, carrying six (or more) passengers. In addition to route-based services, smaller vehicles (minivans, three-wheelers, motorcycle taxis) may operate point-to-point hired services.

Figure 2: Examples of rural route-based three wheelers in Nepal, Bangladesh, Pakistan and Myanmar

Rural transport services are generally operated by the informal private sector. Small vehicles may be operated by the owner, or someone leasing the vehicle for a daily fee. Large rural transport vehicles are often old, an indication of low profitability. Operators try to maximise their income by taking more passengers than regulations permit. There are many safety and regulatory issues related to such overloading.

Another way of maximising income is to wait until the vehicle has a profitable load. This makes rural transport services unpredictable. Bigger vehicles need more people before departure, which is why they are not used on roads with low transport demand. It is quicker to get a 'full load' with a smaller vehicle. Waiting for 'full loads' is not compatible with predictable timetables and can stimulate a descending spiral of transport services. If transport is unpredictable with long waits, people do not travel, unless it is essential. This reduces demand, increasing waiting times and unpredictability and further depressing the market. Public transport systems can generate ascending spirals of passengers by increasing trip frequency which encourages more people to travel. With timetabled services, operators cannot be sure of full loads on every journey. This is acceptable for transport companies provided their average loads are profitable. Informal sector operators generally avoid starting a journey without a significant load as they must make a daily profit. However, small-scale transporter associations (using minivans or three-wheelers) can stimulate market demand by operating informal timetables, with everyone benefitting, on average.

5. Importance of Motorcycles

In most LMICs, motorcycles are now the commonest vehicles on rural roads. This significant change has become apparent in the past twenty years. More than 250 million two-wheelers are registered in India. Similar motorcycle adoption is seen in other South Asian countries. In a recent rural transport survey in Punjab Province, Pakistan, about 50% of 60,000 rural transport movements by all modes of transport involved motorcycles. Motorcycles accounted for one third men's journeys. Men's use of transport services had declined (Starkey et al., 2021). In South Asia, motorcycles mainly provide mobility for individuals, their families and their businesses. In many countries, motorcycle taxis offer timely point-to-point transport services in urban and rural areas. These are expensive per passenger-km compared to larger vehicles.

Motorcycles can travel on trails and over inexpensive bridges. This has led some countries to construct motorcycle trails and trail bridges to connect off-road villages to the road network. The influential

Universal Rural Access document, published by the World Bank, considered motorcycle trails a serious option to improve rural connectivity (Sum4All, 2019). Motorcycle trail and trail bridges construction can be implemented speedily and they are a fraction of road costs. Politically, motorcycle trails must be presented as *additional* to roads, providing access and connectivity to small, off-road communities. Motorcycle trails have large beneficial impacts permitting service delivery to remote villages and allowing motorcycle taxi services.

Figure 3: Examples motorcycle trails and trail bridges in Nepal, Bangladesh and Myanmar

6. Regulation of Rural Transport Services

Government authorities responsible for regulating transport services are small (compared with roads authorities) and concentrate on administrative compliance and revenue raising. They concentrate their limited resources on urban and inter-urban transport sectors, where most transport services operate. They seldom engage in proactive planning of rural transport and their enforcement officials seldom visit rural routes.

In most countries, regulations separate the functions of passenger and freight vehicles. It is generally illegal to carry both passengers and freight, but that is one of the key requirements of rural passengers: they depend on transport services and want to travel with their produce. Some people load produce onto pickups and travel on them too, while others get passenger vehicles to carry their produce. This is possible due to lack of enforcement.

Transport operators often form associations, which are important for controlling loading and queuing at the urban terminals. Some associations become powerful cartels, controlling market entry. Cartels can reduce healthy competition between operators, removing incentives to improve their vehicles and services.

Transport services should be appropriate for all users, The principles of 'universal access' are fundamental to modern bus designs. Bus entry is preferably a horizontal step, allowing older persons, people with wheelchairs or pushchairs and people of reduced sight or mobility to board easily. Such buses are rarely seen on rural routes. Steep steps and thin handrails can make access to rural buses difficult. Jeeps and minibuses can also be difficult to access for people with disabilities or people travelling with loads. Progress towards universal access may be gradual due to the cost of retrofitting. However, education promoting empathy towards vulnerable travelers should help transport operators to better understand how to assist vulnerable people.

7. Enforcement of Transport Services

Transport services regulatory bodies have minimal presence on rural roads. Regulatory enforcement is left to police. Local police living near rural communities are sympathetic to rural transport operators and do not rigidly enforce regulations concerning loading levels. In some countries, police benefit from non-compliant transporters by extorting payments (bribes). Such police may not favour compliance as it would reduce extortion income. In remote and hilly areas, one can observe over-crowded dilapidated vehicles providing rural transport services. While far from ideal, the people do have affordable means to reach markets.

8. Battery-Powered and Smart Transport Services

Battery-powered transport is increasing, including electric bikes, motorcycles, three-wheelers, cars and buses. However, rural transport services are likely to lag behind urban transport services, due to the longer distances and the limited charging infrastructure. Rural transport vehicles are also often old, suggesting rural transport will be slow to electrify.

Similarly, the benefits that can come from smart ticketing and GPS-tracking are likely to be greatest for urban transport (with different routes and modes) and inter-urban buses. Adoption is likely to be slow on rural transport services.

However, ride-hailing apps will be very appropriate in rural areas, where there is need to link low transport demand to available vehicles. The apps can be used by groups of transport operators (motorcycles, three-wheelers, rural taxis or minibuses). The apps will stimulate innovation in the organisation of the transport services.

9. Need for an Integrated Approach

Rural roads and transport services should be planned together as part of an integrated continuum of transport provision. The authorities responsible for road provision and preservation and those responsible for transport services operate in different 'silos' and seldom have a common perspective. Similarly, the contractors responsible for building and maintaining infrastructure have no direct links with rural transport service operators. Road agencies and contractors are dominated by engineering professionals with limited background in the socio-economic implications of mobility and transport services. When socio-economic studies are required for monitoring and evaluation purposes, these are frequently contracted out to consultancy firms or university departments. Instead of task delegation there should be collaboration, so road engineers can learn the implications of rural mobility and transport services.

10. Collecting Indicators of Transport Services

Rural roads and transport services have beneficial long-term impacts on communities. Measuring impacts requires significant time and resources: it only happens occasionally and is delegated to other organisations. Measuring *outcomes* that contribute to impacts is much easier, quicker and cheaper. It is easy to collect outcome indicator data showing how transport services and road usage change over time. These can illustrate how transport services respond to road improvements and to road deterioration. Simple outcome indicators include transport tariffs, public transport frequency and the modal composition of traffic and public transport. With road investments (construction or maintenance), there is often a modal shift in transport types. Road surfacing can cause a reduction in jeeps and increases in minivans and minibuses.

The Rural Transport Premium (RTP) is the ratio between the fare per passenger-km of transport services on low-volume rural roads and the fare per passenger-km of long-distance standard bus services. It is an indicator derived from easily collectable transport data that allows comparisons within and between countries. Being a ratio there are no units, so issues such as changing fuel prices or exchange rates are cancelled out. There will always be a Rural Transport Premium as long-distance buses will be cheaper, per passenger-km, as they run on national roads, with large loads over long distances. Rural transport services typically use smaller vehicles for shorter distances on poorer roads. However, as rural roads improve fares should decrease (lower vehicle operating costs and higher capacity vehicles) reducing the RTP. Fare data is required for the different vehicle types operating along a road, to allow disaggregated calculations (as commuter bus services will have lower RTPs than minibus or three-wheeler services). Collecting transport services tariff data is simple and quick and can be achieved during a site visit. The frequency of transport services (of different types) and modal frequency of traffic can be obtained through stakeholder recall (on low volume roads) or simple traffic counts (for busier rural roads).

Road agencies maintain databases providing records of each road's status, condition, investment history and maintenance requirements. It is recommended that such databases should now include some key transport services data (types, numbers and tariffs). This would allow outcome indicators including the Rural Transport Premium to be used in decision making for road maintenance and planning, to help ensure investments are fit-for-purpose for transport services and rural people.

11. Conclusions

Rural transport services are essential to ensure the beneficial impacts of the PMGSY roads, but the subject tends to be neglected by roads authorities as responsibility for transport services is not part of their mandate. However, this should not prevent road authorities collecting some very simple data on transport services, to include in the roads database, to help road planners understand how road investments are affecting rural transport outcomes. At the devolved level, discussions on road construction and maintenance should involve local communities and the providers of transport services. At this level, it is also possible to consider how the small communities that are not on the road network could be easily connected to the road by motorcycle trails and trail bridges.

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Livelihoods through Road Maintenance International Experience (ILO)

Tomas Stenstrom & DP Gupta

Abstract

Livelihoods through road maintenance, international experience by ILO including principles of decent work, local resource-based approaches and contractor training with examples from Lebanon, Nepal and India.

1. Introduction

The International Labour Organization (ILO) is a specialized UN Agency devoted to promoting social justice and human and labour rights. ILO's Decent Work Agenda aims to promote rights at work, encourage decent employment opportunities, enhance social protection and strengthen dialogue on work-related issues.

The Employment Intensive Investment Programme (EIIP) is one of the largest development cooperation programmes within the ILO. EIIP targets the most vulnerable people – mainly in rural societies – to combat unemployment, underemployment, and improve livelihood conditions. EIIP projects apply Local Resource-Based (LRB) and environmentally sound work methods and technologies in infrastructure development that optimize employment creation and ensure environmental sustainability. The construction industry, and in particular the road sector, has great employment absorption potentials. This is why the ILO has been involved in rural road rehabilitation and maintenance over the last 40 years with experience from more than 60 countries, mostly low- and middle-income countries in Africa, the Arab States, Asia and Latin America. EIIP mainly focuses on small- to medium-scale infrastructure investments where employment-intensive investments can be successfully applied.

Local resource-based approaches

- Comprises work methods and technologies where the **use of local resources and local labour is favoured** and optimized in the delivery and maintenance of infrastructure assets. ➔ i.e. employ as many people as possible from the vicinity of the project.
- **Local resources, capacities and materials** are used to the greatest possible extent, but without adversely affecting the costs or duration of the specified works.
- **Appropriate (light) equipment** is used for support activities
- Work is carried out with the above resources in a **cost-effective manner without compromising on the quality.**

ILO aims to generate productive employment and decent work for all. This requires the protection of workers' fundamental rights, their fair treatment, and the provision of safe and healthy working conditions. The application of environmentally sound principles and practices constitutes an integral part of the design and implementation of EIIP activities. The focus on LRB approaches and technologies already ensures a balanced use of natural resources.

A key element in the EIIP approach is the focus on providing capacity development support to public and private sector stakeholders – like technical line ministries and local contractors – for the planning, design and implementation of investments in infrastructure.

2. The Importance of Good Access

The majority of the population in developing countries lives in the rural areas. Their primary means of transport is through the use of an access road, linking into district roads before connecting to the national roads. Isolation is a fundamental characteristic of poverty and good access provides the way to reduce that isolation. Currently, a large portion of rural communities do not have this access facility and despite the fact that governments and rural development programmes are involved in building local roads, the combined effect of an insufficient network and the lack of maintenance keeps the rural population isolated from the rest of society.

All year round access requires a continuous road maintenance regime. When applying labour-based work methods its employment generation potential should not be underestimated. These employment opportunities, whether they are temporary or on a continuous basis, provide a significant cash injection into rural communities where subsistence farming constitute the mainstay of the economy. Cash for work schemes in many developing countries have clearly demonstrated that road maintenance can generate much needed jobs and income for people living in rural areas. By establishing a permanent system for maintenance of the road network, employment opportunities can be sustained while at the same time maintaining the investments made in the country's road network.

Any development plan which has a poverty reduction objective needs to have within it the appreciation of the fundamental value of effective rural road maintenance for the achievement of those objectives. Rural road maintenance is not therefore just a financial and economic issue. It is also a humanitarian priority.

The purpose of road maintenance

- Reduce rate of deterioration and prolong life of road
- Reduce vehicle operation cost for road users
- Provide safe and reliable transport services for road users
- Act as instrument of poverty alleviation
- Provide access to schools and hospitals (social infrastructure) in a sustainable manner
- Provide access to Agricultural Markets and Fairs
- **Provide opportunity for gainful employment**

Note: *Small investments in maintenance can multiply the impact and give much better returns. Several studies by the World Bank have indicated that one dollar invested in regular maintenance saves 4-5 dollars required for rehabilitation and reconstruction.*

3. Training for Road Maintenance

ILO's training programme outlines the specific requirements and arrangements for implementing tailored LRB road maintenance trainings for engineers (and/or senior managers) from road client authorities Ministry of Public Works, Municipalities) and engineers and/or company managers from contractor firms. There are a number of factors that influence and determine the training programme for routine road maintenance and spot improvement works, including nature and volume of works and arrangements for road maintenance works. Typically, pre-bid training and a LRB certificate is a requirement to participate in a bid: Key aspects usually include:

- **To organize and supervise LRB operations:** The client engineers/senior managers and contractors have to be able to cope with the specific requirements of the EIIP approach and LRB work methods. These are to some extend different from conventional construction engineering methods. Technical standards and norms remain in principle the same but the work activities and methods of production can be different, especially in the case where equipment is replaced with labour.
- **To prepare costing and work plan for LRB**: General technical and managerial training for simple maintenance works may not be necessary, however planning and budgeting for LRB operation may be important to ensure that employment objectives are fully met. Particular attention is given to establishing realistic production norms (task rates), estimating and costing works, as well as preparing appropriate work programmes.
- **To implement principles of decent work, environmental & social safeguards**[1] Inclusion of decent work conditions and safeguards including occupational safety and health: This implies mainly: i) how labourers are employed, organised and managed by the contractor; ii) how other social safeguard issues are managed and controlled; iii) how environmental protection measures are integrated into work implementation; and iv) how occupational safety and health measures are managed and enforced.
- **To tender for LRB road maintenance:** The ILO uses contracts with particular conditions, specifications and bills of quantities that are suitable for LRB work methods and with procedures that ensure fair and transparent contract management administration. A careful and comprehensive introduction to all involved parties is thus important.

4. Road MTC Example from Lebanon - EIIP Lebanon 2017-2022

EIIP Lebanon is funded by Germany through KfW and implemented by the ILO in partnership with the Government of Lebanon. It focusses on improving livelihoods and decent employment creation for Lebanese host community members and Syrian refugees. One project component is introducing a new concept of labour-intensive road maintenance of tertiary roads with the Ministry of Public Works and Transport.

4.1. Approach to road maintenance

The current condition of the existing road network in Lebanon demands a combined approach of routine maintenance activities and improvement works. Improvement works are required to bring roads back to a standard that allows routine maintenance through **Performance-Based Contracts** to be carried out. Routine maintenance, as a preventive operation, can only be effective if roads are in good (maintainable) condition. Therefore a hybrid tender document has to be prepared for the procurement of works (*Performance Based and Unit Rate Based road maintenance type of contract*).

Figure 1: Maintenance cycle

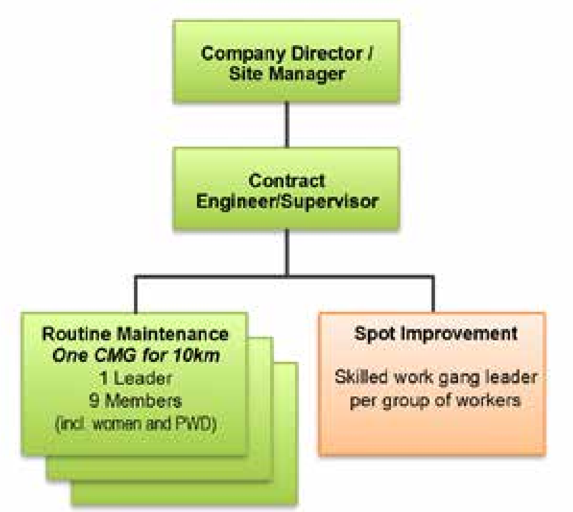
[1]EIIP Environmental and Social Safeguards (ESSF) 2022 https://www.ilo.org/global/topics/employment-intensive-investment/publications/WCMS_841170/lang--en/index.htm

Another factor to consider are the seasonal conditions, which means that the right activities must be carried out at the right time. For example, drains must be cleaned and made functional before the wet season starts, grass has to be cut when it grows, road marking has to be renewed during the dry season, repair works are preferably carried out during dry seasons, etc. Consequently a systematic approach applies as shown in the following example:

4.2. Organisational arrangements

The contractor organises his/her work teams in accordance with the contract requirements. The total length of road(s) under contract determines the number of CMGs to be formed. For every 10 km one CMG consisting of a team leader and 9 members carry out the routine maintenance activities. The team leaders of the CMGs are also responsible of inspecting their 10 km road section and carrying out light routine maintenance activities during the times when the CMGs are not active. A separate team of skilled and unskilled workers carries out the spot improvement and repair works during the period between the routine maintenance operations. (*see Figures 1 and 2*).

Figure 2: Maintenance organisation



4.3. Community maintenance groups

The contractor is tasked with the planning, management and supervision of the routine maintenance activities carried out by the local community members. The responsibility of the contractor is therefore to organise, instruct and supervise community members. The contractor organises them into "**Community Maintenance Groups** (CMGs)" and has to provide the CMGs with appropriate and good quality hand tools, protective gear and safety equipment plus the required materials. The CMG leader ensures that the tools are in good order, maintained, brought to site by the members on every workday and informs the contractor when tools have to be replaced, repaired or added.

The contractor must employ Lebanese and Syrians from the local community as members of the CMG and each CMG group must include at least 2 women and 1 person with disability.

Only contractors who have been trained can participate in a bid. Contracts are let for one year in packages of 30-50 km with 40-50% of the contract cost allocated wages.

5. Road MTC Example from Nepal - SNRTP 2014-2019

The Strengthening the National Rural Transport Program (SNRTP) forms part of the Government of Nepal's efforts to improve road access in rural areas by improving and providing maintenance to local roads identified as part of the District Road Core Network. The development objective of the SNRTP is to enhance the availability and reliability of transport connectivity for rural communities in participating districts.

The project was implemented by the Department of Local Infrastructure (DoLI) under the Ministry of Federal Affairs and General Administration (MoFAGA) with financial support from the World Bank. The project covered 37 districts located in all seven provinces of Nepal reaching approximately 15.7 million people (more than half of the total population of Nepal). About 25% of the people living in the project area are considered poor.

With the ILO technical assistance, SNRTP developed the Doli OSH Guidelines and introduced an effective system for planning and implementation of rural road maintenance and built capacity in the District Technical Offices for the effective implementation of such works, the Rural Transport Information Management System (RuTIMS). This capacity was eventually also installed in the Infrastructure Development Offices of the new provincial administrations when the local government structure was reorganised in 2018 and 2019. Each of the districts selected 150 km of roads and prepared annual road maintenance plans using RuTIMS.

Routine maintenance was implemented through an output-based approach establishing Road Maintenance Groups (RMGs). The RMG members were selected based on the Road Maintenance Guidelines developed for DoLI. The recruitment criteria give priority to women, ethnic groups, Dalits and disadvantaged people from rural communities. Each RMG member were allocated 1.5 km and 3 km of road lengths in earthen/gravel and bituminous pavement respectively. The works were based on monthly work plans and payment based on monthly inspection of completed works.

The routine maintenance works generated 3.4 million paid days of decent work relying to a high degree on employment-intensive work methods. The works carried out by the RMGs constituted 63% of the total cost of routine maintenance works. Moreover, the project initiated linkages to livelihood options and cooperatives to create additional economic opportunities. Among 2,697 road maintenance workers, 64% of the workforce consisted of women and 80% were recruited from disadvantaged and vulnerable groups. On average, workers received NPR 15,184 (USD 138) per month based on the established district wage rate for unskilled workers.

As opposed to construction works, which is of a temporary duration, routine maintenance is a continuous process. Rural roads in Nepal as elsewhere need continuous maintenance and repairs inputs. The RMGs were therefore engaged on one-year maintenance contracts issued by the DTOs that were renewed on good performance. In practice, this meant that a majority of the workers had secured employment for the duration of the project.

Due to longer terms of employment, 30% of RMG workers have been able to purchase land for agriculture purposes, 60% are able to engage their family in animal husbandry, vegetable cultivation and grocery shops. Their wage income has become the main source for the education of their children. Among the RMG workers, 20% have newly constructed toilets and 30% have renovated their house from savings from their wages. The project has not only contributed to their livelihood development, RMG workers have also been provided with financial literacy including opening individual bank accounts and 80% of them are now members of a local cooperative, with an average saving of NPR 60,000 in different banks and financial institutions.

6. Road MTC Example from India - Assistance to PMGSY 2012-2018

Dialogue between the Indian government and the ILO resulted in a partnership agreement in September 2012 between the National Rural Roads Development Agency (NRRDA), Ministry of Rural Development, and the ILO. This partnership focussed on providing technical support to promote good maintenance practices under the World Bank-funded Rural Road Project (RRP II) that in eight states (Himachal Pradesh, Jharkhand, Meghalaya, Punjab, Rajasthan, Uttar Pradesh, Uttarakhand and Bihar).

The collaboration included:

- Development of a rural road maintenance policy framework at the national and state level resulting in seven out of eight states adopting their rural road maintenance policy – many more have since followed.

- Enhanced knowledge of current maintenance practices and challenges among state agencies that were in charge of rural roads.
- Creating standard templates for road inventory and road condition surveys along with a Rural Roads Maintenance Management Manual.
- Comprehensive training material developed and training eventually extended to engineers and contractors for all states, covering the entire spectrum of rural road maintenance issues. Demonstration of innovative processes for contracting rural road maintenance works - in the form of Performance Based Maintenance Contract (PBMC) for routine maintenance. Various models of community contracting were also put in place.
- Strategy for strengthening the capacity of PRIs for execution of maintenance works.
- Integration of ILO's Decent Work elements in the standard contract documents and implementing guidelines of the NRRDA.

6.1. Impact Assessment Study of Improved Rural Road Maintenance System under PMGSY[2]

This study was commissioned with an objective to assess the impact of rural roads maintenance under PMGSY. The concept of rural road connectivity is based on construction of all weather roads. The continuity and uninterrupted connectivity has opened up flow of goods and services to the villages and regular and faster access to facilities outside the villages for the villagers. The real impact of rural roads is only possible when the round the year connectivity is sustained.

State Governments, however have not been very judicious in effectively utilizing their budgets to target road maintenance and have been more inclined in building new roads ignoring the maintenance needs or existing rural roads. It is believed that unless a strategic approach for rural road maintenance starting from adequate funding provisions to building capacities to making the local authorities more accountable is adopted, it will not be long before the benefits of these capital investments will be lost. Better planning and small investments in maintenance can multiply the rural roads' impacts and give much higher returns on the investments made on rural roads.

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Low-Cost Surfacings with a Focus on Chip Sealing

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Abstract

Various surfacing alternatives exist for the upgrading of unpaved roads and include bituminous and non-bituminous surfacings. Bituminous surface treatments are appropriate for surfacing of low volume roads in most situations and often at a cost of less than 50% of other alternatives. From experience and studies in southern Africa, specific surface treatments have been identified as "Low Risk" alternatives with excellent performance for more than ten years while also enabling labor intensive construction. This paper provides practical guidelines for the selection of appropriate surface treatments, cost ratios of different alternatives and highlights the non-sensitivity of binder application rates on low volume roads.

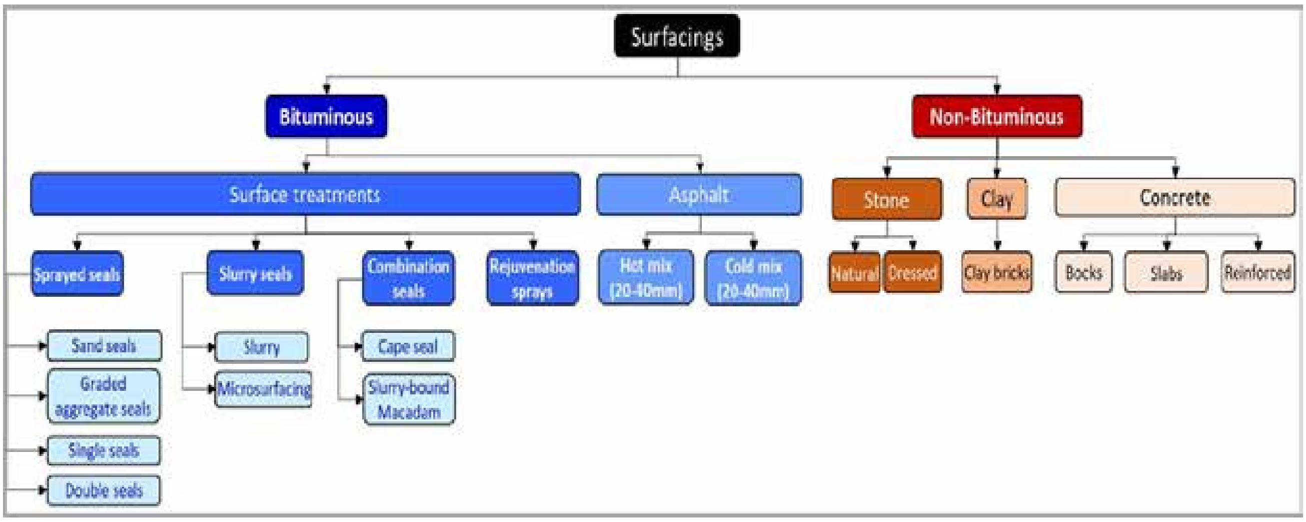
1. Introduction

The surfacing of any road plays a critical role in its long-term performance. It prevents gravel loss, eliminates dust, improves skid resistance, and reduces water ingress into the pavement. The latter attribute is especially important for Low Volume Roads (LVRs) where moisture sensitive materials are often used.

There are a large number of surfacing options, both bituminous and non-bituminous, that are available for use on LVRs. They offer a range of attributes which need to be matched to such factors as expected traffic levels and loading, locally available materials and skills, construction and maintenance regimes, and the environment. Careful consideration should therefore be given to all these factors in order to make a judicious choice of surfacing to provide satisfactory performance and minimize life cycle costs.

Alternative surfacing types that could be considered for LVRs are summarized in Figure 1.

Figure 1: Surfacing alternatives



Variations and further alternatives include:

- Reclaimed bituminous surfacings e.g. asphalt millings
- Roller compacted concrete
- Various forms of concrete blocks e.g. geocells, grass blocks
- Track applications as alternative to full-width applications

Terminology differs across the world. For this paper:

- Bitumen = Asphalt
- Asphalt = Asphalt concrete
- Surface treatments = Surface dressings = Seals

Although the non-bituminous surfacings are highly effective in specific situations, they are mostly used for spot applications e.g. very steep grades, high stress environments or in situations where suitable materials for bituminous surfacings are not available.

The use of bituminous surfacings for upgrading in southern Africa is estimated to be in excess of 95%, with bituminous surface treatments being the preferred option on rural low volume sealed roads (estimated at more than 80%).

The focus of this paper is on the selection of appropriate surface treatments for LVRs, which should provide effective service lives in excess of ten years.

2. Low Risk Surface Treatment Types

Even though single seals, sand seals, single graded aggregate seals and thin slurry seals on newly constructed roads could perform well, experience suggests that a double application of bituminous binder and aggregate drastically reduce the risk of poor performance.

The main distress types leading to terminal conditions and need for maintenance or renewal/resurfacing, are aggregate loss/stripping, bleeding, disintegration, delamination and loss of skid resistance.

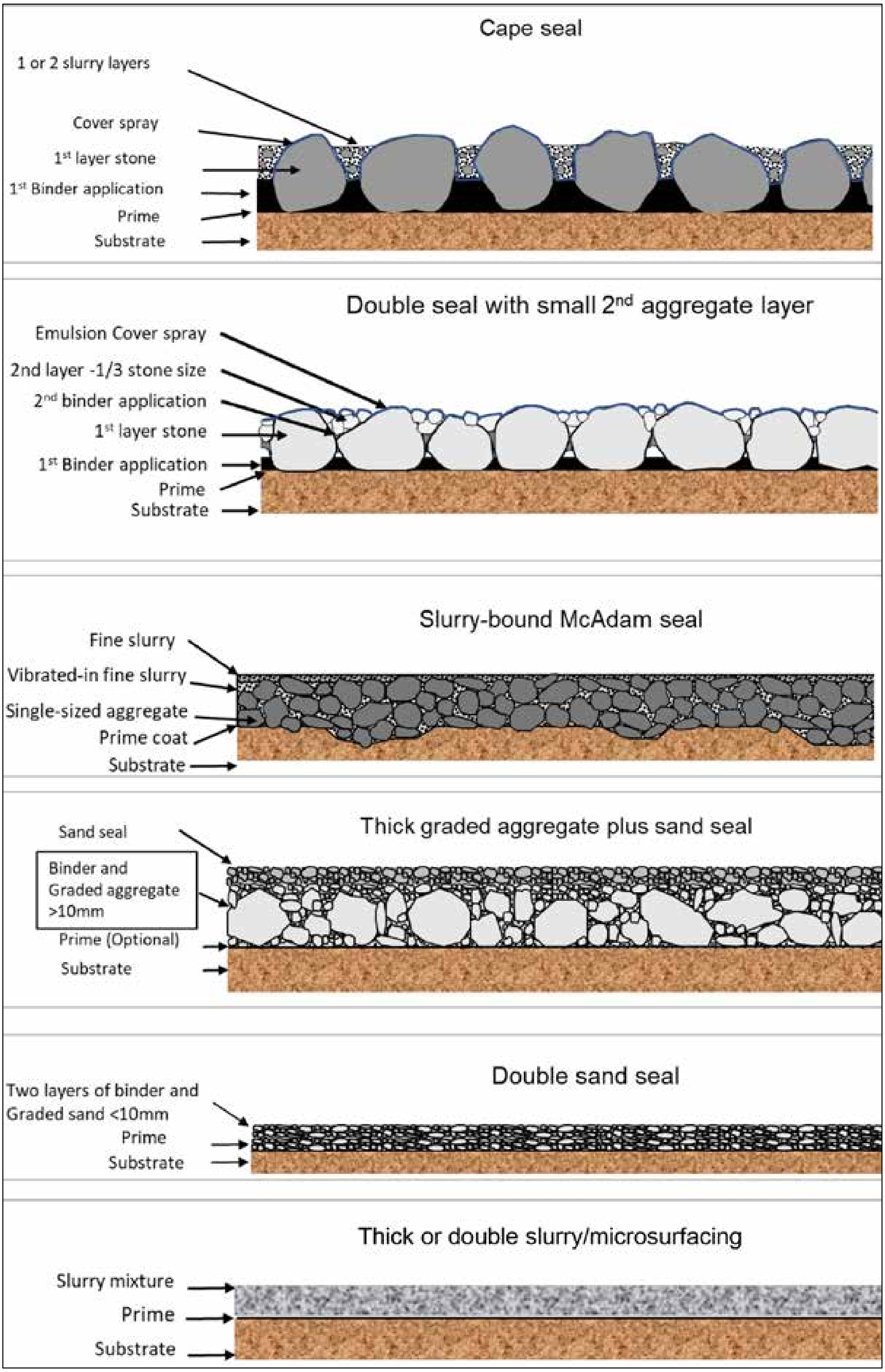
Whereas the surfacing of high-volume roads is carried out by experienced contractors applying strict quality assurance measures, this activity on LVRs is often allocated to emerging contractors and/or executed maximizing labor-intensive methods.

Following studies on appropriate bituminous surfacings by Emery et al. (1991) and Van Zyl et al. (2015), the conclusion was drawn that the risk of chip loss due to inclement weather or vehicle actions could be minimized by selecting a seal structure where small aggregate or slurry, as a second layer, prevents the larger aggregate from dislodging. The lowest risk seals identified, both in terms of chip loss and bleeding were:

- Cape seals
- Double seals with the second layer one third of the first layer (or smaller)
- Slurry-bound McAdam seals
- Double graded aggregate seals e.g. Otta seals and double sand seals
- Double slurry seals

Schematic diagrams for the above-mentioned seals are provided in Figure 2.

Figure 2: Low risk initial surface treatments



3. Selection of Initial Surfacing Type

3.1. General

The first and most important aspect is to select a surface treatment that will perform well under the prevailing conditions. The main factors influencing the performance of initial surfacing treatments, as further discussed are:

- External stresses expected on the road
- The macro texture of the base before surfacing
- Grades at which construction will take place

Other factors influencing the decision are:

- Material availability and costs
- Available skills/equipment and complexity of surfacing types
- Climatic conditions during construction and service life
- Additional environmental factors e.g.:
  - Population density with risk of people crossing during or shortly after construction, influencing the use of hot binders and surfacing type e.g. slow setting slurries
  - Social requirements e.g. the use of streets as playgrounds for children
- Maintenance capability of the local authority to do repairs and to resurface when required
- Noise and skid requirements, which are mainly functions of the posted speed limit, macro texture and material properties

3.2. External stresses

External stresses are categorized in Table 1, based on potential damage to the surfacing.

Table 1: External stress categories

Category	Risks
Very high	High risk of regular water overflow High risk of farm or industrial equipment damage High risk of landslides and subsequent material removal
High	High occurrence of heavy vehicles turning/breaking High probability of loose material on the road surface (Construction materials) High probability of grey water on the road Risk of barricades, fires on the road High speed stormwater accommodated on the road (urban environments) and, Low risk of the risks mentioned under "Very high"
Mild	Occasional turning/breaking of heavy vehicles, and Low risk of aspects mentioned under "High"
Low	Very low risk of damage due to external stresses mentioned above

3.3. Macro texture

The macrotexture of a pavement refers to the visible roughness of the pavement surface and is defined as texture ("bumps and dips") in a pavement with a wavelength (distance from "bump" to "bump) ranging from 0.5 mm to 50 mm. The Volumetric Texture Depth (VTD) is determined through the spread of a known volume of sand or glass beads and dividing the volume by the area covered, as described in ASTM-E965 (2015).

Thin surface treatments cannot fill the voids and properly cover large particles in very coarse textured surfaces, resulting in the base aggregate too close to the surface or even in contact with the vehicle tires.

For purposes of selecting surfacing types, the VTD is categorized as shown in Table 2.

Table 2: Broad categories of base macrotextures

Category	VTD	Example	
Coarse	> 3 mm (Typical WBM surface or excessively broomed crushed stone)		
Medium	1.0 – 3.0 mm (Well broomed Crushed stone base)		
Fine	< 1.0 mm		

3.4. Grade

Limiting grades for surface treatments are mainly based on the availability and ability of equipment to construct at steep grades.

Table 3: Road grade categories

Category	Grade
Very steep	> 10%
Steep	6 - 10%
Mild - Flat	0 – 6%

Cognizance should also be taken of the geometry of the road in terms of curvature and whether large equipment such as the binder distributor and chip spreader could maneuver properly.

3.5. Selection process

A first level conservative selection matrix is provided in Figure 3.

Notes:

- It is assumed that the base is properly compacted, without any loose material and a prime coat applied
- Although the Otta seal is considered a graded aggregate seal it could be constructed with screened material from a local borrow pit
- Natural graded angular sand has been used with success in sand seals Louw (2002)

Figure 3: Conservative selection matrix for LVRs

External Stresses	Gradient	Base texture	Material availability						
			Crushed stone					Graded gravel	Graded angular sand
Very high	Any gradient	Any texture							
High	Very steep	Any texture							
Mild	Very steep	Any texture							
	Steep	Very coarse	SBM	VF + CS		Double slurry	DGAS	Otta seal	
		Coarse		CS		Double slurry			
		Medium		CS		Thick slurry			
		Fine		CS					
	Mild - flat	Very coarse	SBM	VF + CS		Double slurry	DGAS	Otta seal	
		Coarse		CS		Double slurry			
		Medium to fine		CS					
Low	Very steep	Any texture							
	Steep	Very coarse	SBM	VF + CS	VF + DS	Double Slurry	DGAS	Otta seal	
		Coarse		CS	VF + DS	Double Slurry			
		Medium to fine		CS	DS				
	Mild - flat	Very coarse	SBM	VF + CS	VF + DS	Double Slurry	DGAS	Otta seal	
		Coarse		CS	VF + DS	Double Slurry			
		Medium to fine		CS	DS	Thick slurry			Double sand seal

SBM = Slurry-bound McAdam seal **CS** = Cape Seal **VF** = Void Fill e.g. Thin slurry **DS** = Double seal
DGAS = Double graded aggregate seal

Following the identification of suitable surface treatment types, the following aspects should be taken into consideration before final selection:

- **Urban versus rural**

  The structure of the double seal is sensitive to erosion where high speed stormwater is carried on the road surface.

  Graded aggregate seals, Otta seals and sand seals require time and traffic to adhere the binder and sand. With urban drainage systems the water will wash the sand from the road and could block sub-surface drainage systems.

  Emulsion in conventional slurry, breaks as a result of evaporation, which could take several hours dependent on climatic conditions. In the urban environment, traffic accommodation is often a problem. Therefore, the use of Microsurfacing, where the speed of breaking is chemically controlled, is recommended.

- **Stiffness and permeability**

  The flexibility and ability to retard crack initiation or crack reflection is a function of the binder film thickness. The film thickness in slurry, microsurfacing and slurry-bound McAdam is very low, resulting in a very stiff layer, sensitive to high deflections.

  Due to the evaporation of water from slurries, the layer is initially permeable, which could allow moisture into the base, causing a low Radius of Curvature (RoC) and rapid fatigue under heavy loads.

- **Requirements in terms of maximizing labor**

  Any surface treatment, except microsurfacing, could be constructed by hand and small equipment. The binder application is the most critical activity. Therefore, application using a calibrated distributor is preferred. Slurry seals and slurry-bound McAdam seals do not require and spray application.

- **Climatic conditions during construction and early service life**

  The graded aggregate seals require soft binders such as MC3000, which with traffic works itself into the aggregate matrix. High intensity rainstorms soon after construction result in significant damage.

- **Selection of bituminous binder**

  For safety and environmental reasons, the world drive is to minimize the use of hot bituminous binders and binders containing low flashpoint solvents. If graded aggregate seals are considered appropriate, alternative binders will have to be sourced.

  The viscosity of conventional emulsions is very low, resulting in run-off at even mild grades of 4%. High viscosity emulsions or shear-thinning emulsions should be sourced to prevent runoff.

- **Maintenance capability of the local authority**

  Surface treatments are relatively thin (less than 20 mm) compared to asphalt alternatives (20–40 mm). Unfortunately, if there is no capability in terms of routine maintenance and periodic maintenance (to resurface when required), surface treatments are not recommended.

- **Noise and skid requirements**

  Road noise is highly influenced by vehicle speed and texture characteristic of the surfacing. The lowest road noise for surface treatments is obtained when the vehicle tire is in contact with aggregate sizes less than 7 mm.

- **Costs**

  For life-cycle strategy analysis it is recommended that all the mentioned surface treatment types be allocated an effective service life of ten years. Therefore, the final choice between surface treatment types, appropriate for a given situation could be based on costs as discussed in the next section.

4. Costs

The cost of a bituminous surfacing is dependent on the construction costs, the binder and the aggregate costs and is also highly sensitive to the haul distance costs of the binder and the aggregate.

In countries where surface treatments are common, the typical cost ratio of a double surface treatment to a 20 mm continuous graded asphalt is approximately 50–70%.

Table 4 has been compiled from published information in SABITA (2021), recent contracts and estimates from local contractors in southern Africa. The cost ratios for continuous graded asphalt in the third column represent haul distances from the plant of less than 50 km.

Table 4: Cost ratios for different bituminous surfacings

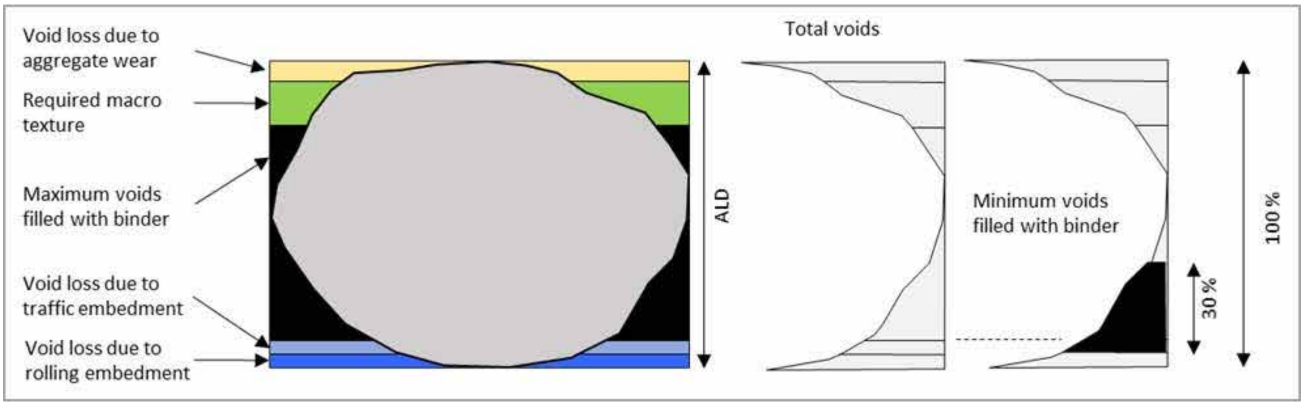
Surfacing type	Size/thickness	Cost ratio to 14 mm Single Seal	Long haul 50-150 km
Continuous graded asphalt	40 mm	3.27	3.90
	30 mm	3.02	3.32
	20 mm	2.30	2.58
	15 mm	1.78	2.15
Cape seal	20 mm	2.24	
	14 mm	1.92	
	10 mm	1.68	
Double seals	20+10 mm	1.44	
	20+7 mm	1.36	
	14+7 mm	1.29	
	14+5 mm	1.23	
Microsurfacing	15 mm	2.10	
Double slurry 2x6 mm	12 mm	2.08	
Slurry Void fill	2-4 mm	0.87	
Slurry-bound McAdam	25 mm	2.55	
Double graded aggregate	12-20 mm	1.85-2.32	
Double sand seal	6-8 mm	1.20-1.38	
Otta + Sand (Local source)	16+4 mm	1.62	
Single Seal	14 mm	1.00	

A policy to force the use of surface treatments will result in contractors being forced to obtain new equipment, which in turn will influence the cost thereof. Uncertainty of success and unknown risks are also priced in with the result that the initial costs could be high. However, with increased confidence and the development of a competitive marked, unit costs will decrease.

5. Sensitivity of Binder Application Rates for LVRs

Design methods in South Africa, New Zealand and Australia are based on a volumetric approach, filling the voids between the aggregate sufficiently to provide a strong bond but at the same time not to overfill to the extent that the macro texture becomes too low for adequate skid resistance. The principle is described in Figure 3, with the main design parameters being the Average least Dimension (ALD) of the stone, traffic volume and the stiffness of the substrate.

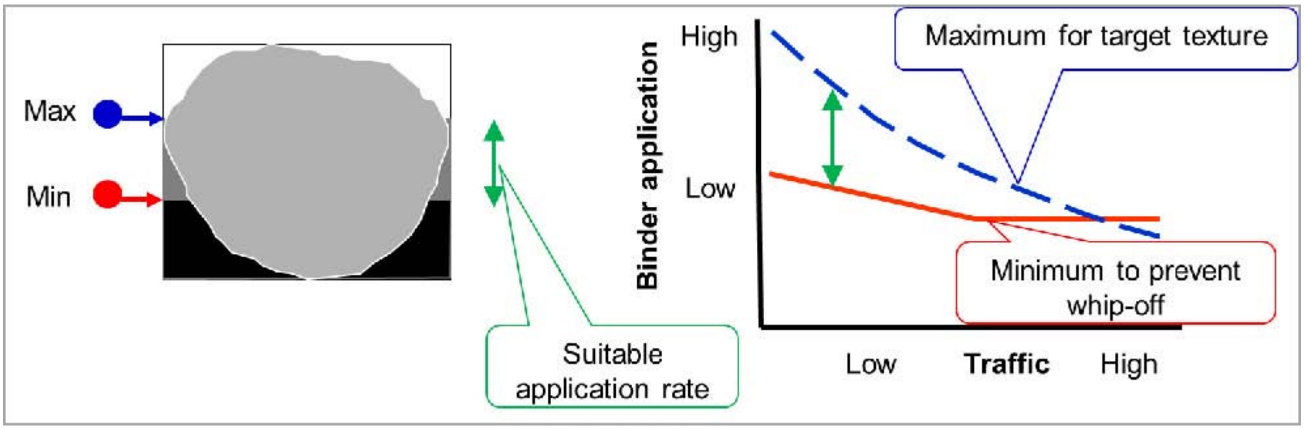
Figure 4: Principles of volumetric design SABITA (2021)



For LVRs the envelope (between minimum and maximum voids filled with binder) is quite large (refer Figure 5), resulting in a low sensitivity to early failure if aimed at the center of the envelope. Therefore, a higher variation in application rates, typically experienced with labor intensive projects, could be accommodated.

The softer the substrate and higher the traffic load, the more voids will be lost due to embedment, effectively reducing the range of suitable application rates.

Figure 5: Low sensitivity of binder application rates for LVRs



The minimum binder will result in a longer effective service life in terms of macro texture retention but has the highest risk for aggregate loss and, due to the low binder film thickness, a shorter service life to crack initiation or crack reflection.

One of the main differences affecting the minimum binder volume between countries is the target minimum binder e.g. South Africa, with a moderate climate uses 30% based also on the philosophy that is easier to add additional binder than to repair a bleeding seal. Countries with colder climates such as New Zealand and Canada recommend much higher voids to be filled before the onset of winter.

6. Conclusions

Surface treatments (Surface dressings) are considered cost-effective alternatives for low volume roads, with construction costs often less than 50% of other alternatives. The performance of a surface treatment is highly dependent on the external stresses, the macro texture of the base and the grade of the road.

Using the guidelines provided in this paper could result in surface treatments lasting effectively for more than ten years.

Except for microsurfacings, all surface treatments recommended could be constructed by hand and small equipment at low risk.

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Effectiveness of Traffic Signs and Road Furniture on Compliance & Road User Behaviour - A Rural Road Study

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Abstract

Rural roads are the backbone of the traffic networks in the country. Rural roads comprise more than 70 percent of the total road network in the country. Despite the attention to all-weather connectivity, crashes have risen on rural roads in recent years. The present study is focused on the proactive assessment of road safety on rural roads in India and evaluating the effectiveness of traffic signs and Markings on road users. Nine road sections were chosen with different attributes in the state of Gujarat. The study selected critical elements of the road and captured the operating speeds of various vehicle categories. On rural roads, the traffic signs were of semi-reflective standards, the critical road sections were improved with Class-IV sheeting type of traffic signs and road furniture, and the speeds were measured for the critical sections. A 13-21 percent reduction was observed with improved night visibility and conspicuity of traffic signs. Also, over speeding was reduced to a range of 4- 32 percent. This showcases the effectiveness of traffic signs and road furniture on rural roads on safety.

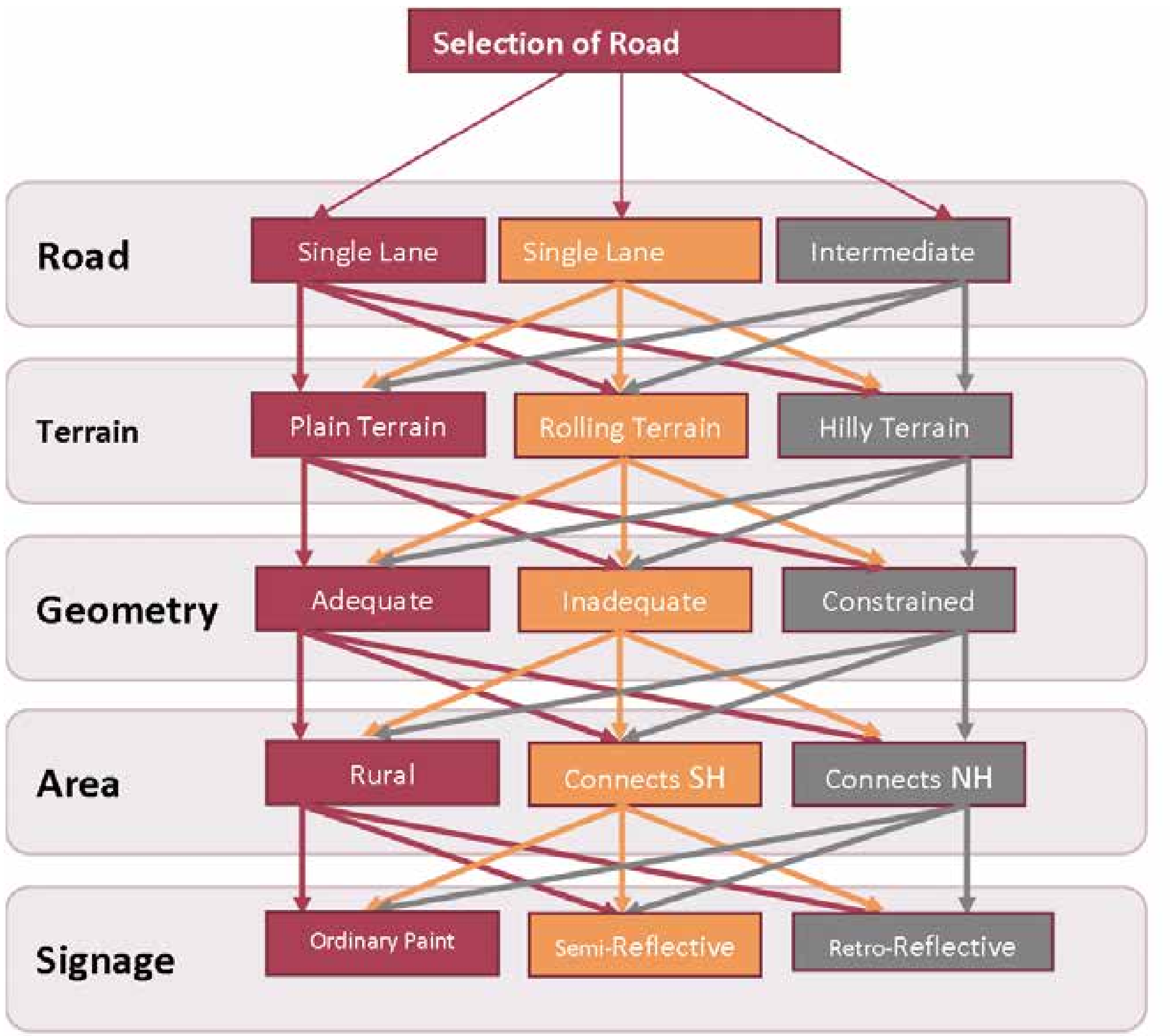
1. Introduction

Rural roads are the backbone of the traffic networks in the country, with more than 70 percent of the total road network in the country. These roads connect rural settlements to nearby markets, urban settlements, and vice-e-versa. Rural Roads have promoted the economic prosperity of the rural settlements. Traffic signs and markings are important tools for safe navigation of roadways (IRC: 67-2012, 2012). The rural roads received a boom after announcing the "Pradhan Mantri Gram Sadak Yojna in 2004. The respective state governments also announced the Mukhya Mantri Gram Sadak Yojna" in their efforts to connect rural settlements with all-weather roads. The Pradhan Mantri Gram Sadak Yojna has entered the third phase of implementation.

1.1. Methodology

In recent years, despite the attention to all-weather connectivity, crashes have risen on rural roads (MORTH, 2019). The rural roads are constructed on pooled land or donated land to provide connectivity, involving minimal land acquisitions. It leads to compromised road geometry at critical locations such as curves and built-up sections. In addition, there are school zones, Hospitals, and other institutional areas near such roads that witness crash vulnerability. The Ministry of Road Transport and Highways issued guidelines to treat the vulnerable crash locations on National Highways (Blackspot Identification, MORTH, 2015). Such guidelines are not yet available on rural roads. The rural roads are witnessing increased traffic with the improvement of connectivity and the economic well-being of the settlers. These roads can be potentially upgraded into district roads in the future, and the vulnerability to accidents would rise if proactive countermeasures were not undertaken.

Figure 1: List of Factors and Conditions Used to Select Study Location



2. Site Selections and Treatment

Nine study sites were selected in accordance with the criteria identified from the methodology. The details of the study section are shown in Table 2.

Table 2: Study Locations

S.No.	Road Name	Terrain	Carriageway	Length
1	Saniya Kande Road	Plain	>3.75 m	1.10 km
2	Ten Barasadi Road	Plain	>3.75 m	1.40 km
3	Maroli Posrawada Road	Plain	5.50 m	4.00 km
4	Palsana - Baleshwar Road	Rolling	7.00 m	3.00 km
5	Mahuwar - Chinnam Road	Rolling	5.50 m	15 km
6	Kunda Silotmal Road	Hilly	>3.75 m	8.00 km
7	Por-Untiya Road	Hilly	3.75 m	6.60 km
8	Khadakiya - Simel	Hilly	3.75 m	2.50 km
9	Asura Masjid Road	Rolling	3.75 m	13 km

The study sites were investigated for road alignment, the condition of curves, signs and road markings, and also identification of vulnerable locations. Safety devices such as traffic signs and other road furniture were used in the study sections. The changes in speed and perception of road signs were investigated. Data was collected both before and after the countermeasures were implemented with the assistance of the rural governing bodies, awareness campaigns were held at the locations (Panchayat). It was found that people were unaware of traffic signs and their intended meanings. It was also learned that the road users were not aware of the safety-related aspects of traffic signage and road furniture.

3. Results

During the implementation of road signs, awareness campaigns were held in the nearby villages and by the roadside of the study areas. The villagers were informed about the road signs and their intended meanings through the awareness camps. The campaigns showed a positive change in recall of traffic signs and markings. The sign recall improved from 8 to 65 percent in the study sections. After installing the road signs and road furniture, the results showed a significant drop in the speeds at curves and built-up sections. The over-speeding phenomenon reduced significantly (23-32%) across the critical locations, and an average drop of 13-21% in speeds was observed in all study sections. The changes in speeds are shown in Table 3.

Table 3: Before-and-After evaluation of vehicular speeds

S.No.	Sites	Min Speed		Max Speed		Mean Speed		85^{th} Percentile Speed		% Over speeding	
		B	A	B	A	B	A	B	A	B	A
1	Saniya Kande	12.6	10.8	47.4	36.5	26.5	19.7	31.9	25.3	14.3	9.8
2	Ten Barasadi	5.6	9.7	53.6	41.2	28.5	21.3	35.8	25	21	12
3	Mahuwar Chinnam	7.7	10	54	47	29.4	21	36.2	24.8	44.9	5.4

S.No.	Sites	Min Speed		Max Speed		Mean Speed		85th Percentile Speed		% Over speeding	
		B	A	B	A	B	A	B	A	B	A
4	Palsna-Baleshwar	7.3	11.1	59.6	63.6	24.2	30.8	30.6	36.8	13.9	7.1
5	Maroli Posrawada	9.7	7.6	50.5	38.3	28	19.6	34.7	20.2	18.5	9.5
6	Kunda Silotmal	8.9	9.5	32.7	28.5	21.5	21.4	26.3	25.5	42.5	42.7
7	Por Untiya	12.1	8.8	46.9	36.7	24.4	21.4	29.9	26.4	41.9	45.2

**Speeds in kmph*

When reliable crash data is unavailable, the speed is used as a safety surrogate (Shrestha & Shrestha, 2016). The reduction in speeds indicates that the vehicles were receptive to the treatments in the critical sections. After implementing traffic signs and allied road furniture, the average speeds have reduced significantly over the study sections. It highlights the importance and positive changes made by the placement of retro-reflective signs and road furniture and sustained awareness campaigns, which are low-cost countermeasures, and highlights the efficacy of such treatments at potential accident locations as a cost-effective alternative. Also, a handheld reflectometer was used for comprehensive testing of pre-installed traffic signs at all study sites. The results are shown in Table 4.

Table 4: Observed Retro-reflectivity values with the Reflectometer test

S.No.	Color	Entrance Angle	Observation Angle (Degree)	Actual Ra (Cd/Lux/sqm) Value at Site				Minimum Requirement Ra
				*R1	R2	R3	Average	(Cd/Lux/sqm) as per IRC 67
1	White	-4	0.2	0	0	0	0.0	70
			0.5	0	0	0	0.0	30
		30	0.2	2.8	2.8	2.8	2.8	30
			0.5	2.8	2.8	2.8	2.8	15
2	Blue	-4	0.2	0	0	0	0.0	4
			0.5	0	0	0	0.0	1.7
		30	0.2	7.7	7.7	8.1	7.8	2
			0.5	4.5	4.7	4.4	4.5	0.8

**R - Readings*

The condition of pre-existing signs is shown in Figure 2. It may be noted that the sign boards are highly deteriorated physically. Moreover, there is minimal reflectivity at night times. This shows the need of the study as to why use of traffic signs with better specifications is desirable on rural roads.

Figure 2: The Traffic Sign Condition Survey and Testing

Comparative Night-Time visibility after implementing retro-reflective signage is shown in Figures 3 (a) and 3 (b).

Figure 3: Before and After Condition of Roads with the implementation of Road Signage and RPMs

(a) A comparison of Night-time visibility with and without retro-reflective signage at the Palsana site

(b) Improved edge line delineation after RPM installation at Maroli Site

4. Conclusions

The study concludes the following:

(a) Rural roads lack geometric consistencies, the curves are deficient, and built-up sections are not treated, leading to crashes.

(b) There is a lack of awareness among road users about the utility of traffic signs and their relation to safety. The road user survey revealed that the drivers could not recognize basic traffic signs despite having a valid driver's license.

(c) The critical sections were identified in the road sections under study; they were identified based on geometric features and their strategic importance.

(d) The identified critical sections were subjected to speed checks, as speeding was directly related to aggressive behaviour. Aggressive behaviour is directly related to crashes.

(e) After installing retro-reflective signages, the speeding behaviour reduced significantly to 4-32 percent at all road stretches.

(f) The average speeds at the road stretch dropped between 15% to 55% across the sections after implementing traffic signs and road furniture.

(g) Testing the retro-reflectivity of signage showed that the signage from retro-reflective sheeting met all the criteria set by IRC 67:2012. In contrast, local authorities' signs installed from non-tested sheeting failed the criteria for minimum retro-reflectivity.

(h) After installing retro-reflective signage, road users reported significant improvement in night visibility, decision making, and edge delineation.

(i) The pre-installed sample board tested failed to meet the minimum reflectivity criteria of Class-A sheeting, which is the minimum grade, retro-reflective sheeting required for Rural Road. Many boards were painted or of vinyl, thereby not fulfilling their purpose of guiding road users at night. Henceforth it is recommended to have a quality check viz warranty certificate, test certificate, on-field testing as mentioned in IRC 67.

(j) As a policy, all the semi-reflective boards should be replaced with retro-reflective Type-IV sheeting on all the rural road stretches. It offers no retro-reflectivity at night, a critical element of positive guidance and road user safety.

5. Acknowledgments

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New Technologies and Innovations in Rural Roads- India

Gordon R Keller, PE, GE

Genesee Geotechnical
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1. Introduction

A great deal of good work has been accomplished under the PMGSY (Pradhan Mantri Gram Sadak Yojana) rural road program. Total program road length is 636,661 km, and it is currently the largest rural roads program in the world. The Indian Roads Congress has developed a large number of very informative and useful publications to aid in the planning, design, construction, and management of the national, state, and rural road systems of India. Documents like the "Hill Road Manual" (IRC: SP 48) and the "Rural Roads Manual" (IRC: SP 20) help define how the planning, design, and construction of the roads will be accomplished.

There are also many areas where the planning, design, and construction practices can be modified and improved. Use of innovative and "appropriate technologies" such as mechanically stabilized earth, use of geosynthetics, rapid bridge construction techniques, more remote sensing, asset management, and more use of bioengineering may be able to reduce program costs and increase speed of construction in various phases of road work. Engineering is an evolving discipline, so keep in mind the quote "Let Perfection Not be the Enemy of the Good" (D.P. Gupta). "Best Practices" can be improved with time, education, and experience!

India is a country that has very diverse conditions, ranging from the steep foothill and mountainous terrain of the Himalayan mountains to the very flat regions near the mouth of the Ganges River where severe flooding of the region is common. Thus, road design considerations are diverse and challenging. Conditions in many hill regions are admittedly difficult, with intense rains, steep unstable terrain, a short construction season, relatively high costs, a lack of good construction materials and equipment, a lack of qualified contractors, and a lack of experienced young engineers. A great challenge is the implementation of Best Management Practices (BMPs), compliance with the existing standards, and incorporation of new technologies and innovative designs into rural road planning, design, and construction.

2. New Technologies and Innovations

In the PMGSY program, some areas where innovation can be incorporated and the process of Value Engineering used that can be applied to reduce cost, reduce planning, design and construction time, and improve road performance, include the following:

Use of Geosynthetics

- 1.1 Using Mechanically Stabilized Earth (MSE) retaining structures;
- 1.2 Reinforced soil slopes and embankments (RSS) and Deep Patch;
- 1.3 Use of Geocells, TRM and Erosion Control Products.

Bridges and Drainage

- 2.1 Accelerated Bridge Construction (ABC);
- 2.2 GRS-IBS Bridge Abutments;

- 2.3 Buried Bridges;
- 2.4 Stream Simulation
- 2.5 Embankment Overtopping Protection.

Tools and Information

- 3.1 Dynamic Cone Penetrometer (DCP);
- 3.2 Using soil bioengineering and deep-rooted vegetation;
- 3.3 Use of GIS/ESRI, remote sensing, LIDAR, and Drones;
- 3.4 Climate Models, such as VIC (Variable Infiltration Capacity);
- 3.5 Asset Management.

Application of BMPs

- Application of Best Practices for roadway drainage, maintenance, and slope stabilization.

2.1. Use of Geosynthetic

A number of relatively new, innovative, and appropriate technologies using geosynthetics exist today to help in the design, construction and management of low-volume roads.Few uses of geosynthetics have been seen on India low-volume roads. Geosynthetics can facilitate construction and to reduce the cost of structures or the road. Uses include reinforcement in mechanically stabilized walls, reinforced fills, and deep patch; geocells for drainage and slope stabilization; Turf Reinforcing Mats (TRM) and erosion control netting; Geosynthetic Reinforced Soil (GRS) bridge abutments; as well as many other applications.

2.1.1. Mechanically Stabilized Earth Structures–

Mechanically stabilized earth (MSE), or reinforced earth structures are commonly used structures today as an alternative to conventional gravity retaining systems. They can be lighter, cheaper to build, and speed up construction when a retaining structure is needed, particularly using onsite materials. MSE structures using geosynthetics often result in the least expensive type of retaining structure, and are the most commonly used structures today. MSE structures consist of layers of a reinforcing material such as geotextiles or geogrids placed at relatively close intervals (0.3-0.6 meter) within a compacted backfill. Backfill material is ideally a granular soil, but marginal, clay rich soils can be used. Facing materials include welded wire, concrete blocks, concrete panels, or wood timbers.

2.1.2. Reinforced Soil Structures and Deep Patch

Reinforced soil structures (RSS) or reinforced fills are somewhat cheaper than a retaining structure for the same site since no facing material is involved, and construction can be relatively rapid. A slope range of 67 to over 150 percent can be achieved, depending on the reinforcement, soils, and facing measures used. Reinforced fill heights commonly range from 15 to 50 feet (5 to 15 m). However, on some highway and mining projects, and reinforced fills have been built over 115 feet (38 m) high. Layers of a geotextile or geogrid reinforcement are placed between layers of compacted soil, similar to an MSE wall.

Deep patch is a variation of a reinforced soils structure, but with several layers of reinforcement only in the top meter or two of the embankment. It is more a "heavy maintenance" procedure than a structural fix. It can stop the settlement of an unstable fill slope and increase the factor of safety of the slope slightly. This technique has been used successfully on hundreds of mountain roads.

2.1.3. Use of Geocells, TRM, and Erosion Control Products

Geocells, or plastic cellular confinement structures, have been used on rural roads to confine fine gravel and rock in low-water crossings, for drainage blankets, erosion control, and slope protection. The geocells are made of an expandable high-density polyethylene plastic (HDPE) with 150 to 200 mm-diameter cells and a thickness of 50 to 200 millimeters. The expanded sheets are about 2.5 meters wide by 5- to 6-meters long but can be cut to size easily. GEOWEB geocells have been the most common type of material used to date, and they can be purchased solid or with perforations (holes) in the cells for drainage.

Turf Reinforcing Mats (TRM) are thin mats made of a woven plastic netting that can contain mulch and seed. They are used for channel lining or stream bank protection. They are durable and, when placed over geocells, can supposedly resist channel velocities of up to 9 meters/second. Plastic netting is also used in a wide variety of erosion control products to confine mulch or straw in bundles (wattles) or on slopes. Erosion control products are one of the fastest growing fields of application for geosynthetics today.

2.2. Bridges and Drainage

Bridges are an ideal structure to pass large flows in streams and rivers, and if properly designed, can pass the increased flows anticipated due to climate change. Thus, they are a key structure on roads for transportation and to provide adaptation to climate change and more intense monsoon storms. Unfortunately, bridges are expensive and the condition of many low-volume road bridges all over the world is poor! Considering this situation, agencies have been looking for creative ways to either replace bridges, close bridges, or find alternative structures or routes.

The main options include either 1) ways to replace bridges with relatively inexpensive new structures, or 2) ways to find alternatives to the use of the conventional bridge. This includes ways to reuse old bridge parts, reducing bridge width or load capacity, using temporary and alternative structures, or closing bridges where reasonable detours exist. Relatively inexpensive bridge replacement, new construction options include Accelerated Bridge Construction (ABC), Geosynthetic Reinforced Soil (GRS) bridge abutments, and building long-span "buried bridges".

2.2.1. Accelerated Bridge Construction (ABC)

Accelerated Bridge Construction (ABC) is to use modular components to simplify and speed up construction of a bridge. Much of this work has been pioneered by the Bridge Engineering Center at Iowa State University and the Iowa DOT. The use of accelerated bridge construction can decrease construction time and costs associated with bridge repair and rehabilitation. Commonly used modular units include precast piers and columns, abutment units and deck panels.

2.2.2. Geosynthetic Reinforced Soil (GRS) Abutment Bridges

The use of Geosynthetic Reinforced Soil (GRS) bridge abutments to support the superstructure of a bridge has been pioneered by agencies such as the Federal Highway Administration and US Forest Service. Several hundred of these structures have been built to date across America, with most showing a significant savings of both time and cost of construction compared to traditional bridge design and construction. GRS structures can be constructed relatively quickly and can be built by maintenance personnel. A principal advantage of GRS bridge abutments is elimination of the infamous "bridge bump" caused by differential settlement between the abutment foundation and the approach fill.

The soil mass of the abutment system is constructed like a mechanically stabilized earth retaining structure, using reinforcing layers of a polymeric geosynthetic material such as geotextiles and geogrids or a welded wire. The bridge girders then rest upon this reinforced soil mass. Various "flexible" facing materials have been used, particularly timbers and modular concrete blocks, depending on the design and site conditions.

2.2.3. Buried Bridges

Buried bridges involve use of large multiplate CMP or precast concrete culverts to support the roadway embankment and surface, as a cost-effective alternative to bridges in many applications. Corrugated metal pipe culverts are commonly used to replace small low-volume road bridges and the cost of culverts are typically much less. Because of the high loads on large structures, specific designs are required for the deep corrugated structure plate structures. Spans of over 15 meters are common, and some have exceeded 25 meters.

2.2.4. Stream Simulation Culverts

Stream simulation is a concept where the natural stream channel is duplicated through the culvert to produce a natural stream channel bottom to promote fish and aquatic organism passage. The width of the culvert is also designed to at least match the width of the bankfull stream channel. This design approach has been used on many sites in the Western United States to improve fish habitat and stream connectivity. It also produces a structure with the capacity of about a 100-year storm event, so it provides resilience against climate change storms.

2.2.5. Fill Overtopping Protection

Culverts often fail due to plugging from debris and sediment. When they plug, they can wash out the roadway fill and cause a great deal of roadway damage. To prevent damage to a fill, either a designed dip can be put into the road to direct the stream water back into its natural drainage, or the fill embankment can be armored to prevent its washing out. Armoring measures have included rock riprap, a layer of HDPE geotextile, armament with Turf Reinforcing mats (TRMs), or armoring with geocells filled with rock or aggregate.

2.3 Tools and Information

2.3.1. DCP- Dynamic Cone Penetrometer

Tools are available today that can be useful to help characterize in-place roadway materials, including estimates for soil strength, pavement strength and soil moisture content.

The Dynamic Cone Penetrometer (DCP) is a relatively inexpensive and simple instrument designed for the rapid in-situ measurement of the structural properties of existing road pavements with unbound granular materials such as a subgrade soil. An 8 kg hammer is dropped 575 mm and the rate of penetration is measured in inches per blow of the hammer, as described in ASTM Test D-6951. Continuous measurements can be made to depths of 900 to 1200 mm with use of an extension rod. The rate of penetration of the cone is inversely related to the strength of the material and correlated to the California Bearing Ratio (CBR) test. Currently South Africa has developed a structural section design methodology based upon DCP.

2.3.2. Soil Bioengineering and Biotechnical Slope Stabilization

Biotechnical methods for slope stabilization, streambank protection, and erosion control commonly are used in road projects today. Their advantage is the use of physical systems in conjunction with vegetation to achieve long-lasting results and results that are superior to either method separately. **Soil bioengineering** is a technology that uses integrated ecological principles to assess, design, construct, and maintain living vegetative systems to repair damage caused by erosion and slope failures.

Biotechnical treatments combine the use of vegetation with other physical structures, such as vegetated gabions or vegetated reinforced soil slopes. Soil bioengineering methods can be very cost-effective compared to conventional hard systems, and are aesthetic, making them particularly suitable for rural road applications. Some more common soil bioengineering and biotechnical treatments include live stakes, fascines, brush layering, vegetated reinforces soil slopes, and live retaining structures.

2.3.3. GIS/ESRI, LIDAR, and Drones

Technology is advancing rapidly today in the fields of geographic information systems (GIS) and use of global positioning systems (GPS) equipment. GIS systems allow road managers to maintain large amounts of data regarding their area and manipulate and evaluate that data in many ways. GIS equipment allows us to locate features, define areas and distances, generate Digital Elevation Models (DEM), and greatly improve the quality of our work. LiDAR (Light Detection and Ranging), is a relatively new technology that offers advantages over traditional methods for representing a terrain surface. LiDAR can have very high vertical accuracy, which enables it to represent the Earth surface with high accuracy, even through a heavy tree canopy.

LiDAR surveys have originally been done from low-flying aircraft, but today the surveys are commonly done from drones or even from a backpack unit.

Drones today offer an amazing alternative to do remote map surveys, site monitoring, bridge inspections, gather site photographs, etc.

2.3.4. Climate Models, VIC, and Weather Forecasting

Many climate models are available today to forecast climate change in the future. One commonly used model is VIC (Variable Infiltration Capacity) which can be used to simulate rainfall projections, snowpack, stream runoff, and temperature projections for various greenhouse gas emission scenarios. This type of information is critical to forecast future climate conditions and infrastructure adaptation measures.

2.3.5. Asset Management

Asset management involves keeping inventories of key infrastructure items such as roads, trails, bridges, culverts, dams, etc. This information is needed for proper infrastructure management, budgets, and for climate adaptation assessment. With this information, combined with GIS data, infrastructure vulnerabilities can be identified, such as likely culvert or road-stream crossing failure risks.

2.4 Best Management Practices (BMPs)

Best management or engineering practices are critical for the proper design and management of rural roads. Beyond the scope of this paper, BMPs provide guidance for cost-effective and long-term design of drainage structures, slope stabilization measures, erosion control efforts, materials selection, and overall road management and maintenance.

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Modular Pre-Engineered Bridge Systems - For Permanent, Emergency, and Temporary Applications

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1. Introduction

1.1. General

Modular bridges are pre-fabricated in modules that can be installed quickly in the field without the aid of any heavy equipment. It is built in a controlled environment typically in a factory environment and then installed at the site. Being modular, it is easy to construct and install. It has major advantages in speed of execution and flexibility. The various components remain small and light enough to be carried in the ordinary truck and lifted and erected at the site manually without the use of a crane. The bridges are also strong enough to carry vehicular loads that normally ply the road.

Many types of prefabricated steel bridge systems have been used in rehabilitation projects to replace deteriorating bridges. Applications of these bridge types are numerous, and can be classified into 3 distinct types:

(a) **Temporary Bridges:** As an alternative to costly detours, maintenance of traffic, and increased traffic volume, prefabricated steel bridges are utilized to divert traffic during bridge repair, rehabilitation, construction, or replacement. These bridges are installed as a temporary structure during construction and then disassembled and stored until used again as a temporary structure. Figure 1 shows a temporary modular bridge in operation.

Figure1: Temporary Modular Bridge in service while construction of permanent bridge in progress

(b) **Emergency Bridges** are also needed from a security standpoint due to man-made non-terrorist hazards like ship impact, truck impact, fire, and blast. Natural disasters such as hurricanes, mudslides, fires, and tornados can destroy a bridge by washout or collapse. Typical prefabricated bridges can be erected much faster than the time of constructing a cast-in-place structure. Moreover, with the increased threat to our nation's infrastructure due to terrorism, these systems could be utilized in a time of national emergency. Figure 2 shows the emergency bailey bridge, which was erected by the Indian Army in a period of 5 days just before the CWG 2010 in New Delhi when an under-construction footbridge collapsed unexpectedly.

Figure 2: Emergency Modular Bridge – Erected in 5 days before CWG 2010

(c) Permanent Bridges: A permanent structure requires a design service life of 75/100 years as per the codes and standards prevailing in the country. A major objective of this study is to provide recommendations that will increase the use of prefabricated steel bridges as permanent bridges.

Figure 3: Permanent Modular Bridge – Erected at Sonprayag, in Uttarakhand after the 2013 Floods

Prefabricated Modular Steel Bridges are suited forquick design, assembly, and launch. Being modular in design, they can be adapted to varying spans and widths using the same basic structural components, manufactured to precise dimensions, and stocked in bulk for supply at short notice. The demand for use of such bridges is growing due to the increase in frequency and intensity of natural disasters that we have seen over the last few years. Figure 3 shows the use of a Modular Prefabricated permanent bridge at Sonprayag, Uttarakhand after the 2013 floods.

1.2. History of Modular Prefabricated Steel Bridges

The modern-day prefabricated Panel/Floor Beam/Deck system was first patented by A.M. Hamilton in 1935. This bridge type was used for a quick mobilization to allow military access to remote locations or to replace destroyed bridges in times of conflict. This system is currently known as the Callender-Hamilton System.

This design was augmented by Sir Donald Bailey in the 1940s and is the predecessor to what became the most popular system, known as "The Bailey Bridge". British Engineer, Sir Donald Coleman Bailey (Figure 4) further improved on Hamilton's design and adapted a methodology that he patented in 1943. This became popular worldwide. The uniqueness of this system is as follows:

- Was Pre-Engineered & Modular & interchangeable
- Could be delivered on-site in standard trucks
- Individual components can be carried by 6 men or less
- Would require minimum equipment to build
- Could be erected quickly. No welding is to be used
- Could support trucks and heavy vehicular traffic

Figure 4: Sir Donald Coleman Bailey (1901-1985)

1.2.1. Post World War II (1940's thru 1960's)

- Bailey Bridges continued to be manufactured & used for emergencies.
- In India, 1st/2nd Generation Modular Bridges (Bailey Bridges & Hamilton Bridges) are manufactured and used even now.
- Miles of WWII vintage Bailey Bridges became available to many governments as "Army Surplus".
- Concepts of pre-engineered bridge systems and accelerated bridge construction are still to be developed

1.2.2. 1960's and 1970's

- Modular Panel bridges find their niche in Emergency Bridges.
- Due to their pre-engineered modular design, panel bridges allowed for a quick replacement of damaged structures.
- Developing countries also created an additional demand for a pre-engineered bridge system that could be shipped in standard 20 ft. and 40 ft. containers

1.2.3. 1970's to Present

- Design of the Modular Panel Bridges evolve.
- Systems improve modularity to maximize the utilization of components.
- Higher strength (S450) steels are now used which increased the strength to weight ratio yielding longer clear spans.

- Painted Bridges are replaced by galvanization to increase service life, reduce maintenance costs, and protect the environment.
- Multi-lane bridges are developed with Modular concept.

The present generation of Modular Bridges is vastly improved as compared to the age-old Callender-Hamilton Bridge System or Bailey bridge System. Design of the Modular Panel Bridge systems has evolved over the years. 3rd generation modular bridges have surfaced which has improved modularity to maximize the utilization of components. Higher-strength (S450) steels are now used which increased the strength-to-weight ratio yielding longer clear spans. Painted Bridges are now replaced by galvanization to increase service life, reduce maintenance costs, and protect the environment. Multi-lane bridges are being developed with the Modular concept.

2. System Details & Bridge Components

Numerous manufacturers globally offer modular prefabricated bridges to the user, accommodating various applications. Some of the known names are as below:

- Callender-Hamilton Bridge
- The Bailey Bridge
- The Acrow Bridge
- The Mabey Johnson Bridge
- The Janson Bridge
- The Quadricon Bridge
- MBS – BERD Modular Bridge Solutions

By no means, the above list is complete. There are many more players worldwide, about which the author is not having information worth sharing. A brief description of these systems is given below:

(a) **Callender-Hamilton (CH) Bridge**

The modern-day prefabricated Panel/Floor Beam/Deck system was first patented by A.M. Hamilton in 1935. The bridge was used for a quick mobilization to allow military access to remote locations or to replace destroyed bridges in times of conflict. The design was centered on a series of gusset plates that allowed the direct attachment of the longitudinal, diagonal, vertical, and cross-framing members. The centralizing of connection points increased the speed of construction and also allowed identical panels to be fabricated from identical members and then installed on-site. Figure 5 shows a typical CH bridge erection by Indian Railways catering to emergencies.

Figure 5: Elevation - Patent Information, Elevation on Callender-Hamilton Bridge

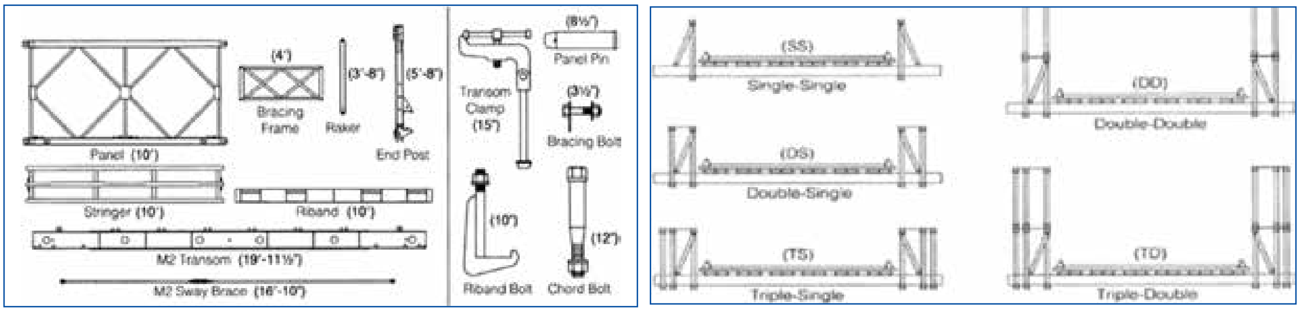
(b) **The Bailey Bridge (BB)**

Sir Donald Bailey, a British military engineer, adapted a methodology that he patented in 1943. The Bailey Panel Bridge System retained the same basic design but adopted a new scheme for both the construction method and the panel connection system. The criterion for the original design consisted of the following:

i. The basic components had to be standardized and fully interchangeable.
ii. The individual components had to be capable of being carried by a group of six men or less.
iii. The parts had to be transportable in a three-ton military truck.
iv. A bridge had to be capable of rapid erection as it was required for military assault purposes.
v. The components had to be capable of producing multiple configurations to provide for various loading conditions and spans.

The design consists of main load-bearing side truss girders built from prefabricated, modular, rectangular panels (10 feet long and 4 feet 9 inches high center to center of pin-hole connections). The panels are pinned or bolted end-to-end at their top and bottom chords to form a truss of the required length. Figure 6 details all of the components that comprised the Bailey Panel Bridge System.

Figure 6: Standard Bailey Components and Bridge configurations

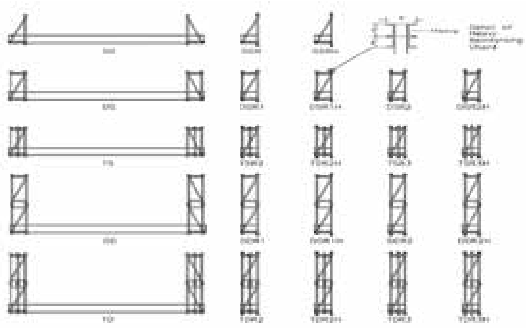


(c) The Acrow Bridge

Acrow Ltd. was granted a patent in 1973, with their system based on the Bailey design. Since that time, the system has been updated and patented in 1990 to be a stronger, longer, and more adaptable design. The current "3rd generation" bridge design is lighter than the original design with a truss that is 50% deeper, 50% stronger in bending, and 20% stronger in shear. These improvements are achieved through an improved shape and design of the panel configuration. Given the modularity of the ACROW system, once the carriageway width, bridge span, and design loading cases are known, an optimum bridge configuration can be determined. Figure 7 shows a typical ACROW bridge in use. Figure 8 shows the possible bridge configurations. The triangular panels deviate from the original lattice design in that the panels can be situated and pinned to eliminate the stresses associated with pinhole sag and elastic

Figure 7: ACROW Bridge in service

Figure 8:Various Possible Configurations with ACROW Bridge in service

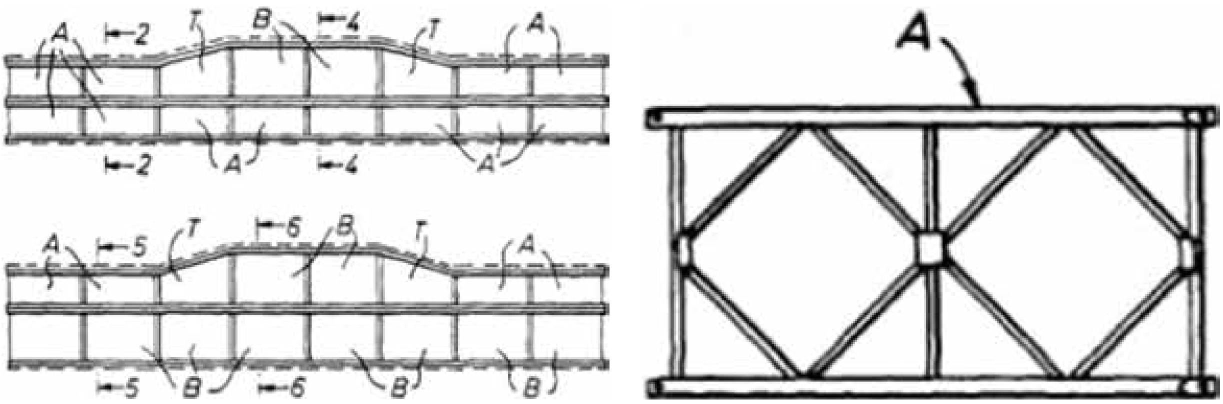


deflection. For longer spans, the panels can also be stacked vertically and connected to create a two-tier system with enhanced stiffness.

(d **The Mabey Johnson Bridge**

Mabey Johnson, Ltd., was granted a patent in 1987 for their system, also based on the Bailey design. Their design is identical to the lattice shape and structure of the original Bailey concept, but it incorporates newly shaped elements into the panel system. The upper-tier panels are fabricated in a transitionary shape to allow the introduction of a sectional truss with a 2-tier system in the center to strengthen the bridge for long spans. The following Figure 9 detail the layout of the innovative panel truss design.

Figure 9: Truss Erection Scheme Showing Mabey Johnson Transitionary Panels



(e) **The Janson Bridge**

With a strong presence in Europe, Janson Bridging has applied a more permanent design to the original Bailey structure. The Bailey and Acrow bridges were introduced initially as temporary bridges; therefore, fatigue was not a design criterion. The Janson Bridge is being used as a permanent bridge, therefore fatigue performance was considered in the development of the system. The bridge system is constructed of high-tensile steel; the Heavy Panel Bridge (HPB) has a greater fatigue resistance and therefore a longer performance life. The unit panel of the HPB system is 12.5 feet and can be designed to accommodate heavy construction loadings. Figure 10 shows a typical Janson Bridge in service.

Figure 10: Typical Janson Modular Bridge

(f) **The Quadricon Bridge**

The Quadricon Modular Bridge System (QMBS) is similar to the Bailey Bridge system but with design innovations. The system consists of prefabricated modular steel triangles joined by an element referred to as the "Unishear Connector" at each corner to form the truss. The final truss can

Figure11: Quadricon Modular Bridge across Dhaman Khad

assume various shapes and configurations with varying load requirements assigned per application. Spans can range from less than 100 feet to more than 500 feet. Figure 11 shows a typical Quadricon Bridge built in Himachal Pradesh.

(g) MBS – BERD Modular Bridge Solutions (From Portugal)

BERD – Bridge Engineering Research & Design – is developing new and innovative Modular Bridges Solutions. They have tied up with M/S Garden Reach, Kolkata for modular bridges in India. The new range of solutions offered by them allows:

- i Spans from 15 m up to 120 m
- ii Incremental launching from one shore;
- iii Modular design to become flexible and reusable;
- iv Reduction of the assembly and launching time;
- v Lower deflection;
- vi Increased load capacity by using unconventional solutions.

The modular bridges by BERD can be permanent, semi-permanent, or temporary and be used in civil or military applications. Figure 12 shows a typical MBS-BERD modular bridge system.

3. Manufacturing & Quality Control

Unlike traditional steel bridge construction, panel bridges are manufactured rather than fabricated, thereby allowing the greater use of automation. Using automation, it is possible for the end user to receive a modern and high-quality product with little or no defects that need to be addressed on-site during the erection. Given below are some of the recommendations in terms of manufacture, factory production controls, engineering services and on-site technical support that is expected from manufacturers of modular bridges

3.1. Factory & Yard

(a) Time-tested technology, conforming to quality standards shall be used in the factory.

(b) QA/QC processes at various points throughout the entire process shall be such as to mitigate product defects from reaching the field.

(c) All materials shall be thoroughly inspected prior to loading into containers for shipment.

(d) Provision for 3rd party inspection certificates shall be available for high demanding Clients.

3.2. Engineering Services

(a) Full-Service design & engineering services shall be provided by the manufacturer. Design & Detailing shall be carried out by qualified, competent and experienced professionals. All drawings shall be duly proof checked by an independent and recognized agency.

(b) Along with engineering designs of Superstructure, full installation drawings shall be provided with all engineering packages.

(c) All materials shall be re-inspected.

3.3. On-Site Technical Support

(a) Dedicated on-site field services shall be a part of the manufacturer's scope of services.

(b) Field Service Representatives (FSR's) shall oversee the installation, working with the Client's assembly crew.

(c) FSR's shall be competent engineers with experience in erection and assembly. They shall be present at all times of the build and shall remain on-site until the bridge is fully installed & certifies that the bridge is built as per design intent.

4. Codification in India

Initiated by Indian Roads Congress (IRC) under the aegis of the B-5 Committee 'Steel and Composite Structure', a sub-committee was formed last year (2021) under the chairmanship of the author, to prepare a guideline for the design of Modular Bridges. At the time of writing this technical paper, work on the drafting of this guideline is in the advanced stage of progress and it is hoped that the document will be published for use by end of this calendar year (2022). The guideline is intended for use by Clients, Manufacturers of Modular Bridges, Designers and Contractors who are in the business of design and performance of modular bridges. The standard is composed of six chapters:

1. Scope
2. Introduction
3. Overview of use of modular steel bridges
4. Selection and acceptance of propriety designs
5. Erection, testing & acceptance
6. Inspection & maintenance

The guideline in the making is going to be a useful document in the toolbox of Bridge Engineers since it is going to provide a rational method for the design, selection, testing, acceptance and maintenance of modular bridges. While the author recognize that standards alone do not eliminate all problems associated with design and construction, this standard is intended to provide minimum criteria for safety and performance.

5. Conclusion

Modular bridges play a vital role in the immediate restoration of rail/road communication and in developing connectivity to forward areas in new road construction. They are also very useful as permanent bridges, in remote areas where conventional bridging solutions are not easy due to problems of access, manpower to execute, supervise and maintain.

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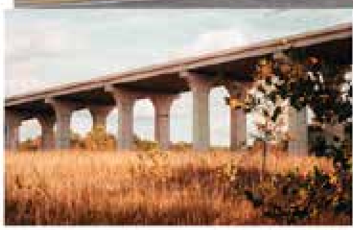

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Challenges and Solutions of Hill Road Construction: Indian Experiences

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Abstract

The main objective of this paper is to document the challenges faced in construction of hill roads in India and solutions to tackle such challenges with few case studies. Due to extreme climatic conditions, snowfall, subzero temperatures, unstable mountain slope, high rainfall and limited working window, construction of durable and sustainable pavements in hilly region has always been a challenging task for engineers. The solution to increasing challenges lies in moving away from the traditional methods of construction, to use of innovative modern technologies like stabilization of base and sub-base layers with stabilizing agents, geo-textiles, cold mixes, and concrete block pavement. Unlike in plain areas, where CBR subgrade and design traffic are the deciding factors for pavement design, the design of pavements adopted in hilly area is based on the altitude, climatic characteristics and type of soil subgrade. Some of the case studies related to mitigation of landslide in heavy rainfall area of Northeast region and restoration of line of communication after flash floods in Himalayan region are also discussed in this document.

Keywords: Challenges; Hilly; Pavements; Rainfall; Landslides; Snow.

1. Introduction

India has vast area in hilly region. Out of twenty eight states in the country, ten states are flanked by the mighty Himalayas in the North and North-East and experience heavy rainfall, snowfall, snow avalanches and landslides. Nine other states have substantial hill areas falling in the Central highlands, Eastern and Western Ghats which do not have snowfall and subzero temperatures, but are having unstable mountain slope and experiences high rainfall. Most of hill roads are not subjected to high traffic volumes but they are more prone to damages as hilly regions receives lot of rains and snow throughout the year which keeps the pavement layers in saturated condition almost throughout the year. Due to extreme climatic and geographic conditions faced in hilly region, construction and maintenance of pavements has always been a challenging task for engineers.

1.1. Challenges of Hill Road construction

The hilly terrain of North Eastern region, Central highlands and the Eastern and Western Ghats has altitudes varying from 500 feet to 8000 feet and experiences heavy rainfall raging from 4000 to 10000 mm. The major challenges to the road construction in these regions are slope instability, rock falls, shooting boulders, sinking of road formation and formation being washed away in flash floods. The problem gets aggravated due to deforestation activity in the hills. The association between slope instability and deforestation has been a subject of considerable research. Dhiman (2013). Formation cutting in heavy rainfall areas is taken up after monsoons as it is prone to landslide and inaccessible due to thick vegetation cover. Problems of rock-fall and shooting-boulders are addressed by creating a huge barrier of wire mesh across the direction of such fall or shooting boulder. Steel wire rope nets for safety against rock slides have been installed at many locations on Jammu-Srinagar Highway. Figure 1 shows safety net installed on a highway location. Rock anchoring and bolting have also been carried out on hill slopes of Western Ghats. Problems of sinking of road formation during monsoons are very common in hilly regions. At many places during monsoon the road formation sinks up to 3 to 4 m in the length of 50 m to 200 m causing disruption to traffic and road blockage. The immediate restoration is carried out by filling the sunken formation with granular material. The permanent solution to this problem can be resolved by providing Geoweb cellular containment system which increases the load carrying capacity of the subgrade coupled with drainage network on uphill and downhill slopes of affected area.

The challenges are very different when the altitudes in hilly region are beyond 8000 feet. Formidable geographical conditions such as high peaks, steep hill slopes, hard rock formations, slide and avalanche prone areas, unstable hill faces, and deep gorges poses unusual technical challenges in planning and execution of highway projects in high altitude areas. The efficiency of manpower and machinery decreases considerably. Climatic conditions are not favourable as low temperature, high speed winds makes it extremely difficult to work for longer durations. Working window is only from May to October. Snow avalanches are very common sites at high altitude areas. Snow galleries, snow sheds, snow racks, snow nets, snow avalanche barriers and snow bridges are various structures which can be used for mitigation of snow avalanches. Snow clearance is one of the toughest jobs as it is done in very adverse weather conditions. The challenges faced during snow clearance are carriage and dumping of fuel at road side camps, immediate availability of fast moving spares for repairs of vehicles, equipment and plants, damage to the cutting edge of the dozers when boulders come along avalanche, reduced output of all machines (60%-40%) due to extreme temperatures. Figure 2 shows deployment of Dozer for snow clearance during winters. The transportation of the construction equipment to the work site located in such high altitude and inaccessible areas is a challenging job. Air lifting of equipment is carried out in such situations. Heavy equipments such excavator, dozer, hot mix plants are disassembled first to reduce the load and then each components are airlifted by helicopter. Assembling is done by crew members, once all the components reach on site.

Figure 1: Safety net to arrest shooting boulders

Figure 2: Deployment of dozer for Snow clearance

Formation cutting in hard rock is very time consuming and dangerous for working team. Due to steep slopes, at times it is not possible to cut the complete hard rock as height of cutting involved is large. Half tunnelling is resorted in such conditions. The construction of protective structures such as retaining wall, toe wall and check wall on steep slopes is very difficult, as the working space is very less and transportation of material and placing of centring and shuttering is extremely difficult in such situations. Execution of bituminous works can only commence when the snow has completely melt and road surface is dry. One gets hardly four months in a working season for carrying out hot bituminous works. Regions of permafrost are also encountered over 15000 feet where the subgrade remains continuously frozen all round the year. A very common phenomenon in the hilly area is the cloud burst which occurs in every monsoon season. This brings in huge amount of water in the rivers and streams and causes bank erosion. Road which runs parallel to a river or stream, are prone to formation breach on the valley side by erosion of river or stream banks. River training and river bank protection works are effective solutions.

2. Pavement Design and Construction

The basic parameters for design of pavements, in a plain and hilly region are subgrade strength and traffic which is represented by California Bearing Ratio (CBR) value and million standard axle (msa). The subgrade material in the Himalayan region is not homogenous. CBR values obtained from field are not a true representative of sub grade strength in many cases (IRC SP:48 1998). The thickness of bituminous layers varies with design traffic. Minimum thickness of granular layer provided is 450 mm in high altitude areas to normalise the effect of frost action and attrition of wearing surface due to movement of heavy snow clearing equipments even if CBR value requires less thickness. In most of the hilly regions beyond 8000 feet the design traffic is less than 2 msa, and pavement generally do not fail in fatigue and rutting due to traffic loads. Most often the pavement gets damaged by heavy snowfall, rainfall, attrition effect of vehicles and equipments on very steep gradients, snow and slide clearance areas and movement of heavy vehicles. These issues are not considered in pavement design

While constructing bituminous layers in hilly regions the main problem faced is the sudden change in climatic condition which has effect on laying and rolling temperature. Air temperature may suddenly drop or unexpected heavy shower of rain may disrupt the bituminous layer construction operations. Utmost care in rolling is taken in bituminous construction on steep gradients and curves. Inadequate rolling on steep gradients and curves results in poor compaction and failure of pavement. Uncontrolled flow of water over the pavement surface can cause severe damage to the pavement in spite of providing adequate thickness of granular and bituminous layers as per design traffic. Therefore provision of proper drainage facility and construction of cross-drainage works such as road side drains, catch water drains and culverts are essential to keep the pavement free of moisture.

3. Sustainable Technologies to Tackle Challenges

To overcome such vast number of challenges in construction and maintenance of roads in hilly terrain, it is prudent to shift from conventional practice which are best suited to all terrains and climatic conditions and have lesser dependency on aggregates and labour. Some proven and suitable alternative techniques, which provide durable and sustainable solutions to overcome the challenges in hilly terrain are discussed here.

Cement treated Base (CTB) is one of the most effective and economical technique. In hilly regions of Northeast where the aggregates have low AIV and high altitude areas where working window is very less, CTB can prove to be a sustainable and effective solution. CTB has been successfully used in Ladakh region, where one gets few months for execution of hot bituminous mix layers. Inclusion of CTB layer in pavement crust reduces the thickness of bituminous layers and allows the use of local material. In Northeast region where subgrade remains saturated for longer duration and aggregates have low AIV, use of CTB can be one of the option to address such issues. Figure 3 shows pulverization of additive by a recycler of a base layer. The use of Geosynthetics is most significant when subgrade soils are weak. Problems of sinking of formation which are very common in hilly regions can be address by use of Geoweb cellular containment system. Figure 4 shows use of Geoweb to address sinking of formation. Besides this Geoweb have been used on a trial basis in permafrost regions of Ladakh. However their durability and performance are yet to be ascertained. To enhance the pace of protective works in high altitude areas where concrete works cannot be executed throughout the year, Geoweb layers have been used in retaining structures.

Cold mix technology offers a wide range of solution for construction and maintenance of roads where use of Hot Mix Asphalt for pavement works is restricted whether due to ecological constraints or low temperature like sub zero conditions. One such works with cold mix have been successfully executed in Gangotri National Park region in Uttrakhand where use of hot mix was prohibited. The specification used was 25 mm thick Cold mix Premix Carpet laid over 50 mm Cold Mix Bituminous Macadam (CMBM). Figure 5 shows rolling of CMBM surface. Interlocking concrete block pavements are used in built up, snow bound and high altitude areas. It prevents damage to the pavements caused by movement of snow clearing equipments. ICLB have been used at many passes in high altitude areas where there is a snow accumulation all round the year. Figure 6 shows one of the passes paved with ICLB in higher reaches of Jammu and Kashmir. Adequate lateral confinement or support has to be ensured by providing suitable edge strip or beam or kerb at the ends of the paved area.

Figure 3: Pulverization of base layer by Recycler

Figure 4: Laying of Geoweb for mitigation of sinking formation

Figure 5: Rolling of Cold Mix Bituminous Macadam layer

Figure 6: Interlocking Concrete Block pavement on a mountain pass

4. Case Studies

The Himalayan environment is extremely hostile to road building. This is because of intensive fractures of rock mass, thrust, faults and a number of major discontinuities. The common resulting effects are landslides and slope failure. Also connectivity is often disrupted due to occurrence of flash floods. A case study on construction of cut and cover tunnel for mitigation of perpetual landslide and restoration of line of communication after flash flood is discussed here.

4.1. Construction of cut and cover tunnel for mitigation of perpetual landslide

The Sonapur landslide located in North Eastern region of the country was one such active rock-cum-debris slide, which got activated in 1988, probably due to after effect of an earthquake. A cut and cover structure was proposed to mitigate the landslide. Various permutations and combinations with shape, size and methodology were studied. One concept which seems to be practicable and implementable in limited construction period available was to provide a structure with base width of 13.5 m and 80 cm thick with five numbers shear keys (base Keys). The cross diaphragms were provided at 10 mtr intervals to give lateral connectivity and stability. Side wall 5 m height, 80 cm thick with counter-forts were provided at spacing of 5 m. 8 m diameter semi circle top 80 cm thick was provided over 5 m straight wall. The construction of structure was completed within ten months in year 2008 and since then no occurrence of landslides has been reported in that area. Figure 7 shows the typical cross section adopted for RCC Cut and Cover structure. Figure 8 shows the gantry fabricated for casting of curved roof.

Figure 7: Typical cross section of Cut and Cover structure

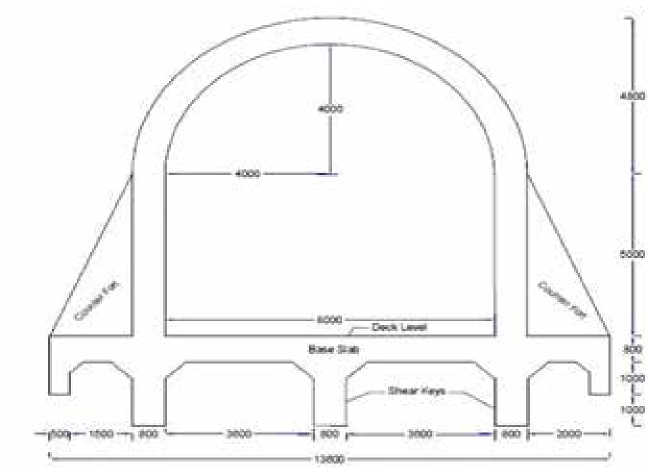

Figure 8: Fabricated Gantry for casting of curved roof

4.2. Restoration of line of communication after flash flood

On 7th Feb 2021, a remote village in upper Himalayan region was hit by a flash flood which demolished two hydel power projects and major permanent bridge PSC box girder of span 90 mtrs which was the only means of communication for 13 villages situated ahead. The disaster left over 200 people either killed or missing. After examination of the satellite images it was found that a hanging glacier situated in higher mountains got cracked and plummeted into a tributary of a one of the rivers situated in that area and caused flash floods. The connectivity was restored within a record time of 13 days by way of launching of Bailey Bridge of 200 feet span. Timely restoration of line of communication ensured uninterrupted logistic support to the troops deployed in forward areas and essential supply to the local population. Figure 9 shows the view of damage bridge site after flash floods and Figure 10 shows view of completed 200 feet span Bailey bridge.

Figure 9: View of damage bridge site after flash floods

Figure10: View of completed 200 feet span Bailey bridge

5. Conclusion

Hill road construction is a real challenge. There are many unpredictable parameters such as snow avalanches, cloud burst, temperature variation, high rainfall and unstable slopes. A thorough understanding of the terrain and experience is required to execute the works under such circumstances. The behaviour of material and efficiency of men and machinery cannot be predicted. The use of innovative modern technologies such as stabilization of base and sub-base layers with stabilizing agents, geosynthetics, cold mixes, and concrete block pavement can play a major role in alleviating the challenges faced during construction of hill roads and pave way for sustainable and durable pavements.

6. Acknowledgement

I acknowledge my senior officers and staff for sharing their experience of pavement construction in various regions and providing me valuable information on work site.

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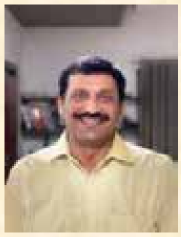

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Hungarian Experiences in Innovative Low-Volume Road Pavement Structures

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Abstract

Hungary – like other countries – places special emphasis on the development of construction, rehabilitation and maintenance technologies that can meet the special needs of low-traffic roads. By setting moderate but still sufficient quality requirements, they seek optimal trade-offs (compromises) between functional, quality of life and environmental aspects. The three typical directions of these efforts in Hungary are as follows: recycling of "old" road materials, use of industrial by-products and utilization of "low quality" (substandard) raw materials. Subsequently, some of the Hungarian results in these topics are outlined.

1. Highway Categorization in Hungary as a Function of Traffic Load

The total length of national highway network in Hungary (93,000 km^2, 9.8 million inhabitants, in Central Europe) amounts to 32,000 km including 2,200 km expressways, while the length of local (municipal) highway network reaches 170,000 km. Highways are categorized by the number of standard load (10 to equivalent single axle load) repetitions during design life. Table 1 presents the traffic categories applied.

Table 1: Traffic categories for Hungarian highways

Traffic design categories		Design traffic, F_{100} (number of 10 to standard axle loads)	
Designation	Sign	from	to
Very light	A	$3x10^4$	$1x10^5$
Light	B	$1x10^5$	$3x10^5$
Medium	C	$3x10^5$	$1x10^6$
Heavy	D	$1x10^6$	$3x10^6$
Very heavy	E	$3x10^6$	$1x10^7$
Extreme	K	$1x10^7$	$3x10^7$
Extraordinary	R	$3x10^7$	-

The highways of traffic category A is considered as "low-volume roads"; their entire length reaches 90,000 km, a high share in the network. Thus, it is not surprising that the Hungarian road experts have concentrated on the development of innovative construction and maintenance techniques for the low-volume roads.

2. Structural Design of Low-Volume Roads (Road Technical Directive)

UT (2006), the relevant Road Technical Directives covers the following main topics:

(a) Basic design principle

(b) Design steps

(c) Role of subgrade soil type

(d) Standard pavement structures

(e) Gradual road construction

ad a.) Pavement structural type is selected in accordance with the standard pavement structural type based on subgrade soil type and traffic design category. The catalogue of standard constructions for low-volume roads can be seen on Tables 2 and 3.

Table 2: Standard pavement structure of low-volume roads with unbound base course

Base course type				
Mechanical stabilization (ZM)		Dense graded stone base (FZKA)		
80 mm asphalt	80 mm concrete stone	60 mm asphalt	80 mm concrete stone	Surface dressing or cold asphalt
200 mm ZM	230 mm ZM	200 mm FZKA		300 mm FZKA

Table 3: Standard pavement structure of low-volume roads with hydraulically bound base course

Base course type			
Cement stabilized base (CK)		Lean concrete (C12)	
40 mm asphalt	80 mm concrete stone	60 mm asphalt	80 mm concrete stone
150 mm CK		150 mm C12	

ad b.) Design steps: identification of traffic design category, soil type, standard pavement structure, checking the resistance to freeze-thaw damage.

ad c.) The upper 0.5 m of subgrade soil is investigated. Granular, slightly cohesive and cohesive soils are differentiated. In case of slightly cohesive or cohesive soil: + 200-250 mm granular soil or 150 mm cement or fly ash stabilized soil layer in order to reach the needed E2 = 40 MPa modulus value.

ad d.) Selection of locally optimal standard pavement structure type of the option in Tables 2 and 3.

ad e.) There are two options: construction of "final" pavement structure for at least 10 years OR two-step (gradual) construction. Influencing parameters: present or future public utilities with eventual pavement cut; future pavement widening. Design and forecasting are decisive in the selection between them.

3. Trial Sections

Trial sections were built on the parallel road for Serbian state border fence against illegal migrants (Péterfalvi et al., 2008). The main aim of the research work was to scrutinize the durable bearing capacity of stabilized soils. The two most widespread soil types in Hungary were tested: running sand and loess. Running sand options: geotextile + geogrid + 100-250-300 mm crushed stone layer + 150-300-450 mm 40-75-100 kg/m^3 ViaCalco C50 hydraulic binder with at least 50% CaO+MgO content + 300 mm 75 kg/m^3 cement stabilization. Loess options: geotextile + geogrid + 100-250-300 mm crushed stone layer + 150-300-450 mm 40-75-100 kg/m^3 cement stabilization. Laboratory CBR values of the 10 stabilized running sand options were between 74.3 and 133.7, while those of the 11 stabilized loess options amounted to between 23.6 and 79.3. The results of static plate load test showed that stabilized test sections had some twice so high bearing capacity than the ones with geotextile and crushed stone layer had. The bearing capacity values of stabilized loess sections had more direct relationship with actual binder content than sand versions had. The springtime thaw period did not influenced the bearing capacity of stabilized layers negatively. Summarized: increasing subgrade bearing capacity can result in the highly economical reduction of the thickness of expensive asphalt layers.

4. A Special Asphalt Mixture for Low Volume Roads

A special asphalt mixture type has been used for low volume roads. The technique named "Finnish asphalt" comes from an asphalt technology, which has been adapted to Hungarian conditions (Kosztka, 2013). This mixture with patented bituminous binder (a product similar to cutback bitumen) can be readily stored and laid for the construction and repair of low volume road pavements, besides the mixture can be produced in close proximity to construction site at a temperature of 90-110°C. Three variants are used, with 8, 11 and 22 mm maximum aggregate grain sizes.

The asphalt type can be used as the top layer of a national or local highway carrying less than 2,000 vehicles per day. It can be placed using asphalt paver or grader.

Due to its high compactibility, the mixture type is appropriate for pothole repair or profile correction. After cutting with the asphalt cutter saw, it is essential to remove any moving parts and clean the pit free of water and dust. It does not require bituminous undercoating under favourable weather conditions. Possible enhancement with bitumen emulsion only recommended in cold weather. It should be spread 15-20 mm higher than the desired level, depending on the depth of the pothole. Compaction can be performed by manual compaction devices or vehicle tyres; post-compaction of 3-4 days can be expected depending on traffic size. If a new layer is placed, it will work together with the former one without any problem. An air temperature above +5°C is needed for the high quality work. A smooth steel or a pneumatic-tyre roller is usually sufficient for its effective compaction. Besides, it is suitable for an intermediate or transitional layer, for bike path or for restoring a utility trail in case of strong base course.

5. Industrial by-Products (Blast Furnace Slag, Fly Ash, etc.) for Low Volume Roads

Blast furnace slag can be widely utilized in pavement construction after having stocked in the open air for at least 4 months before it can be used. Its resilient modulus exceeds those of traditional granular materials; its use results in thinner and cheaper pavements. Thus, it provides remarkably good technical quality and economic advantages, among others, for low quality roads. Blast furnace slag surface dressings have proved to be extremely long lasting due to their durable skid resistance as well as their good adhesion to binder and the underlying pavement structural layer.

The use of granulated blast furnace slag (GBFS) – a poorly graded by-product of the iron industry – mixed with an old base and wearing course aggregate on a low-volume gravel road is an economical option, since GBFS has latent hydraulic properties (Gáspár et al., 2021).

Addition of self-cementitious fly ash improves significantly the stiffness and strength of the base materials of low volume roads, whether recycled pavement material, road surface gravel or subgrade soil. In order to estimate the target resilient modulus that can be measured during construction, the modulus obtained from laboratory mixed specimens during mix design should be reduced by some 1/4 to 1/3. A resilient modulus of 50-100 MPa can be reached for fly ash stabilization base material at the end of construction. The degree of resilient modulus reduction does not exceed 50% in the laboratory due to many freeze-thaw cycles for a range of fly ash stabilized materials. There is no evidence of frost-induced degradation in the field based on Falling Weight Deflectometer surveys. Long-term monitoring of modulus and leachate quality has proved a generally favourable strength gain and leaching behaviour with time.

6. Cold Remix as an Environmental Friendly Option

In case of proper maintenance actions, these kind of layers can have a high level of service, for a relatively long period. When – because of the synergetic detrimental effect of mechanical and environmental loads – one or more of the condition parameters of these stabilized pavements reaches the respective intervention level, some kind of pavement rehabilitation is necessary. Of the possible pavement renovation techniques, especially in case of poor bearing capacity, an appropriate remixing technology can be a promising solution. A 5 km long cold remix renewal project of a forest road was built in Hungary (Markó et al., 2013). After having measured the bearing capacity of the road before the reconstruction, a 3-year long pavement monitoring on annual basis was decided including bearing capacity measurements and condition observations. The results obtained were better than expected contributing to the recent state-level new specification, which considers the broken asphalt as a product, not a waste material any more.

There can be problems with the economy of cold remix technology when it is applied for the renovation of relatively short (e.g. 2-3 km long) road pavement sections since the rental of the necessary machine park may not be a cost-effective solution.

The relevant Hungarian specification is planned to be modified soon in order to extend its application areas to medium traffic volumes up to 5,000 vehicles/day based on the favourable experiences gained with several test roads of low volume.

The use of cement as binder of cold remix technology is more and more rarely chosen because of the excessive rigidity of and the danger of reflective cracking in remixed pavement layer; this technique does not allow the quick opening of the ready course to traffic. That is why the use of bituminous emulsion or foamed bitumen as binder is preferred.

COLAS Hungária Technology Directorate developed the recipe for the asphalt technology of a mixture containing milled asphalt (asphalt granulate), 0/11 crushed stone, a small amount of cement and a slow-breaking bitumen emulsion (Görgényi, 2019). The mixture was produced in a continuous type WIRTGEN mixing plant as a cold asphalt mixture, paved by a finisher and compacted using a pneumatic tyre roller. A 500 m long pavement strengthening trial section on a Hungarian secondary road (80 mm thick experimental layer as binder course) has performed excellently after 3-year heavy traffic. It has been proved that this kind of COLAS technology saves energy and primary raw material need, besides it reduces carbon footprint.

7. Use of Substandard Materials in Low Volume Roads

It is an option for low volume road construction and rehabilitation, to use local, substandard materials (poorly graded and uncrushed aggregate, cohesive fines in aggregates, dune sands, etc.) in pavements instead of relatively expensive conventional materials, since significant economic savings could be reached. However, these low-quality materials are often difficult to evaluate and may invalidate generally accepted pavement design assumptions. Besides, they may adversely affect the pavement performance. Eventually also adjustments in construction procedures are needed to accommodate their characteristics. The economics and the obvious environmental advantages of using these low quality materials in pavements must be balanced against the additional potential difficulties of adequately evaluating the materials, designing to account for their characteristics, and adjusting construction procedures for them; the cost savings must be compensated for the potential loss in pavement performance.

8. Concluding Remarks

Hungary – as other countries – places special emphasis on the development of construction, rehabilitation and maintenance technologies that can meet the special needs of low-traffic roads. By setting moderate but still sufficient quality requirements, they seek optimal trade-offs (compromises) between functional, quality of life and environmental aspects. The three typical directions of these efforts are recycling of "old" road materials, use of industrial by-products and utilization of "low quality" raw materials. Some of the Hungarian results in these topics were outlined before.

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Data-Driven Planning of Rural Roads: Algorithms, GIS and Process Re-engineering in PMGSY-III

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Abstract

Emerging technologies such as algorithms, AI/ML and other technologies have the potential to improve governance of government welfare programs. While, many government programs are piloting the use, there are few documented examples where algorithms and other emerging technologies have played a pivotal role in administration of a government program. Integrating algorithms or AI/ML within core e-governance will require proper policy and process re-engineering, upgrading existing IT MIS infrastructure, synergy with existing proven e-governance technologies and investment in additional capacities. PMGSY-III is a nation-scale rural road upgradation program launched in 2018 by the central government with a budget of 80,000 Cr to upgrade 1,25,000 km of rural roads. Using the case of PMGSY-III, we provide our learning and critical insight into the use of algorithms and other emerging technologies in administration of government programs.

1. Introduction

Pradhan Mantri Gram Sadak Yojana or PMGSY was launched in 2000 by the Government of India to provide all-weather connectivity to rural habitations which were still unconnected. With a target of 200,000 habitations at the start of the millennial, the target is almost achieved in the last two decades with over 600,000 km rural roads constructed (1). In the year 2015, the government launched the 2nd phase of the program ie PMGSY-II. The objective under this phase was to upgrade existing rural roads which were now facing higher traffic or were connecting large rural population to growth centers (2). This phase had a relatively small target of 50,000 km. On completion of the second phase, the government launched the third phase of PMGSY i.e PMGSY-III (3). PMGSY-III is also a rural road upgradation scheme such as PMGSY-II but is more focused on roads which provide connectivity to educational, health and agriculture related facilities. It also has a considerably large target of 1,25,000 km and has a budget of Rs. 80,000 Cr. This paper highlights the technical interventions made under PMGSY-III, specifically in planning and selection of roads under the program. India is estimated to have more than 4.16 million km of rural roads, selecting 1,25,000 km (~3%) out of this which best fit the government's policy objectives is a hard problem. The arterial or high traffic through routes targeted under the policy will be limited in nature but to ensure that the roads selected under the program are infact optimal and meet our policy requirements is a non-trivial task. For example, a road can be important for mining and serve high traffic but it is not necessarily useful in bolstering access to school, hospital and markets. The presence of special interests, varied stakeholders and the necessity to think from a network perspective makes it a hard problem. The case-study highlights how Ministry of Rural Development achieved this objective by relying on state of the art algorithms, AI/ML, mobile apps, GIS and careful re-engineering of policy and IT. Having used emerging technologies at the core of the policy, PMGSY-III provides a futuristic insight into how emerging technologies can be meaningfully used in governance and the pitfalls to be careful about.

2. Existing Process

The intervention discussed in the paper is relevant to PMGSY-III ie the third phase. The closest reference point for comparison in policy is PMGSY-II which was also related to upgradation of rural roads and acted as the base document for the policy preparation for PMGSY-III.

Life of a rural road under the PMGSY program can be divided into the following sub-components:

1. Selection of road under the program.
2. Design and Cost estimate calculation ie DPR preparation
3. DPR Scrutiny (PRE-EC and EC)
4. Sanction of Project by Central Government
5. Tendering and Award
6. Construction
7. Maintenance

Majority of our intervention is around the selection and design process, so we'll detail the steps involved further.

The selection or planning process in PMGSY-II can be simplified as follows:

S.No.	Title	Detail	Example
A	Inventorization	Inventory of all existing roads, habitations and points of interests (facilities) in tabular form	Eg. Block A has 100 roads, 70 habitations and 20 facilities of interest (CHC, police station etc)
B	Identification of Candidate Routes	Identification of important candidate routes which fit the policy objectives. A candidate road can be a continuous combination of one or more roads hence the list of potential candidate roads is non-trivial.	District Engineer identifies 5-10 candidate routes which best fit the policy objectives and can be considered for the upgradation under the project.
C	Scoring & Prioritization	Each candidate road is scored and sorted in descending order of their Utility Value. Utility Value is a simple formula which scores a candidate road based on the habitations benefitted by the road directly and the facilities in those habitations. The score is then divided by the length of the candidate road to get a per unit value. The candidate with the highest per-unit Utility Value is then prioritized over others.	Eg. The 10 candidate roads are scored and sorted in descending order of Utility Value.
D	Elimination of Non-eligible Candidates	Not all high-priority candidates may be eligible for the program. Some may already be in a good condition (Pavement Condition Index) or are still under contractual liabilities and therefore cannot be taken under a new project yet.	Eg. The 1st, 3rd and 5th candidates are eliminated for one or the other reasons.
E	Preparation of Detailed Project Reports	Preparation of design and cost estimates for the upgradation of selected roads.	The PIU starts preparing design estimates of the 2nd, 4th, 6th, 7th etc roads in order of rank and till the target for the Block is saturated.

2.1. Limitations of Baseline Process

One of the characteristics of the above planning process is that the final result depends on the list of 10 routes (in the example) which were picked by the District Engineer. While, the calculation of utility values in Step 3 would ensure prioritization in the 10 routes selected, the competition is limited to the roads considered important by the District Engineer in the first place. The District Engineer could pick a specific combination of roads as candidates to ensure that a pre-decided road comes on top when the priority lists are generated. In other words, it is not necessary that the priority list is a result of a fair competition of eligible roads. The policy does include safeguards by mandating the District Engineer to seek recommendations and approval from various local and state elected representatives. This ensures sanctity to a level in the process.

There are competing demands which could affect this process. Certain routes are important to service trucks on-route to recently found local mining blocks, or roads leading to sites of religious importance or servicing politically important villages. Importance could depend on various local socio-political reasons and depending on who in the system has a louder voice. Further, the District Engineers routinely get transferred from one district/block to another and might not know the ground reality. Balancing competing demands might not always mean that the District Engineer picks routes consistent with the programme's specific objectives.

The identification of important arterial routes is further exacerbated by the absence of updated existing traffic data across the rural road network. Conducting a traffic survey and collecting data on every route at the scale of a country like India will be a humongous and resource intensive exercise, not the mention that the quality can be questionable because of the incentives at play and burden on the state capacity (4) (5).

The national target of 1,25,000 km is split across states and then divided across districts and blocks. On average, this would translate into 1-5 roads per block. The number of rural roads in a block can vary from 20 to 5000+ depending on the geography and the state.

Key concerns with the existing process can be simplified as follows:

1. Tabular inventory of roads, habitations and facilities which are inherently spatial for rural road planning
2. Entirely offline process prone to manipulation with no point for early intervention
3. Subjective selection of candidate roads leading to unfair competition
4. No independent source of data for road-use or traffic for rural roads at nation-scale
5. Manual mapping of "Benefitted Habitations" for Utility Value calculation allowing for rigging [excess/insufficient mapping]
6. No evidence to prove roads being proposed exist in poor condition [except for scrutiny sample]
7. Random sampling to identify roads to be scrutinized leading to sub-optimal cost reduction and time-use
8. MoRD doesn't have GIS alignments of the roads being sanctioned at the time
9. No stage to audit the selection of roads [Primary focus was cost of roads selected]

3. Intervention

There is no single solution to the problems identified and a bouquet of interventions was introduced. Overall, the policy was modified, MIS was revamped, a mobile app was launched for geo-tagging rural facilities, an algorithm was developed called Trace Maps to simulate rural traffic to identify important routes and an AI model was developed to flag ineligible roads.

3.1. Trace Maps Algorithm

A key limitation of the existing process was that one can cherry-pick the candidate roads to get the desired outcome. If an engineer is interested in a particular route to be selected, he or she can identify 3-4 other routes with predictably lower utility value and enter all of them together in the system. This way the final results or sorting can premeditated. There could be in theory other probable high scoring candidate routes in the block which weren't considered by the engineer and hence weren't scored. This problem can be solved if there were a way to ensure that candidate roads selected were competitive and represented roads which best fit our policy within a block. This is a difficult task to do because there can be unlimited candidate routes possible (combinations) within a block and there is no third party data on the usage of roads within a block which makes us rely only on the District Engineer. Which roads make good candidates for PMGSY-III? The policy objective is to consolidate existing rural road network by upgrading/ strengthening through routes or major rural links that provide habitations with affordable and easy physical access to agricultural markets, higher secondary schools and hospitals. Put in a different way, which road on deteriorating will affect access to above mentioned facilities for the most number of habitations? To solve for this, NRIDA prepared a Trace Maps algorithm which simulates rural traffic from every habitation to its nearby rural facilities. The algorithm iterates through every habitation within a block to identify the nearest facility each among 23 kinds of facilities as listed by the policy (bedded hospital, degree colleges etc). For a habitation, you'll get a maximum of 23 such routes. Once all the shortest routes have been identified, the algorithm iterates through each of the roads identified as part of various habitation-facility shortest routes and sums population relying on the road weighed by the policy prescribed importance of the facility. The total weighted population benefiting from each road is then used to rank all the roads in descending order of priority order [Equation 1]

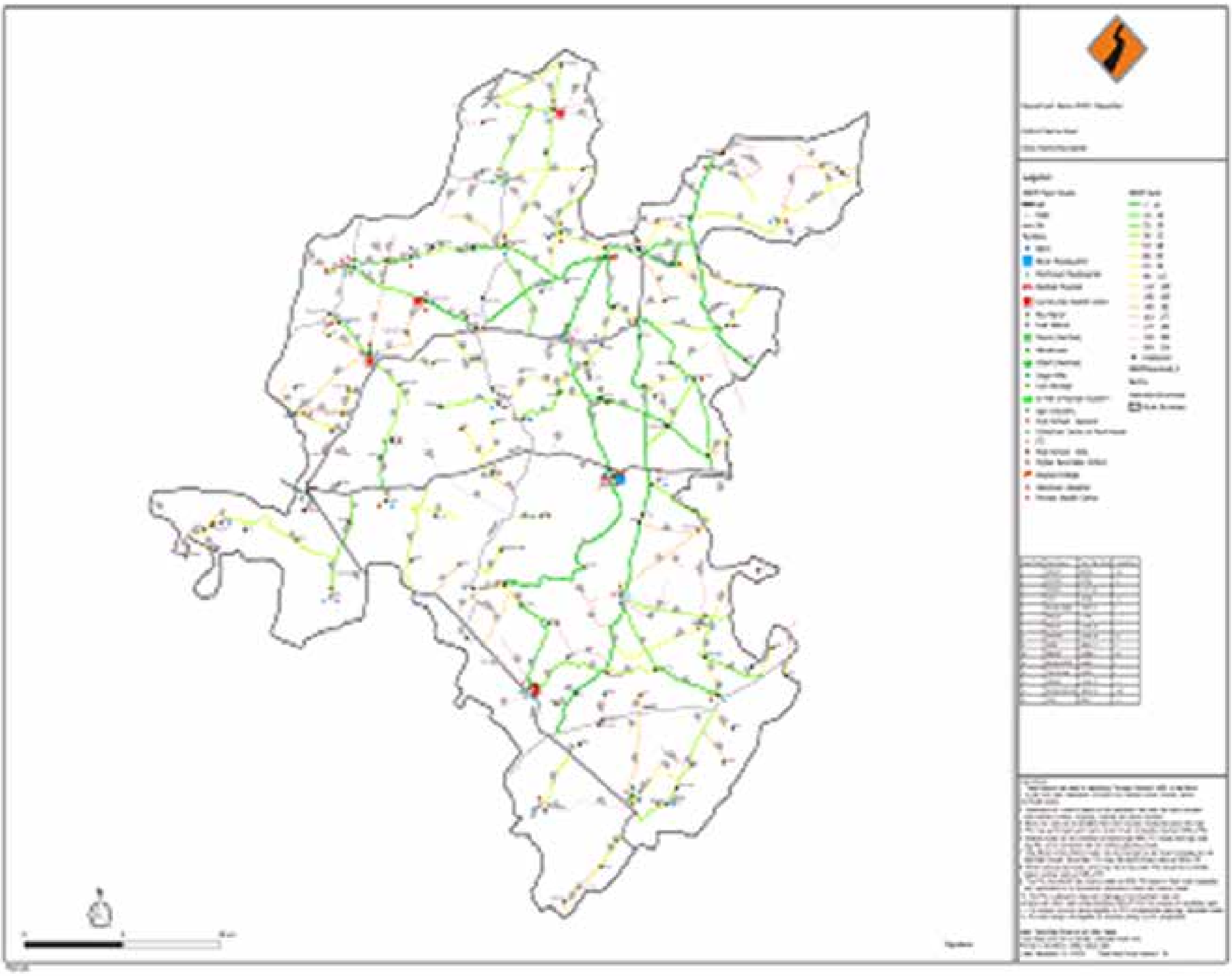
Algorithm 1: Trace Map | Calculating population benefiting for every road

```
Input  : H is list of habitations in the Block,
         FacilityListsByCatogory is collection of facilities
         by category (Eg. Schools, Hospitals etc),
         RoadNetwork is the road network of the Block
Output : RoadMaster is mapping of all roads in the Block
         and the population depending on it
initialization;
foreach habitation h in H do
    population p = h.population;
    foreach FacilityList in FacilityListsByCategory do
        path = FindShortestRoute(h, FacilityList,
          RoadNetwork);
        foreach road in path do
            RoadMaster[road] = RoadMaster[road] + p
        end
    end
end
```

Equation 1

The algorithm operates at block level and ranks each road within the block. A user friendly A1 sized PDF map is generated which displays the entire map of the block along with rural facilities and habitations. Additionally, the roads are colour coded from green to red and have varying thickness based on the population depending on them as per the algorithm. Other elements such as tabular representation of the top-15 roads, legends, instructions to interpret the map etc are part of the map Figure 1. The tool was developed as a Python based QGIS (6) user script which has been tested to work on QGIS 2.18 with GRASS.

Figure 1: Trace Map



Usage: In each Block, the District Engineer was mandated to consider the top-15 Trace Map ranked roads to create candidate routes. They can combine them as they think fit with other connecting (and low Trace Map ranking roads) based on local knowledge. Apart from the high ranking roads, the District Engineer can consider as many other roads they wish to.

Now in the case of cherry-picking, even if the District Engineer identifies 4-5 candidates scoring lower than his or her preferred route, the mandate to add the top-15 roads recommended by the Trace Map will possibly prevent the rigging by ensure the completion is fair with the assumption that Trace Map rank roads also eventually do good at Utility Value.

To check if our assumption held true, we can identify the number of roads which eventually get proposed and whether they contained any of the Trace Map's recommended roads. For a road to be proposed, not only does it have to have a higher Utility Value within the Block as compared to other candidate roads, it also has to not get eliminated by one of the many eligibility requirements (poor condition, out of contractual warranty etc).

As of writing, 8037 roads of length 62,658 km have been approved by the central government across 16 states and every 2 out of 3 roads approved [Table 1] contain at least one of the top-15 recommended trace map roads within the Block.

Table 1: Trace Map cut for approved projects (May 2021)

Min Trace Map Rank	Number of Roads Proposed	Percentage
1-15	5316	66.2
15-50	1962	24.4
50-100	544	6.8
100+	211	2.6

3.2. Moving from MIS to ERP

The existing MIS ie OMMAS (1) was modified into a more modular and maker-checker based system. Earlier the entire planning process was completed offline and then uploaded in one go online along with the selected roads. This didn't allow for any intervention in the middle of the process or allowed for system level validations. Without an online first and modular system, it is difficult to ensure that the process is followed in the sequence intended. For example, the Trace Map algorithm should only be run after the facility survey, DRRP and habitation updation is 100% complete. For example, the MIS was modified such that the necessary files to run the Trace Map algorithm could only be generated once the Facilities, DRRP and Habitations were finalized by the state following a maker-checker mechanism. Also early intervention in mistakes made in following the process are only possible if the process is online and allowed for instant visibility across the different levels of government.

3.3. GeoPMGSY – Mobile App

A key concern with the earlier process was that the facilities surveyed were not verified or substantiated with evidence. The facilities were listed earlier as a yes/no against each habitation. This form of data collection made it prone to same facility being counted for more than one habitation but also didn't provide any way to substantiate the facility (name, photo or lat-long). The list of facilities form of the core of the planning exercise and play a key role in the calculation of Utility Values. To fix this, a mobile app was launched to survey facilities along with geo-tagged photographs and additional details. This were further checked on random basis and made open to public scrutiny. Till date more than 7,70,000 facilities have been geo-tagged and these formed the core of the planning exercise under PMGSY-III.

3.4. Policy Integrations

The guidelines of the scheme mandated that Trace Maps need to be prepared prior to the selection of Candidate Roads. Having backing of the policy ensured the intervention had the necessary backing. Similarly, a stage called "Planning Audit" was introduced similar but prior to the PRE-EC. In existing PRE-EC, the primary motive is to ensure the costing and design of the roads proposed is appropriate. A separate stage was added called "Planning Audit" which followed a similar format. Here, processes followed.

3.5. Web GIS - GeoSADAK

While QGIS is Free and Open Source, it still requires certain skill sets to be operated. This would make the departmental civil engineers highly dependent on the GIS staff for small things. Further, roads are best represented visually or as a map/network and they lose a lot of context when represented in a tabular form. A login based web-GIS system called GeoSADAK was developed to make it easy for non-GIS users to visualize the proposed roads, benefitted habitations against candidate roads and even update the GIS data without any need of software or GIS expertise. Every action in the web-gis is point and click and catered to PMGSY-III processes. This made it easy for state and central staff to audit proposed roads, check candidate roads etc along with additional layers such as the geo-tagged facilities, satellite imagery, Google Maps, water bodies, forest layers etc. GeoSADAK ensured that GIS was democratized within the PMGSY structure and not limited to only expert staff. Without this, many of the activities envisaged wouldn't have been so wholly accepted by the departmental staff.

3.6. SADAK-AI

There are instances when the District Engineer proposes a road which is already in a good condition. In such cases either the entire road is not eligible under the program or large sections of the road are in a good condition and therefore the cost of the proposals can be reduced if the existing good surfaces are given credit. While 15% of the DPRs are supposed to checked in detail by the central team, it is not necessary the 15% will include these proposals. For every proposal the District Engineer will upload pictures of the existing road on the online MIS and the central team would randomly check certain pictures to see if any particular proposal contains most of the pictures depicting road in good condition. Given such anomalous roads are few in number, randomly checking proposals is time taking and not efficient. To solve for this a deep learning model was developed in-house which classified road pictures as good condition or poor condition. A typical batch would contain 100-500 road proposals and therefore 1000-5000 images. The model is used to parse through all the images and flag the road proposals which contain most of pictures depicting good road surface. The central team then only looks at the flagged proposals to confirm if the model's assessment is correct and if so forward the proposals to the state for further action. This is a good example of using AI/ML in conjunction with human expertise to improve precision in audit work as compared to random sampling.

4. Evaluation

While, evaluation many of the interventions is not possible given the setup and lack of a perfect counter-factual, a key limitation of the earlier process was cherry-picking of candidate roads to get preferred roads selected under the program which may not be optimal as per the policy objectives. Trace Map was introduced as a method to ensure fair selection of candidates. To this, more than 66% of the roads proposed till date under the PMGSY-III program are also recommended by the Trace Map algorithm in the top-15. Maybe some of these roads would have still been proposed without Trace Maps, but nonetheless the high proportion of these roads in the final selection based on Utility Value validates the intervention. Apart from that, removal of many duplicate facilities, elimination non-optimal roads through geo-sadak, rejection of blocks during planning audits etc are testament to the functioning of the process.

5. Discussion

5.1. Investment in Data and Infrastructure

Most of the work was dependent on the digitization of the rural road network and habitation data. This is a massive exercise and couldn't have been completed from scratch had it been initiated with the launch of PMGSY-III. Infact, the digitization exercise was initiated in the year 2015, much before PMGSY-III or its policy was even envisaged. It is necessary for departments to invest in such strategic infrastructures even before its precise usage can be envisaged as these exercises take significant time. Further, even though the digitization exercise was started years ago, it only got momentum when it was linked as a pre-requisite for

PMGSY-III. Hence, digitization exercises with no clear usages need to be linked with incentives for them to be completed with adequate quality.

5.2. Data Quality is linked to State Capacity

Algorithmic or data-driven interventions commonly require data to be in a clean and structured format. For example, the Trace Map algorithm requires the data for all the roads and habitation to be digitized on GIS even if most of the smaller tracks/links which are added to complete the network have little chance of being taken under the program, they still nonetheless contribute to the network and help in identifying other important routes. Poorly digitized network will lead to poor or non-optimal results from the Trace Map algorithm. The data-gap between OMMAS data and GIS data was to be reduced to zero for the states to be eligible to start preparing Trace Maps and therefore proceed further with remaining selection process. Further, the Trace Map algorithm depends on the quality of the GIS data prepared for the road network ie the network should be complete, topological errors should be minimum, habitations shouldn't be hanging etc. While every state eventually was able to ensure every road was digitized on GIS, the quality varied greatly as each state independently prepared this data with the help of local remote sensing centres or private vendors. Functioning data systems are often manifestation of functioning operations, bureaucracy and available of local resources. The states with poor data will be further punished by poor algorithmic results (assuming the algorithm is net positive). One can argue, the state most in need of welfare support will require more time to meet algorithmic or data prerequisites, thereby delaying welfare even more.

5.3. Algorithmic Assumptions

There is growing research on how AI/ML systems should be made fair, accountable and transparent. In many cases, algorithms don't impact different subsets of people in the same manner. During the design of the algorithm, there are many abstractions are assumptions made about the domain. These assumptions though appear trivial, can impact outcomes in non-trivial manner and adversely impact certain end-users more than others. A few of the assumptions taken in the Trace Map algorithm and their impact is listed below:

(1) People access their nearest facilities: This assumption is the basis of the Trace Map algorithm. If there are more than one degree colleges in the block, the algorithm assumes everyone goes to their nearest college. This assumption may be true for primary or even high school but may not be true for degree colleges. Further, even if nearest facilities are preferred, it is not necessary that the shortest path to the facility are always taken (7).

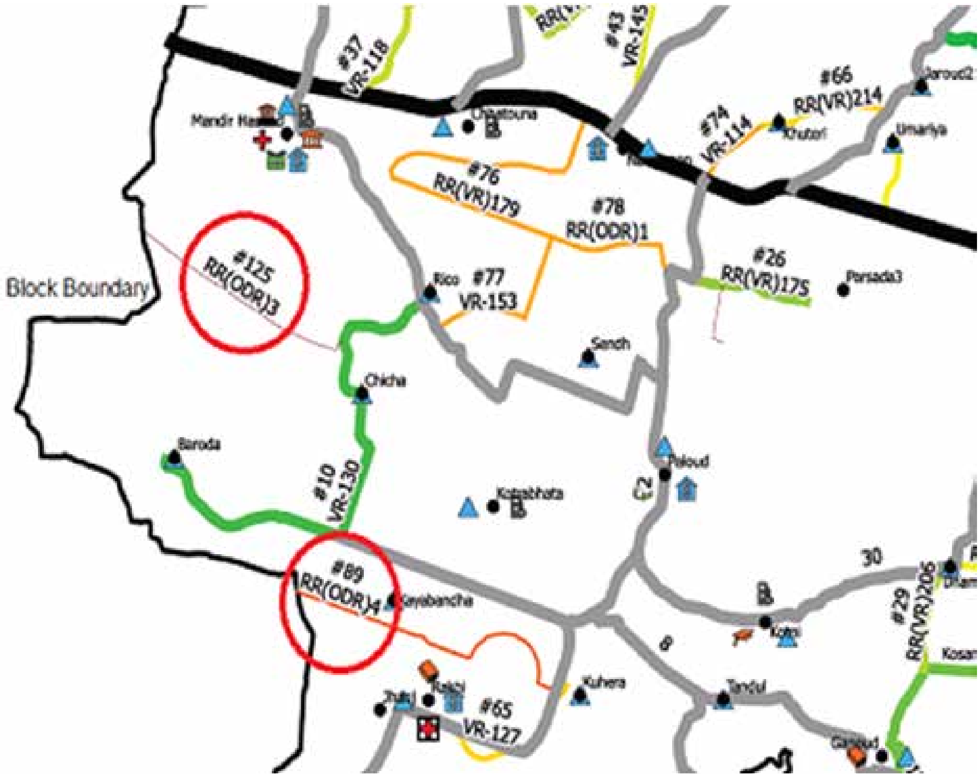
(2) Habitations can be represented as points: In GIS, the habitation data is represented as points as compared to polygons. This is a fair assumption given the scale of the maps and the relatively small size of the rural habitations (Figure 2). Further, the distance calculation within the Trace Map algorithm is point to point based. While this works in most areas, in some large states we found that the habitations are instead spread thin linearly across roads or spread over an area instead of being clustered together (Figure 3).

Figure 2: Settlement pattern in Madhya Pradesh

Figure 3: Settlement Pattern in Assam

(3) People access facilities only within the Block: The Trace Map algorithm operates at a block level given the priority lists are to be generated for each block. The process allowed a single block to proceed with all the necessary steps independent of other blocks in the state. The Trace Map algorithm took as input the facilities, habitations and road network in the block as inputs. This meant that for habitations near the block boundary, even if there were nearby high schools in the adjoining Block, the algorithm would trace a route from the habitation to the nearest high school in the same block. This meant that roads which were inter-block or inter-district would not score highly in Trace Map Figure 4. To solve for this, the engineers were repeatedly asked to consider inter-block roads themselves as part of candidate roads even if they scored low in Trace Map.

Figure 4: Inter-block ODRs ranked poorly by Trace Map



5.4. Building Capacities for Emerging Technologies

It is important to inject necessary capacities to the eco-system before introducing technologies which are non-traditional or even extensive. The Trace Map algorithm was developed in-house by the Data Scientist and GIS Specialist employed at NRIDA. Creating a custom algorithm with so many adaptions commercially would have been an expensive and long-drawn process which wouldn't have been able to meet the necessary timelines. Similarly, the states were provided funding and support to setup GIS Cells within their rural road departments so that they can lead the GIS related pre-requisites for PMGSY-III. Depending on existing staff for the same wouldn't have been practical and even counter-productive to existing duties of the staff. Apart from funding and policy support to setup GIS Cells, a GIS curriculum catered to PMGSY was prepared in-house to upskill the existing civil engineers at the state level on the practical uses of GIS. In addition to the algorithm, there were many modules updated on the MIS and a new mobile app was also launched. To address the added requirements, the agreement with C-DAC i.e. the technical service provider incharge of the MIS, was also updated to add additional resources to the team to be able support all the new requirements without harming the maintenance of the existing modules. The new planning process also increased the workload at the District Engineer level as compared the earlier process. In some states, the capacity at the District/Block level was supplemented by additional consultants to help complete the processes. Administrators and decision-makers need to be mindful of the future increase in burden associated with heavy process re-engineering or use of emerging technologies and take necessary steps to alleviate the work load otherwise there is a possibility that the increase in work load impacts the other duties of the staff and therefore is detrimental to the very outcomes one wishes to improve.

5.5. Relying on Free and Open Source Technologies

The entire algorithm and the digitization effort were centered around QGIS which is a free and open source GIS software. Essentially the cost of developing the algorithm was limited to the salaries paid to the Data Scientist and the GIS specialist. Depending on open source software also made it easy to incorporate modifications quickly and also disseminate the software to every state without depending on purchasing extra user licenses etc. Depending on other commercial alternatives would have made the exercise very expensive and prohibitive. Many free and open source libraries are available for creating custom algorithms (optimization, AI/ML etc) and a more effective way for governments to explore algorithms would be to hire to skilled staff who can train their own models or create algorithms as compared to depending on buying these services or models directly.

5.6. Balancing Human Discretion is Vital

The re-engineering or the Trace Map algorithms recommendation don't take away from the existing mechanism of incorporating democratic and citizen voices in the selection of roads. In PMGSY-II and in PMGSY-III, at various stages elected representatives are asked to provide feedback on the DRRP etc. In particular, when identifying candidate roads, the PIU has to specifically request the MPs and MLAs of the region for recommendations. The roads recommended by the elected representatives along with the roads recommended by Trace Map are together submitted into the system. The final scoring and prioritization is based on Utility Value which is the same in PMGSY-II. The only key difference is that with Trace Maps, the competition within the candidate road pool is increased and made more fair, but eventually the candidates are only judged based on their Utility Value which was a provision that existed and was accepted already. More than 30% of the roads that were proposed were not really recommended by the Trace Map algorithm, it means that there were infact many candidates which were proposed through other sources that score highly on Utility Value and therefore it was wise decision to not purely depend on the Trace Maps recommendations.

5.7. Using Old Media Technologies

The deliberating designed the Trace Map tool to generate an user-friendly A1 size PDF which can be printed. An alternative would be to create a digital, interactive and online map which our engineers can login and use. That would definitely allow us to embed more information but it would have reduced the accessibility of the map for various reasons. As earlier discussed, the engineering staff on the ground is not very IT-savvy and they spend most of their time on the field i.e. away from the computer. The ground staff already use paper maps and are comfortable with them. Also, *paper* holds special value in government (8). Often e-governance projects are about replacing *paper,* but we argue that we can use paper strategically to navigate space and build trust for newer forms of technologies. In our case, we added special design elements to the Trace Map's printable forms such as place to keep the department's logo and also a place for people to add their signature on the map. This helped us embed the outcome of the algorithmic in the existing values of government.

6. Conclusion

PMGSY-III provides a futuristic insight into how algorithms, emerging technologies and process re-engineering can be integrated within the core of e-governance and welfare delivering projects. In the future, a lot of government programs will experiment with the use of algorithms to improve governance. It is important to understand the limitations and strengths of such interventions and understand the necessary allied process re-engineering that are required to meaningfully and responsibly use these technologies. PMGSY-III provides a futuristic insight into how we can meaningfully employ emerging technologies, their limitations and what we can do to address them meaningfully.

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Performance Assessment of Rural Roads in Maintenance: Development and Implementation of an Objective Evidence Based IT Solution in PMGSY

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Abstract

This paper discusses the implementation of concept of Performance Assessment of roads during maintenance in lieu of work based system as per traditional system of contracting. This innovative concept of performance assessment ensures that payment is made to contractor on outcome rather than on output basis. The conventional wisdom of BoQ based measurement of works and payment in maintenance ignores the performance rating of assets, users involvement, transparency and objectivity in maintenance before making payment. The real challenge of performance assessment of assets during maintenance is, laying down of the objective criteria and marking system, an objective evidence based fool proof system, auto generation of bills based on pre decided criteria. For assets distributed over pan India like rural roads, implementation of this concept required technological, digital intervention to make it adaptable, implementable and accepted by all ensuring minimum human intervention/errors, dispensed with huge manual records and meets requirements of objectivity and aligned with legal requirements of contract enforcement. This paper discusses such a system developed for rural roads in PMGSY, called digital maintenance of rural roads by e-MARG. e-MARG is a web based IT intervention of NRIDA developed by CDAC and NIC on the concept tried and tested in MP as pilot project and further enhanced by NRIDA. This paper discusses the journey from concept, training to thousands of stakeholders, adaptation of state specific conditions to its full fledged implementation in shortest possible time of 2 years by all states executing agencies.

1. Introduction

PMGSY is a flagship scheme of Govt of India providing all weather connectivity at habitations level in villages. States are executing agencies and centre provides budgetary support, NRIDA is a technical organization for Project Management and support to states executing agencies. There have been several technological innovations/intervention by NRIDA for successful implementation of the scheme providing technical knowledge and support in construction and management. There have been several innovations implemented in the scheme necessitated due to its vastness, so far 7,06,506 kms of roads have been constructed at an investment of Rs. 2,77,789 crore (35,8622 M US$)

The rural network is very vast and spread over in remote areas, management of such a scheme has been a challenge, however due to use of cutting edge technologies and innovative IT solutions, real time project management right form DPR stage to maintenance of roads after construction has been exemplary and praised by several agencies.

While creating infrastructure is a onetime capital investment, however to keep it in good condition over the years with effective and economical maintenance is a nightmare to all executing agencies. To ensure that roads constructed lasts for a long time with minimal maintenance having quality construction, NRDA introduced the concept of 5 year defect liability period and responsibility of maintenance by the same contractor who has constructed the roads on nominal monthly payment based on performance of roads.

The five year defect liability has been a game changer as contactors are in centivize for quality construction due to provision of 5 year defect liability period on payment of pre decided rates if roads are maintained properly. During 5 year defect liability period,the payment is linked to the Performance assessment of roads every month and payment is done if roads gets minimum marks of 80% on parameters specified in the DLP period.

Management and maintenance of rural roads in the Pradhan Mantri Gram Sadak Yojna ("PMGSY") has been a challenge due to its vast PAN-India spread. The extent of road maintenance management is quite huge, on an average every year there are about 1.5 lacs KMs of roads in maintenance with liability of around Rs. 1100 Crore spread over all states. The concept of performance assessment of roads every month in traditional manual system demands lot of manual paper work and still it was not evidence base and therefore on site its actual implementation was a challenge and no engineer was willing to make payment in absence of record keeping and foolproof evidence. With the result as the trends of maintenance expenditure reflects that roads were not maintained and contractors were not being paid. The asset quality was deteriorating and due to absence of record contractual actions against defaulting contractors was not legally feasible though provisions of same were provided in the standard bid document. Some states have found via media of making payment based on actual work done measurement and brought hybrid concept of BoQ based and performance based payment, which was not producing desired results of upkeep of roads in good condition.

2. Performance Assessment Concept in Maintenance

The conventional practice of maintenance of any asset, including roads, is the measurement of work done and making payment(s) as per contractual rates. This, by itself, is not sufficient to ensure perennial performance of assets. PMGSY, for the first time, introduced an innovative concept of Performance Based Maintenance Contract ("PBMC") with a five year defects liability period. The contractor who constructs the road has to ensure performance of the road during this period on a nominal cost. The liability of the contractor to maintain the road for the next five years, and getting regular payments for it, compels him to ensure quality construction also. To ensure that roads are always maintained in good condition, PMGSY makes it incumbent upon contractors and engineers to keep a record of the conditions of the complete road infrastructure throughout the year.

Execution of PBMC through the existing manual system was a challenge and its efficiency and acceptability was low. PBMC, though a well-researched concept in asset maintenance, remained in nascent stages through its implementation in PMGSY. This called for a solution which unburdened engineers, made it truly evidence based, transparent, effective, and automated, in order to make it more objective and less labour intensive. To fulfil these objectives, the eMARG (Electronic Maintenance of Rural Roads under PMGSY) System was designed to bring in a simple yet effective solution to these problems. eMARG is conceptualized on PBMC, which took over from the earlier BOQ concept for payments and manual PBMC.

3. eMARG Development and Implementation Timeline

eMARG was developed and implemented on a very unique and modular approach of simultaneous development and implementation, differing from the traditional way of developing the complete product first and then implementing it. From the month of Feb 2019 to Apr 2019 a detailed discussion was done among the stakeholders i.e. NRIDA, NIC Bhopal and all the officials from state engineering departments. Regular meetings were conducted on a large scale for brainstorming about the requirements of the product from user's perspective and a software requirement document was prepared and within a month period of Apr 2019 to May 2019, first version of eMARG was developed that contained modules of data verification and contractor's registration. As soon as the first version was developed, simultaneously trainings were conducted for 10 states from May 2019 to July 2019, to start the work on eMARG. In the first version of training, officials from states were trained about registering the users like Engineers and contractors in eMARG.

4. Integration with NRIDA PMIS

The major challenge in the development process of eMARG was to integrate it with the existing Project Management Implementation System ("PMIS") of PMGSY. PMGSY has a very elaborate PMIS called OMMAS (Online Management, Monitoring and Accounting System). This PMIS is extensively used by all states to enter data right from the planning stage to the completion of roads, including construction, contract management and payment of bills through PFMS. As eMARG was to be developed for taking care of the Routine Maintenance of roads to be done for 5 years after completion of construction of roads, the parent data of roads till construction was needed to be transferred to eMARG. Ideally the data between the two systems should have been exchanged through web services before the ful-fledged implementation of eMARG. But for the initial development, the data from OMMAS to eMARG was exchanged as a data dump through excel file in July 2019.Once eMARG received the basic data, it was validated by following the process described in (**Figure 1**). PMIS of PMGSY i.e. OMMAS is developed and maintained by CDAC and eMARG IT web based solution is developed by NIC, Bhopal. The challenges of integration was well planned, documented and executed by NIC Bhopal in close coordination with CDAC while NRIDA facilitated protocols approvals after due deliberations with all divisions of NRIDA.

Once the Validations were put in eMARG, the valid data was used for the development of second version of eMARG. In the manual system of making payments, the contractor first submits the bill, the engineer then carries out the inspection of road to verify if the road has been maintained properly as per the guidelines or not, after verification, the payment to contractor was done through cheque. As eMARG replaced the manual system of payment completely with the digital payments, so modules were developed in eMARG for digital bill generation and submission by the contractor, a separate android app was developed for carrying out the inspections and taking random geo-tagged and time-stamped photographs for every km of road. Modules were also developed for carrying out the performance evaluation, making digital vouchers and signing it digitally with a DSC token. All these developments took place from July 2019 to Sep 2019.

5. On Boarding States Executing Agencies

While these developments were taking place, efforts were being made from NRIDA to convince states to convert traditional Bill of Quantity (BOQ)/hybrid system to PBMC system of payment. NRIDA Projects-I team & NIC took it as a challenge to explain to state officials and contractors about the benefits of PBMC based eMARG system over manual BOQ based system of routine maintenance. Several rounds of discussions were held between state and NRIDA officials. It was explained to them that maintenance of assets is a low-ticket and high-volume activity. It means that roads need to be inspected routinely to ensure serviceability, repairs need to be frequent and payments need to be processed continuously to the contractor. The fact that payments are small-ticket compared to new construction of assets and that there is so much paperwork and administrative burden in processing bills every few months, maintenance doesn't appear as an attractive proposition for contractors or to the executing agencies having very lean yet agile organizational setup. Further in PBMC system, there is no requirement to measure work done in term of material and labour administrators were sceptical making such payments in the fear of being audited later. State officials were explained that PBMC based eMARG addresses all these challenges through e-MARG as a tool. eMARG reduces the friction/efforts, manual work of submitting bills by contractors and makes it easy for administrators to verify work done based on outcomes, save systemic proof in terms of random locations geo-tagged time stamped photographs for future scrutiny and process bills quickly by pressing few buttons right from submission to payments. Even the processed bill amounts are calculated by the system based on the marks given to the road thereby reducing discretion. By removing inputs and instead focussing outcomes, engineers need not to wait for bills submission by the contractor but can instead inspect roads every 2 months to record the performance. Digitization of the entire process also brings forth transparency and information flow allowing inspection records, dashboards, data-driven reporting and use of nudges and notifications. This new system on the whole reduces indirect administrative cost of maintenance in the short-term and maintaining roads routinely saves significant future costs of repair in the long run. Even the quality of maintenance is improved by focussing on outcomes and not inputs. This gives added incentive to contractor to construct good quality roads in the beginning, such that when it comes to maintenance, he can be rewarded with complete payments without necessarily incurring inputs costs.

6. Development of Advance Module of e-Marg

Once the module in second version of eMARG was developed, trainings on large scale were conducted to 16 states with more than 2000 participants from Sep 2019 to March 2020 by NRIDA and NIC Bhopal officials by visiting respective states. The first big milestone in the implementation journey of eMARG was achieved on 9th Oct 2019, when first payment was done successfully through eMARG by the state of Tamil Nadu. On 1st April 2020, Ministry of Rural Development made it mandatory for all the states to make the payment of routine maintenance of PMGSY roads through eMARG only.

7. Challenges in Implementation

Another big challenge was to correct the invalid data that was rejected by eMARG. Also as completion of road is a dynamic process, so a solution was needed to be developed for regular exchange of data between OMMAS and eMARG. To resolve this the system were integrated through Restful API/Web Services for data exchange using JSON (JavaScript Object Notation) lightweight data-interchange format and all the data exchange between the two systems would happen through these services only. As OMMAS and eMARG was developed by two different organizations, OMMAS by C-DAC Pune and eMARG by NIC Bhopal, Integration of two systems were itself a challenge. Fortunately, all issues were resolved and this task was also completed in the month of April 2020 even during Covid-19.

Once the web services were exchanged between the two systems, another challenge was ensuring and maintaining the integrity of the existing data in OMMAS like the PAN details of the contractor, the date of completion, maintenance rates, length under maintenance, name of the contractor, etc. Innovative solutions were designed to address these issues during implementation. A separate module named "Maintenance Data Correction module" was developed in OMMAS from where the concerned engineer of the road would first check all the details of the road like completion length, completion date, Carriage way width, etc and if any inconsistency was found in any data, then he could make the necessary correction and then push it to eMARG. This same module was used to correct the invalid data which was obtained from the validations initially put by eMARG in the data dump that was sent in the form of excel sheet. In this way, the integrity of the data was ensured and it was made sure that correct data is only being used for implementation of eMARG. Once the data was pushed, the same was exchanged through web service to eMARG. This development was completed in the month of May-20.

8. COVID Adversity as an Opportunity

With these developments implemented in both OMMAS and eMARG, major integration process of the two systems was completed and during the time of pandemic, large scale trainings were conducted for all the states through the medium of Video Conferencing from the month of June-20 to Sep-20. Covid brought adversity along with the concept of video conferencing, thus saving lot of time in travelling and expenses. This opportunity was well utilized to expedite implementation through VC involving thousands of state officials, contractors, banks etc. Around 5000 working staffs were trained by NRIDA and NIC Bhopal officials across the country familiarizing them with eMARG. The training sessions were successful and the total payment done through eMARG across the country increased at an exponential rate from Rs. 8.4 Cr in the month of June-20 to Rs. 121.3 Cr in the month of Oct-20.

9. Additional Module of e-Marg

Even though eMARG became a stable system by the end of Oct-20, still states raised few exceptional cases which needed to be tackled and development of separate modules were necessitated in both OMMAS and eMARG. Through brain storming with all stakeholders and finally discussions between NIC Bhopal and NRIDA team, innovative solutions were developed to tackle all exceptional cases. The developments were completed by the end of Nov-20 and states were also imparted training through video conferencing about new developments in the month of Dec-20. With all these efforts, eMARG became a successful story that despite the pandemic situation of Covid-19, a total of Rs. 513.3 Cr payment was done through eMARG in the FY 2020-21 (**Figure 2**).

10. Features of eMARG

eMARG is an e-Governance solution developed to assist all stakeholders, i.e., state implementing agencies, civil contractors and banks. It is an end-to-end solution which provides role-based access via the internet, and helps monitor and administer maintenance contracts for rural roads. Following the principles of PBMC, prior to making payments to the contractor, bi-monthly inspections are carried out by engineers for every 1 km section of the road in which they click two photographs at randomly generated locations through the mobile app to capture the actual condition of roads as evidence. Thereafter, they give a grading of Satisfactory/Unsatisfactory based on the condition of road. Furthermore, based on these photographs and grading, the condition of the road is evaluated on a scale of 100 based on pre-defined performance standards, **parameters as per Figure 1A**. Finally, on the basis of marks obtained out of 100, a proportional payment is made, as explained before. The bi-monthly inspections ensure that the road is maintained throughout the year. Furthermore, eMARG allows contractors to submit e-bills in one click on the system and auto-generate vouchers based on the result of the performance evaluation. The vouchers are sent to the accounting officer in-situ and forwarded to the bank for digital payment. End-to-end processing of bills is achieved through the system, thus drastically reducing the administrative friction and making routine payment of small ticket bills both attractive and efficient. The work flow of eMARG is described as below (**Figure 3**).

After the introduction of eMARG, one of the major transformations was that the entire process was fully digitized (**Figure 4**).

A comparison of the process of making payment for routine maintenance before and after eMARG can be summarized in the following table:

Table 1: Comparison of process before and after eMARG

Process	Before eMARG	After eMARG
Bill Submission	• Bills submitted manually based on labour/material involved in maintenance • No control/record of date or frequency of Bill submission	• eBill submitted in one click online with fixed maximum monthly amount • Monthly alerts for bill submission • No dispute around date of submission of bill
Routine Inspections	• Inspection triggered by bill submission. A bad road without bill submitted will not be inspected • No permanent record or evidence of routine inspection	• Bi-monthly Inspections done through eMARG mobile app with geo-tagged photos • Mobile notifications for reminders
Verification of Work & Bill	• Primarily on the basis of volume/labour/material of work executed i.e. based on inputs • Done Manually by Engineers against the bill raised by contractor	• Bill amount calculated by system based on marks awarded in Performance Evaluation ie outcomes • Photographs clicked in RI are used as base for this evaluation
Voucher Generation	• Done Manually by Account Officer after deducting taxes manually from the approved Bill Amount	• System generated with automatic tax deductions etc under Account Officer Login & DSC for digital signing of vouchers
Payments	• Done manually by Cheque Payment and then entered into online accounting software	• Directly into contractors account; single account per contractor. • Transaction sent to accounting software automatically by API

eMARG is a fusion of innovative open source technologies, remote sensing, GIS, cryptography, mobile, messaging and e-mail. Some of the innovative features of eMARG are the automation of the entire cycle of bill generation and payments for maintenance contracts, the eMARG Mobile-app to take geo-tagged photographs of the roads as part of routine inspections of roads, etc. The photographs at randomly generated location ensure evidence based proof of road condition over frequent intervals of time during the entire five year defect liability period. The use of the mobile app and mobile technology is summarized in the **Figure 5**.

The engineers play the most important role in implementation of eMARG as most of the activities are to be carried out by them. For their ease of operation, as soon as one Logs into eMARG, a PIU Task Sheet (**Figure 6**) is displayed to him in which a detailed number and list of tasks pending at the concerned user is shown. The tasks have a direct call to action button also using which the user can directly go to the module from where one has to perform the particular task.

Apart from this eMARG has a plethora of reports and dashboards through which all users as well as officials of senior management can keep a track of progress done on eMARG. Some of the important reports include No. of bills pending at contractor for submission, No. of roads due for RI, No. of roads on which Performance Evaluation is pending, No. of bills that are made zero due to marks given in performance evaluation. One very important report available in eMARG is Inspection Analysis report where one may select any road on satellite imagery (**Figure 7**) and instantly check the pictures as clicked by the respective district engineers, and match them with the payments made against those roads to contractors for their upkeep. Evaluation is done completely online through eMARG. The evaluation done can be cross-checked by observing the uploaded photographs. The redressal of public complaints can thus be handled in a better way. This makes the system more transparent.

11. Outcomes and Results of Implementing eMARG

So far, all states have on-boarded on eMARG and have started making payments through eMARG. eMARG is currently being utilized by 1,375 Project Implementation Units (PIU) comprising more than 10,000 engineers from all districts and 13,590 contractors from all over India to perform inspections, generate and approve single click bills and make payments, thus significantly easing the burden manual and tedious tasks. 61,907 roads having a length of 2,38,733 km spread across the country are covered by eMARG. As on April 30th, 2022, 10,59,718 bills have been submitted and a total amount of Rs. 1435.91 Crores have been released as maintenance related payments through eMARG. eMARG has been a win-win for both the government and the citizens. It has reduced the burden on the frontline staff and has also promoted transparency in the overall system of rural road maintenance.

12. eMARG to Bring in Transparency, Citizen Participation and Compliances

As the end users of eMARG are contractors and Deptt Engineers who may not be very Tech savvy, system was made simple during initial implementation and development phase for them to get familiar with the system. Strict implementation of clauses of the SOP of eMARG in respect of Routine Inspections (RI) and Performance Evaluation (PE) for every road mandatorily to be conducted in every two month has been built into the system with proper checks by the system itself. This is necessitated to ensure that roads are kept and maintained all the time as per contractual obligations of contractors in 5 year defect liability period. These checks and balances were developed and implemented in the period of June-21 to Oct-21 after consultation with all stakeholders.

eMARG is evolving day by day based on users feedback, improvements are being made continuously to make it transparent, use of artificial intelligence and system driven with no manual work. One of the steps towards it was taken on 7th March 2022, when Pilot was done for the state of Madhya Pradesh for the use of AI to detect the anomaly in the condition of road as seen through photographs and marks given in performance evaluation. The development is expected to be implemented soon for PAN India.

13. Awards and Recognitions Won by eMARG

eMARG as a system tool and e-Governance initiative of Govt of India has won several accolades at National level. Some of these awards at National level conferred to e-MARG and to its team are as follows:

1. Gems of Digital India Award 2020 (Analyst's Choice)
2. SKOCH Governance Award– "Gold Award"
3. National Award for e-Governance 2021 – "Silver Award" NCEG2022 by Department of Administrative Reforms and Public Grievances, MoPP&P, Government of India
4. CSI SIG eGovernance Awards 2021 - "Award of Appreciation"

14. Learnings and Conclusion

1. Maintenance of government assets is a global problem faced by developing and developed countries alike. It is a hard problem to solve given the low-ticket high-volume nature of maintenance and the incentives involved which promote new construction of assets over maintaining existing ones. This impacts roads, bridges, schools, health centres and countless other government infrastructure assets. eMARG provides a framework to tackle and disrupt maintenance activities across government assets. It gives confidence that outcome based performance evaluation during maintenance is feasible through use of technology to bring in transparency, adaptability and public confidence in the scheme.
2. The eMARG model is a proven implementation of outcomes based monitoring which makes small ticket payments efficient and attractive. It can be scaled across all assets categories by simply adapting to the 100 point rubric used to evaluate the outcomes of the asset in question.
3. eMARG is an example of how to combine multiple e-governance and emerging technologies under one roof: Open Source, Remote Sensing, GIS, Cryptography, Mobile, Messaging and Mail. It is not an example of using a particular technology but what all is possible when all technologies are combined.
4. eMARG implementation across the country in such a short time has proved that the modular approach of simultaneous development and implementation can be opted for the projects dealing with a large number of stake holders rather than waiting for developing the whole product at once and then implementing it.
5. eMARG implementation reduced the burden on frontline staff in maintaining manual records and it is an example of bottom-up technology, centered solely around reducing administrative burden. This is very important given the context that our frontline staff is the face of governance and is tasked with increasing responsibilities, this e-Governance solution meets the aspirations and appreciations of all stakeholders at National level.

Figure 1A: Process of data validation in eMARG

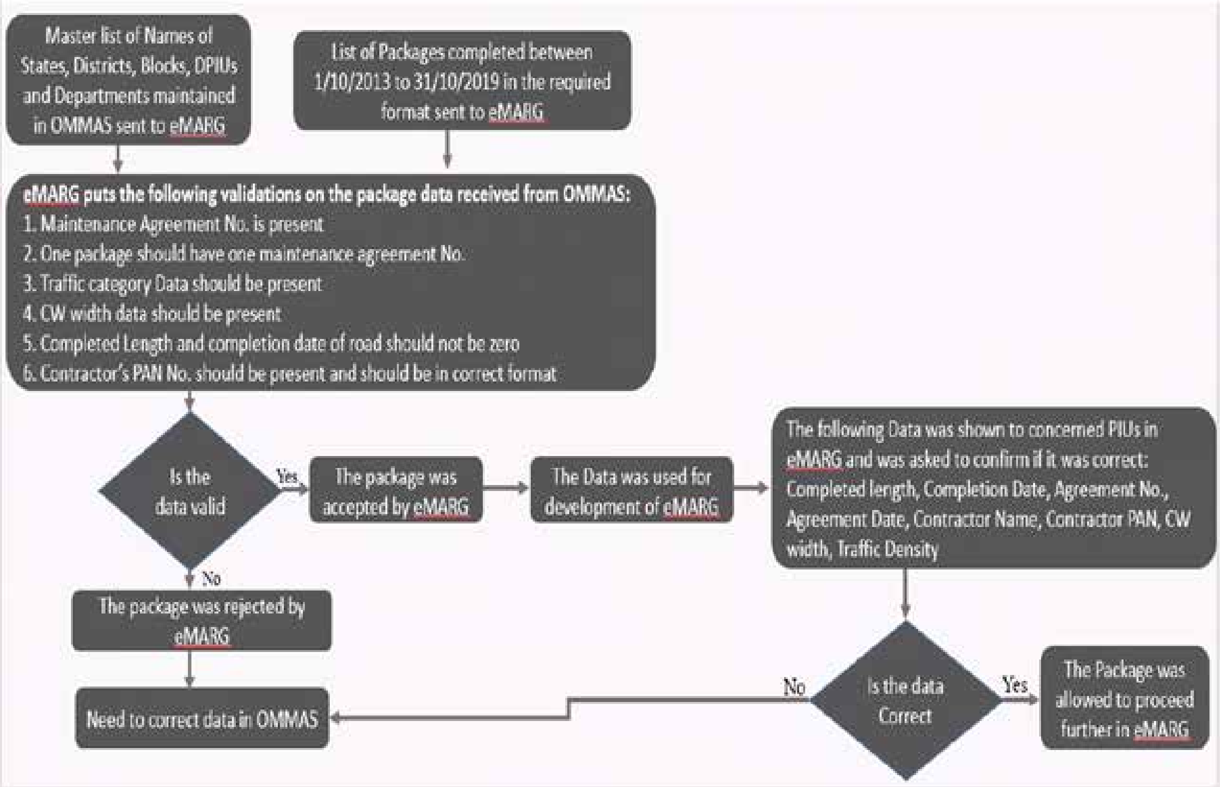


Figure1B: Parameters for Routine Inspections and Performance Evaluation

Sr No.	Name of Item/Activity	Performance Index
1	Maintenance of Bituminous surface road and / or gravel road and/or WBM road including filling potholes and patch repairs etc. as per clause 1904, 1906 of the MoRD Specifications (As per Annexure-14.1 of Operation manual)	50
2	Restoration of rain cuts and dressing of side slopes/berms as per clause 1902 of the Specifications. (As per Annexure-14.1 of Operation manual)	10
3	Making up of berms/shoulders as per clause1903 of the (As per Annexure-14.1 of Operation manual)	20
4	Maintenance of drains as per clause 1907 of the Specifications. (As per Annexure-14.1 of Operation manual)	3
5	Maintenance of culverts and cause ways as per clause 1908 and 1909 of the MoRD (As per Annexure-14.1 of Operation manual)	4
6	Maintenance of guard rails and parapet rails as per clause 1911 of the MoRD Specifications (As per Annexure-14.1 of Operation manual)	1
7	Maintenance of road signs, speed breakers, standing trees adjacent to road wherever required as per clause 1910 of the MoRD Specifications (As per Annexure-14.1 of Operation manual)	2
8	Maintenance of 200 m and Kilo Meter stones as per clause 1912 of the MoRD Specifications (As per Annexure-14.1 of Operation manual)	2
9	Cutting of branches of trees, shrubs and trimming of grass and weeds etc. as per clause 1914 of the MoRD Specifications (As per Annexure-14.1 of Operation manual)	3
10	White washing parapets of Works including CD (As per Annexure-14.1 of Operation manual)	2
11	Painting of guard stones	2
12	Re-fixing displaced guard stones	1
	Total	**100**

Figure 2: Progress of payments done through eMARG

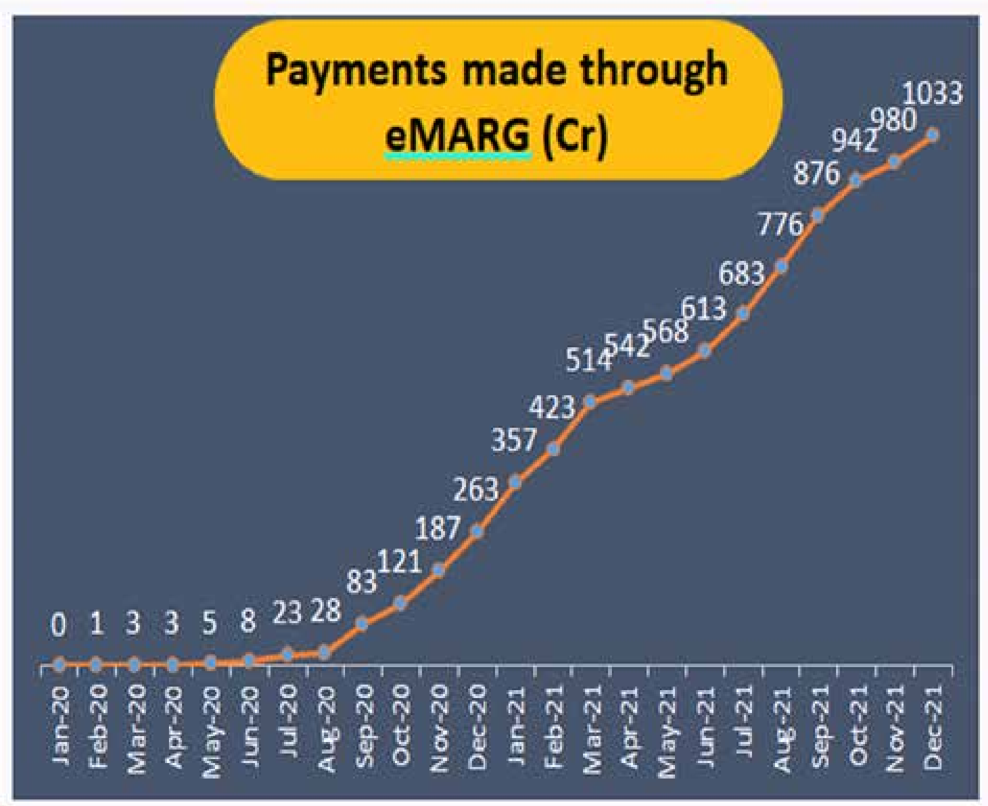


Figure 3: Work flow of eMARG

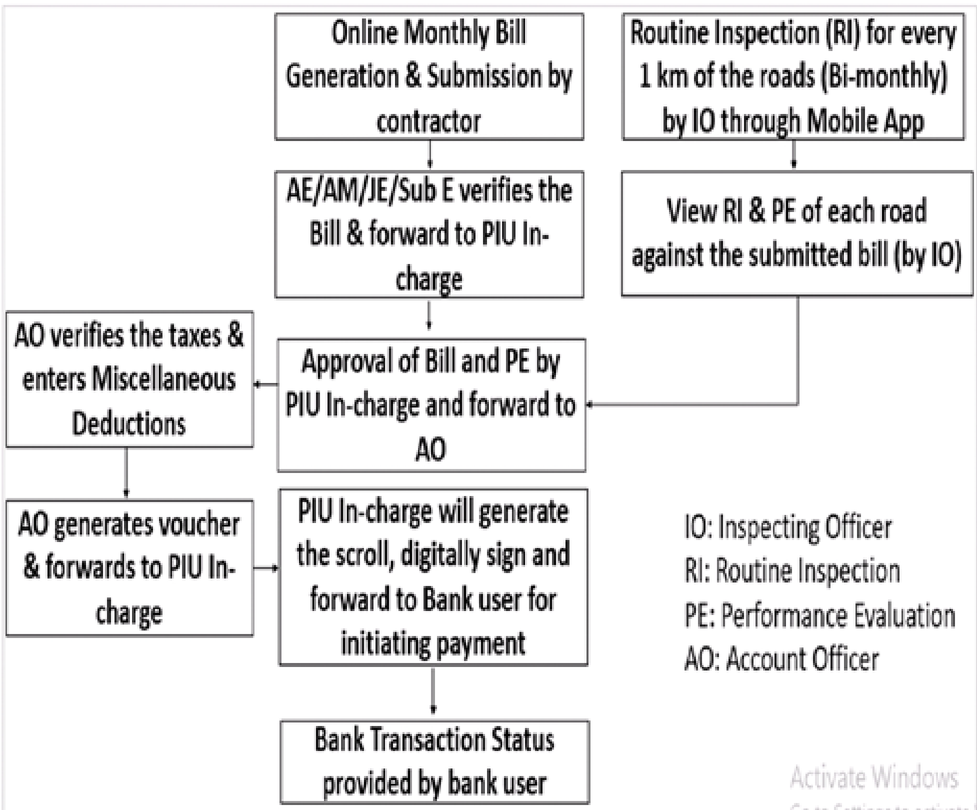


Figure 4: Digitization of Maintenance process

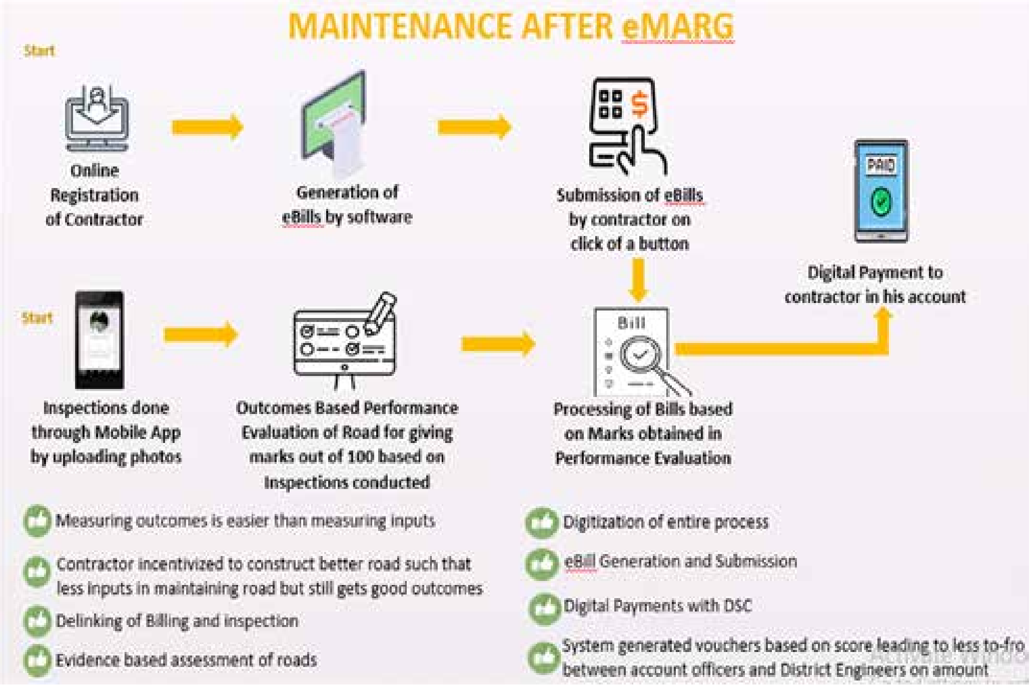


Figure 5: Mobile App and Mobile Technology used in eMARG

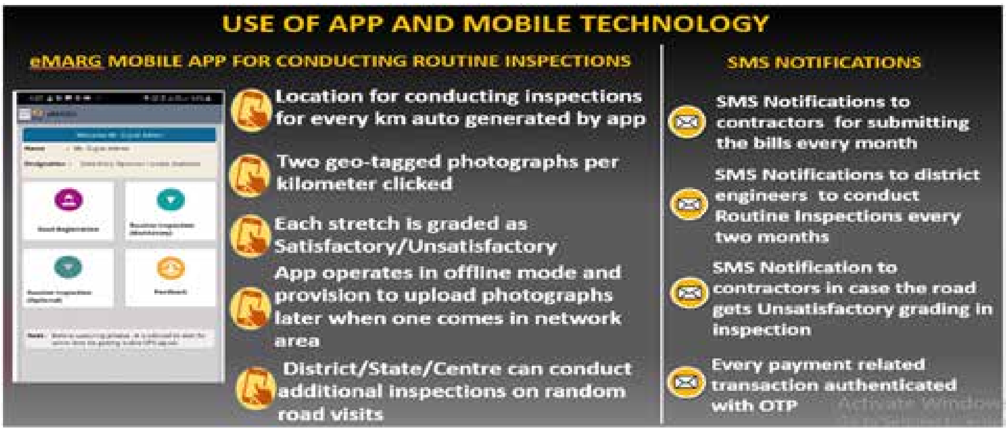
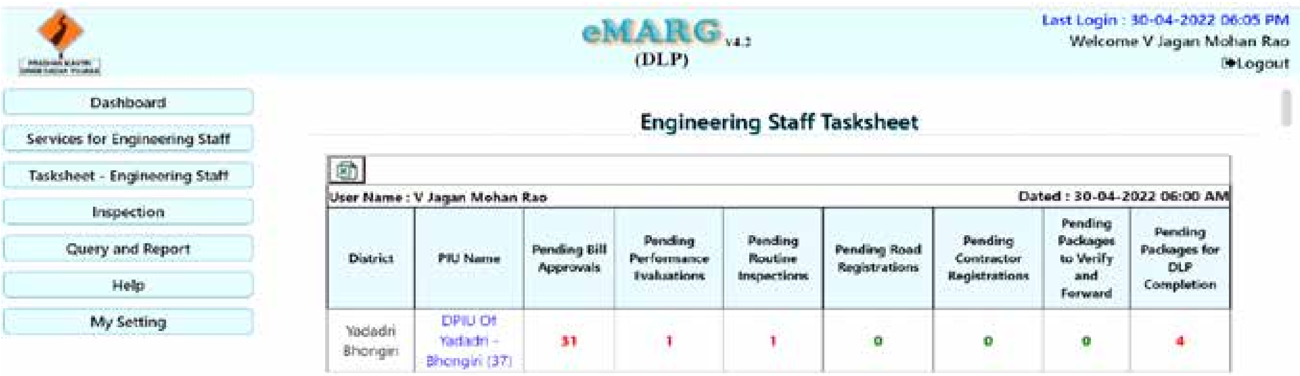


Figure 6: PIU Task Sheet



District	PIU Name	Pending Bill Approvals	Pending Performance Evaluations	Pending Routine Inspections	Pending Road Registrations	Pending Contractor Registrations	Pending Packages to Verify and Forward	Pending Packages for DLP Completion
Yadadri Bhongiri	DPIU Of Yadadri - Bhongiri (37)	31	1	1	0	0	0	4

Figure 7: Condition of road as seen on Satellite Image

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Linking Farmers to Markets – Experience from Malawi

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Abstract

Agriculture remains the mainstay of Malawi's economy. The sector is also the main contributor to the national and household food security and nutrition. Malawi's agriculture sector is dualistic, comprising the smallholder and the estate sub-sectors. The smallholder farmers mostly grow food crops (including maize, rice, sorghum, bananas, cassava, sweet potatoes, Irish potatoes, and legumes), and some cash crops such as tea, tobacco, sugarcane and coffee.

Limited access to markets for acquiring agricultural inputs, and for produce commercialization continues to be a major constraint for farmers to realize their full potential. Many agricultural areas remain inaccessible or are difficult to access due to poor road conditions and broken linkages especially during the rainy season.

In order to improve productivity and access to markets by farmers in Malawi, the Ministry of Agriculture implemented Agriculture Sector Wide Approach (ASWAp) project through a Multi Donor Trust Fund (MDTF) with financing from EU, Irish Aid, Flanders, USAID and Norway. Through ASWAp SP I which was implemented in 10 selected districts from 2008 to 2016, twenty-one roads and three bridges covering a total of 469 km were rehabilitated. ASWAp SP II is a follow up to the ASWAP SP I and was implemented from 2018 to 2021 in 12 selected districts of Malawi.

ASWAP SP II project was implemented through District Councils who were the Clients as a way of building capacity to the Councils. The total project cost was US$ 55 million with US$ 30.64 million allocated to the Roads Component. A total of 926 km of rural roads were rehabilitated and 76 km of rural roads were upgraded using Low Volume Seal concept. The project also included construction of small bridges and culverts/drainage structures. A total of 94 market centres were connected to farms by the end of the project, out of the targeted 100 market centres.

1. Introduction

Malawi is a land linked country located in Southern Africa with a population of about 17 million people spread over an area of 118,484 square kilometers. It is an agro-based economy with approximately 85 percent of the population living in rural areas that thrives on rain fed agriculture as the main economic activity. Currently, only about 4 percent of the cultivatable land is under irrigation.

Many rural areas of the country remain inaccessible or are difficult to access due to the poor conditions of the roads and broken linkages especially during the rainy season. In 2004 Roads Authority carried out Road Reclassification Study where close to 25,000 km of public roads were identified of which 80 percent (20,000 km) were unpaved and most of these unpaved roads were in the rural areas.

A Multi Donor Trust Fund (MDTF) was established in 2013 to support Agriculture Sector Wide Approach (ASWAP) program. The MDTF was administered by the World Bank with the primary objectives of improving effectiveness of investments aimed at food security and sustainable agricultural growth and strengthening the natural resource base. ASWAp SP I was implemented from 2008 to 2016 where selected roads in 10 districts were rehabilitated under the road component. The main objective of the road component was to improve the unpaved rural roads connectivity and accessibility to markets in order to support the diversification and commercialization of agricultural production. Under this Component, works concentrated in areas with proven agricultural potential.

The ASWAp SP II is a follow up to the ASWAp SP I Project and was implemented from 2018 to 2021 with the aim of improving productivity and market access for farmers. Five donors supported the program namely: EU, Irish Aid, Flanders, USAID and Norway. The project was implemented in 12 selected districts of Malawi and it involved improvement of roads and bridge infrastructure through labour intensive rehabilitation and upgrading of roads using Low Volume Seal Concept.

2. Implementation

2.1. ASWAP SP I

ASWAP SP I was implemented in 10 selected districts of Malawi from 2008 to 2016. The project was funded by the MDTF and managed by the World Bank. Under the Road Component of the project, two interventions were implemented:

1. Rehabilitation of rural roads through spot improvements - rural roads were improved through gravelling and construction of concrete pads.
2. Upgrading to Low Volume Seal using Cold mix Asphalt surfacing.

2.2 Achievements of the Project Development Objectives (PDO)

1. Improved market access through the rehabilitated and upgraded feeder roads. A total of 469 km were improved including three bridges and other drainage structures. There was significant change in motorized and non-motorized traffic volumes on the rehabilitated roads.
2. Project beneficiaries - a total of 3 million people benefited from the project through their participation in road works and other agricultural programs of which 42% were women.
3. Trainings were conducted in Principles of Low Volume Seal, Construction materials, Drainage Systems Design, Gabion Design and Installation.

2.3 ASWAP SP II

ASWAP SP II was a follow up to ASWAP SP I program and was implemented from 2018 to 2021. The project was implemented in complementarity with the Rural Roads Improvement Program (RRImp) funded by the European Union through the National Authorizing Officer Support Unit in the Ministry of Finance. The project was implemented in 12 district Councils of Malawi as shown in Figure 1 below.

The Project Development Objective (PDO) for the project was to improve productivity and market access of selected commodities for small holder farmers in selected districts of Malawi. The key outcomes were:

- Increased volume of production of selected agricultural commodities;
- Number of agricultural marketing centers connected by rehabilitated roads;
- Farmers reached with agricultural assets or services of which 50% are female farmers.

Beneficiaries of the project included

(i) smallholder farmers and local communities who benefitted from improved agricultural interventions and jobs created through road rehabilitation

(ii) road users who benefited from improved road infrastructure

Support under the road component was provided in form of two main areas of interventions:

1. Improvement of the 1200 km of unpaved rural roads through labor-intensive rehabilitation and upgrading works using Low Volume Sealing Concept in 12 selected districts
2. Implementation support to the 12 District Councils to facilitate proper monitoring of works

Road selection and prioritization was based on agricultural productivity (actual and potential), economic aspects and connectivity. A consultant was engaged to prioritize the roads, design and prepare tender documents in consultation with District Councils.

The project was implemented through District Councils who were the Clients as a way of building capacity to the Councils. The role of the Councils was to monitor the contractors and supervision consultants whereas the role of Roads Authority was to provide technical support to the Councils.

ASWAp-SP II project cost was US$ 55 million with US$30.64 million allocated to the Roads Component. Allocation for Road Component included US$ 3.27 million for Implementation Support to District Councils. A total of 926 km

Figure 1: Showing Map of Malawi and ASWAP SP II Project Districts

of roads were rehabilitated through labour based method and 76 km of roads were upgraded using Low Volume Seal concept including small bridges and culverts. As a result, 94 market centres out of the targeted 100 market centres were connected to farmers.

3. Low Volume Seal Concept

3.1. Background

Most unpaved roads in Malawi carry relatively low volumes of traffic i.e. less than 200 vehicles per day. Some of these roads with such low traffic were surfaced with thin bituminous surfacing and performed beyond expectation and lasted over 20 years. However, the construction was done without any approved manuals for geometric or pavement design of geometry or pavement.

In 2013, the Roads Authority of Malawi through assistance from the UK under the African Community Access Programme (AfCAP) developed a Design Manual for Low Volume Sealed roads using DCP design method. The manual was among the first to be produced in Africa and was developed following a back analysis study and formulation of specifications for low volume roads also funded under the same programme. The ASWAp-SP was used as a first formal pilot for the design manual.

During implementation of ASWAP SP II it was specified that the roads earmarked for upgrading would be designed using this low volume approach. This was on the basis that the roads in question would not carry more than a million equivalent standard axles in their design life of 15 years. The Roads Authority engaged the services of an international consultant to prepare the designs including drawings, specifications and works bidding document.

Below is the list of roads under the ASWAP SP II project:

Table 1: Design Traffic Loading for Project Roads

Road Number	District	Name of Road	Estimated Traffic Loading (MESA)	Design Traffic Class (MESA)
1	Lilongwe	Mitundu – Kambanizithe	0.24	0.3 (0.10-0.30)
2	Mchinji	Ludzi T/Off to Ludzi Trading Centre	0.67	0.7 (0.30-0.70)
3	Ntchisi	Ng'ombe to Nyalavu	0.23	0.3 (0.10-0.30)
4	Kasungu	Mphomwa to Kamtuwale	0.28	0.3 (0.10-0.30)
5	Mzimba	Ehehleni – Chipata – Jenda Trading Centre	0.05	0.3 (0.10-0.30)
6	Chitipa	Kapoka – Chendo	0.46	0.7 (0.30-0.70)
7	Dedza	Dedza - Kasumbu	0.24	0.3 (0.10-0.30)
8	Ntcheu	Chinyamula – Mphepozinayi	0.14	0.3 (0.10-0.30)
9	Zomba	Mpotola School – Namadidi Market Road	0.5	0.7 (0.30-0.70)
10	Phalombe	Phalombe – Mpata - Nkhulambe	0.03	0.3 (0.10-0.30)
11	Mulanje	Savama – Mathambi	0.27	0.3 (0.10-0.30)
12	Thyolo	Chiperoni – Khonjeni Railway Station	0.44	0.7 (0.30-0.70)

3.2. Impact Study Report

The Impact Study Report for the project has highlighted the following impacts:

i. Improved accessibility of the roads

ii. Availability of motorised transport services to and from market centres

iii. Reduction in travel time to and from the main markets especially for farmers

iv. Improved livelihoods for those that worked on the road projects

3.3. Technical Audit Findings

A post construction technical audit was carried out on the project and the following successes were highlighted:

1. District Councils gained practical experience in terms of management of road contracts
2. Paving of road sections of the rural roads has uplifted communities. Accessibility of the roads has improved and the roads are now passable in all weather conditions.
3. Reduction in vehicle operating costs due to improved road conditions

However, the following shortcomings were also identified during the audit:

3.3.1. Road Design

(a) Design did not provide minimum crown height (h_{min}) to ensure adequate drainage

(b) Design introduced a 'hybrid' specification that included elements of the DCP – DN pavement design and conventional (CBR) design

(c) The recommended Double Chip Seal surfacing required high contractor expertise which was found lacking in the local contractors

3.3.2. Quality of Supervision

(a) The locally based consulting firms contracted by the District Councils were understaffed and poorly trained for the task as it was a new approach

3.3.3. Cost per km

The average cost per km for the LVS upgrading under ASWAP II is around USD 216,000. However, if we take into consideration drainage for the whole road length, the cost per km could be around USD 300,000 which is cheaper as compared to the cost of conventional cost of USD 1 million.

3.4. Way Forward for Low Volume Design Approach

The Roads Authority considers the low volume approach as the best approach in terms of upgrading rural roads to bitumen standard as it ensures that with the same financial resources more roads will be constructed since the cost per km for low volume approach roads is only a third of the conventional approach. It was noted that most of the key findings from the technical audit emanated from lack of training on the approach for both the design consultants, supervision consultants and the contractors. The RA will therefore embark on a series of trainings in order to improve the delivery of the approach in future projects of such nature.

4. Project Outcomes

1. Rehabilitation – 926 km of rural roads were rehabilitated using labour intensive method.
2. Upgrading – 76.2 km of rural roads were upgraded to bitumen standard using LVS concept.
3. Market Centres – 94 market centres were connected out of the targeted 100.
4. Beneficiaries – Over 15,000 people were employed during road rehabilitation out of which 43% were women.
5. Training – District Council staff were trained in Procurement, Project management, Financial Management and Road Prioritization.

5. Challenges

1. Lack of capacity – This being a new technology, there is need for training in the design and use of the LVSR methods for consultants, contractors and clients, as well as the use of DCP – DN method for design of road pavements.
2. The design combined DCP – DN pavement design and conventional method (CBR) that was somehow confusing. This resulted in hybrid specifications for upper pavement layers. This will need to be keenly monitored in future designs.

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Roads Authority, Impact Study Report (April 2022), Aswap SP II MDTF, Lilongwe, Malawo.

Appendix

Pictures of Upgraded Roads & Bridge (Before & After)

Thyolo – Khonjeni Road in Thyolo District

Before

After

Sayama – Mathambi Road in Mulanje District

Before

After

Phalombe - Fortlister Road in Phalombe District

Before

After

Upgrading of Ntcheu (M001) Junction-Mphepozinayi Road in Ntcheu District

Before

After

Mpasadzi Bridge in Kasungu District

Before/During

After

Innovations in Technologies, Materials, and Designs For Long-Lasting Low-Volume Roads

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In the dwindling budget scenario, the necessity for innovations in pavement construction technologies, materials, and pavement designs is imminent to ensure economic, long-lasting, and durable pavements. This paper presents two case studies demonstrating the innovations in construction technology, such as intelligent compaction and innovative materials such as fiber-reinforced concrete in low to moderate traffic volume roads in cold climate areas.

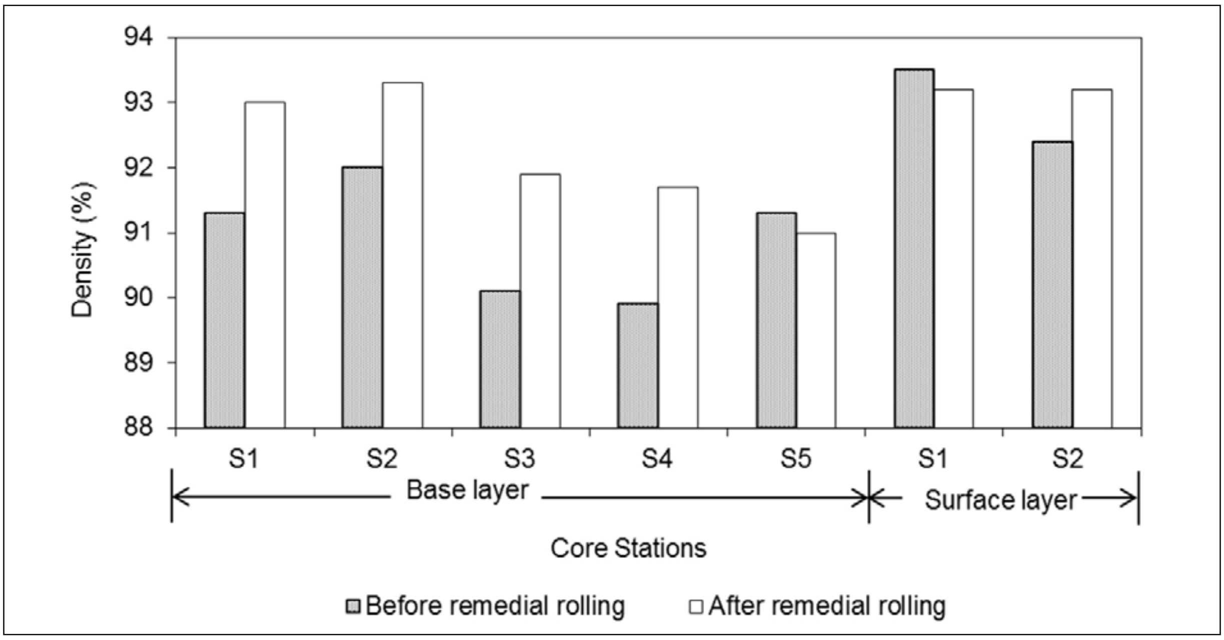
Case Study 1: Intelligent Compaction of Asphalt Pavements

Traditionally, the asphalt layers are compacted at 6 to 8% air voids or 92 to 94% relative density. While the relative density of the high volume roads increases with the traffic loads up to 96 to 98%, the same does not occur in the low and moderate volume roads because of less traffic load application. Under-compacted low-volume asphalt layers thus entrap water in the voids, resulting in premature distresses like localized depressions, raveling, stipping, and potholes. Therefore, achieving the required air voids or relative density in low-volume roads is essential to avoid environmental-driven distresses. The real-time monitoring of the asphalt layer density can undoubtedly help achieve the required relative density for rural low-volume roads. The traditional quality control procedure, which involves collecting asphalt cores and conducting volumetric analysis, does not measure the air voids or relative density level during the compaction; thus, under-compacted spots remain undetected and leave the pavement vulnerable to the premature distresses. The intelligent compaction methods are able to continuously monitor the air voids or density of asphalt layers during the compaction process. The University of Oklahoma of the United States of America (USA) has developed an intelligent compaction analyzer (ICA) *(1-4)*. The ICA is based on the hypothesis that the vibratory roller and the underlying pavement form a coupled system whose response during compaction is influenced by the stiffness of the pavement layers. The ICA is capable of generating as-built maps providing information on coverage and quality of compaction of the compacted asphalt layers. The principle of ICA and its application in measuring the density of asphalt layers, the procedure for installing the ICA in the field, working operation, calibration, and validation of the ICA asphalt density can be found in *(1, 5-7)*. The paper includes a case study about the application of the ICA for the compaction of a low-volume road in Oklahoma, USA.

In this study, the application of the ICA in quality control (QC), as well as quality improvement (QI) of asphalt pavements, was demonstrated. The intelligent compaction was used on the compaction of base and surface layers of a rural asphalt road (Name: Acme Road at Shawnee, Oklahoma, USA). Asphalt mixes of both layers were prepared with the PG 64-22 binder. The nominal maximum aggregate size (NMAS) for the base and surface layer was 25.4 mm (1 inch) and 12.7 mm (½ inch), respectively. Both the mixes contained a significant percentage of reclaimed asphalt pavement (RAP), 25% in the base and 35% in the surface layer. More extensive detail about the pavement structure, asphalt mixture, and work scope could not be accommodated in this paper; however, the presentation of this study will include these components and can also be found at *(8)*.

During the compaction of the base layer, six under-compacted spots (S1 to S6) were identified by the ICA. Three remedial roller passes were applied on the first four spots (S1 to S4), whereas only one additional pass could be provided on spot S5. The roller operator could not provide any additional pass on spot S6 because of time constraints. In the surface layer, four under-compacted regions (S1 through S4) were identified. However, because of time constraints, remedial passes could only be applied on the first two spots (S1 and S2). It may be noted here that the contract of this construction work did not have any scope for ICA compaction, so additional roller passes could not be applied on all the identified under-compacted spots. Figure 1 presents a comparison of the ICA-estimated density measured before and after the remedial passes. For the base layer, it can be seen that the density at the four spots (S1 through S4) was increased with the three remedial passes. The density at spot S5 could not be increased because only one additional pass was provided at this spot compared to three remedial passes on the other spots. The average relative density of the five spots could be improved from 90.9% to 92.2%. In the surface layer, the density was found to increase in one spot (S2), while it remained almost the same in the other spot (S1). The average density improved from 93% to 93.2% for the surface layer.

Figure 1:. Improvement in ICA-estimated density with remedial roller passes at the under-compacted spots



The ICA-estimated densities were validated by comparing them with the relative density of asphalt cores extracted from selected locations on the compacted asphalt layer. A t-test conducted with the ICA-estimated densities and core densities verified that the difference between the above-mentioned two types of densities is insignificant at a 95% confidence level. Based on this observation, it can be concluded that the intelligent compaction can be helpful in identifying and remediating under-compacted regions in asphalt layers for low-volume roads.

Case Study 2: Ultra-thin and Thin Fiber Reinforced Concrete Pavements for Low to Moderate Volume Roads for Extremely Cold Climate Areas

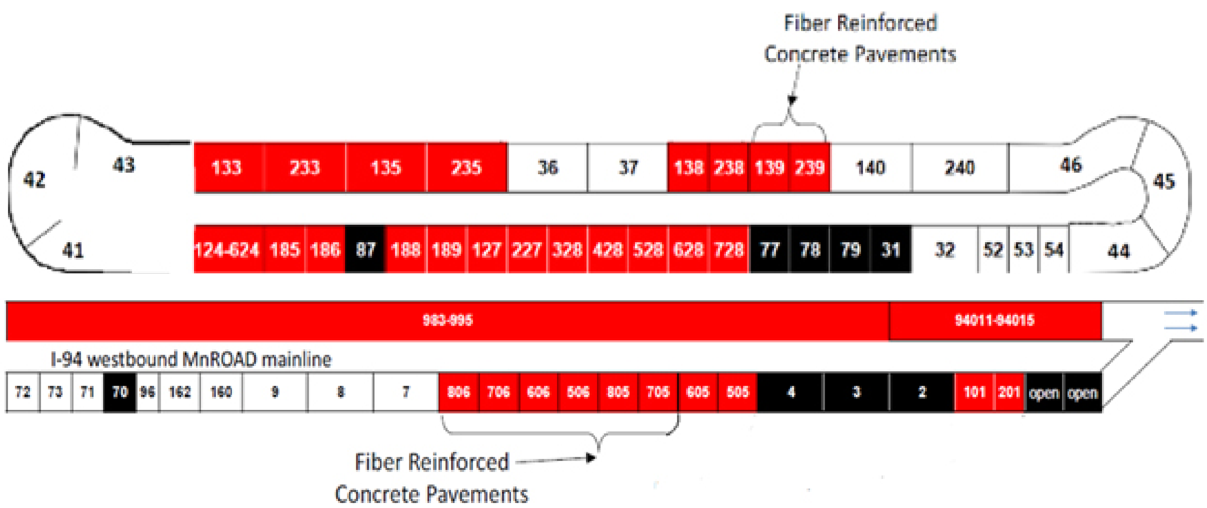
Thin concrete pavements and overlays are potentially economic pavement structures. Synthetic structural fibers can improve the performance of concrete by holding cracks tight, increasing the load transfer between slabs, and arresting slab migration. While it is evident that synthetic structural fibers can improve the performance of concrete overlays or pavements, limited research has been conducted to understand the performance benefit of fiber reinforced concrete (FRC) and quantify the structural fibers' influence in mitigating the distresses in concrete overlays or pavements. This knowledge gap is why current concrete pavement and overlay design procedures do not accurately account for the benefits of the inclusion of structural fibers.

This study, funded by the National Road Research Alliance (NRRA) of the USA, is designed to understand and quantify the influence of synthetic structural fibers in mitigating common distresses like panel fatigue cracking and transverse joint faulting in thin concrete overlays and thin concrete pavements on a gravel base. In addition, this study explores whether the construction of 3- and 4-inch-thick, ultra-thin FRC pavements is feasible for low-volume roads and city streets in the cold climate areas, where roads experience subzero temperature for many months.

Under the scope of this study, the Minnesota Department of Transportation (MnDOT) constructed eight test cells at MnROAD in 2017 as shown in Figure 2. Seven cells were constructed with FRC, and one control cell was constructed with plain concrete (Cell 506). Cells 139 (3 inches thick) and 239 (4 inches thick) were constructed as ultra-thin FRC pavements (8 lbs./cy synthetic structural fiber dosage) on an unstabilized marginal (6-inch-thick) gravel base. Cells 506, 606, 706, and 806 were constructed as thin concrete pavements (5 to 6 inches thick) on a relatively stiff (11-inch-thick) unstabilized gravel base with varying fiber dosages (0%, 5, 8, and 11.7 lbs./cy fiber dosages, respectively). Cells 705 and 805 (5 inches thick) were constructed as thin unbonded concrete overlays on a geofabric interlayer on existing concrete pavement, with varying panel widths (~ 6 ft vs ~ 12 ft); these two cells contained a 5 lbs./cy fiber dosage. A photograph of the structural fibers used in the Cells are provided in Figure 3.

Cell 139 and 239 were constructed on the low-volume test track, and the other cells were constructed on the interstate traffic-loaded portion of MnROAD, as shown in Figure 2. Exposing several test sections to live interstate traffic allowed for accelerated development of distresses. All eight cells were equipped with different types of sensors for measuring responses such as (i) dynamic strain due to wheel loads, (ii) strain induced by the environmental forces, (iii) pavement temperature and gradient, and (iv) transverse joint movement. Periodic surveys of cracks, spalling, and faulting were conducted to keep track of the distresses. Falling weight deflectometer (FWD) tests were periodically conducted to determine joint performance in different seasons. Based on the performance and distresses observed in this accelerated study in the first three years of service life with approximately 3 million equivalent single axle load (ESAL), the following conclusions were made.

Figure 2: Location of the 2017 FRC test cells at the MnROAD test facility, USA (9)



2017 FRC test cells on I-94 mainline

Figure 3: Photograph of the fibers used in 2017 FRC test cells.

(1) Between the two ultra-thin cells constructed in this study, it was found that the 4-inch-thick Cell 239 provided significantly better performance compared to the 3-inch-thick Cell 139. The construction of a 3-inch-thick pavement on a marginal base layer may not be a good design, irrespective of the inclusion of the structural fibers. Many panels under Cell 139 were shattered (but remain intact), with the pavement surface depressed along the wheel path. The performance of Cell 239 indicated that longitudinal fatigue cracking would be the most critical distress by far.

(2) The distresses observed in thin pavement Cells 506-806 indicated that 5- to 6-inch-thick concrete pavements placed on a stiff gravel base layer are not prone to fatigue cracks for the typical low-volume road design life (2 million ESALs). The contribution of the fibers was evident in mitigating transverse joint faulting, with faulting magnitudes decreasing with an increase in fiber dosage. Compared to Cell 806, which incorporated a much higher dosage rate than typically specified by most road agencies (11.7 lbs./cy fiber dosage), Cell 506 (no fiber) experienced more than twice the amount of faulting at 2 million ESALs. The IRI results also clearly showed the contribution of fibers in improving the ride quality of the thin concrete pavements.

(3) This study has provided quantifiable evidence that structural fibers can positively influence joint performance, transverse joint faulting, IRI, etc. Therefore, it will be prudent to take the initiative to incorporate the performance benefits of the structural fibers into the mechanistic-empirical design procedure, which currently just artificially enhances the material's flexural strength t all this clearo account for the inclusion of fibers.

Lastly, it should be cautioned that the results from this experiment represent the behavior of three dosages of one synthetic fiber. It should not be construed that the results represent the behavior of other types and dosages of synthetic fibers or concrete mixtures, for that matter.

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M/s Doon Associates

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Doon Associates

GSTIN: 05AAEFD0882H1ZN

on behalf of

Mob. No. 9412055128

Uttarakhand Rural Road Development Agency (PMGSY),
Directorate of Panchayati Raj, 2nd Floor, Opposite - IT Park, Sahastradhara Road, Dehradun (Uttarakhand)

FULLY DEDICATED FOR THE ROAD CONNECTIVITY (ROADS & BRIDGES) IN HILLY TERRAIN OF THE INDIAN HIMALAYAN REGION

PMGSY

M/s VIJAY BUILDERS

Hotel Vijay Palace, Kedarnath Road,
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VIJAY BUILDERS

GSTIN: 05AADFV2488E1Z6

on behalf of

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FULLY DEDICATED FOR THE ROAD CONNECTIVITY (ROADS & BRIDGES) IN HILLY TERRAIN OF THE INDIAN HIMALAYAN REGION

A Review of use of Additives like Kiln Dust and Rice Husk for the Improvement of Earthen Shoulder Performance

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Abstract

An earthen shoulder is an important component of a rural road and if it gets eroded it might lead to accidents. Hence it is necessary that the shoulder is strong enough to withstand the load of vehicles. Keeping this in mind, it is preferable that the soil of the shoulder needs to be strengthened with different additives which are available easily. Hence different waste materials which can be used as additives in soil are looked upon which will not only help in soil stabilization but also help in reducing solid wastes. These wastes if not reused will ultimately end up in open dump sites or unmanaged landfills causing environmental concerns. Cement kiln dust, Rice husk ash and Brick kiln dust are some of the waste produced in huge quantities which has potential to fit in several construction and soil stabilization. The paper reviews some of the studies on soil stabilization using the above mentioned waste materials.

Keywords: Shoulder; Cement Kiln Dust; Rice Husk; Brick Kiln Dust.

1. Introduction

An important component of a roadway, a shoulder is the part of pavement adjacent to the carriageway of a road. It acts as an emergency space for vehicles coming to a stop, or for damaged vehicles without interfering the traffic movement on a carriageway. It also provides support to the pavement structure and effectively helps in drainage of water. The shoulder is very important when it comes to rural two way undivided roads having curves. A shoulder prone to erosion and soft soil condition can be detrimental for a vehicle traversing a curve as it might lead to accidents. Hence a strong shoulder would prove to be of extreme importance to avoid roadway departure related accidents. The general forms of failure of shoulders are – cracks, potholes, failure of stability, edge break and settlement. With regards to stability failure, the materials used for construction are a major issue. To facilitate the use of soil as shoulder for road, the soil needs to be reinforced with suitable material such that its strength and durability characteristics are improved. Conventional methods to improve soil stabilization include addition of lime and cement as additives. Research for alternate materials locally available which can improve stability and durability of existing soil could greatly reduce costs while maintaining sustainability.

Towards proper management of waste, the importance on the reuse of solid waste materials has in the recent times received much attention. Rapid urbanisation and infrastructure growth in important developing cities has led to the generation of challenging waste management problems. Cement kiln dust (CKD) and rice husk ash (RHA) wastes are two of such wastes which otherwise unused/unmanaged will ultimately end up in open dump sites or unmanaged landfills causing environmental concerns (Miller & Zaman, 2000)[26]; (Setyo Muntohar et. al., 2012)[34]. To address the waste management issue, many researchers have been exploring ways to re-utilize such wastes in various alternate applications. In this regard, the use of wastes as soil admixtures have often been studied for improving the geotechnical characteristics of problematic or weak soils (Hossain, 2011)[5]; (Eberemu et. al., 2019)[14]; (Ekpo et. al., 2020)[15]; (Etim et. al., 2021, 2022[16],[17]; (Gupta & Kumar, 2017)[8]; (Zhou et. al., 2021)[38].

Soil stabilization by waste materials with pozzolanic properties can induce cementitious effect by strongly binding soil particles together (Jauberthie et. al., 2000)[22]. (Ali et. al., 1992)[4] found that the use of RHA as a standalone stabilizer for sandy clay soil was insignificant and lacked cementitious properties. The use of single type of waste material as a stabilizer has limitations and often for attaining significant soil improvements, different waste materials are mixed together to attain the required strength (Ali et. al., 1992)[4]; (Hossain, 2011 [5]; (Attah et. al., 2021)[7]. Several studies have shown evidence in soil improvement by the combined use of CKD and RHA admixtures in soil up to certain optimum proportions. In one of the earlier works, a study by (Ali et. al., 1992) [4] confirmed improvements in unconfined compressive strength (UCS) of lime and cement stabilized soil due to the addition of RHA. Stabilised CKD-RHA-clayey soil mixtures in different proportions of CKD and RHA varying from 0 to 20% showed good strength development and durability characteristics (Hossain, 2011)[5]. (Gupta & Kumar, 2017) [19] reported higher soil stabilization potential in the case of cement-RHA as compared to the pond ash counterpart with RHA showing more self-cementing properties similar to Portland cement. (Attah et. al., 2021) [7] observed increased soil maximum dry density (MDD), reduced optimum moisture content (OMC), and significant increase in soil strength measured by California bearing ration (CBR) and UCS tests. The pozzolanic properties of rice husk ash is largely attributed to its high silica content (about 80%) and in combination with CKD which has high calcium content can induce pozzolanic reactions (Attah et. al., 2021)[7].

Traditional techniques of soil stabilization involve use of chemical additives such as cement and lime (Chen & Lin, 2009) [9]; (Little, 1995)[25]; (Prusinski & Bhattacharja, 1999)[29]. However, they are not regarded as sustainable practices as that they can contribute to high greenhouse gas (GHG) emission and are uneconomic (Attah et. al., 2021)[7]; (Kajaste & Hurme, 2016)[16]. Alternate materials which are locally and abundantly available are thus preferred while considering extensive engineering projects. With emphasis towards relieving regional issues in waste management, CKD and RHA, two of the major industrial and agricultural wastes can be used as soil stabilizers for waste management as well as favour economic and environmental benefits (Attah et. al., 2021)[7]; (Gupta & Kumar, 2017)[23].

Another waste material which can be used for soil stabilization is Brick Kiln Dust (BKD). Keeping in mind the huge volume of waste generated by the brick industry, the air pollution is something that needs to be dealt with. Brick Kiln dust can be a good option to use in soil stabilization and at the same time the volume of waste may be also managed[8].

2. Characteristics of the Materials

Cement kiln dust contains partially calcined and unreacted raw feed, clinker dust and fuel ash, enriched with alkali sulphate, halides and other volatiles. CKD may be divided into pre calciner kiln dust, which is coarser, higher in free lime and contains alkali volatiles, and long wet or long dry kiln dust which contain lime as constituent.

Table 1: CKD Chemical and Physical Analysis (Resource Material Testing)

Chemical Analysis	Percentage
Silicon Dioxide	17.62
Aluminium Oxide	4.90
Iron Oxide	2.58
Calcium Oxide	62.09
Magnesium Oxide	1.93
Sodium Oxide	0.56
Potassium Oxide	3.76

Brick kiln dust contains alumina, silica and other carbonates and oxides. Clay in brick kiln dust is responsible for the pozzolanic behaviour of brick. Clay doesn't have pozzolanic properties. But it gains so when burnt together with lime during brick making process[31].

Table 2: Characteristics of Brick Kiln dust

Parameters	Value
pH	9.5
Cation exchange capacity	7.10
Water holding capacity	90
Sulfate	27.3
Chloride	85
Nitrogen	65
Phosphorus	18.5

Rice husk is formed when rice is grinded and the quantity of rice husk is only 20 to 30 percent by grain weight. Rice husk contain 28 to 30 percent inorganic compound [33] and 70 to 72 percent organic compound.[24].

Table 3: The composition of the rice husk organic compounds

Content, % weight			
C	H	O	N
39.8-41.1	5.7-6.1	0.5-0.6	37.4-36.6

Table 4: Composition of rice husk ash

Content, % wt						
SiO_2	Al_2O_3	Fe_2O_3	C_aO	MgO	K_2O	Na_2O
93.4	0.05	0.06	0.31	0.35	1.4	0.1

3. Use in Soil Stabilization

Rimal et. al. [32] carried out UCS test by mixing the soil with CKD at various proportions. Samples were prepared with and without CKD. The test was carried out in dry and immersed conditions. Significant increment in UCS was seen on addition of CKD in natural soil. Laguros and Davidson [21] found that CKD has similar property with cement as it shows decrease in void spaces on hydration, for which there is increase in strength. CKD reduces the swell potential of clay. The swelling of clay is reduced from 9% to 0% when treated with 25% CKD. Voids in the CKD stabilized clay samples decreases with addition of CKD. Raw clay has about 7% voids while CKD mixed soil has void spaces between 1 and 2.3 [1]. As a result of decrease in void ratio, there is an increase in strength. The hydration process and the placement of CKD in the voids modifies the morphology of the stabilized soil [19]. Southgate and Mahboub [20] performed CBR test and made correlations between modulus of elasticity and strength of stabilized soil. Sandy soil used in pavement layers, addition of 15% CKD having 5.9% (free CaO and MgO) and 0.9% total alkalies (K_2O + NaO) ensured a compressive strength of 360 psi (2.5 Mpa) [30]. Baghdadi and Rahman [36] used a mix of 30 % CKD and 70% sand which gave good results for application as base materials.. Baghdadi et. al. [37] mentioned that use of CKD between 12% and 50% gives good result for light application and about 50% CKD for heavy construction results in good soil stabilization. Study made by Azad [18] also stated that there is increase in the UCS of soil on mixing of CKD. He also mentioned that the increase in UCS is inversely proportional to the plasticity index (PI) of the untreated soil. Mohamed [2] studied on effect of CKD on hydraulic properties of soil and found that 6% by weight of CKD works as an optimum mix which increases the shear strength of the soil and also decreases the hydraulic conductivity to less than 10-9 m/s. Such mixture may be ideal for preparing landfill containment layers.

Various studies have been conducted on characteristics of soil by adding different admixtures. Dr. Robert M Brooks [13] used Rice Husk Ash (RHA) and fly ash with expansive clay and found that the UCS value increases by 97% when RHA content was increased from 0% to 12%, while the CBR improves by 47%. Ali Rehman Z. et.al. [35] studied the effect of rice husk ash and found that the liquid limit and plastic limit decreased with the increase in RHA content from 0% to 20%, while compaction test showed increase in maximum dry density and decrease in optimum moisture content.

Mohammed et. al. [27] also studied on three different soil improved with different percentage of rice husk and concluded that the liquid limit decreases by about 11% to 18% with addition of 9% RHA, while the plasticity index decreases by 32% to 80%. With the increase in rice husk content, the unit weight reduces while the optimum moisture content shows an increase. Abd El-Aziz and Abo Hashema [3] has used crushed clay bricks with lime homra which has resulted an increase in CBR, angle of internal friction and cohesion and decrease in plasticity, swelling and MDD. Shrivastava et. al. [12] mixed rice husk and lime with soil and the experiments resulted a significant increase in CBR and UCS. While Aparna Roy [35] made some experiments using RHA and concluded that increase in RHA content increases the OMC but decreases the MDD and both CBR and UCS increases.

Borthakur and Singh [28] worked with brick kiln dust along with a small portion of stone dust and the results shows that there is increase in CBR when brick kiln dust was used as stabilizer. Similarly Deepa B [11] also used Brick Kiln Dust (BKD) as soil stabilizer and concluded that BKD stabilizes well expansive clayey soil and it can be well used to stabilize subgrade and sub base layers as in both the layers CBR value seems to increase. Choobesti et. al. [10] also made similar study but using both BKD and rice husk along with lime and found that adding lime and rice husk decreases the dry density with an increase in optimum moisture content. But it was seen that there was an increase in shear strength and CBR value when rice husk and BKD was used to stabilize the soil.

4. Conclusions

Cement kiln dust, Rice husk and Brick kiln dust works well to stabilize soil, especially in low volume roads. Utilizing CKD, RHA and BKD to stabilize soil is a sustainable method as it helps to manage with the huge waste quantity which otherwise would have found its place in the landfill. Using such waste may make the project cost effective. The review helped us understand that both the CBR as well as UCS value increase with the increase in the quantity of all the three waste stabilizer upto an optimum value. Through more experiments we might be able to understand the effect of CKD, RHA and BKD better.

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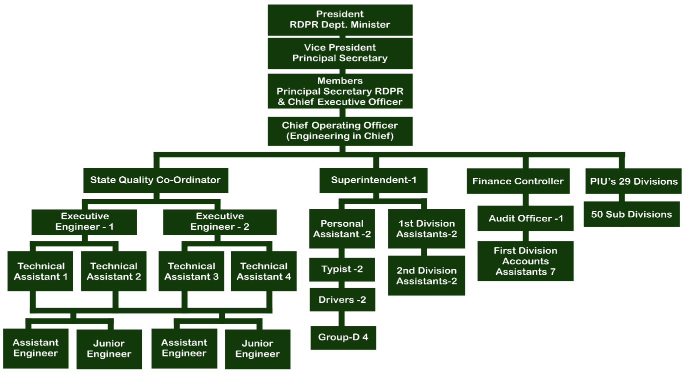
Organization Structure



Karnataka Rural Road Development Agency (KRRDA)

- Is Nodal Agency for the implementation of PMGSY in Karnataka since 10-10-2005.
- The Hon'ble Minister for RDPR is President & Pr. Sec. RDPR is Vice-President.
- Secretary to Government, Panchayat Raj is the Ex-offcio CEO of the Agency.
- Has dedicated 29 no of PIUs and 50 no of Sub-divisions.
- Has established 17 no of Quality Control Laboratories.
- Is supported by 5 State Technical Agencies (STAs) & 1 Principal Technical Agencies (PTAs).
- Has empanelled Road and Bridge Consultants Separately.

KRRDA : Track record of PMGSY Implementation

PMGSY - I

Road Length Completed
16357.16 kms (2014-15)

PMGSY - II

Road Length Completed 2218.16 kms (2017-18)
LSB's Completed 11 Nos

PMGSY - III

Achievement 100% Achievement

Physical 2524.697 Kms

Financial 1504.42 Crs

Sl. No.	Phase	Sanctioned				Progress (as on 31.03.2022)			
		No of Roads	Length in Kms	No of LSBs	Cost Rs in Crores	No of Roads	Length in Kms	No of LSBs	Expenditure Rs in Crores
1	2019-20 Batch-I of PMGS III	441	3195.44	26	2112.72	170	2460.98	10	1337.26
2	2020-21 Batch-I of PMGS III	50	321.93	0	214.68	6	116.29	0	41.96
3	2020-21 Batch-II of PMGS III	300	1860.26	75	1246.11	11	515.82	3	185.22
	Total	791	5377.63	101	3573.51	187	3093.09	13	1564.44

Angular Shaped Fly Ash Aggregate - An Innovative Material for Use in Road Pavement

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Abstract

The paper discusses a quick and cost-effective four-step process (mixing, compaction, curing, and crushing) for producing angular shaped fly ash aggregate and compares its engineering properties with that of conventional stone aggregates. After various trials, 96-98% Class C fly ash with 2-4% binder mix is found suitable to produce lightweight fly ash aggregate that is having dense structures, angular shapes for better interlocking, excellent mechanical properties such as toughness and hardness, and high durability. The developed fly ash aggregate satisfactorily fulfils the specifications of MoRTH (2013) and IS 383 (2016) for road aggregate and structural concrete aggregate, respectively. It is found that results of compressive strength test, split tensile strength test, flexural strength test and pull out test on M25 grade of cement concrete prepared with fly ash aggregate and natural sand are quite comparable with that of conventional concrete for the same cement content, which confirms the suitability of fly ash aggregate for concrete work. The financial analysis for setting up of a pilot plant for production of angular shaped fly ash aggregate with capacity of 2 tons per hour is also presented in this paper. The production cost of fly ash aggregate is found to be Rs. 454 per m^3 which is about 33% of the cost of natural stone aggregate as per the rate of DSR, CPWD, 2021.

1. Introduction

With the rising need for coal as an energy source, there is a growing requirement for fly ash disposal. Annual fly ash production in India has reached to 232 MT in the year 2020-21. Fly ash aggregates can successfully replace natural stone aggregates, the primary material for all civil engineering infrastructures. Lightweight aggregates have lot of potential for use as a construction material in concrete and highway construction for specific purposes (Baykal et al. 2000). A 2-lane road requires around 8500 tonnes of stone aggregates per km in the base and sub-base layers. India's aggregate demand is anticipated to be between 4,500 and 5,000 million tonnes. The Government of India's main highway projects, the Bharatmala, Sagarmala, and Samrudhi Yojna, are expanding the market for fly ash-based aggregates. The technology for making fly ash-based aggregate is still in its early stages of development, with limited manufacturing capacity. Several researchers have reported manufacturing method for artificial aggregate in the past based on the pelletization and sintering process. This method has the disadvantages of consuming higher energy and complicated process to make the aggregates from the mixture of fly ash and various additives. This method is also expensive and time-consuming resulting in non-use of these aggregates on a large scale in civil engineering applications. It is also found that the pelletization process manufactures round shaped aggregates that have negligible interlocking properties leading to lower load bearing capacity. Therefore, a cost effective angular shaped fly ash aggregate has been developed and presented in this paper.

2. Recent Development

The author has developed a technology (Indian Patent No. 362571 granted on 23 March, 2021) for producing angular-shaped high-strength fly ash aggregate from Class C fly ash using an accelerated curing process to overcome the drawbacks of sintered fly ash aggregates. A detailed stepwise process for the production of angular shaped fly ash aggregate from Class C fly ash is explained below and the process flow is shown in Figure 1. Typical physical properties of the developed aggregate are presented in Table 1.

1. **Raw material collections and mixing:** Homogeneous mixture of fly ash (96-98%) and hydraulic binder (2-4%) with water equal to optimum moisture content (IS: 2720-VIII) was prepared using a pan mixer.
2. **Compaction using high pressure hydraulic press:** After mixing, the material was being compacted using a high pressure hydraulic press machine to achieve dry density equal to maximum dry density of the mix (IS:2720-VIII) and blocks of size 23 cm × 11cm × 6 cm were prepared.
3. **Hot Water Bath Curing:** Then green blocks were placed in hot air at a temperature of 50^{0}C for 6±1 hours for initial setting followed by hot water bath curing for 24 hours at a temperature of 65^{0}C.
4. **Crushing**: After curing the blocks were placed for minimum 12 hours at room temperature to cool down. Then blocks were crushed in the crusher to produce various required sizes of angular shaped coarse aggregates.

Figure 1: Pictorial process-flow for production of fly ash aggregate

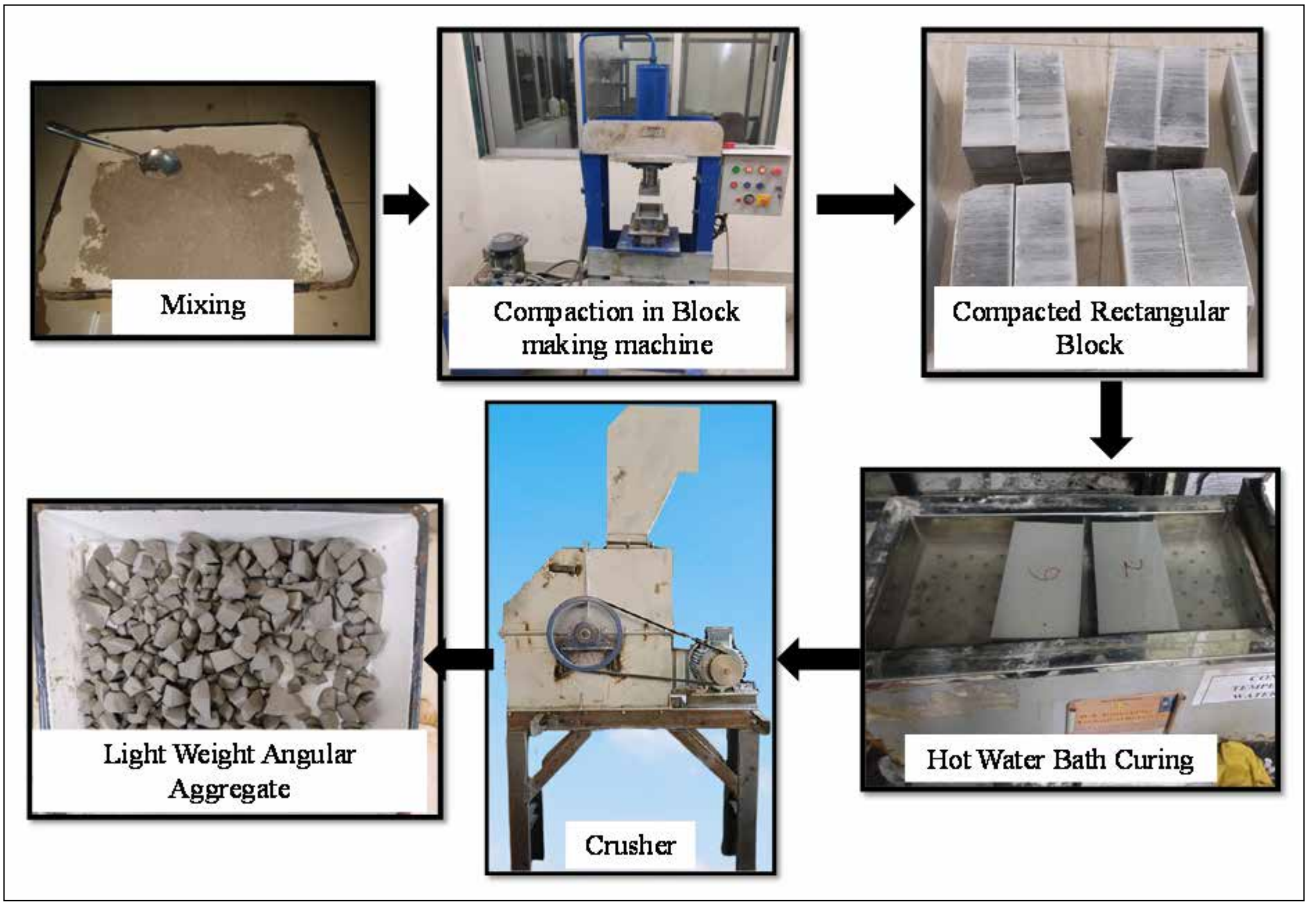

Table 1: Comparison of typical physical properties of fly ash aggregate

Parameters	Authors' Fly Ash Aggregates	Sintered Fly Ash Aggregates (From literature)	Natural Aggregates (From literature)	IS:383 (2016) requirements for concrete aggregate		MoRTH-2013 Requirements	IS 9142 (Part 2) 2018 Requirements
				Wearing surfaces	Non-wearing surfaces		
Specific Gravity	1.48	–	2.9	–	–	–	–
Bulk Density Loose (kg/m^3)	890	650-1050	1350	–	–	–	≤ 950
Water absorption (%)	19	15-30	0.5-2	≤ 2	≤ 2	–	≤ 18
Impact value (%)	21	15-55	12-20	≤ 30	≤ 45	≤ 30	≤ 40
Abrasion Value (%)	36	29	10-18	≤ 30	≤50	≤ 40	≤ 40
Crushing Value (%)	23	–		≤ 30	–		≤ 45
Soundness (%) in Na_2SO_4	9%	–	1-5	<12	<12	≤ 12	≤ 12
Shape of Aggregates	Cubical	Rounded	Cubical	–	–	–	–
Production Cost (Rs. Per m^3) (Approx.)	454	1900	1400	–	–	–	–

3. Application of Developed Lightweight Fly Ash Aggregate in Concrete

M25 grade cement concrete was prepared with fly ash aggregate and natural sand with w/c ratio of 0.41 and cement content of 330 kg/m^3. The results of compressive strength tests, split tensile strength tests, flexural strength tests, and pull-out tests were compared with that of conventional M25 grade concrete for the same cement content in Table 2.

Table 2: Comparison of properties for proposed M25 grade of fly ash aggregate concrete with conventional concrete

Parameters	Concrete with fly ash aggregate and natural sand	Concrete with natural aggregate and natural sand	28-day target values for M25 as per IS: 456-2000
Density of concrete (kg/m^3)	2015	2370	–
7 Day Compressive strength (MPa)	28.4	25.2	–
28 Day Compressive strength (MPa)	33.8	35.7	31.6
Split Tensile Strength (MPa)	1.7	1.9	–
Flexural Strength (MPa)	8.2	8.3	3.5
Bond Strength (MPa)	4.7	5.3	2.2

4. Financial Analysis

This section discusses the financial analysis for installation and operation of a pilot plant for manufacturing angular-shaped coarse aggregates from Class C fly ash. This calculation is based on standard parameters and may change according to site location.

A. **Capital Investment:** Total 220 Lakhs
- Production shed: 50 Lakhs
- Plant and machineries: 140 Lakhs
  1. Press machine & batching plant: 40 Lakhs;
  2. Pellets & Curing Racks: 40 Lakhs;
  3. Hot Water bath: 8 Lakhs;
  4. Crusher: 25 Lakhs
  5. Fork Lift & Loader: 27 Lakhs
- Electrical installation: 30 Lakhs

B. **Manufacturing Cost of Aggregate**

1. **Plant Capacity:**

Rated plant output = 43.9 tons/day (2 tons/hour),

Actual Plant Output at 95% PLF = 41.7 tons/day;

Number of working days per year = 300;

Aggregate quantity = 45.1 m^3/Day = 13,524 m^3/Year

2. **Manufacturing cost of aggregate:**

Raw material (24% of total cost)	Rs. 14,99,140/year	Rs. 110.85/m^3
Electricity expenses (13% of total cost)	Rs. 7,93,688/year	Rs. 58.69/m^3
Man Power (37% of total cost)	Rs. 22,44,750/year	Rs. 165.99/m^3
Depreciation (15% of total cost)	Rs. 9,00,000/year	Rs. 66.55/m^3
Total Maintenance cost (11% of total cost)	Rs. 7,00,000/year	Rs. 51.76/m^3
Total	Rs. 61,37,578/year	Rs. 453.84/m^3

3. **Profitability:** Schedule rate of coarse aggregate as per DSR, CPWD, 2021 is Rs. 1400/m^3
   1. Total Production Cost per year = 13,524 m^3/year @ 453.84 Rs/m^3 = Rs. 61,37,578
   2. Sales Realization per year = 13,524 m^3/year @ 1,400.00 Rs/m^3 = Rs. 1,89,33,600
   3. Profit Before Tax (PBT) = Sales Realization – Total Production Cost = Rs. 1,27,96,022
   4. Profit Before Depreciation and Tax (PBDT) = PBT + Total Depreciation = Rs. 1,36,96,022

5. Conclusions

1. The present study recommends a simple and cost-effective four-step process for the production of eco-friendly angular-shaped fly ash aggregates. The proposed fly ash aggregates are sufficiently tough, strong, hard, and durable and provide effective interlocking, which also fulfils the specifications of MoRTH (2013) for road aggregate and the requirements of IS 383 (2016) for structural concrete aggregate.
2. For the same cement content and w/c ratio, the compressive strength of fly ash aggregate concrete is found to be similar to that of normal concrete. M25 grade concrete can be successfully prepared from the proposed angular shaped fly ash aggregate with cement content of 330 kg/m^3 and w/c ratio of 0.41.
3. The various engineering properties of concrete prepared from fly ash aggregates such as compressive strength, split tensile strength, flexural strength and bond strength were found to be comparable with that of normal concrete.
4. The density of the developed fly ash aggregate cement concrete is 15% lower than that of the natural aggregate cement concrete.
5. The production cost of aggregate from Class C fly ash was found to be Rs. 454 per m^3, which is about 33% of the cost of natural stone aggregate as per the rate of DSR, CPWD, 2021.

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B D I P L

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Strength and Durability Evaluation of Clayey Soil using Flyash in Chemical Stabilisation

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Abstract

The use of industrial waste had been very effective in the stabilisation process of soils that are having poor engineering properties. These materials improve the soil strength by changing the properties and also lead to a cost-effective method for road construction. In the current study, clayey soil has been considered for strength and durability evaluation. The utilisation of fly ash from local thermal plants has been made used for the stabilisation of clayey soil. It was mixed with cement in different ratios as per AASHTO guidelines to assess the maximum strength. The initial consumption of lime (ICL) was determined for reducing the plasticity of clayey soil. The cylindrical soil samples were prepared and subjected to unconfined compressive strength (UCS) and California bearing ratio (CBR) test. The results revealed that the use of fly ash had led to a significant increase in the strength of the soil. The CBR test reported a substantial increase in the value by stabilisation technique. Also, the durability results showed a magnificent increase in the percentage of the prepared samples.

Keywords: Fly ash, clayey soil, lime, UCS, CBR

1. Introduction

In the current scenario, the availability of good quality material is limited in the nearby road construction sites, especially in rural areas. Even the good material is found to be uneconomical if it is far away from the construction sites. The use of locally available materials plays a great role in reducing the overall cost of construction. The black cotton soil which are having high clay content weakens when it comes across to excess moisture. It tends to expand, swell or shrink due to ingress of water and experiences losing engineering properties that lead to a settlement which mainly depends on the stress level and the swell pressure of the soil (Horpibulsuk et al. 2012; Sharma et al. 2012). Clayey soil is problematic due to its properties such as low strength, swelling tendency and high compressibility. The two main clay minerals i.e. montmorillonite and kaolinite are responsible for low strength and high swelling index (Latifi et al. 2016). Therefore this issue can be tackled by the stabilization process. Soil stabilisation techniques have been used for several years for the treatment. It works by changing the properties of the soil and rendering the poor soil making capable of fulfilling the requirements. Several techniques have been used for treating clayey soils (Al-Jabban et al. 2017; Horpibulsuk et al. 2012; Kolias et al. 2005; Roohbakhshan and Kalantari 2013; Sharma et al. 2012). Most of them were having traditional techniques i.e cement lime, fly ash etc. Also, there was the utilization of various industrial waste such as marble dust, brick dust etc (Bhavsar and Patel 2014; Patel and Bhavsar 2014). All the results have shown improvement in the properties of the soil and make the soil suitable for road construction. There was a change in the UCS value with the utilization of waste stone dust with lime (Roohbakhshan and

Kalantari 2013). The addition of marble dust has shown significant improvement in engineering properties with the clayey soil (Patel and Bhavsar 2014). Also, the addition of brick dust showed improved strength and CBR value (Bhavsar and Patel 2014). The use of waste plastic fibre has shown improvement in another study (Dhar and Hussain 2019). The utilisation of waste calcium carbide residue was treated with fly ash and found to be suitable for changing the properties of clayey soil (Horpibulsuk et al. 2012).

All the techniques and waste materials had led to an improvement in the strength and durability of clayey soil. However, very little information was found on the stabilisation with the high calcium fly ash. In the present study, the use of high calcium fly ash obtained from nearby thermal plants has been utilised for the stabilisation process by varying ratios. The cement to fly ash ratio was by determining the initial lime content for high plastic soil and the samples were subjected to various strength tests such as unconfined compressive strength and California bearing ratio test. Furthermore, the durability test was also conducted for the stabilised soil through a wetting and drying test.

2. Methodology

In the current study, the soil was taken from the Shekhpura district in South Bihar. The soil was found to be clay of high plasticity. To decrease the plasticity initial lime consumption was determined for the soil. Lime varied from 6% at 1% increment as per (Rogers and Glendinning 2000). The soil was found zero plasticity at 9% lime. Then the cement to fly ash ratio was adopted in the ratio of 1:4 as per AASHTO guidelines for the stabilisation process. The ratio varied from 2% to 8% for cement and corresponding fly ash to 8 to 32%. The cylindrical sample of diameter 50 mm and 100 mm in height was prepared and subjected to an unconfined compressive strength test and California bearing ratio value. The durability test was conducted by the drying and wetting method as per ASTM 559.

3. Results

Soil: The soil was obtained from the Shekhpura zone a southern district of Bihar, India. The physical properties of the soil have been assessed and found to be highly plastic soil. The result of the various tests are as follows in Table 1.

Table 1: Physical properties of Soil

Properties	Test Results	Test codes
Liquid limit,%	78	ASTM D4318-10
Plastic limit,%	36	ASTM D4318-10
Plasticity Index,%	42	ASTM D4318-10
Type of Soil	CH-Clay of high plasticity	(ASTM D2487-11)
Optimum Moisture content,%	23.5%	ASTM D698
Maximum dry density, gm/cc	1.52	ASTM D698
California bearing ratio,%	3.24%	ASTM D1883
Unconfined compressive strength ($N/mm^{2)}$	0.31	ASTM D2166

Fly ash: The fly ash was obtained from nearby thermal plants viz Barh, Bihar. It is estimated to 8 million tonnes (CSE, India, 2019) of fly ash is generated every year from Bihar thermal plants and disposing of such a large quantity is also a serious problem. The physical and chemical properties of fly ash are shown in table 2 below. Based on chemical composition it was that the fly ash is of class F category.

Table 2: Physical and chemical properties of Fly Ash

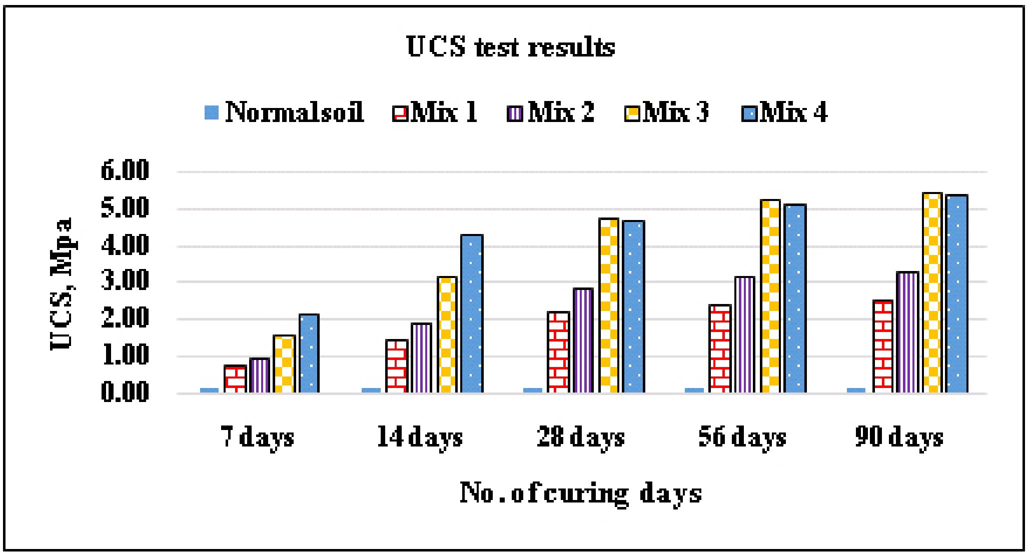
Fly Ash Composition			
S. No.	Test Conducted	Observed Values (%)	Requirement as per IS:3812 2003
1	Loss of Ignition	1.16	5.0 (max)
2	Silica as SiO_2	59.25	35 (min)
3	SiO_2+Al_2O_3+Fe_2O_3	89.45	70 (min)
4	Available alkalis as Na_2O	0.38	1.5 (max)
5	Reactive silica	27.52	20 (min)
6	Lime Reactivity, N/mm^2	4.76	4.5(min)
7	Specific Surface area (SSA),m^2/kg	364	--

Unconfined Compressive Strength (UCS)

The UCS test was conducted on the cylindrical sample conforming to ASTM D-2166. This test is adopted because of its simplicity, less cost and reliability way for the assessment of soil. The results are shown in Figure 1 below. Table below shows the nomenclature foe the ratios adopted.

Particulars	Mix 1	Mix 2	Mix 3	Mix 4
Cement to fly ash ratio	02:08	04:16	06:24	08:32

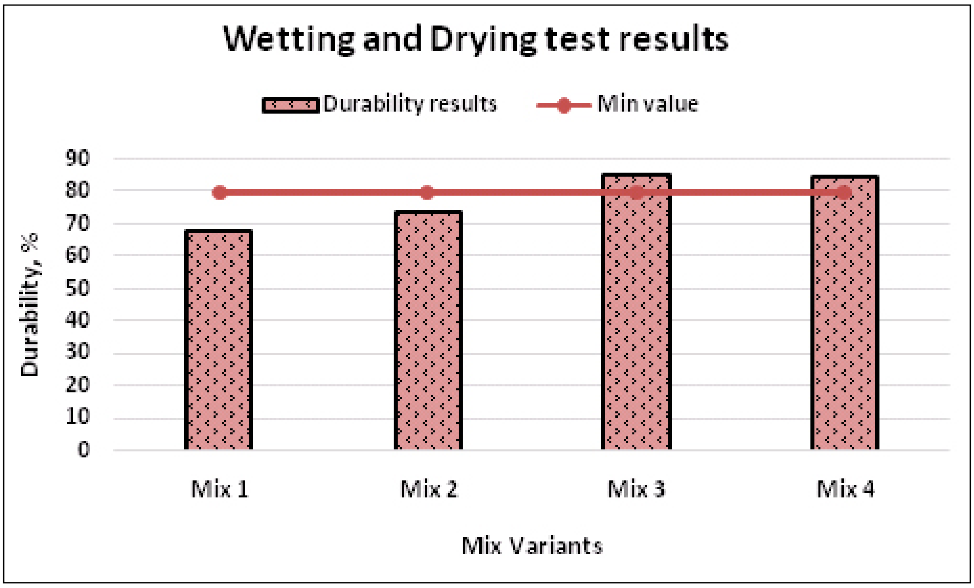
Figure 1: Results of UCS for the mix variants



Durability

The durability test was calculated for the material reliability and to retain the permanency of the strength for long days exposed to severe climatic conditions. The test was conducted by wetting and drying test conforming to IS 4332 (Part IV) and also followed as per ASTM (D 559). The results are as shown in Figure 2 below:

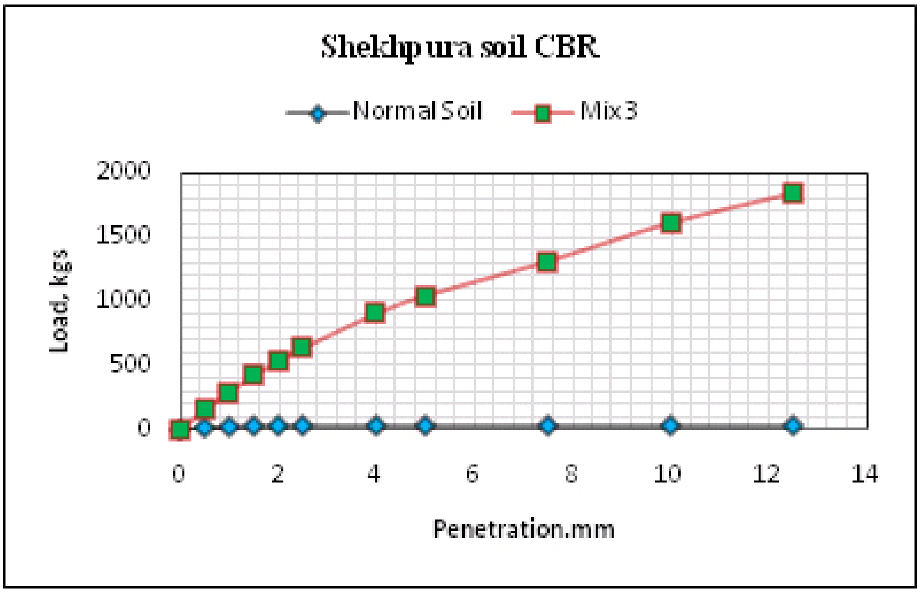
Figure 2: Shows the durability results for all the mixes



California bearing ratio

The CBR value was attained for the mix 3 which attained the maximum UCS and durability value and compared with the CBR of normal soil. The results of CBR are as shown in Figure 3 below.

Figure 3: CBR test plot



4. Conclusion

It was observed that the inclusion of lime at 9% was able to make a plastic free state for the clayey soil and thus can be defined as initial consumption of lime. The utilization of Fly ash with cement in different ratios showed a significant increase in strength. The samples were tested at 7 to 90 days for UCS. It was noticed that the UCS value has drastic change as the days and ratios increased. The maximum strength was obtained at mix 3 i.e 6% cement and 24% fly ash. Higher increments of ratios lead to a decrease in strength. This might be due to an increase in cement content which makes it brittle and leads to decreasing the strength. The UCS requirement of the sub base layer for rural roads as per the IRC 37:2012 code is 1.5 Mpa and in the current study the UCS was higher than this value which indicates that this would be beneficial to the replacement of GSB layer. Similarly, the maximum durability result was obtained for the mix3 ratio. The initial mixes i.e mix 1 and mix 2 fails to attain the minimum requirement of 80% durability value as per IRC: SP 89 2010. The CBR value reported a drastic increase i.e from 3.24% to 46.72% for normal soil and mix3 ratio. It indicates that the design thickness of the pavement can be significantly reduced by using this mix ratio. Therefore it can be concluded that the cement to fly ash ratio of mix 3 can be adopted for stabilisation by adding lime at 9% initially when working with such highly plastic clayey soil. However, further properties such as flexure, tensile strength and linear shrinkage are to be evaluated for better assessment.

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Full Depth Reclamation as an Effective Method of Rehabilitation for Rural Roads

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Abstract

Full depth reclamation is gaining popularity as method of pavement rehabilitation with its effectiveness as an economic and sustainable way to revert the function ability of deteriorating low volume roads. However, a serious lack in back end study in case of design aspects right from the pavement condition specifications for the suitability of FDR, depth of reclamation required, requirement and type of stabilization and mechanical characterization of reclaimed pavement crust are evident. All those stated are factors of high concern when it comes to the performance of pavement rehabilitated with FDR. This study is an effort to investigate in depth the design aspects and performance of FDR rehabilitated pavements and to arrive at a unified procedure for the project selection and design of pavements for FDR. The study includes the formulation of a set of guidelines for arriving at the applicability and effectiveness of FDR as a way of rehabilitation of a deteriorating pavement, laboratory characterization of reclaimed pavement crust and formulating a design methodology for FDR with cement using IITPAVE and IRC recommendations.

Keywords: Full Depth Reclamation, UCS strength, rural roads, IITPAVE, rehabilitation.

1. Introduction

The aging transportation infrastructure of the nation is in a serious need for maintenance and rehabilitation, and the situation is being worsened with the ever-shortening natural resources. Extensive overlaying done repeatedly over a period, apart from monetary costs and serious impacts it makes in the natural resource reserve, also leads to an increased crust thickness which ultimately ends up in formation of huge amount of latent material underneath. However, removal or replacement of the existing deteriorated crust in turns leads to the piling up of unmanageable amount of solid waste. The idea of recycling becomes more relevant in these aspects. FDR is the process of reusing the existing deteriorated pavement to construct a stable base for a better performing one. This involves the reclamation of existing pavement further pulverized to be used in place of fresh aggregates and treating the same with some suitable binder as suggested by IRC: SP: 89 - 2018 and compacting to a density of desire to form a stable base (CTB) and laying of a surface course over the base so made. Though the major limitation of the process involves the shutting down of the pavement for a period of at least 7 days for curing, the perks include reduction of emissions and use of fresh aggregates. However, FDR do bear some potential limitations regarding its applicability and requires a wiser selection of candidate roads to ensure expected benefits.

For assessment of the method formulated, a candidate road was selected which is the Kalungu Jn. 8 acre road in Manikkal Panchayat, Vamanapuram block, up-graded through PMGSY scheme in 2011 and handed over to district panchayat in 2016 after 5 year maintenance. The pavement has completed its 10 years of life and now under severe deteriorated condition.

2. Objective

- To identify criteria for candidate roads for FDR.
- To arrive at a proper sampling and mix design procedure for FDR.

3. Methodology

On understanding the required base thickness for the expected traffic volume using IITPAVE, the depth of reclamation shall be arrived at and a representative sample mix shall be prepared. As FDR involves heavy compaction, to attain a certain base thickness, 10% additional depth of material should be reclaimed. Using this depth, the proportion at which the various layers to be included to arrive at a representative sample shall be arrived at.

OMC shall be determined through modified proctor test and using the so found OMC, UCS specimens shall be casted with various cement content and cured for 7 days. The cement content at which a satisfactory UCS strength of 4.95 (~5) % cement content is arrived may be selected as design cement content as recommended by IRC: SP: 89. However, cement content if more than 6% is found to be making the specimen brittle when hardened and so it shall be limited to a maximum of 6 %. An aggregate crack relief layer or SAMI must be provided above the FDR layer to prevent reflective cracks on pavement surface as it is a kind of cement stabilized base and this should be included in pavement design using IITPAVE as per IRC: 32 - 2015.

SAMPLING: 50 x 50 cm square pit shall be dug out from the selected distressed locations. Sampling of various layers separately is important as the segregated pavement fraction is later mixed in proportion to the existing layer thicknesses to form a representative mix prior to performing mix design. Frequency of sampling shall be mainly based on distress frequency, pavement cross section and expected traffic. Quantity of materials to be sampled shall be based on IRC: 120 -2015 recommendations.

FIELD CBR: The Dynamic Cone Penetrometer shall be used to arrive at the field subgrade CBR as per IRC: SP: 72 - 2015.

4. Works Done

Site Selection Criterion

Candidate roads for FDR

- *Pavement distress:* Pavements with more than 50% of pavement area distressed or not functional due to severe base or sub-base failure, if surface course distress due to low base failure has led to poor service condition (PCI< 55). Also those pavements with reduced ride quality with significant bumps and dip.
- *Other kind of rehabilitations required in excess:* When patching in excess of 15 to 20 % of existing pavement area is required to bring back the serviceability and if excessive removal and replacement required.
- *Need for pavement geometric improvement:* Roads for which widening/reshaping, cross slope correction or super elevation adjustments required.

- *Need for structural improvement:* forecasted future increase in demand.
- When fresh aggregate availability is less.
- *Pavement age:* Pavements completed its design life and have met maintenance period.

Conditions to avoid FDR

- *Pavement base failure by drainage issues:* For such failures GSB and effective cross drainage should be ensured. Saturated subgrade should be avoided. FDR shall also be avoided in region where GWT fluctuations possible below pavement crust.
- *Support condition:* Unstable embankments or week subgrade, highly plastic or with CBR less than 5%.
- *Economic feasibility:* FDR requires heavy equipment including reclaimer and also aggregate crack relief layer/SAMI layer above FBR base. These may be sometimes uneconomical for the rural road being considered.
- *Existing pavement composition:* Pavement materials if weak to be recycled and if pavement crust is very thin i.e. less than 250 mm, corrective aggregates or incorporation of subgrade may be required.

5. Mix Design

Materials

Pavement crust reclaimed and graded to ensure mechanical stabilization is the primary material requirement in FDR and so is in lab evaluation as well. Addition of external fresh aggregates to ensure gradation may also be considered in lab evaluation as well. Cement, preferably OPC grade 43 and portable water conforming to construction standards are the other important materials.

Depth of reclamation

The minimum depth shall be determined using IITPAVE and it shall be limited to 341 mm as it is difficult to ensure uniform curing if base thickness exceeds 310 mm.

Representative sample

A representative sample is to be prepared to ensure the typical field condition in the lab to minimize deviation of results from the actual condition. This is done by mixing the reclaimed material collected from the test pit in a proportion to sum up to the depth of reclamation. For example the layers obtained from test pit are A, B, C and if depth of reclamation is d mm, the bottom most layers shall be included in a proportion d-(A+B).

Tests

Optimum moisture content at which the reclaimed crust would attain the maximum density shall be found as per IS 2720 (Part 8). IS: 4332 (Part V)-1970 shall be followed for the determination of Unconfined Compressive Strength of Stabilized Soils. The mould shape and size may be selected based in recommendations made by IRC: SP: 89 - 2018. For FDR which involves coarse grained fraction, cubical specimen of side 15 cm shall be used.

6. Conclusion

- Mix design is important for attaining desired performance in FDR and a unified method of mix design and sample collection has been suggested. The results show that a cement content of at least 3.5 to 5 % would be required for stabilizing the base. However, the tests are carried out at sites with a pavement crust thickness less than 200 mm by incorporating subgrade. The effect of inclusion of subgrade is yet to be studied under various conditions and at various compositions of the crust. Assessment of the methodology formulated in the selected candidate road is yet to be carried out.
- FDR is not the ultimate solution for all kinds of pavement distresses; the candidate road selection is important in the structural performance of the pavement.
- FDR base layer being cement treated stiff base, an aggregate crack relief layer either or by geotextile SAMI layer may be applied. Of these, aggregate crack relief layer would be economical especially for rural roads, whereas SAMI will be more sustainable option when seen for reducing usage of fresh aggregate.

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Reducing the Construction Cost of Rural Concrete Roads by Replacing 100% Sand with Fly Ash Using an Innovative Technique

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Abstract

The aim of this study was to evaluate the technical and financial effects of replacing conventional fine aggregates with ultra-high volumes of fly ash in rural concrete roads. A case study was carried out at NTPC Mouda, Maharashtra wherein 500 m stretch of pavement concrete was cast incorporating more than 500 kg/m^3 of fly ash. The mix was evaluated in terms of workability and physio-mechanical properties and found to comply with the Indian codal requirements. Durability studies were also carried out by extracting cores from the site and evaluated in terms of abrasion resistance. Finally, the cost implications of proposed technique were studied in contrast to the conventionally adopted concrete mix design. The obtained results revealed that a feasible mix can be obtained by replacing the conventional fine aggregates in concrete with fly ash which will not only reduce the unit cost of concrete production but also tackle the dual issues of effective ash utilization and sand scarcity in the country.

Keywords: Fly ash; Sustainable construction; Concrete pavements; Sand replacement

1. Introduction

Bituminous roads have been widely used in India over the past decades for construction of rural roads. However, they require continuous maintenance and hence incur a lot of cost over their design life. Concrete roads have thus gained a lot of attention recently. The cost of concrete roads is initially high as compared to bituminous roads, however, the low or negligible maintenance needed for concrete roads offsets this high initial cost. Overall, the life cycle cost of concrete roads has been found to be lesser in contrast to the same for bituminous roads. Conventional mix designs for concrete roads incorporate roughly 100 kg/m^3 of fly ash (FA).

According to the latest data, there are a total of 202 coal-based thermal power plants currently operating in India which generated 232.56 million tons of FA in 2020-21 [1]. Out of this, 17.65 million tons of FA went unutilized. This value is over and above the quantities lying in ash dykes as legacy ash. Multiple studies have been carried out in the past pointed toward investigating the alternate avenues where this unutilized FA can be utilized. The primary focus of the past studies has been to partially replace the cement in concrete with FA [2–9]. Few studies have also been carried out by replacing the aggregates in concrete with FA [10–18]. However, these studies were either limited to lower FA consumption in concrete or were practically unfeasible due to their increased costs. According to a recent study [19], this unutilized FA can be incorporated in concrete in lieu of traditional fine aggregates in the presence of polycarboxylate ether (PCE) based superplasticizers (solid content > 60%). As such, a case study was carried out at NTPC Mouda, Maharashtra wherein a trial stretch of 500 m concrete pavement was laid incorporating ultra-high volumes of FA.

To further increase the FA utilization percentage thereby consuming the legacy ash stored in ash dykes, NTPC Mouda has undertaken a pilot project to construct a 500 m stretch of rigid pavement inside the plant premises made with substituting conventional river sand in concrete with high volumes of FA as shown in **Figure 1**. The subsequent sections describe in detail the mix design adopted and results obtained at site.

Figure 1: Constructed Road patch at NTPC Mouda

2. Materials & Mix Design

Ultratech Ordinary Portland Cement 53 grade (OPC 53) conforming to IS 8112: 2013 [20] was used in this study. FA was procured from NTPC Mouda. The chemical analysis of FA was carried as per ASTM C311 [21], and it was characterized as a low-calcium Class F fly ash. Crushed stone coarse aggregates from Pachgaon, Maharashtra (maximum size 20 mm) were procured from local vendors and used in accordance with the stipulations laid down in IS 383: 2016 [22]. PCE based superplasticizer (Trade name: Aaradhya Master Fly Ash) was adopted in accordance with the stipulations laid down in IS 9103: 1999 [23]. The mix design adopted for this study is presented in **Table 1**.

Table 1: Concrete Mix Design

Particular	Proportions
Cement – OPC 53 (kg/m^3)	400
FA (kg/m^3)	512
10 mm (kg/m^3)	473
20 mm (kg/m^3)	945
Free Water (kg/m^3)	160
Total Water (kg/m^3)	211
PCE Admixture (kg/m^3)	3.2
Density (kg/m^3)	2584

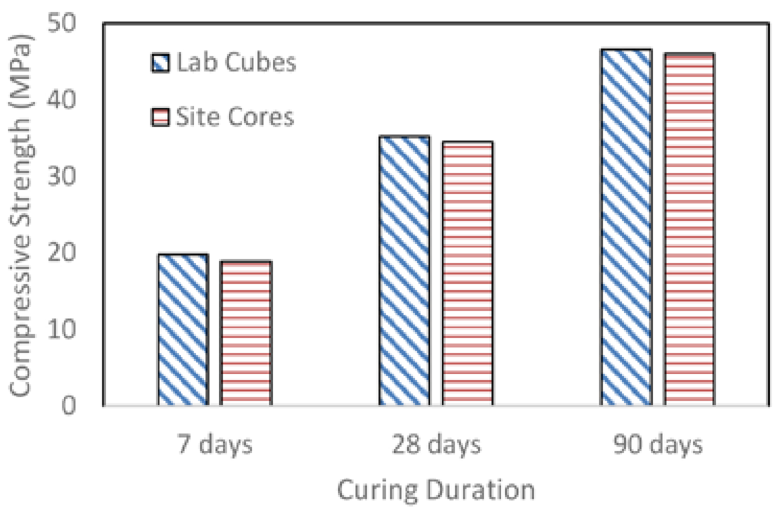
3. Results and Discussion

3.1. Workability of mixes

The workability of concrete was investigated through slump tests as per IS 1199: 1959 [24]. A rich mix was observed with no bleeding or segregation as shown in **Figure 2**. A true slump of 60 mm was obtained after 90 min. It was observed that addition of FA, in general, led to a viscous/sticky concrete with increased the flowability. This can be attributed to the finer size of FA which reduces the void spaces in concrete and provides a much denser packing.

Figure 2: Initial slump of the mix

Figure 3: Compressive strengths observed



3.2. Compressive strength

To assess the compressive strength of the batch, six cubes of 150 x 150 x 150 were tested, and their mean was accounted for as the compressive strength. The testing was done as per Cl. 5.5 of IS 516: 1959 [25]. It was observed that the addition of FA as a substitute to fine aggregates in concrete led to a slow strength gain during the initial 7-days. However, owing to the presence of higher volumes of pozzolanic FA, the 28-days and 90-days strength of the trial sample surpassed the IS codal requirements of M30. Overall, the mix exhibited strengths of 19.8, 35.2, and 46.6 MPa in 7-days, 28-days, and 90-days respectively as shown in **Figure 3**.

Cores extracted from site were also brought to VNIT lab and sawed to the required lengths using an electrically operated saw, maintaining a L/D ratio of 2. The samples were then capped with molten sulphur as suggested in IS 516 [25]. Six samples were assessed for each curing duration and the average compressive strength obtained are reported. The mean compressive strength was recorded as 18.9, 34.5, and 46.0 MPa in 7-days, 28-days, and 90-days respectively.

3.3. Flexural strength

The flexural breaking strength was determined as per Cl. 8 of IS 516: 1959 [26] Initial lab trials at VNIT Nagpur revealed that flexural strength of the mixes linearly increased with higher dosages of FA in the concrete mix. The denser inter-particle packing along with the pozzolanic propertied imbibed by FA contributed to the 28-days and later strengths of the concrete. Overall, the trial mix exhibited a 28-day flexural strength of 5.9 MPa which easily surpassed the minimum requirements of 4.5 MPa as per IS codal provisions.

3.4. Abrasion resistance

Abrasion resistance of concrete pavements is a crucial parameter evaluated to determine the wear resistance [11,27,28]. The same was evaluated in terms of wear depth as reported in literature [11]. The test cube of 71 mm side was cut from the core specimens extracted from site and subjected to abrasion test as per IS 15658: 2006 [29] for 16 cycles. It was observed that the core samples extracted from site exhibited an acceptable average depth of wear as 2.2 mm.

3.5. Cost Implications

The cost implications of the proposed technique were evaluated in contrast to the conventionally adopted concrete mix designs. The proportions along with total cost of materials are presented in **Table 2**. There is a reduction in the material cost Rs. 450/m^3 which is roughly 10% of the total material cost. Looking at the aforementioned technical advantages along with the cost saving potential, the proposed technique is in fact a viable option for construction of rural roads.

Table 2: Concrete Mix Design

Particular	Unit cost (INR/kg)	Conventional Mix		Proposed Mix	
		Quantity (kg)	Cost (INR)	Quantity (kg)	Cost (INR)
Cement – OPC 53	7.00	400	2800.00	400	2800.00
FA	0.30	-	-	512	153.60
River Sand	1.20	800	960.00	-	-
Coarse Aggregates	0.80	1158	926.40	1418	1134.40
Water	0.20	185	37.00	211	42.20
General Admixture	45.00	4.0	180.00	-	-
PCE Admixture	100.00	-	-	3.2	320.00
Total			**4903.40**		**4450.20**

4. Summary and Conclusions

This work was pointed toward investigating the possibility of using ultra-high volumes of FA (>500 kg/m^3) as a substitute to traditional fine aggregates in concrete pavements in the presence of a PCE - based superplasticizer. The workability of the concrete thus prepared was evaluated in terms of slump and a slump of 60 mm was observed after 90 min. The 7-days and 28-days compressive strength were recorded as 19.8 and 35.2 MPa respectively which suffices the requirements of M30 grade concrete. The 28-days flexural strength of 5.9 MPa along with acceptable abrasion wear of 2.2 mm and chloride penetration of 984 coulombs also indicate acceptable physio-mechanical and durability properties of the mix. The results indicate that this is a sustainable technology which can effectively reduce the dependency on river sand and serve as an avenue for effective ash utilization in the country. The proposed technique also has a potential for reducing the cost of construction of concrete roads by roughly 10% and hence, it may be used for developing sustainable rural roads and PMGSY schemes for low-volume roads.

5. Acknowledgment

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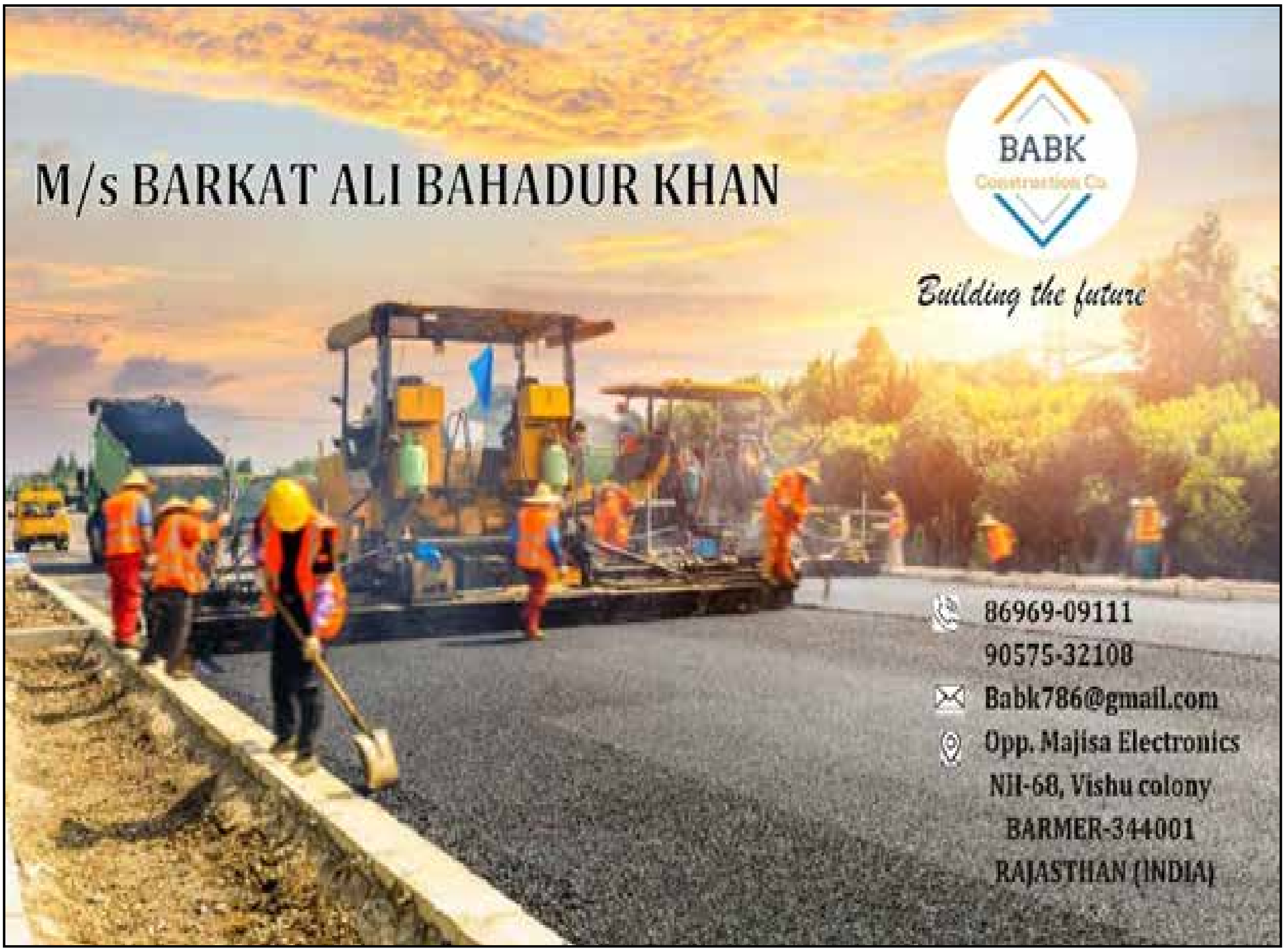
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Use of Nano-Lime Extracted from Egg Shell in Cold Bituminous Mix

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1. Introduction

Flexible pavements constitute maximum length of road network in India. Generally, these roads are constructed with hot bituminous mixes with temperature during various stages varying from 100 to 180 °C. The use of hot bituminous mixes has several drawbacks like environmental degradation, high energy consumption, increase in carbon foot print, unsuitable for laying in rains and cold weather, health and safety hazard to the construction labour. Hence, it is desirable to move to cold mix technology as a suitable alternative for hot mix technology. Cold bituminous mixes are currently used in surface courses of roads having low traffic volume like, roads constructed under PMGSY scheme. The application of cold mix is limited due to its low early structural strength and slow rate of curing. There is a need to improve the curing and rut resistance of cold bituminous mixes by the addition of suitable additives.

Adding nano particles like nano-clay, nano-silica, and nano tubes in bituminous binder normally increases its viscosity and thus improves the resistance to rutting and moisture susceptibility of bituminous mixes. Thanaya (2007) reported that cold bituminous mix (CBM) doesn't have the early strength like hot bituminous mix, and can increase the strength of the CBMs by adding the additives like cement and hydrated lime within the range of 2.5% by dry weight of aggregates. Cheng (2011) found that the sub-nano-sized hydrated lime improves the resistance to moisture susceptibility of warm-mix-asphalt. In this work, an attempt is made to assess the potential of nano-lime produced from Egg shell, which is a waste material, to improve curing rate and rut resistance of CBM. The study's objectives are to determine the potential of nano-lime to enhance CBM performance and to determine the optimal dosage of nano-lime.

2. Materials and Methods

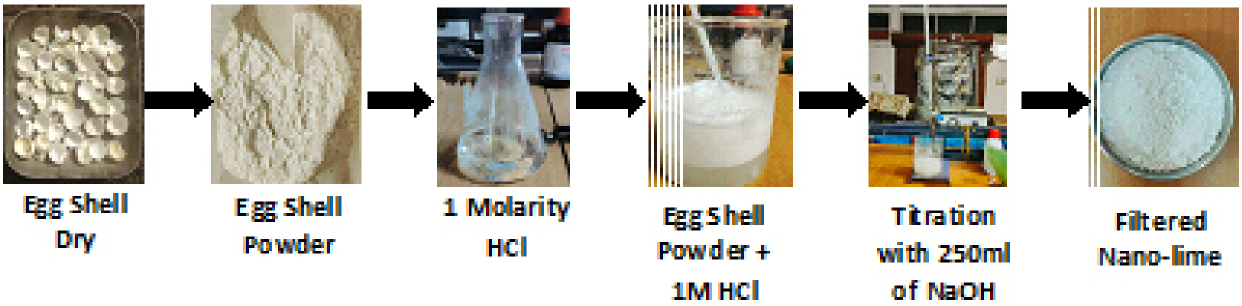
The aggregate used in this study was granite obtained from a nearby quarry. The aggregate gradation for cold bituminous mixture was selected as per MoRTH specifications (2013) of 13.2 mm Nominal Maximum Particle Size (NMPS). The investigations were carried out with a cationic medium setting bitumen emulsion. The aggregates and emulsion in the study were tested using Indian Standard Specifications. Based on the results of the coating test, the optimum pre-wetting water content (OPWC) was determined as 2.0%.

3. Production of Nano-lime from Egg Shell

Nano-lime was extracted from egg shell, a waste material collected from local eateries, following the procedure shown in Figure 1. The egg shells were crushed into fine graded particle of size passing through

75 microns IS sieve before the chemical process. The average size of lime particles is in the range of 100 nm to 200 nm as per the scanning electron microscopy image analysis.

Figure 1: Preparation of nano-lime from egg shell



Marshall mix design was used for finding optimum emulsion content. Mixes with and without nano-lime were kept under fan for one hour immediately after preparation. Then it is cured at 40 °C in an air oven for 2 hours. Thereafter, the specimens with 63.5 mm height and 100 mm diameter were prepared using the cured mix for different tests. Specimens were cured for 3 days at room temperature before conducting the Marshall stability test. The presence of moisture in a bituminous mix is a critical factor, which leads to premature failure of the flexible pavement, and in the case of porous bituminous mix, it becomes an essential parameter of performance. The moisture in the CBM is due to the water added during mixing and the water in the bitumen emulsion. Moisture loss by evaporation is defined as the difference between the initial weight of the specimen and the weight at a given time divided by the weight of the specimen. During the curing period, weight measurements were made at 2, 3, 5, 7, 10, 14, 28 and 54 days.

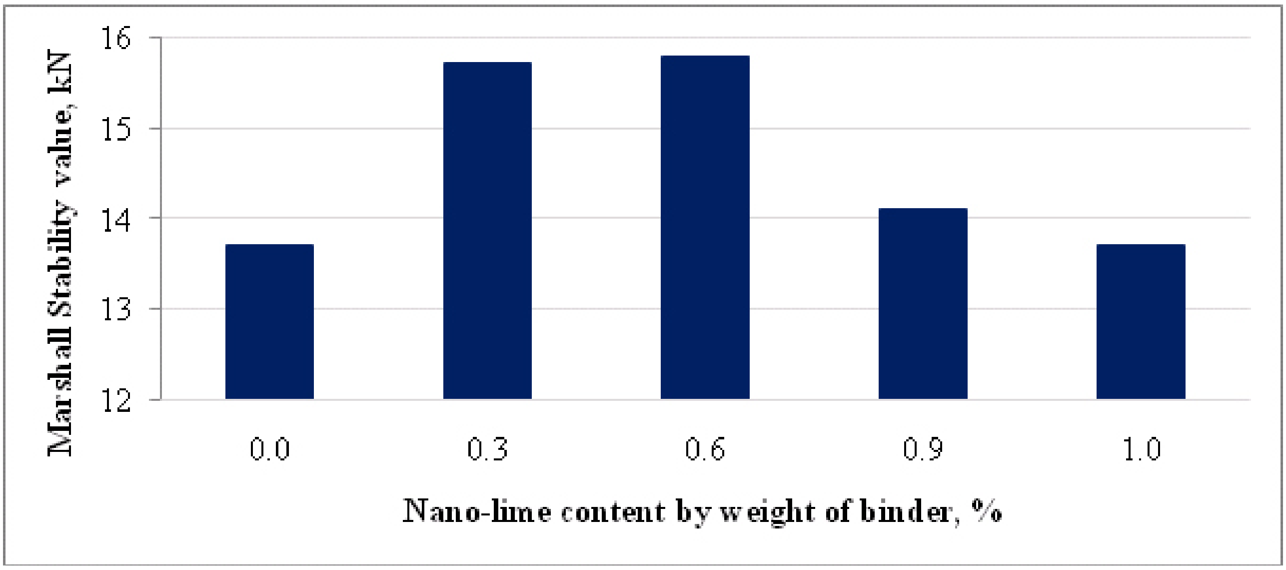
$$\text{Moisture loss rate} = \frac{\text{initial weight of specimen-weight of specimen at a given time}}{\text{initial weight of specimen}} \times 100$$

After specimen preparation, they were kept in room temperature for 3 days. The Hamburg wheel tracking test was carried out to assess the effectiveness of nano-lime in resisting permanent deformation (rutting).

4. Results and Discussions

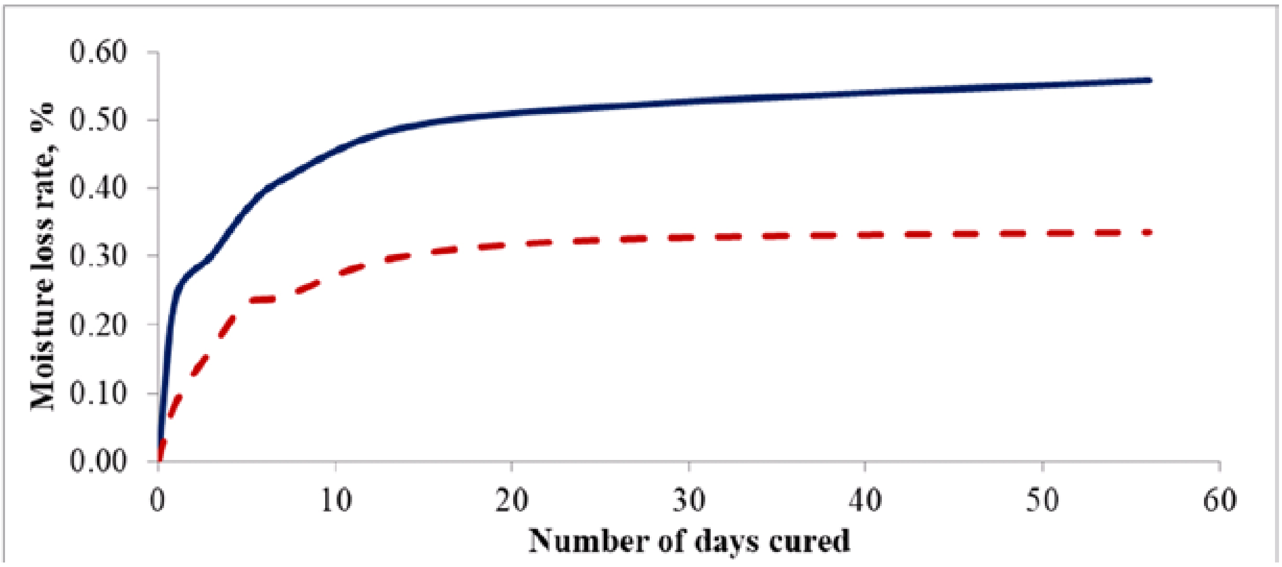
For the gradation used in this investigation, the Optimum Emulsion Content (OEC) was found to be 8% specimen with nano-lime. Marshall specimens were prepared and tested with the varying dosage of nano-lime. The results of the Marshall stability test of CBM with different dosages of nano-lime are given in Figure 2. It can also be observed that the stability value increased with an increase in nano-lime content up to a certain limit and decreased thereafter. The optimum dosage of nano-lime is 0.6% by weight of binder. The increase in stability value for nano-lime is because of quick moisture loss and improved hydration process of the material. In the case of nano-silica, one of the reasons for this phenomenon is early moisture loss during mixing. As the dosage of nano-lime increases above a certain limit, there will be excess loss of moisture that adversely affects the coating and strength of the mix.

Figure 2: Marshall stability value for different dosage of nano-lime



Moisture loss was monitored for mix with and without nano-lime. The moisture loss rate of the mix before compaction and after compaction was monitored separately. Curing of CBMs can be broadly classified as curing before compaction, which is called mix curing and after preparation of compacted specimen, which is called specimen curing. The test results are given in Figure 3.

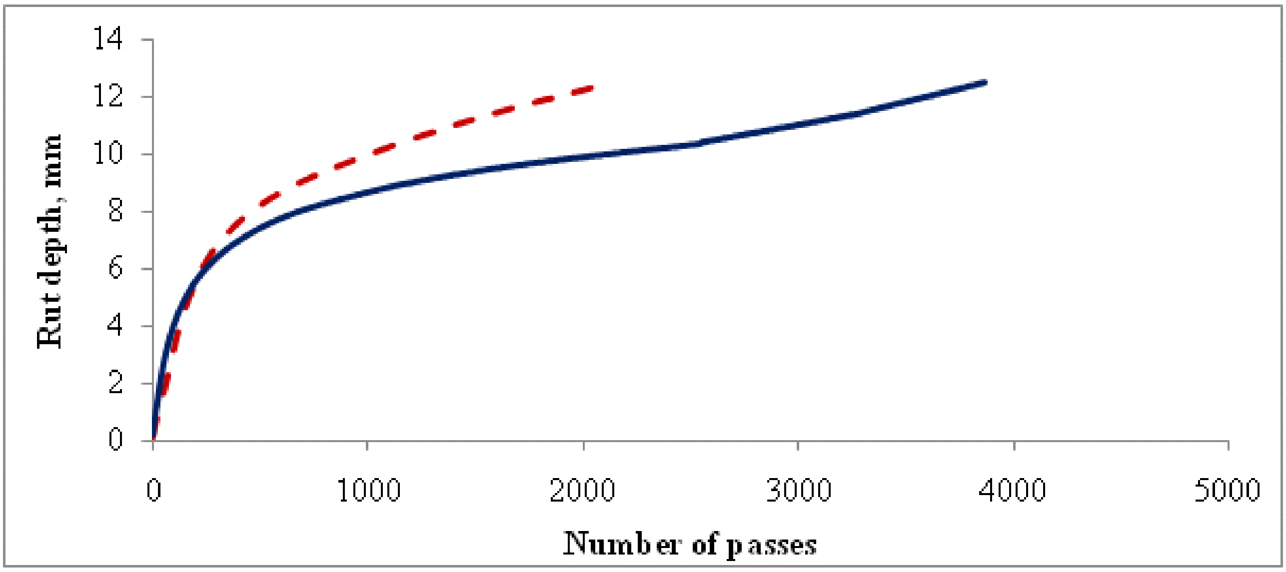
Figure 3: Moisture loss monitoring test results



Moisture loss is less in control cold bituminous mix compared to that in CBM with nano-lime. Nanomaterials are known to be extremely helpful in breaking and curing emulsions. In the case of nano-lime, in addition to the effect of nano-size material, water in the emulsion is absorbed by the material due to the hydration property of lime.

Hamburg wheel tracking test was conducted to evaluate the potential of nano-lime to improve rutting resistance of CBM. The test was conducted on specimens prepared with OEC of 8% and without/with nano-lime (0.6% by weight of binder) till the rut depth reached 12.5 mm. The graphical representation of wheel tracking results with and without nano-lime are shown in Figure 4. The number of passes for a rut depth of 12.5 mm for CBM with nano-lime is twice that of CBM without nano-lime.

Figure 4: Rutting characteristics of CBM with and without Nano-lime



5. Conclusions

For the selected aggregate gradation, OEC was found to be 8.0%. Mix was prepared with and without nano-lime. Moisture loss monitoring test and Hamburg wheel tracking test were conducted to evaluate the curing rate and resistance to permanent deformation. It was observed that Marshall stability value increased 15.09% by the addition of nano-lime. Optimum dosage of nano-lime was obtained 0.6% by weight of binder. Observations from curing study show that addition of nano-lime improves curing rate of CBM. Rut resistance of CBM also improved with the addition of nano-lime. Based on this study, it can be inferred that the addition of nano-lime improves curing rate and rut resistance of CBM.

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Use of Jute Geotextiles as Sustainable Materials in Construction of Low Volume Roads

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Abstract

Jute Geotextile - a natural technical textile has emerged as a high potential civil engineering material for mitigating soil related problems. Geotextiles made of natural fibre– Jute Geotextile (JGT) is one such material that can address many soil related adversities if used judiciously. The products have been standardized by BIS, IRC etc. and application guidelines have also been published by the Competent Authorities of State and Central Govt. department. Various departments have included JGT as an item of work in their schedule of rates. JGT can functionally compare with its synthetic counterpart and has the added advantage of being eco-concordant. The geotechnical features of the road have improved along with increase in CBR of the sub-grade soil in low volume road construction.

1. Introduction

The use of JGT in road construction is gaining acceptability in the country mainly because of its eco-compatibility, availability and economy along with its proven effectiveness. The unique features of jute fibres have prompted the scientists/engineers to develop Jute Geotextiles (JGT) with the desired geotechnical features. The properties of JGT are found comparable with its synthetic counterpart, besides the added advantage of its eco-concordance & the back-up R&D and industry-expertise to manufacture site-specific JGT. Use of JGT helps reduce carbon foot-print in road & other soil-based constructions. The features of jute fibre conforms to technical requirements and performs the four basic functions – (a) separation, (b) filtration, (c) drainage and (d) initial reinforcement expected of any geotextile.

There are enough evidences that one of the basic reasons behind road failures is poor drainage conditions coupled with poor soil of the sub-grade. Poor sub-surface drainage in rural roads lead to large amount of costly repairs or replacements long before reaching their design life. JGT have high capability of permitting flow of water across and along plane of fabric (permittivity & transmissivity).

JGT acts as a change agent in the consolidation process by triggering gradual development of effective stress within sub-grade and facilitating sub-surface drainage.

2. Design & Specifications of Woven Jute Geotextile for use in Rural Roads (IS 14715 Part I: 2016)

Construction	Double Warp Plain Weave for application in rural road	Standard Method of Test Ref.
Construction 1/1 DW plain weave	Construction 1/1 DW plain weave	-
Width (cm)	≥ 200 cm	IS 1954
Weight (gsm) at 20% MR	724 (- 5%, +10%) (Untreated)	IS 14716
Tensile strength (kN/m) MD X CD	≥ 25 X 25	IS 13162 (Part 5)
Ends X Picks/dm	≥ 94 X 39	IS 1963
Thickness (mm)	1.85 (± 10%)	IS 13162 (Part 3)
Elongation at break (%) MD X CD	≤ 12 X 12	IS 13162 (Part 5)
Puncture Resistance (kN)	0.500 (± 10%)	IS 13162 (Part 4)
Burst Strength (kPa)	3500 (± 10%)	IS 1966 (Part 1) or IS 1966 (Part 2)
Permittivity at 100 mm constant head (m/s)	0.35 (± 10%)	IS 14324
A.O.S. (Micron) O95	150 - 400	IS 14294

3. Standards & Guidelines of Technical Textile of Jute

a. BIS Standards:

i. Guidelines for application of Jute Geo-textiles for rain water erosion control in road & railway embankments and hill slopes (IS 14986:2001)

ii. Guidelines on rural road construction with JGT (IS 14715 Part I: 2016)

iii. Guidelines on river bank protection with JGT (IS 14715 Part II: 2016)

iv. Guidelines for jute sapling bag for growth of sapling in nurseries (IS 16089: 2013

v. Jute Agrotextiles for growth of plants and suppression of weeds (IS 17070:2018)

b. Indian Roads Congress (IRC) Code & Publications:

i. Guidelines for the Design and Construction of Low Volume Rural Roads Using Jute Geotextiles, **IRC:SP:126-2019**

ii. State-of-the Art Report on JGT prepared jointly by CRRI, IJIRA & NJB has been published by Indian Roads Congress in November 2011

iii. Specifications for road & bridge works (2001) & Recommended practice for treatment of embankment slope & erosion control (1991)

c. **Schedule of Rates:**

PWD, WBSRDA & I/W – Govt. of WB, PWD – Govt. of Assam & Meghalaya, BRO and all the 17 Divisions of Indian Railways

d. **RD&SO, Ministry of Railways**:

i. Guideline no GE:G1 (July 2003)

ii. Guidelines for earthwork in railway projects, 2007

iii. Unified Standard Schedule of Rates (Earthwork in Cutting & Embankment, Bridge Work and P.Way Works) - 2019

4. Installation Guidelines of JGT for Road Construction

Sequences in installation of JGT:

(a) Sub-grade is to be excavated to the required level, cleared of all foreign materials and compacted to the OMC. Sub-grade should be done up with the specified profile. Vegetation, if any, should be uprooted and the area leveled with earth and rolled.

(b) A thin cushion of local sand of about 25 -50 mm thick to be spread over the prepared subgrade to facilitate better drainage and less chances of microbial attack.

(c) JGT as selected should be laid by unrolling, ensuring proper drapability so that the fabric touches the sand layer at all points and stapled at an interval of about 750 mm with longitudinally overlaps of 150 mm. Staples should be preferably U-shaped nails (11 gauge) or suitable similar material.

(d) A thin cushion of local sand of about 25 mm thick to be spread over the JGT to prevent puncture/damage due to rolling of the overlying sub-base/base-layer.

(e) The first layer of aggregates in the base-layer should be spread with grading as recommended. No traffic should be allowed on an un-compacted base with less than 200 mm (300 mm for CBR greater than or equal to 3) thickness laid over JGT.

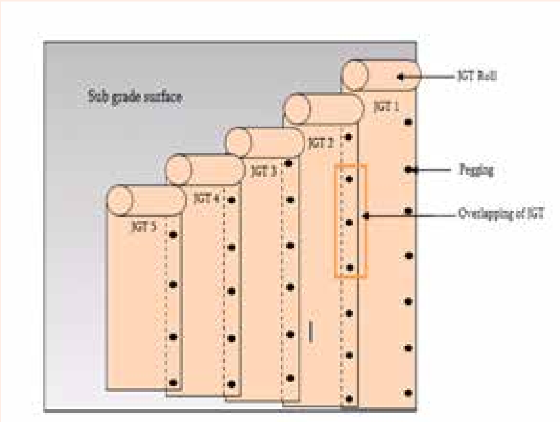
(f) Any rut that may develop during construction should be filled in.

(g) Parallel rolls of JGT should be overlapped by 100 mm and stapled

(h) For application in curves, JGT should be folded or cut and overlapped in the direction of the turn. Folds in JGT should be stapled at an interval of 300 mm in curves

(i) Before covering up the JGT, its condition should be assessed for any construction/installation damage. Torn/damaged portions may be covered by pieces of JGT and duly stapled on all sides preferably at an interval of 300 mm. The extent of overlap should be such as to fully cover the damage/torn portion plus at least 75 mm beyond on all sides.

(j) Often the sub-surface water is drained through the JGT and sand medium to the shoulders of a carriage way. In such cases, shoulder drains are required to be constructed either beneath the edge of the shoulder or immediately adjacent to its edge. In the event of existence of black cotton soil or expansive clay, porous drain pipes may also be inserted within the shoulder drain to augment drainage-efficiency.



Schematic diagram of Installation of JGT in Road Construction

Laying of JGT followed by Spreading of Sand

Result - Improvement of CBR value with the use of JGT in few roads both in India and Bangladesh:

INDIA						
S. No.	**Name of the Road**	**Type of Soil (Before Road Construction)**	**CBR before construction**	**CBR after construction**	**Span of time while the CBR increased**	**Performance Evaluation done by**
1.	Udal to Chakbrahma, South Dinajpur, West Bengal	Silty Clay	2.8	11.39	47 months	IIEST
2.	Nihinagar to Hazratpur, South Dinajpur, West Bengal	Silty Clay	2.2	7.93	47 months	IIEST
3.	Kanksa to Bati, Murshidabad, West Bengal	Clayey Silt	2.6	7.42	33 months	IIEST
4.	Bagdimarimulo Barada Nagar to Damkal Kheya Ghat, Mathurapur, South 24 Paraganas, West Bengal	Clayey Silt	3.5	11.11	29 months	IIEST
5.	Promod Nagar to Muga Chandra Para, Agartala, Tripura	Sandy Loam	8	10.86	19 months	NEST laboratory (NABL & ISO accredited)
6.	Koracharahatti to T-10 Road, Bidar, Karnataka	CL-Inorganic clays of low to medium plasticity	4	13.4	36 months	University B.D.T. College of Engineering
7.	Devarahospet to Gundur, Davangere, Karnataka	CL-Inorganic clays of low to medium plasticity	2.8	14.6	36 months	University B.D.T. College of Engineering

BANGLADESH						
S. No.	**Name of the Road**	**Type of Soil (Before Road Construction)**	**CBR before construction**	**CBR after construction**	**Span of time while the CBR increased**	**Performance Evaluation done by**
1.	Turag - Rahitpur Bourvita Road	Silty Sand	3 (With JGT) 3 (Without JGT)	13.57 9.64	50	BUET
2.	Circular Road at Savar Cantonment	Medium to High Expansive Silty Clay	3.6 (With JGT) 3.6 (Without JGT)	12.68 7.61	34	BUET
3.	Bancharampur southpara, Brahmanbaria	Silty Clay	2.3(With JGT) 2.3 (Without JGT)	13.10 6.50	31	BUET
4.	Tezkhali - Titas Riverghat Road Brahmanbaria	Clayey Silt	3.3 (With JGT) 3.3 (Without JGT)	8.2 7.7	33	BUET
5.	Noabanki Shamnagar Road Sathkira	Silty Clay	1.4 (With JGT) 1.4 (Without JGT)	19.80 5	39	BUET

Source: Study report of the Project on "Development and Application of Potentially Important Jute Geotextiles (CFC/IJSG/21)" funded by the Common Fund for Commodities.

5. Functions of Jute Geotextile in Road Construction

JGT behaves as a change agent to improve or enhance the geotechnical features of soil on which it is applied by following process occurring concurrently-

(a) JGT prevents pumping of fine particles/soils up in coarse base aggregate (***separation***).

(b) JGT retains soil particles as well as being an hygroscopic material and having high capability of transmissivity and permittivity, absorbs water towards the interface of sub-grade and sub-base, where it is laid, through gravitational and capillary actions and dissipates it, reducing hydrostatic pressure (***filtration and drainage***).

(c) JGT is designed in such a way that it can resist installation stresses (***initial reinforcement***). JGT provides reinforcement through following mechanisms.

- Membrane support of the wheel loads.
- Lateral restraint at the interface of sub-base & sub-grade through combined friction of soil GSB (sub-base) and JGT. JGT exerts confining action on soil

6. Conclusion

In this paper, attempts have been made to present observed performance of road using JGT, a natural biodegradable technical textile, it can be interestingly concluded that JGT and soil play mutually supporting roles. Initially, JGT's role is dominant but with passage of time JGT starts degrading and soil becomes self-reliant needing no extraneous support. The CBR value goes on increasing with the continuing process of consolidation of sub-grade till it. Consolidation is a protracted process and goes on for years under dynamic load. Use of JGT accentuates the initial process of consolidation by its concurrent functioning of separation, filtration and drainage.

National Jute Board (NJB), a statutory body under Ministry of Textiles, Govt. of India, provides technical support and guidance to the manufactures for producing standard quality of JGT, customization of JGT to address site-specific requirements and also provides technical support and guidance in selection of right type of JGT & its installation at site apart from other remedial measures. NJB conducts awareness programme all over the country and also take classes for the trainee engineers at IAHE, IRICEN. CRRI, RCTRC, NIT etc. as guest faculty.

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4. Construction Of VC Bunglow, Guest House & Women's Hostel At JP University , Chapra (BSEIDC)
5. Tender Package no. MMGSY WB-20-BAISI-01 (RWD)
6. Tender Package no. MMGSY WB-20-BAISI-02 (RWD)
7. Tender Package no. MMGSY WB-20-Araria -001 (RWD)
8. Construction of gated weir for irrigation creation on jhim river under Tirhut Canal Division(WRD)
9. RCC Bridge in Bheja over Koshi River in Jhanjharpur Div(PMGSY)
10. Construction of Girls hostel in college of horticulture & Forestry at Piprakothi (NPCC)

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Soil Stabilization Using Nano Technology in Arunachal Pradesh – A Case Study

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Abstract

As per the guidelines of the NRIDA, Ministry of Rural Development, construction of minimum 15% of road length by using New Technologies under PMGSY is mandatory, which is a good initiative. The Zydex Nano-Technology was used on a few roads in the districts of Longding, Shi Yomi and Tirap districts for soil stabilization. In general, the life and strength of rural pavements depends on the quality of soil. In situ, sub grades often do not provide the support required to achieve acceptable performance under traffic loading and environmental demands. Therefore, enhancement in the stability of the underlying soils is needed. Although stabilization is an effective alternative for improving soil properties, the engineering properties derived from stabilization vary widely due to differences in physical and chemical interactions between the soil and candidate stabilizers. Use of soil stabilized sub-base or base is economical considering significant economics that can be affected by adopting soil stabilization. Due to scarcity of stone aggregate, road construction using stone aggregate is economically unviable. In India, soil stabilization techniques can be adopted in rural road construction. This paper intends to present the influence of using nano-materials in soil stabilization. In Arunachal, the major soils are inceptisols, entisols and ultisols. The study area is predominantly red and alluvial soil coupled with hilly & mountain soil in Longding district. In the present study, an attempt is made to study the performance improvement of soil stabilization using nano-materials. In this study, cement (3%) stabilization is used to modify soil properties along with small quantity of nano-materials. Soft soil treated with nano-materials has beneficial effects on their engineering properties, including reduction in plasticity and swell potential, improved workability, increased strength and stiffness, and enhanced durability, which is also supported by the results of the investigation that showed significant improvement in Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). The performance of the nano-technology was studied for the road work "Mopakhat to Hasse-Russa" in Longding district.

1. Introduction

Rural Development plays a pivotal role in the overall development strategy of the country. The vision and mission of the current government is sustainable and inclusive growth of rural India through a multipronged strategy for eradication of poverty by developing infrastructure for growth, increasing livelihood opportunities and providing a social safety net. This is expected to improve quality of life in rural India and correct developmental imbalances, by reaching out to most disadvantaged sections of society.

Low cost, low maintenance, waterproofed, dust resistant, gravel/soil all weather road in low stone availability areas for last mile connectivity is a key bottleneck for increasing the productivity of farmers.

The New Technologies addresses the challenges of construction in sub-bases, bases, bond coats and bituminous layers. A length of 1022.74 km has been completed under new technology and 1589.29 km is under progress in the State of Arunachal Pradesh. Details of various new technologies sanctioned and completed are given in Table 1:

Table 1: Road length sanctioned & completed under New Technologies

S. No.	New Technology Name	No. of Districts	No. of Blocks	No. of Roads			Sanctioned Length	New Technology Length (in km)		
				Total	Completed	Ongoing		Total	Completed	Ongoing
1.	ANT Stabilizer	1	2	2	0	2	62.000	28.000	0.000	28.000
2.	Bitumen Stabilization	3	5	17	13	4	171.860	171.860	78.100	93.760
3.	CC BLOCK	1	1	1	1	0	5.000	5.000	5.000	0.000
4.	Cement Stabilization	2	2	2	1	1	16.420	16.420	3.920	12.500
5.	Cold Mix Technology	17	57	130	76	54	1895.933	1854.294	736.235	1118.059
6.	Nano Technology for Water proofing	6	18	42	22	20	530.955	530.955	199.486	331.469
7.	Waste Plastics	1	1	1	0	1	6.500	5.500	0.000	5.500
	Total	**31**	**86**	**195**	**113**	**82**	**2688.67**	**2612.03**	**1022.74**	**1589.29**

Nano-chemicals are nano-technology based products which can provide solutions to moisture and bonding issues in pavements. Addition of nano-particles as an external factor to soil will result in soil manipulation at atomic or molecular level and it influences the strength, permeability indices and resistance properties of soil. Nano-technology is a reformed mode which can address the rising concern of improving road quality.

The replacement of Combined Granular Base/Sub-base layer with a stabilized soil layer is technically feasible under the enhanced CBR of subgrade soils. The thickness of the stabilized soil that to be provided in lieu of WBM/GSB layer is technical justified based on the Odemark's theory of Equivalent Layer Thickness. The composite modules of the WBM/GSB is related to the modules of the stabilized soil, which means comparison of the layer stiffness based on the unique thickness of the layer. Hence, it can be concluded that the stabilization using cement with nano-chemicals is an efficient and economical way of stabilizing the base layers and replacing WBM/WMM and GSB layers of road construction.

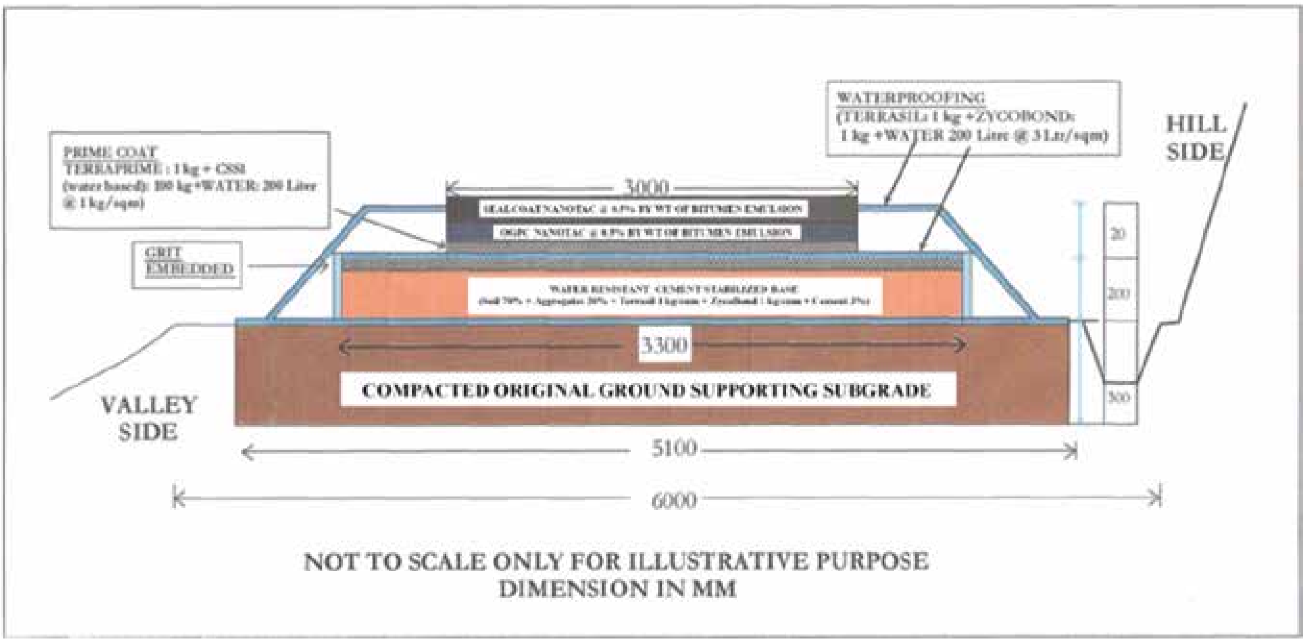
2. Soil Stabilization Using Terrasil Organosilane and Zycobond Acrylic Co-Polymer Nano Material and Cement

The solution of Organosilane (Terrasil) and Acrylic Co-polymer (Zycobond) is prepared by filling in the water tanker at the Optimum Moisture Content of soil. The solution prepared with water of Terrasil organosilane and Zycobond acrylic co-polymer are used in a proportion of 1 kg Terrasil and 1 kg Zycobond per cum meter of soil and 3% cement by weight of dry soil for soil stabilization of sub-base/base course.

The excavated soil from the borrow pit is scarified and pulverized and laid over the subgrade and it is mixed with cement with rotavator mounted in a tractor till uniformity is attained. The solution of Terrasil and Zycobond prepared at OMC is sprayed over pulverized soil-cement and mixing is done properly with rotavator and subsequently the compaction of treated soil is done using vibratory roller. Immediately after compaction, a 50 mm thick aggregate (size 37.5 mm – 20 mm) as stone grafting/grit layer is laid and compacted immediately with a roller ensuring that the aggregates are fully embedded over stabilized base. The water proofing layer using mix solution of Terrasil and Zycobond with the ratio of Terrasil 1 kg: Zycobond 1 kg: Water 200 liter) is sprayed on the surface of stabilized sub-base/base and shoulder at the rate of 3 liter per sqm meter. The solution of Terraprime organosilane mixing with CSS1 emulsion and water is prepared in a proportion of ratio 1 kg Terraprime: 100 kg CSS1 emulsion: 200 liter water for prime coat and the solution of Nanotac organosilane mixing with MS bitumen emulsion, 0.5% by weight of bitumen emulsion for open graded premix carpet.

The study was conducted for the following road work "Mopakhat to Hasse-Russa – 10.57 km" in Longding district, which has been completed in April, 2019.

Typical Cross-Section of a Hill Road



3. Test Summary

It was observed that, cement stabilization is used to modify soil properties along with small quantities of nanomaterials. The addition of organosilane eliminates capillary rise and water ingress from top, and reduces water permeability. Stabilization has been done using 3% cement and organosilane 1 kg/m^3 of soil. Results of improvement in engineering properties of soil for use in sub-base and base course construction are as in Table 2.

Table 2: Test Summary [Mopakhat to Hasse-Russa – 10.57 km]

S. No.	Parameters	Measure	Soil w/o additive	Soil + Terrasil 1 kg/m^3 + Zycobond 1 kg/m^3 + Cement 3%
1	CBR	%	7	128.76
2	UCS	MPa	1.09	3.29
3	MDD	gm/cc	1.76	1.90
4	DCPT	mm/blow	-	2.1

Field Observations

(i) Waterproofing effect achieved on OGL surface and stabilized compacted surface and more than 100% compaction density of stabilized layer achieved in the field

(ii) The mix was observed to be jet black and shiny

(iii) The improved workability of the mix was evident during the laying and compaction of the cold bituminous mix.

(iv) DCPT TEST was conducted on 2nd July 2021 during monsoons. The field CBR was found ranging between 126% to 130% at different locations.

(v) Grit layer/Stone Grafting over compacted stabilized layer with aggregate size less than 25 mm is not sustainable under the influence of traffic load during construction especially in a stretches of longitudinal gradient of limiting and exceptional. It is more reasonable to provide aggregate size ranges from (63 mm - 30 mm) as grit layer for proper embedding of grit materials in hilly terrain. AIV of grit aggregate should be more than 30%.

(vi) Results of DCP test at chainages 0.05 km, 3.15 km and 7.20 km in tabular form is given below inter-alia presentation of data on the graph regarding DCP & CBR values;

Ch.: 0.05 km					
D.C.P. Blows		Penetration Reading, mm	Cumulative Penetration, mm	Penetration between Reading, mm	Penetration Per Blow, mm/Blow
From	To				
0	0	110	0	0	
0	5	125	15	15	3.00
5	10	131	21	6	2.10
10	15	138	28	7	1.87
15	20	149	39	11	1.95
20	25	158	48	9	1.92

Ch.: 0.05 km					
D.C.P. Blows		Penetration Reading, mm	Cumulative Penetration, mm	Penetration between Reading, mm	Penetration Per Blow, mm/Blow
From	To				
25	30	164	54	6	1.80
30	35	172	62	8	1.77
35	40	180	70	8	1.75
40	45	187	77	7	1.71
45	50	199	89	12	1.78
50	55	236	126	37	2.29
55	60	269	159	33	2.65
60	65	298	188	29	2.90
Avg.					**2.1**
Log_{10} CBR =		2.465-1.12 LogN			
Log_{10} CBR =		2.100875			
CBR		126.1464			

Ch.: 3.15 km					
D.C.P. Blows		Penetration Reading, mm	Cumulative Penetration, mm	Penetration between Reading, mm	Penetration Per Blow, mm/Blow
From	To				
0	0	107	0	0	
0	5	118	11	11	2.2
5	10	120	13	2	1.3
10	15	133	26	13	1.7
15	20	145	38	12	1.9
20	25	152	45	7	1.8
25	30	161	54	9	1.8
30	35	172	65	11	1.9
35	40	178	71	6	1.8
40	45	189	82	11	1.8
45	50	209	102	20	2.0
50	55	243	136	34	2.5
55	60	280	173	37	2.9
60	65	321	214	41	3.3

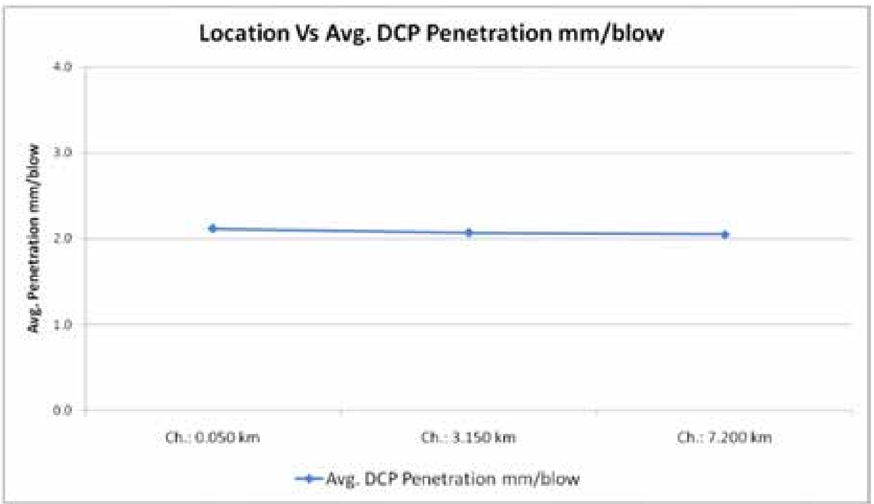
Ch.: 3.15 km					
D.C.P. Blows		Penetration Reading, mm	Cumulative Penetration, mm	Penetration between Reading, mm	Penetration Per Blow, mm/Blow
From	To				
Avg.					2.1
Log_{10} CBR =		2.465-1.12 LogN			
Log_{10} CBR =		2.111727			
CBR		129.3382			

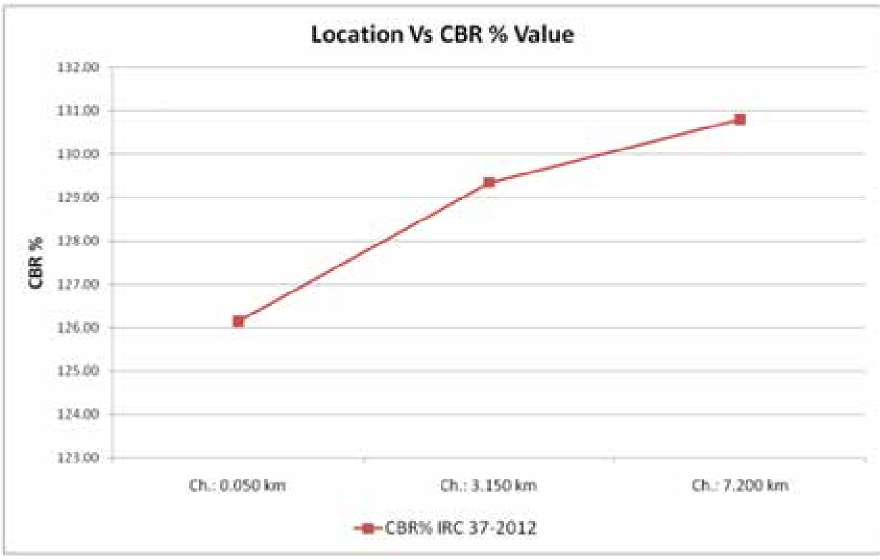
Ch.: 7.20 km					
D.C.P. Blows		Penetration Reading, mm	Cumulative Penetration, mm	Penetration between Reading, mm	Penetration Per Blow, mm/Blow
From	To				
0	0	108	0	0	
0	5	120	12	12	2.4
5	10	124	16	4	1.6
10	15	132	24	8	1.6
15	20	144	36	12	1.8
20	25	154	46	10	1.8
25	30	160	52	6	1.7
30	35	170	62	10	1.8
35	40	174	66	4	1.7
40	45	185	77	11	1.7
45	50	204	96	19	1.9
50	55	240	132	36	2.4
55	60	274	166	34	2.8
60	65	330	222	56	3.4
Avg.					2.0
Log_{10} CBR =		2.465-1.12 LogN			
Log_{10} CBR =		2.116604			
CBR		130.7989			

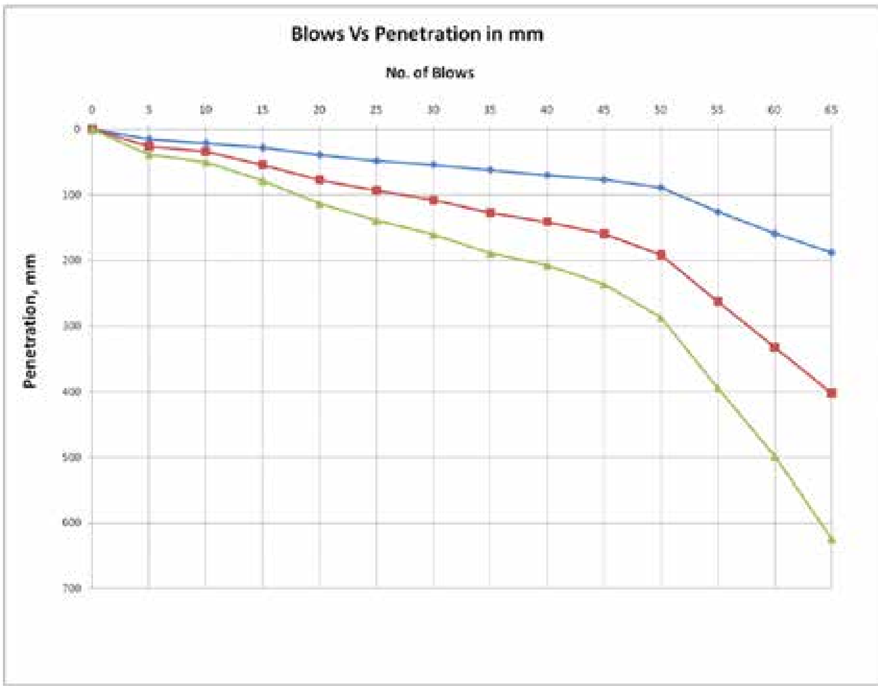
Comparison of DCP data

D.C.P. Blows	Ch.: 0.05 km	Ch.: 3.15 km	Ch.: 7.20 km
0	0	0	0
5	15	11	12
10	21	13	16
15	28	26	24
20	39	38	36
25	48	45	46
30	54	54	52
35	62	65	62
40	70	71	66
45	77	82	77
50	89	102	96
55	126	136	132
60	159	173	166
65	188	214	222

Section	Avg. DCP Penetration mm/blow	CBR % IRC 37-2012
Ch.: 0.05 km	2.1	126.15
Ch.: 3.15 km	2.1	129.34
Ch.: 7.20 km	2.0	130.80
Avg.	2.1	128.76







Soil-cement stabilization process in progress

Compaction of OGPC layer

6. Conclusion

The performance of the completed pavement was investigated through DCPT testing. The use of nano-materials stabilized base leads to a significant improvement in the structural capacity of the pavement and it can replace the combined granular base/sub-base layer with a stabilized soil layer (Stabilized with Terrasil and Zycobond organosilane nanomaterials + Cement). It was further observed that the behaviour of soil changes with the addition of organosilane. The amount of stabilizer required for appreciable stabilization depends on the characteristics of the soil. The following conclusions can be drawn from the results, such as:

- It is observed that organosilane works well with the combination of cement and makes the soil stiff, so that in low traffic area stabilized gravel road can be constructed.
- It is observed that CBR values increases 1800 times with the combination of cement, organosilane & nanopolymer.
- It is observed that UCS strength increases with increase in dosage of organosilane and curing period.

This signifies that such stabilization technologies optimize the potential improvements to strength of pavement foundation thereby increasing the load carrying capacity of pavement. Utilization of organosilane nano-materials with cement is attractive and supports the sustainable development in road construction. Nanotac additive added in bitumen emulsion for preparing open graded premix carpet and seal coat enables a chemically bonded aggregate-bitumen interface thereby eliminating water damage and improved bonding with prime coated surface.

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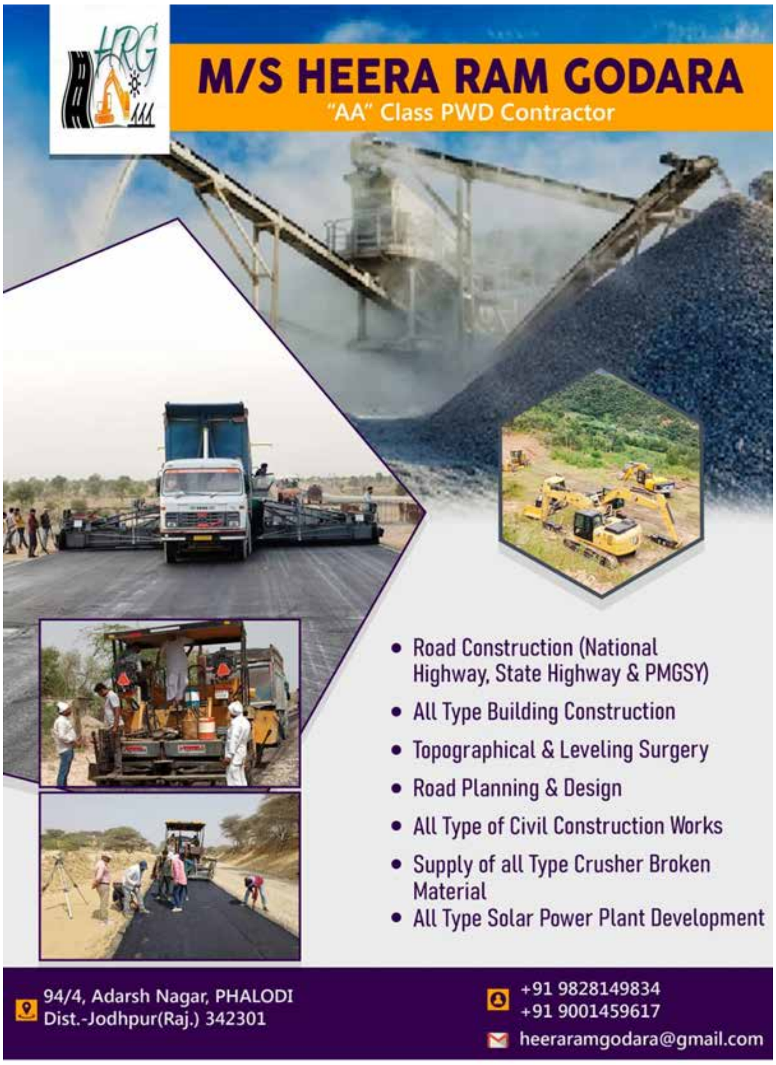
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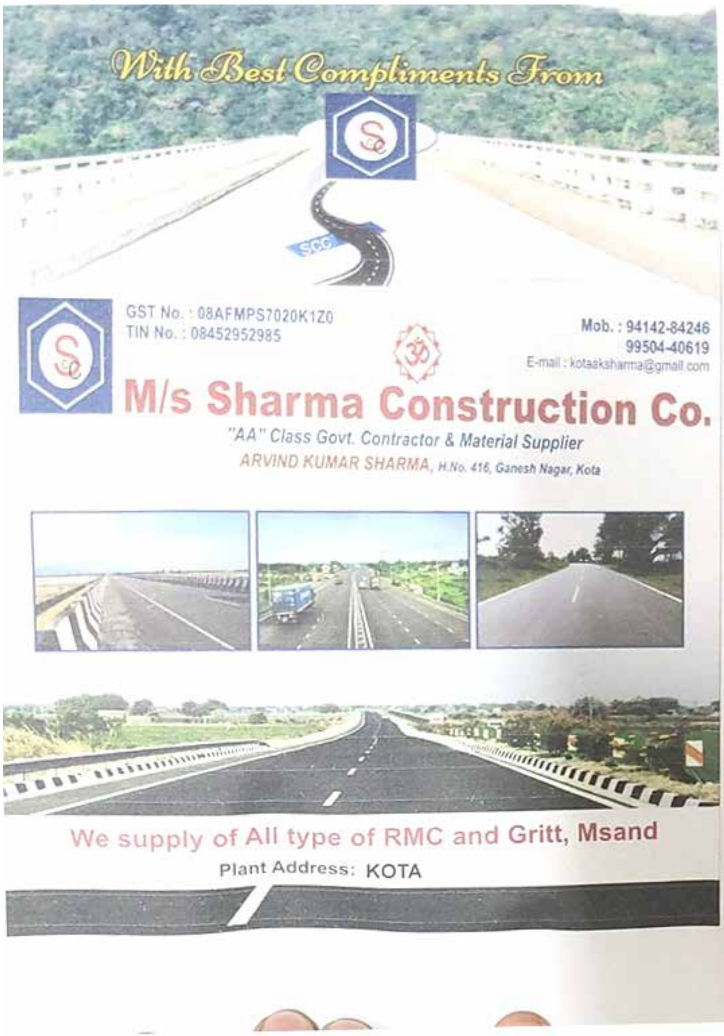

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Rejuvenation of Reclaimed Asphalt Pavement for Rural Roads

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Abstract

In this study, a laboratory investigation was carried out to understand the effect of aging on two rejuvenators, which were applied on two different sources of Reclaimed asphalt pavement (RAP) binders blended with and without virgin binder. In this process, 53 samples were tested. Among which two RAP sources were unaged, and 1 virgin binder & 16 blend combinations were unaged, short-term aged, and long-term aged. On each sample, physical tests (i.e. penetration, softening point, absolute viscosity, and rotational viscosity), as well as rheological tests (i.e. true high-performance grade (PG)) were performed. In this study, both the rejuvenators show a reverse trend after aging, which also includes their temperature susceptibility. In addition, this study also concludes the best methods to be used for stiffer blends like RAPs.

1. Introduction

The inflation of petroleum costs around the 1970's forced the road industry to explore new avenues for acquiring road construction materials(Sukhija and Saboo 2021). Since then, various new recycling techniques have been developed. The term recycled asphalt pavement (RAP) is typically used for materials obtained from scrapping/milling/demolishing existing asphalt pavement layers of flexible pavement (Al-Qadi, Elseifi, and Carpenter 2007). The use of RAP in the construction of new pavements can lead to significant savings in terms of cost, raw materials, and energy(Aurangzeb and Al-Qadi 2014).

As recently stated, "The Pradhan Mantri Gram Sadak Yojana (PMGSY) scheme has been a pioneer in the use of new and green technology in the construction of rural roads. Technology Vision 2013 for PMGSY mandated construction of a minimum 15% road length using new technology and locally available materials. The objective was to achieve economy and speed in the construction of roads, reduce carbon emission and environmental degradation, and provide sustainable roads with reduced maintenance costs. More than 100,000 km of road length has been approved for construction using new and green technologies, against which more than 66,000 km has already been completed. During the last year alone, 19,000 km of road length was approved under new and green technologies, which is more than 40% of the total road length approved in the year. Recently, full-depth recycling is being adopted in a major way to achieve cost economy and reduction in carbon footprint". Therefore, RAP will always be an asset in achieving PMGSY goals.

India is the second-largest road network in the world after the United States (Pradyumna, Mittal, and Jain 2013) but in the US It has been found that 33 million tons of RAP material are used for recycling purposes each year, which is about 80% of the total RAP material collected from the old asphalt pavement. RAP material can enhance the performance of the bituminous mix, such as stiffness and rutting resistance. The previous researchers stated that 15% to 70% RAP material was used successfully to construct the flexible pavement in the base course and the sub-base course whether only 15% to 30% RAP material was used in the surface course on the flexible pavement. Furthermore, the investigation is needed to use a higher proportion of RAP material to construct the surface course of flexible pavement (Application and Karati 2021).

In the same direction, this study is targeted. To increase more replacement of virgin binder with RAP binder it is mandatory to rejuvenate lost properties of the extracted binder. However, different oils may react to temperature change due to aging in a different way. In this study, efficacy of both the oils have been monitored under short-term and long-term scenario.

2. Objective

In this study, the objective was to find out how two rejuvenators work under different aging conditions. For this Two-rap sources binder with or without virgin binder were rejuvenated with two rejuvenators. Physical and rheological test were performed on each blend. Based on results both the rejuvenators were categorized based on their respective temperature susceptibility.

3. Materials

3.1. RAP and Aged Binder

RAP material is one of the very usable recycled materials that has been very useful in recent times. Nowadays, utilization of RAP material is going to increase rapidly day by day(Application and Karati 2021). RAP material was collected from two sources, one from Panipat-Shamili road {abbreviated as PS} and other from Shamili-Muzaffarnagar road {abbreviated as SM}. The age of the former was 5-7 years and the later was 8-10 years. Aged binder from RAP was extracted and recovered as per ASTM code (ASTM D2172-17 2017)(ASTM International 2015).

3.2. Virgin Binder

Viscosity-graded (VG) asphalt binder, VG 30, was used in this research work as the control binder for making all the blends. The number 30 in VG 30 indicates that the dynamic viscosity of the binder at 60°C ranges from [$30 \times 100 \pm 80$ Pa·s to $30 \times 100 \pm 60$ Pa·s (Saboo, Sukhija, and Singh 2021). VG 30 was collected from a single source to maintain the consistency of original binder characteristics.

3.3. Rejuvenators

3.3.1. Tall oil (TO)

TO is a byproduct of paper manufacturing and is obtained from Kraft liquors. TO is available either in crude form or as refined product. In this study, refined product is used. Crude tall oil contains fatty acids, resin acids and unsaponifiables in varying ratios depending on the type of tree used. TO have a long history of use in hot mix manufacturing with many emulsifiers, anti-strip agents and warm mix additives (Zaumanis et al. 2014).

3.3.2. Waste Engine Oil (WEO)

WEO is petroleum based and is often contaminated by impurities during physical and/or chemical processes. As a result, the oil is no longer suitable for its original purpose and have to be replaced by virgin or re-refined oil. The WEO consists of non-degradable components that are hard to be decomposed. As a petroleum-based product, waste engine oil has similar molecular structures as asphalt binder. (Dedene 2011).WEO may supplement the missing soft components for aged binder, and act like a rejuvenating agent. From this perspective, the use of WEO may potentially improve the performance of asphalt binder obtained from RAP. (Jia et al. 2015)

4. Experimental Program

Firstly, combination of samples was made in such a way that RAP proportion varied in two proportion; one is 50% and other is 100%. In 50% case, rest 50% was VG30. In addition, rejuvenator was varied in two proportions w.r.t. RAP binder one is 5% other is 10%. Table 1 shows the following combinations. These were blended as per standard blending process.

Table 1: Properties of various blends

S.No.	Name	RAP Present	RAP Proportion	VG30 Proportion	Rejuvenator Present	Rejuvenator Proportion
1	P50-T10	PS	50	50	TO	10
2	P50-T5	PS	50	50	TO	5
3	P100-T10	PS	100	0	TO	10
4	P100-T5	PS	100	0	TO	5
5	P50-W10	PS	50	50	WEO	10
6	P50-W5	PS	50	50	WEO	5
7	P100-W10	PS	100	0	WEO	10
8	P100-W5	PS	100	0	WEO	5
9	S50-T10	SM	50	50	TO	10
10	S50-T5	SM	50	50	TO	5
11	S100-T10	SM	100	0	TO	10
12	S100-T5	SM	100	0	TO	5
13	S50-W10	SM	50	50	WEO	10
14	S50-W5	SM	50	50	WEO	5
15	S100-W10	SM	100	0	WEO	10
16	S100-W5	SM	100	0	WEO	5

The following standard codes were followed for the physical and rheological testing as shown in Table 2.

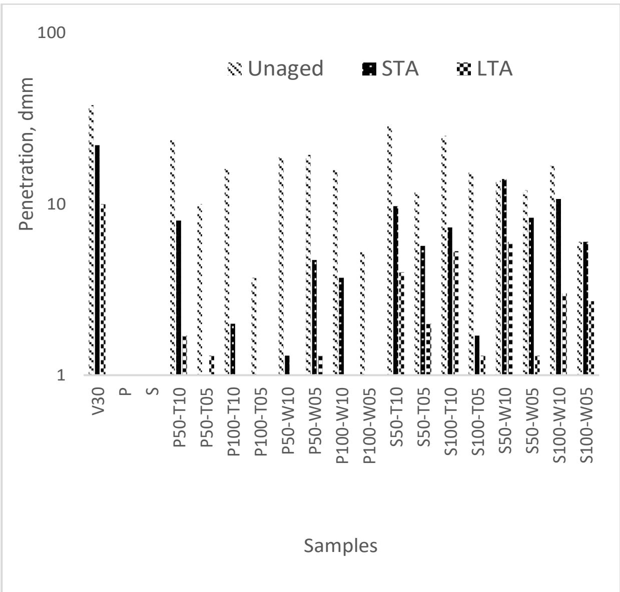
Table 2: Physical and rheological tests conducted in the study

Test Name	Specifications Followed	Reference
Penetration	ASTM D5/D5M-20	(Drews 2008a)
Softening Point	ASTM D36/D36M-14(2020)	(Drews 2008b)
Absolute Viscosity	ASTM D2171/D2171M-18	(Drews 2008c)
Rotation Viscosity	ASTM D4402/D4402M-15	(ASTM D 4402 2000)
PG High	ASTM D7643-16(ASTM D7643 2016)	(ASTM D7643 2016)

Once above (Table 2) testing were completed on all the blends as shown in Table 1, samples were short term aged using Rolling thin film oven test (RTFO) (ASTM D2872 2006) and were tested for same tests. Similar trend was repeated for long term aged sample which was prepared using Simple Aging Testing (Farrar et al. 2012).

5. Results and Discussion

Figure 1: Physio-rheological test results under unaged, short-term aged and long-term aged condition (a) Penetration Test results (b) Softening point test results (c) Absolute Viscosity Test results (d) Rotation viscosity test results @ 160°C (e) Rotation viscosity test results @ 180°C.



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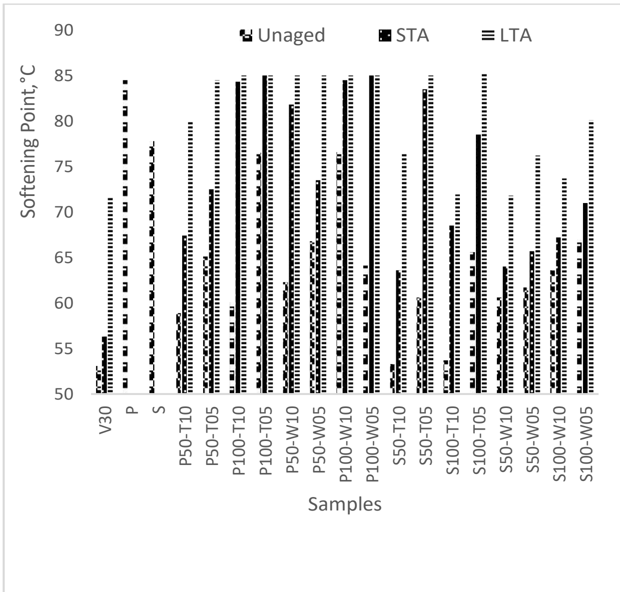

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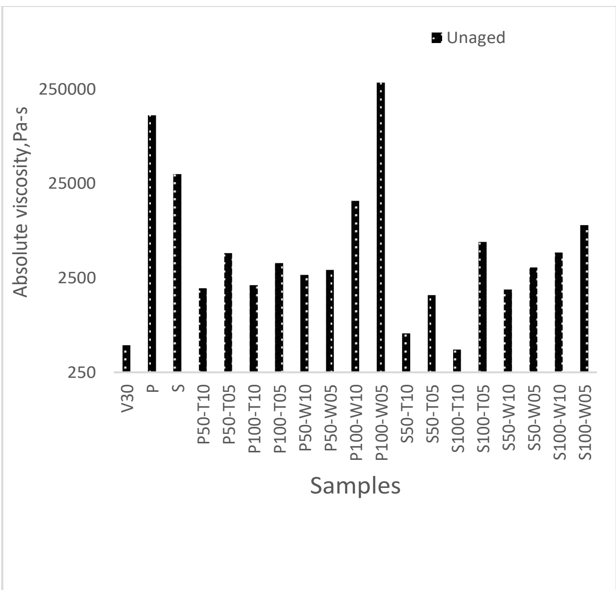
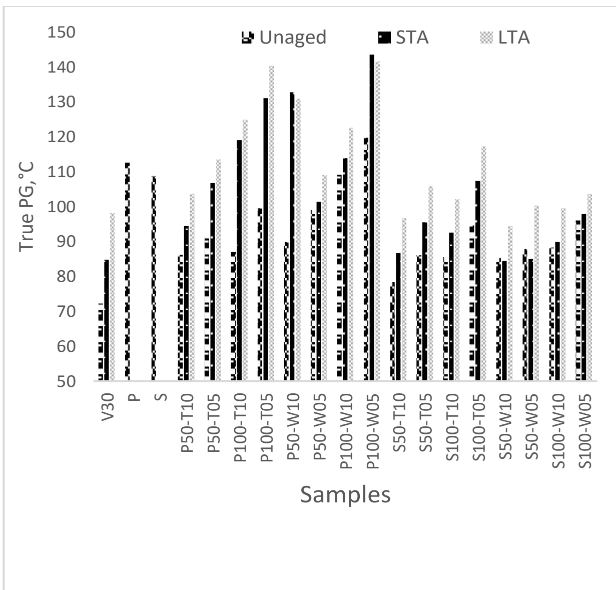
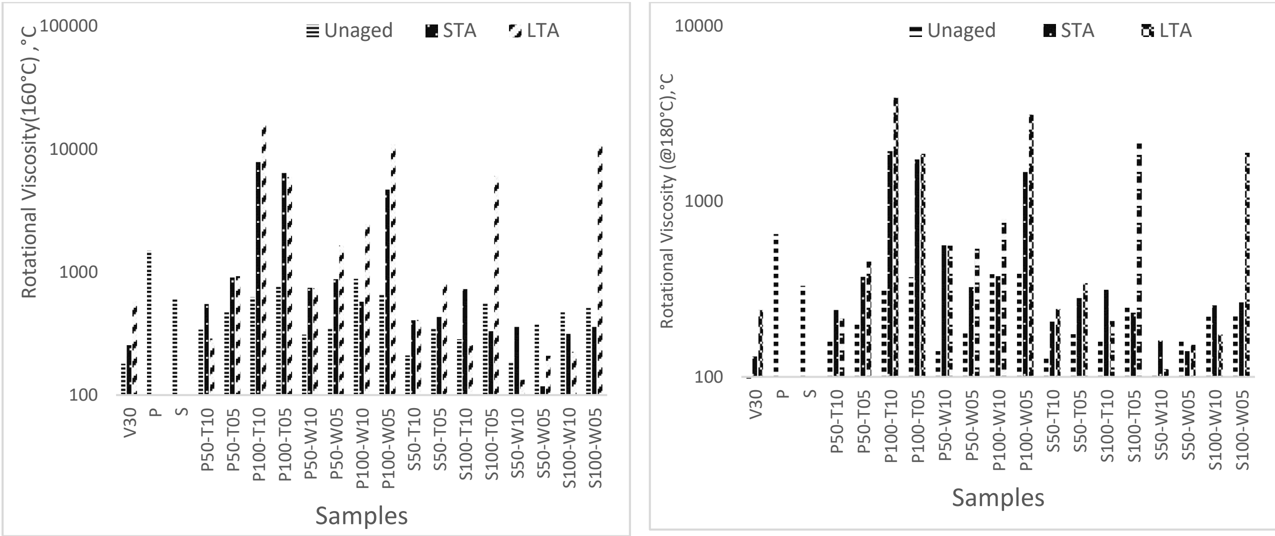


(c)



(d)

Figure 1: Contd...



(e) (f)

Figure 1(a) & (b) represent test results of penetration and softening test which show that with increase in rejuvenator percentage, stiffness reduces and this reduction is more pronounced in second source which indicated second source i.e. SM is less stiff than first source i.e. PS. When both the rejuvenators are compared Tall oil is more effective in reducing stiffness than Waste Engine Oil. This trend can be seen in Unaged and short term aged (STA) sample but trend reverses in long-term aged (LTA) sample. In addition, the softening point test cannot be trusted for blends having Softening point more than 85°C due to the limitation of equipment used. Figure 1 (c) shows result of absolute viscosity. It is clear from the experiment that absolute viscosity test should not be used for stiff binders as it gives no or inconclusive results. Figure (d) shows True PG test results and it shows PS is stiffer than SM. However, comparison of rejuvenators shows that WEO blends are stiffer in unaged condition only as ageing (both STA and LTA) takes place TO blends become stiffer. This may be attributed to the lower rate of aging of WEO than TO. Figure 1(e) and (f) results show the results of rotational viscosity test. As per the standard codal provision, this test needs to be done at 135°C at 20 rpm but due to the stiffness of blends all samples give results at different temperature. For uniformity of test, Arrhenius model was used to predict readings at 160°C and 180°C (Yang, Zhou, and Kang 2020). From the forecasted results it can be seen that rest of the results are in agreement with above test but here in all three conditions Unaged, STA and LTA, TO blends are stiffer than WEO oils. Here test temperature is very high, so the change in trend may be due to lower temperature susceptibility of WEO than TO.

6. Conclusions

From the study following conclusions can be drawn:

(a) For more eco-friendly and cost-effective road network more and more RAP should be used.

(b) To increase RAP proportion, their stiffness needs to be counteracted so that they can replace new virgin binder and have same and even better performance.

(c) To reduce stiffness of RAP rejuvenators are best options.

(d) While comparing Waste engine oil and tall oil, Waste engine oil comes out to be less temperature susceptible due to which it can be favored over tall oil.

(e) For stiff binders absolute viscosity test and softening point test should be avoided.

(f) Penetration test also have less temperature control.

(g) Rotational viscosity test can be used but should conclude any result only after PG high test.

(h) Thus, True PG high is the best method due to greatest temperature precision and exact result.

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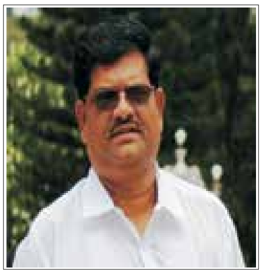

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- Construction of H.L RCC Bridge at Lihari Amgachhi Road under MMGSY RWD
- Construction of Road Under NABARD RWD Bihar
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Bending and Buckling Response of Pile Foundations in Layered Liquefiable Deposits

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Abstract

Pile foundations are still the preferred deep foundation system for problematic soils, especially in the case of liquefiable soil. However, pile foundations have shown failures during many past earthquakes. The major design codes across the globe have suggested the designers to design pile foundations in liquefiable soil deposits for higher bending moments. The experimental and numerical studies have credibly shown that pile foundations may fail in buckling even though they could withstand the possible bending moment generated due to liquefaction. Most of the design codes have overlooked the buckling failure criteria for pile foundation in liquefiable soil deposits. In the natural occurrence of soil deposits, liquefiable and non-liquefiable soil layers can occur in alternative layers. The literature shows that the sandwiched non-liquefiable soil layer in liquefiable soil would give a partial fixity effect to the pile foundation. However, there are no guidelines available on how to consider the effect of sandwiched non-liquefiable soil layer on pile response. The present work discusses the effect of sandwiched non-liquefiable soil layers on the bending and buckling response of pile foundations in layered liquefiable soil deposits.

Keywords: Pile foundation in liquefiable soil deposit, Layered soil deposit, Buckling failure, Kinematic bending moment, pile-soil interaction (p-y curve).

1. Introduction

Earthquake causes liquefaction in saturated cohesionless soil deposits, which results in the failure of structures. Pile foundation is often used to transfer heavy superstructure load to deeper stratum when the soil layer in the upper region is weak or liquefiable. The mixed performance of pile foundations during liquefaction essentially highlights the need for the development of a more rational design method considering the governing failure mechanism against the conventional practices.

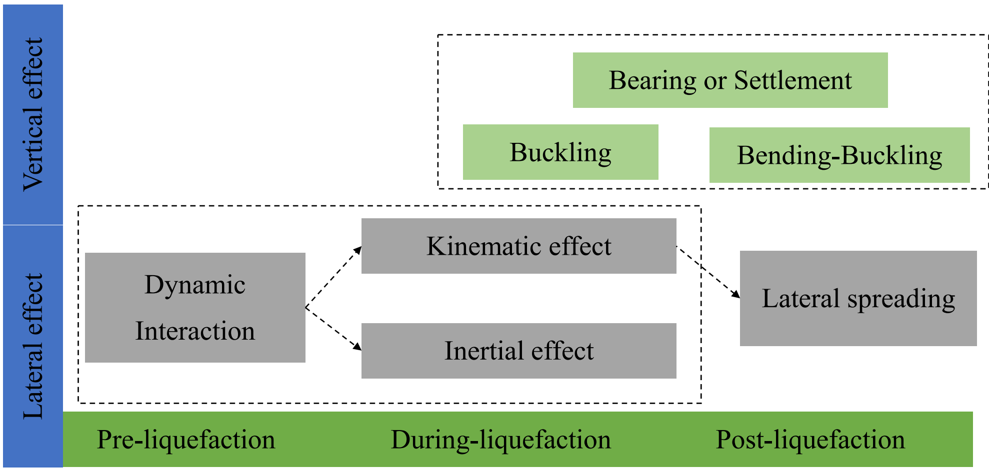
1.1. Liquefaction effect on Pile foundation during an earthquake

Liquefaction happens during sudden earthquake shaking in saturated medium dense to loose cohesionless soils. Many researchers tried to model pile foundation response considering different forces that would be in dominance at different times of an earthquake. As per the present understanding, Figure 1 shows typical causes of the pile failures along the timeline of liquefaction during an earthquake.

1.1.1. Bending failure of pile foundation

Most of the reconnaissance studies aftermath of earthquakes showed that the lateral pressure applied by the flowing liquefied soil or due to the combined movement of liquefied as well as the non-liquefied soil layer present above the liquefiable soil layer as a critical load causing the failure termed as bending failure theory. There is still no conclusive opinion about the pressure exerted by the flowing liquefiable soil on the pile foundation in the engineering community.

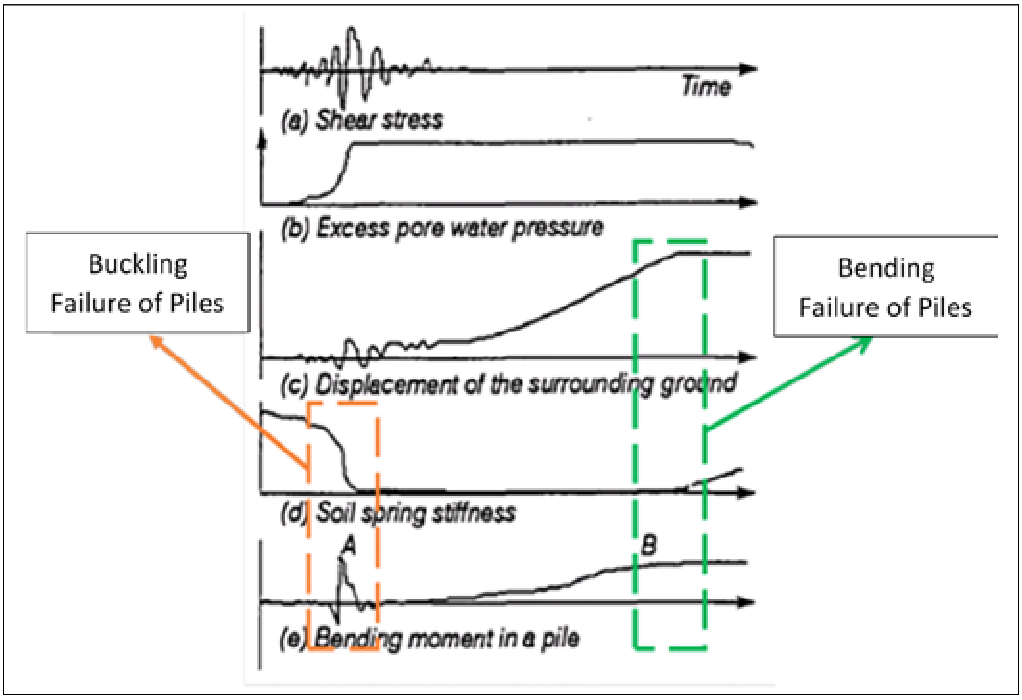
Figure1: Causes of pile failure in liquefiable soil deposit (after Wang, 2016)



1.1.2. Buckling failure of pile foundation

Berrill and Yasuda (2000) conceptually depicted the variation of different parameters as the earthquake proceeds, which can be seen in Figure 2. Piles are structurally slender columns laterally supported by soil confinement. Once the soil surrounding the pile liquefies, the lateral resistance offered by it to the pile becomes minimal, and the lateral load acting on the pile along with gravity load may cause buckling instability. Bhattacharya (2003), Knappett and Madabhushi (2009, 2012), and Huded et al. (2022) demonstrated through centrifuge tests and numerical study that the pile foundations act like slender columns and fail in buckling during the initial phase of liquefaction. It has been illustrated in Figure 2, where piles in liquefiable soil can fail due to bucking in the earlier phase of liquefaction or bending during the later phase of liquefaction-induced lateral spreading.

Figure 2: Time history of pile response during an earthquake (after Berrile and Yasuda, 2000)



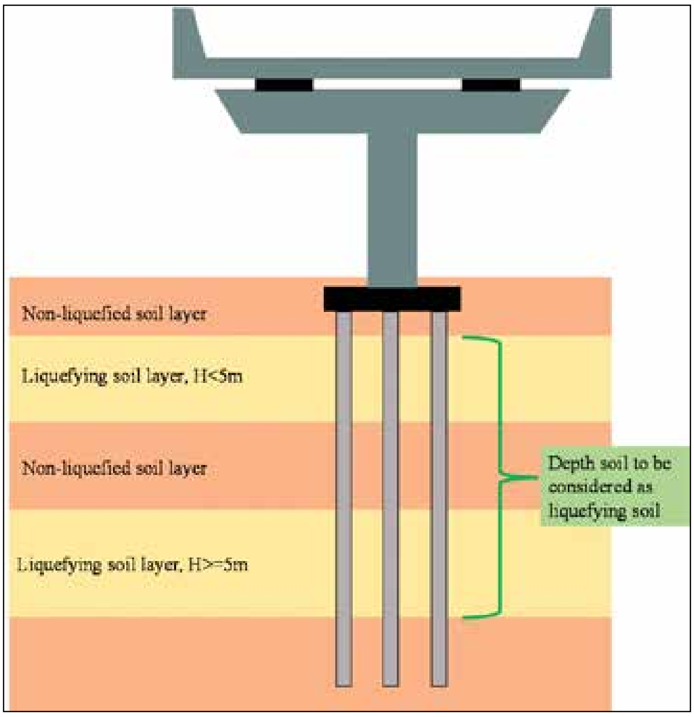
2. Can a Sandwiched Non-Liquefiable Soil Layer in a Liquefiable Soil Deposit Provide Lateral Restraint to the Pile?

In the natural formation of soil layers, it is possible that liquefiable and non-liquefiable soil layers can occur in alternative layers. The pile foundation of the bridges and buildings often passes through such soil deposits. Bhattacharya and Goda (2013) have stated that a non-liquefiable soil layer sandwiched between two liquefiable soil layers provides lateral restraint to the pile. However, the conventional design guidelines have suggested neglecting the effect of a non-liquefiable soil layer which may not be a conservative approach.

3. Recommendations in the Codes of Practices

JRA (2003) is the only code that considers layered soil profile, as shown in Figure 3. However, the code suggests considering the entire thickness of soil, including the sandwiched clay layer for the lateral movement onto the pile. The code essentially neglects the restraint effect of the non-liquefiable soil layer. Also, the code does not comment on what type and thickness of sandwiched non-liquefiable soil is to be neglected. None of the Indian seismic codes provide any recommendations to this effect as well.

Figure 3: Model for calculating lateral movement forces for soil strata of alternate layers of liquefiable and non-liquefiable soil (JRA, 2003)



4. Effect of Sandwiched Non-Liquefiable Soil Layer on the Bending Response of Pile Foundation in a Layered Liquefiable Soil Deposit

The layered soil deposit shown in Figure 4 is considered to understand the effect of sandwiched non-liquefiable soil layer on the bending moment profile of the pile foundation. The coupled soil-pile system is modeled in OpenSees® platform. Pressure-dependent multi-yield and Pressure-independent multi-yield materials are used to model liquefiable and non-liquefiable soil deposits, respectively. The soil-pile system was subjected to the Kobe earthquake of 1995 (scaled to 0.2 g). Figure 5 shows the variation of the normalised maximum bending moment diagram for all the soil profiles. It can be observed from the figure that the presence of non-liquefied soil (soft, medium, and stiff clay) alters the bending moment of the pile foundation. Also, in most cases, the kinematic bending moment is maximum compared to the inertial bending moment. The conventional method suggests neglecting the effect of the sandwiched non-liquefiable soil layer, which essentially neglects the kinematic bending moment due to the layered effect. Therefore, the presence of sandwiched non-liquefiable soil layer must be considered in the analysis.

Figure 4: Layered soil profiles considered for pile response study

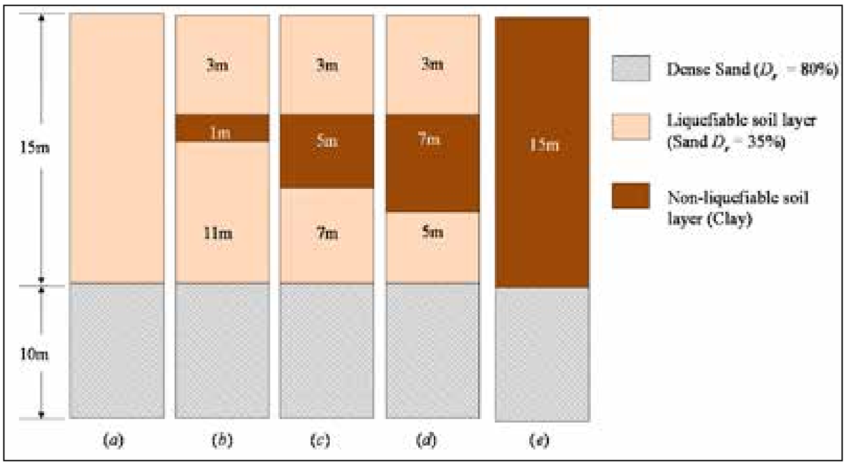
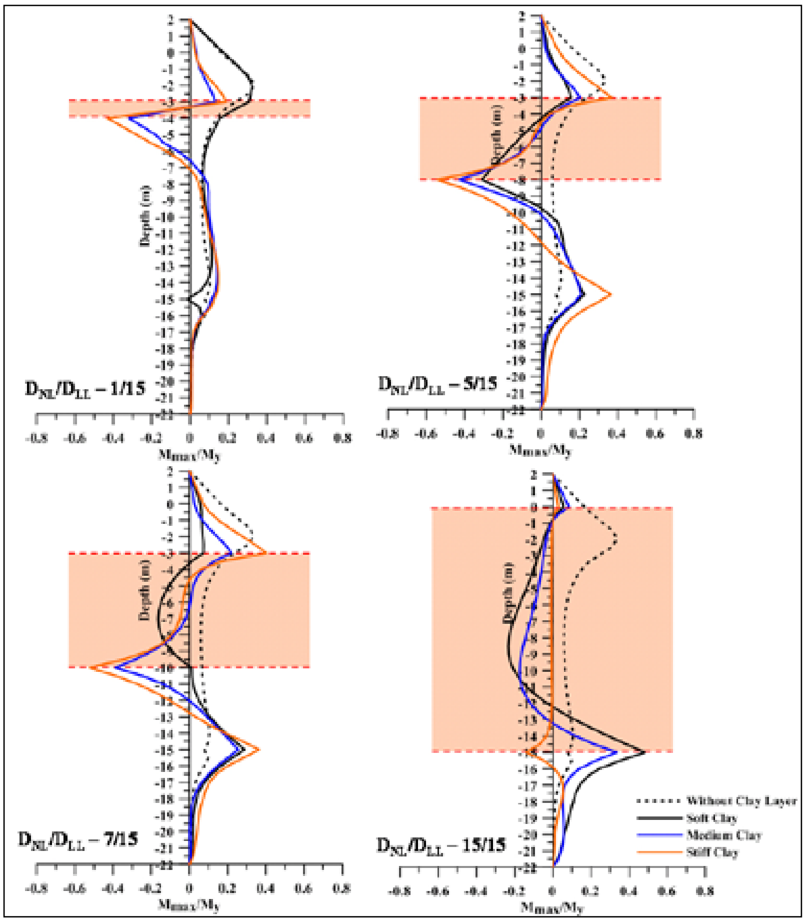


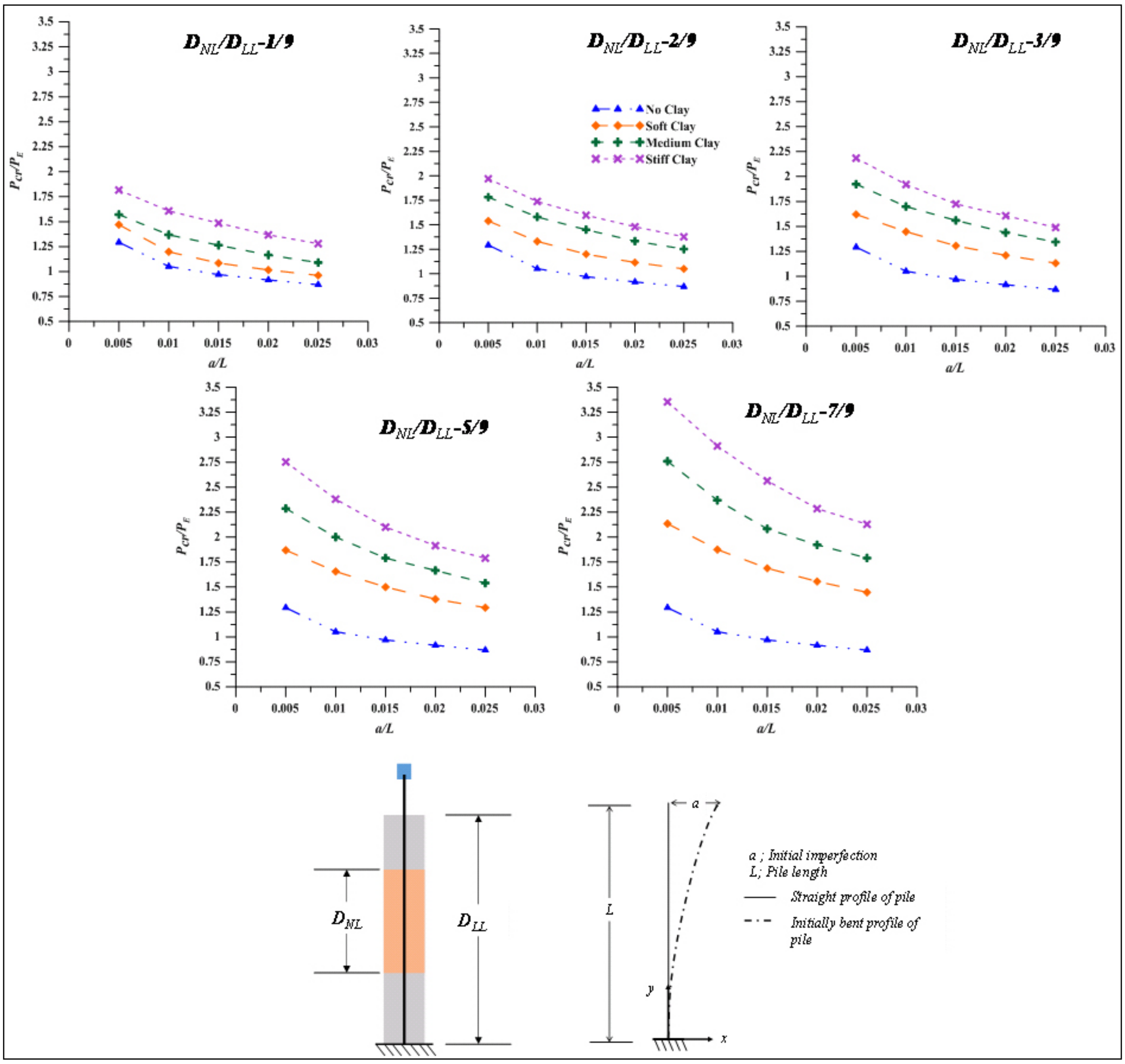
Figure 5: Normalized bending moment for varying depth of sandwiched soil layer



5. Effect of Sandwiched Non-Liquefiable Soil Layer on the Buckling Capacity of Pile Foundation in a Layered Liquefiable Soil Deposit

The effect of sandwiched non-liquefiable layer on the buckling capacity of the pile foundation in liquefied soil deposit is studied in detail numerically. Details of the modelling scheme and its verification can be referred to in Huded et al. (2022). Three types of non-liquefiable soil layers are considered in the present analysis (soft, medium, and stiff clay). The buckling capacity of the pile is evaluated considering pile material non-linearity and geometric non-linearity. The normalized buckling load (P_{cr}/P_E) with reference to Euler's elastic buckling load for a free-standing cantilever pile is plotted for different types of non-liquefiable soil (clay) in Figure 6. All the plots include one case without any sandwiched non-liquefiable soil layer for comparison. It is observed from the figure that an increase in the strength of sandwiched clay layer increases the buckling load of the pile. This essentially implies that sandwiched clay layer provides some amount of lateral fixity that reduces the effective length of the pile, thereby increasing its buckling capacity. As the thickness of the clay layer increase, the buckling capacity also increases for all the soil profiles.

Figure 6: Effect of sandwiched non-liquefiable clay layer on the buckling capacity of pile



6. Concluding Remarks

All the governing failure mechanisms for pile foundation in layered liquefiable soil deposits are still not well understood and defined in codes of practices. The present recommendations of neglecting the effect of sandwiched non-liquefiable soil layers of design codes may not necessarily result in a conservative design approach, particularly in the layered liquefiable soil deposits. The literature and numerical study show that the sandwiched non-liquefiable soil layer in a liquefiable soil deposit would give a higher kinematic bending moment to the pile foundation as compared to the case when the sandwiched layer is ignored. Also, the sandwiched non-liquefiable soil layer increases the buckling capacity of the pile in a layered liquefiable soil deposit. Therefore, it is recommended to consider the effect of sandwiched non-liquefiable soil in the analysis and design of pile foundations in layered liquefiable soil deposits.

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3. MMGSY-NDB-BRRP-77-Forbesganj (Tender ID-82258) Under MMGSY (NDB), Division RWD Forbesganj.
4. T01 Kathamatha Tappu Part II (Package No.-BR18P2R-15) Under PMGSY-II, Division RWD Kishanganj-1
5. RCC Bridge at Manikpur to Rahik Pathra More Road at Chainage-8.7 KM Pakage No.BR-01R-353 (Tender ID-81143) Under PMGSY, Division RWD Forbesganj.
6. MMGSY-NDB-BRRP-123-Jagdishpur Division RWD Jagdishpur.
7. Harnatar To Mauhawa village (Tender ID-51757) Division RWD Bagha-1.
8. Package No. MMGSY-WB-20-Forbesganj-07 Under MMGSY (W.B) Division RWD Forbesganj.
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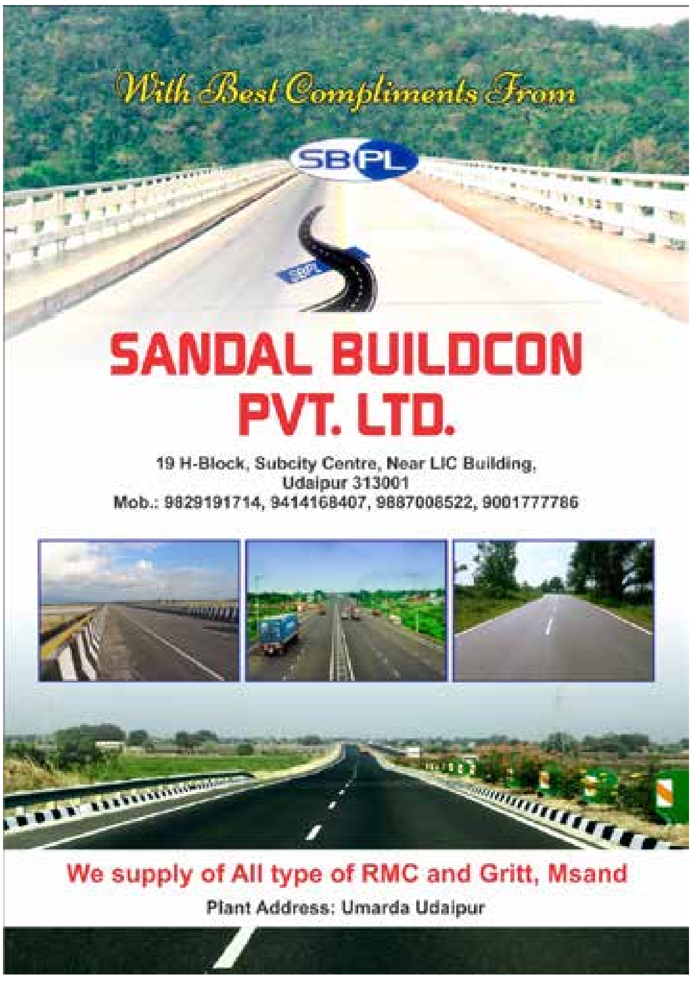
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An Overview of Bridge Approach Settlement and Various Mitigation Schemes

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Abstract

Whenever a driver is about to enter the main part of a bridge, they feel a momentary discomfort (sudden jerk) because of differential settlement of the approach fill relative to the bridge deck, which is normally called 'bump' at the end of the bridge. Differential settlement at the roadway/bridge contact often causes a sudden grade shift, creating driver discomfort, compromising driver safety, and potentially overloading the abutment with traffic. To keep the effects of differential settlement within acceptable limits, bridge approaches are provided with approach slabs. The eventual magnitude of settlement, on the other hand, frequently exceeds the working range of an approach slab, necessitating costly roadway and slab repairs. Typically, settlement reflects an aggregate effect of subsoil conditions, materials, construction techniques, drainage provisions, and quality control methods. The performance of bridge approaches, both with or without approach slab, has not been satisfactory as per the present practices. This study reviews various mitigation techniques which can be chosen for various bridge construction projects to reduce the effect of a bump near the bridge approaches.

1. Introduction

In a bridge project, as the main focus is primarily given to the structural components of the bridge, its approaches often lack due importance it deserves. In the case of most of the bridges on highways (especially on rural roads), the approaches are often considered to be a minor element of the project in terms of cost as well as the engineering challenges involved in their design and construction.

Although a bump felt when driving onto or away from a bridge is commonly recognized, no unified set of engineering solutions has emerged yet, primarily because of the number and complexity of the factors involved. Very seldom the settlement at bridge approaches can be traced to a single cause. Typically, settlement reflects an aggregate effect of subsoil conditions, materials, construction techniques, drainage provisions, and quality control methods.

In major bridges, an approach slab is provided, which acts as a transition from the compacted embankment to the top of the abutment/top of the deck slab level. This slab completely rests on the compacted gravel backfill of an abutment, which helps to distribute the wheel loads (pt. loads) of the moving vehicle evenly along the entire area of the slab and transmitted to the backfill. Whereas, in the case of culverts (Span <6 m), the provision of approach slab can be dispensed, as per IRC-SP 13. These culverts are present in an average of 2 to 3 numbers per kilometer of road and perhaps much higher in number as compared to minor and major bridges. The performance of bridge approaches, both with or without approach slab, has not been satisfactory as per the present practices. Every rider must have experienced a bump near a bridge, whether it is with or without an approach slab, although, with an approach slab, the settlement is often less than the latter case. Figure 1 shows the approach failure and formation of bumps near bridge ends.

Figure 1: Bridge approach failure with the formation of a bump

2. Bridge Approach Settlement Mechanism

Bridge approaches are typically made up of concrete reinforced slabs that link the bridge deck to the nearby paved road. The slab is normally supported by a bridge abutment on one side and the embankment on the other, and their purpose is to ensure that there is the transition of different vehicles from the roadway to the bridge structure safely and smoothly, but motorists always complaint about the bad ride quality of vehicles due to creation of 'bump' between the approach slab and bridge, when they approach bridge or leave the bridge.

The bump between the bridge deck and the approach slab usually occurs due to the differential settlement of the approach slab relative to the bridge deck (Chen and Murad, 2016). In the field, one side of the RCC approach slab placed over subgrade soil gets settled due to the settlement of the soil fill near the approach, whereas the abutment of the bridge founded on strong, competent soil does not settle. This typically leads to the formation of bumps as a change in slope of grade at the approach slab-bridge deck interface or a vertical fault at the approach slab-roadway pavement interface (Figure 2). These bumps pose a danger to fast-moving traffic, providing an unpleasant experience for drivers and passengers, and cause short- and long-term damage to bridge decks (Hao Liu, 2020).

The causes of settlement of approach slab can be attributed to many factors such as:

(a) Poor performance of Approach Pavement

(b) Type of Bridge Abutments and Foundation Support

(c) Vertical and Lateral Deformation of Backfill

(d) Vertical and Lateral Deformation of Foundation Soil

(e) Poor Drainage

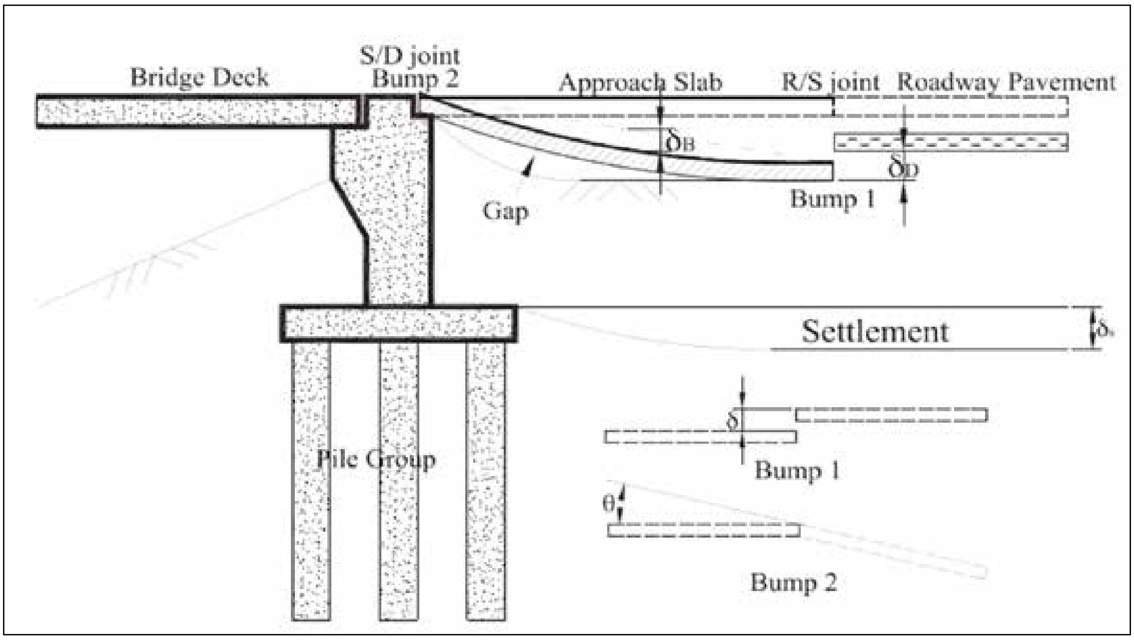
(f) Poor design of approach slab

(g) Inadequate thermal movement resistance

(h) Formation of void below abutment head corbel

It is understood that proper drainage near the bridge approach, good backfill material, proper compaction of the backfill, and construction of approach slab can help mitigate the differential settlement near the bridge approaches significantly and provide a smooth ride for passengers. In some situations, additional treatment may be required for ground improvement. Various codes like the American Association of State Highway and Transportation Officials (AASHTO, 2005), Indian Railway Standards (IRS), and Indian Roads Congress (IRC) standards have provided the guidelines to prevent approach settlement (with approach slab) near a bridge by incorporating proper drainage and backfill material. However, the difficulty associated with compaction of approach fill and construction of approach slab, leaves it susceptible to settlement, which is widely visible at most of the bridge approaches in India.

Figure 2: Illustration showing the formation of bridge bump at slab-bridge deck interface and at slab-roadway pavement interface (Chen and Murad, 2016)



3. Mitigation Techniques

Choice of the method of mitigation is site-specific, i.e., weak soil may need more treatment compared to a firm foundation. Some researchers also suggested going for numerical analysis of the bridge approach settlements before going for constructing new bridges, which can save a lot of expenditure to be spent on repairing differential settlements otherwise. Factors considered while evaluating the need for bridge approach slabs include the amount of expected settlement and the type of bridge structure. Figure 3 shows the mitigation schemes, which are broadly divided into three categories, such as:

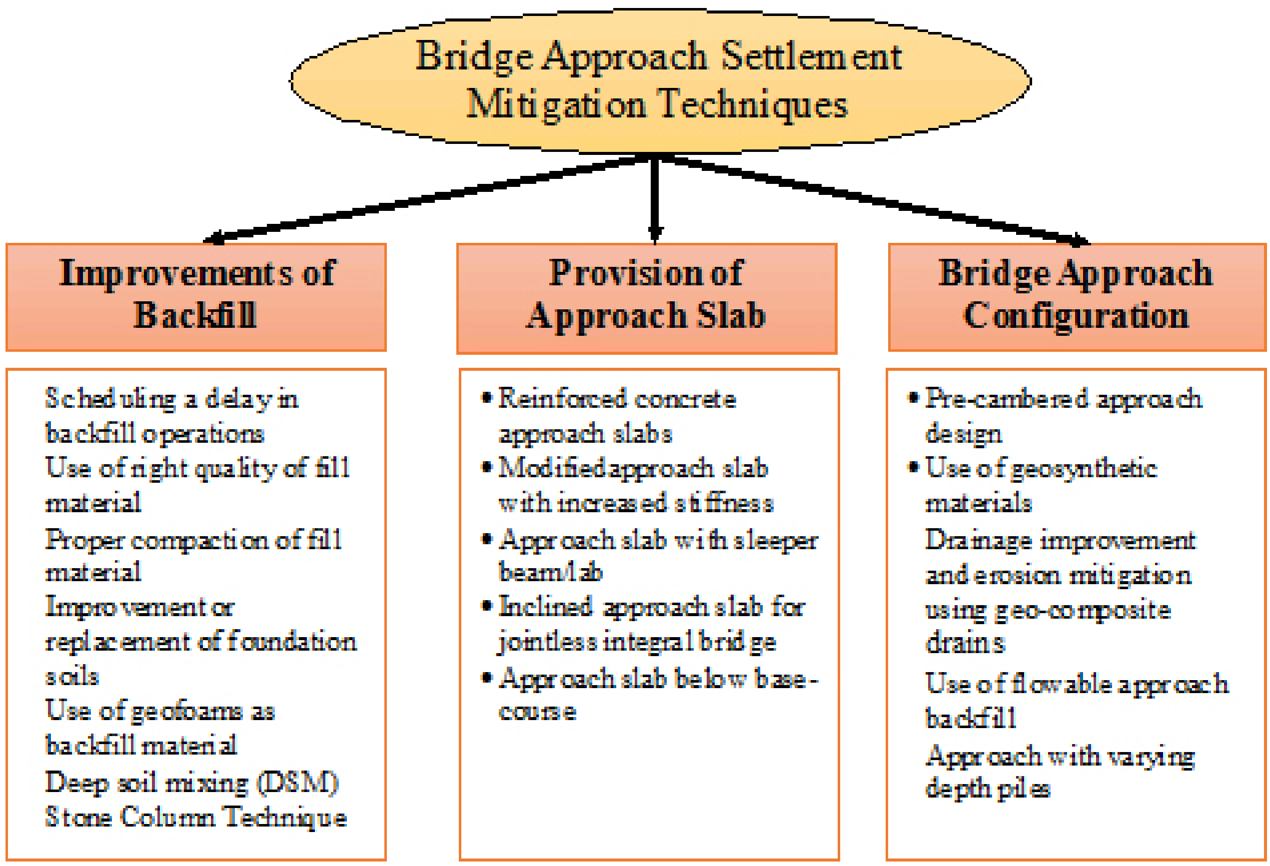
- Improvement of Backfill
- Provision of Approach Slab
- Bridge Approach Configuration

Some of the available mitigation techniques under each broad category are reviewed and presented below.

3.1. Improvement of Backfill

There are various methods available for improving the backfill near the bridge abutment to control bridge approach settlement. One of the cheapest ways to achieve this would be by allowing a delay in the construction of the backfill and compaction operations. If we allow for the embankment itself to settle before finishing the final roadway grades, then the settlement can be reduced significantly. However, often this delay in construction is not acceptable neither by the authority nor the users. In another way, the quality of the fill and embankment material significantly impacts the degradation of the approach geometry. It is advantageous to have rock, gravel, and/or sand as desirable fills, as they tend to compress immediately after the load is applied. In places where the foundation soil is very weak, it is better to go for the complete removal and replacement of the weak soil (Helwany et al., 2007). Many researchers recommended the use of Geofoam as a lightweight, compressible fill material with high strength, high stiffness, and low compressibility properties. Deep soil mixing treated columns provide substantial improvements to soil properties such as strength and compressibility. This stabilization technique has been proven effective on soft clays, peats, mixed soils, and loose sandy soils. Also, the stone columns technique can improve the load-carrying capacities of weak foundation soils and provide long-term stability to the embankments, and control settlements beneath the highway embankments.

Figure 3: Mitigation techniques



3.2. Provision of Approach Slab

The concrete approach slab bridges the voids and settlement of the underlying backfill to produce a smoother transition by stiffening the approach and to seal it from surface water from entering the backfill. Many researchers found that when the approach slabs are tied with embankment or the abutment of the bridges, the settlement is reduced (Wong and Small, 1994). Also, the approach slab with the increased stiffness performs better and reduces the severity of the bump (Abu-Farsakh and Chen 2014). They have suggested that Geosynthetic reinforcement should be added to help with the stiffness issue in addition to increasing the bearing capacity and reducing the settlement of the soil.

3.3. Bridge Approach Configuration

A pre-cambered roadway approach may be used to compensate for the anticipated post-construction settlements. Hoppe (1999) recommended implementing pre-cambering of bridge approaches for up to a 1/125 longitudinal gradient. Wong and Small (1994) conducted laboratory tests to investigate the effects of constructing approach slabs with an angle of 5° to 10° from the horizontal on reducing the bump at the end of the bridge. Several researchers have concluded the use of Geosynthetic material to reinforce the soil, which in turn, reduces the settlements. Flowable fill is a low-strength mixing concrete used as a backfill behind the abutment wall to reduce the possibility of approach settlements near the surface. The low-strength mixing concrete works well to prevent erosion of the backfill and to improve the constructability/ compactability of the fill behind the walls and around corners. The self-leveling ability property allows the flowable fill material to fill voids without the need for any compaction (Du et al., 2006).

Although there are various mitigation schemes available, the use of any particular scheme in a bridge project is a tradeoff between its effectiveness, cost, and ease of construction. To provide a qualitative assessment, a comparison between these schemes has been made in Table 1.

Table 1: Comparison of some of the bridge approach settlement mitigation schemes

Scheme	Effectiveness	Cost	Ease of Process
Scheduling a Delay in Backfill Operations	It helps in reducing settlement up to a few extents but is not effective in the long run.	Less costly as no new material is added, the compaction number is increased in time	Very easy to apply during the construction period.
Geosynthetic Reinforced Backfill	They are very much effective as compared to scheme 1.	Geofoam is costly. Hence, the process is overall expensive	This scheme is very easy to adopt in the construction
Lightweight fills	Not so effective, adopted where cost is the governing factor.	Less costly to make use of reused fills	Easy to apply during the construction
Reinforced Concrete Approach Slabs	Effective but design improvement is still necessary for better performance	Costly as RCC construction is required.	Easy to construct
Pre-cambered Approach Design	The most effective and used scheme nowadays	Costly as pre-cambering is done	The construction sequence is very important
Drainage and erosion control methods	Effective if designed and constructed properly.	Less expensive	Difficult to apply and achieve proper drainage in construction
Use of Geofoams	Very effective, but maintenances are required	Geofoam is less costly hence a less costly process overall.	Easy to provide during the construction process
Vertical Drains	Not so effective adopted where cost is the governing factor	Less costly as no new material is added, the compaction number is increased	Very difficult to apply this scheme during construction
Stone column technique	One of the few early techniques for bridge settlement mitigation	Not so costly as rocks and stones chips are used	Can be adopted easily

Scheme	Effectiveness	Cost	Ease of Process
Deep Soil Mixing (DSM)	Very effective, but requires skilled design and execution	Very costly as heavy instruments and machinery are used	Very difficult to apply this scheme during construction

3. Concluding Remarks

Bridge approach settlement is a widely visible issue that needs careful technical attention. It is a complex interaction between the bridge type, pavement, approach fill, and sub-soil condition. Although the approach settlement is attributed to multiple causes, the major one being the performance of backfill soil leading to bump formation at the bridge approaches. Cohesive soils are found to perform poorly as compared to cohesionless soil, due to their swelling and longer consolidation time. Although many mitigation techniques have been considered in the past with field tests, the practice still needs a more robust and reliable solution to have a better approach construction without large bumps.

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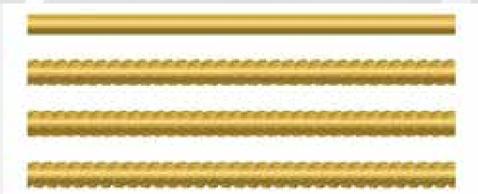

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Bituminous Emulsion Treated Base Layers for Low Volume Roads

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Abstract

Stabilization of pavement layers using cement and bituminous emulsion is gaining increasing popularity, considering the scarcity of virgin construction materials and the need for more durable pavements. Although Indian Road Congress has provided guidelines for the design and construction of highways using cement and emulsion treated base layers, the present guidelines for Low Volume Roads (LVR) are still confined to Cement Treated Base (CTB) layers. The present study aims to explore the possibility of constructing LVR with Emulsion Treated Base (ETB) layers and to evaluate the early age strength characteristics of ETB through field studies. Efforts have been made in the present study to assess the potential benefits of using ETB in LVR and to identify the major hurdles of adopting this technology. The immediate strength gain in ETB after construction was evaluated using Dynamic Cone Penetration (DCP) test and also using Indirect Test Strength (ITS) of the samples cured at field conditions. Later, the early age strength gain in ETB layers after 1 year of service period was measured using Falling Weight Deflectometer (FWD). The moduli of the ETB layers were back calculated using KGPBACK software and was compared with that of conventional granular base layers. The back calculated moduli of ETB layers were found to be 1.5 to 2 times that of the conventional granular base layers, depending up on the dosage of emulsion used in the mix. It was also inferred that the ETB layer has gained more than 90% of target strength within 7 days of curing and was capable enough to take up the traffic loading. Hence, it is recommended to complete the surfacing of ETB layer immediately after 7 days of curing, so as to avoid loss of aggregates from the surface. Although the application of ETB layer provides the advantage of improved structural support and pollution free environment, unavailability of proper blending mechanism and price of emulsion makes it unaffordable to many Government agencies.

1. Introduction

During the last few decades, substantial efforts are being made by various Government agencies to promote the use of innovative pavement materials, so as to reduce the consumption of virgin construction materials. Emulsion Treated Base (ETB) is one such cold mix application in which granular aggregate base layer materials are treated with bituminous emulsion. The aggregates that can be used in ETB mixes include natural aggregates, Reclaimed Asphalt Pavement (RAP) milled aggregates, or even Recycled Concrete Aggregates (RCA). The emulsion to be used in ETB can be cationic or anionic, depending up on the properties of the aggregates to be used. Since the aggregates available in India are generally rich in silica, cationic emulsions are preferred to facilitate breaking of emulsion. Since ETB uses dense aggregate gradation, slow setting emulsions (SS-2) are preferred, to ensure sufficient breaking time. In addition to aggregates and bituminous emulsion, ETB mixes also contain 1-2% active filler such as lime or cement, to facilitate early age strength gain. Pre-wetting water is yet another important constituent of ETB, which helps to ensure proper coating and densification of ETB layer. Mix design of ETB primarily involves the procedures to determine Optimum Fluid Content (OFC) based on workability criteria, followed by determination of Optimum Emulsion Content (OEC) from the target strength criteria. Factors such as relative compaction, premixing water content, curing conditions, residual bitumen content, active filler type and content, properties of base bitumen used in emulsion and aggregate petrological features affect the strength gain characteristics of ETB mixes. Since fine particles in ETB mixes are encapsulated and immobilized by bituminous binder, these mixes become more durable, moisture damage resistant, and resistant to pumping of fines under the action of wheel load (TG 2, 2009). ETB mixes are expected to have huge potential as base layer material for low volume roads, which are generally surfaced by thin bituminous surfaces.

Although India Road Congress (IRC 37, 2018) guidelines recommends the use of ETB, not many projects are coming up using this technology, primarily due to lack of field experience and unavailability of appropriate machinery. Currently the LVR in India is constructed following the Indian Road Congress (IRC SP 72, 2015) guidelines, which provides specifications for pavements with granular base layer materials and Cement Treated Base (CTB) layer materials. Since LVR is constructed using thin bituminous surface layers such as Open Graded Premix Carpet (OGPC) or Mixed Seal Surfacing (MSS), there exists a possibility of surface cracking, if the CTB layer is applied without Stress Absorbing Membrane Interlayer (SAMI). In such situations, it would be more appropriate to use ETB layer, which can even accommodate marginal materials to limited extend. However, the lack of construction guidelines and absence of reliable estimate of structural layer coefficient or resilient modulus values makes it difficult for the field engineers to adopt this technology. It is also expected that the ETB layer can mobilize much improved resilient modulus, very close to that of binder layers like Bituminous Macadam (BM). Although researchers have proposed the idea of using Bituminous Concrete (BC) as surface layers in LVR, the present guidelines do not permit to apply BC directly over the granular layer (Kandhal and Veeraragavan, 2016). Since ETB is capable of mobilizing a resilient modulus value close to that of BM, it should be capable enough to replace both the granular layer and binder course. Hence ETB can bring out the possibility of using BC layers in LVR, without the application of binder courses such as the BM or Dense Bituminous Macadam (DBM). Although there are several reasons to promote the use of ETB, lack of adequate construction guidelines, uncertainty associated with the initial strength gain, lack of appropriate construction equipment and increased price of ETB mix possess major challenge towards the field application of ETB. The present study primarily focusses on assessing the benefits of using ETB in LVR and identifying the factors that need to be addressed for facilitating this technology. Hence the specific objectives of the present study are formulated as follows:

1. To evaluate the immediate strength gain in bituminous emulsion treated base layers using dynamic cone penetration test and indirect tensile strength of field cured samples
2. To assess the strength gain in emulsion treated base layer mixes using falling weight deflectometer and to compare the back calculated moduli with that of conventional granular base layers
3. To summarise the merits of using emulsion treated base layers and to identify the hurdles that need to be addressed for facilitating this technology

2. Methodology

To satisfy the objectives of the present study, test sections have been constructed using 6 different combinations of ETB layers. The test sections were funded by the Local Self Government Department (L.S.G.D.) of Government of Kerala, and was constructed in Kannadikkavala NKR Kallappuram Road in Muhama Grama Panchayath of Alappuzha District, Kerala, India. Three out the six test sections were constructed using 100% virgin aggregates and the remaining three were constructed using a blend of 50% virgin aggregates and

50% RAP materials. In sections with 100% virgin aggregates as well as in sections with 50% virgin aggregates and 50% RAP materials, emulsion content was varied in the range of 2%, 3% and 4%. In addition to these six test sections, an additional test section was also constructed using conventional granular base layers, so as to have a comparative analysis of the test results. In the present study, test section with conventional granular base layer is represented as S1 and the test sections with 100% virgin aggregates and 2%, 3%, 4% emulsion contents are represented as S2, S3 and S4 respectively. The remaining three test sections with 50% virgin aggregates and 50% RAP materials, and with 2%, 3%, 4% emulsion contents are represented as S5, S6 and S7 respectively. All the test sections were constructed over a subgrade with 7% CBR and with a granular sub base layer of 150 mm thickness. The difference in the test sections were made only in the combination of materials used in the base layer. The thickness of base layer was fixed as 150 mm, and 20 mm thick Open Graded Premix Carpet (OGPC) along with 6 mm seal coat was provided as the surface course for all the test sections. The design traffic of the test sections for a period of 10 years was calculated using the Vehicle Damage Factors (VDF) specified in IRC SP 72 (2015), and was found to be 1 million standard axle load (msa) repetitions.

2.1. Materials and specifications

The materials used in the construction of test sections includes aggregates, RAP materials, cationic slow setting (SS-2) emulsion and active filler. The physical properties of the aggregates and emulsion used in the construction are summarized in Table 1 and Table 2 respectively.

Table 1: Properties of aggregates

Sl. No.	Property	Result	Test Method
1	Specific Gravity	2.71	BIS 2386- Part 3
2	Angularity Number	9	BIS 2386- Part 1
3	Combined Flakiness and Elongation	29%	BIS 2386- Part 1
4	Los Angeles Abrasion Value	28%	BIS 2386- Part 4
5	Impact Value	24%	BIS 2386- Part 4

Table 2: Properties of cationic slow setting emulsion (SS-2)

Sl. No.	Property	Result	Test Method
1	Residue on 600-micron sieve	0.02%	BIS 8887 (2018)
2	Storage Stability after 24 hours	0.40%	
3	Residual bitumen	62%	
4	Miscibility with water	No coagulation	
5	Stability to mix with cement (percentage coagulation)	1.84%	
6	Particle Charge	Positive	
7	Penetration of residual bitumen (25˚C, 100 g, 5 sec)	71	

Figure 1 and Figure 2 respectively shows the SS-2 emulsion and RAP used in the construction of the test sections. RAP used in the construction was procured from a hot mix recycling project between Cherthala to Aroor stretch, in Alappuzha, Kerala of National Highway (NH-66). From the bitumen extraction test conducted on the RAP materials, it was inferred that the residual bitumen content was 4%. 1% (percentage by weight of dry aggregate) Ordinary Portland Cement (OPC) was used as the active filler in the ETB mix. The ETB mix used in the construction of the test section was prepared as per the guidelines of Indian Road Congress (IRC 37- 2012, Annexure IX). These guidelines were prepared based on the experiences in South Africa, documented in Technical Guidelines (TG-2, 2009), published by Asphalt Academy.

Figure 1: SS-2 Emulsion

Figure 2: Reclaimed Asphalt Pavement Materials

The aggregate gradation specified for ETB in IRC 37 (2012), is summarized in Table 3, along with the specifications for Wet Mix Macadam (WMM), which is the conventionally used unbound granular base layer in flexible pavement construction. The gradation specified for ETB is slightly denser than the gradation specified for WMM by the Ministry of Rural Development (MoRD, 2014). In the present study, aggregates were blended in such a proportion than the combined gradation is closer to the target mid gradation specified for ETB. Although IRC 37 (2012) does not restrict the quantity of RAP to be used in ETB mixes, the proportion of RAP was limited to 50%, so as to maintain the combined gradation within the specified limits. RAP mostly consists of aggregates in the range of 2.36 mm - 13.2 mm and hence it would be practically difficult to achieve the target gradation when RAP materials are used in excess of 50 percentage by total weight of dry aggregates. The OFC required for the ETB mix was designed as per the guidelines outlined in Annexure IX of IRC 37 (2012). It was inferred that OFC for 100% virgin aggregates was 7% and the OFC reduced down to 6.5% when 50% RAP was used along with 50% virgin aggregates. The in-situ water content in the aggregates was found to be 2%. Pre-wetting water was added in such a quantity that sum of pre wetting content, in situ water content and emulsion content is equal to OFC.

Table 3: Recommended aggregate gradation for ETB and WMM

Sieve Size (mm)	Percentage passing- For ETB	Percentage passing- For WMM
53	100	100
45	100	95-100
37.5	87-100	-
26.5	77-100	-
22.4	-	60-80
19	66-99	-
13.2	67-87	-
11.2	-	40-60
4.75	33-50	25-40
2.36	25-47	15-30
0.6	12-27	8-22
0.3	8-21	-
0.075	2-9	0-5

2.2. Construction of emulsion treated base layers

The construction of ETB layer still remains as a major challenge due to the absence of appropriate machinery. In the state of Kerala, the number of WMM mixing plants are limited and the plant owners often hesitate to use them for the preparation of ETB mixes. It is not economical to prepare the mix in a WMM plant, which is more than 50 kilometres from the construction site. More often, the quantity of materials required for the construction of LVR is limited and hence the contractors prefer to make local arrangements for the preparation of the mix. In the present study, two different approaches have been adopted for the mixing of ETB material. In the first approach, ETB was prepared in an Ajax mobile concrete mixer of 2 m^3 capacity and was transferred directly to a truck (Figure 3). In the second approach, ETB was prepared in a conventional drum mixing type concrete mixer of 0.5 m^3 capacity and was transferred to a customized auto rickshaw (Figure 4). In both these approaches, segregation of aggregate was a major concern. The output from the drum mixer will initially consist of large sized aggregates and the remaining fines will settle down towards the bottom. This condition severely affects the uniformity and coating of the mix. In the first approach, larger quantity of mix can be prepared at a time, however the outflow rate is comparatively lower, since the machine is basically designed for the aggregate size and workability specified for concrete mix. In the second approach, quantity of mix prepared at a time is comparatively lower, but the rate of production and transfer is much faster than the first approach. In effect, both these methods of blending are not good enough to produce the ETB mixes at an economical rate. This is currently the major challenge faced by the field engineers and contractors for implementing this technology in the field. However, it is understood that many states in India owns WMM batch mixing plants, where it is possible to blend aggregates and emulsion in large quantity and that too at affordable rates. Such a mechanism is necessary for the implementation of ETB technology at affordable rates.

Figure 3: Preparation of ETB using Ajax mobile concrete mixer

Figure 4: Preparation of ETB using conventional concrete drum mixer

The ETB mixes were laid in two lifts of 100 mm each and was compacted to 75 mm using a static roller of 8 tonne capacity. The target thickness of ETB was 150 mm and it was ensured by checking the levels as shown in Figure 5. In order to evaluate the density achieved at the field, sand replacement test was conducted as shown in Figure 6. However, it was inferred that the density achieved at the field was only 93-95% of Maximum Dry Density (MDD) obtained under laboratory condition. This is primarily due to variation in the field gradation from the target gradation and also due to insufficient compaction. Although it was aimed to achieve the target mid gradation specified for ETB in IRC 37 (2012), the actual gradation achieved at the field was very much closer to the lower limit of the aggregate gradation specified for ETB. Suppose if a vibratory roller of 8 tonne capacity was used for the compaction, the density would have been much better than that achieved by the static roller.

Figure 5: Verification of layer thickness

Figure 6: Sand replacement test on ETB

In order to compare the behaviour and performance of ETB with conventional granular base layers, an additional test section was constructed using WMM, following the guidelines specified in MoRD (2014). Figure 7 and Figure 8 respectively shows the compacted surfaces of ETB and WMM layer. The construction of WMM layer was completed at a much faster rate as it does not require blending of aggregate with emulsion and active filler. However, there are several other practical difficulties associated with the construction of WMM layer. The surfacing of WMM layer is often completed only after a minimum period of 7 days, considering the time for technical approval of the layer and time required for arranging the additional material required for the construction of surface layer. Since the aggregates in WMM are completely unbound, the material starts to get separated due to construction traffic. This creates substantial problem of air pollution and the workers often need to level the WMM surface prior to the construction of the next layer. Since the aggregates in ETB is partially bound, there is only minimal loss of aggregates and hence the pollution associated with the construction traffic will be significantly reduced. In the present study, the surface layer for all the seven test sections, were constructed using 20 mm OGPC and 6 mm seal coat. The pavement was opened to traffic in November 2020.

Figure 7: Compacted ETB surface

Figure 8: Compacted WMM surface

2.3. Strength gain in emulsion treated base layers

One of the major concerns associated with the field application of ETB is the uncertainty associated with the initial strength gain. It is evident that the ETB layer will have an improved modulus value, when compared with conventional granular base layer materials. But it important to estimate the moduli value mobilized at the field, so as to design LVR with ETB, following mechanistic empirical design principles. Hence attempts were made in the present study, to evaluate immediate strength gain using changes in DCP slope and to evaluate early age strength using back calculated moduli. In the present study, immediate strength gain refers to the condition of ETB layer during the first two weeks of curing and early age strength refers to the strength of ETB layer after 1 year of service life. The design strength for ETB with 3% emulsion and 1% cement, cured at 40 °C for 72 hours was 230 kPa. As per the specifications of Indian Road Congress (IRC 37, 2012) guidelines, the minimum dry ITS for 100 mm dimeter sample is 225 kPa. It was important to understand the minimum number of days required to attain at least 90% of the design strength. Hence ITS samples were prepared using the field mixes and was kept exposed to air, so as to attain similar curing conditions as that of the actual pavement. 12 samples of 100 mm diameter samples were prepared and 3 each from the total set was tested after 1 day, 4 days, 7 days and 14 days. Although the field density immediately after compaction was only 95% of MDD, samples were prepared at 97% of MDD, with the assumption that the field density will gradually increase during the first few days, due to the combined effect of curing and densification. The percentage curing of these samples was evaluated in terms of the weight loss of the samples. ITS value depends up on the curing conditions of the specimen and hence the percentage curing of the ETB mix at the field, along with the density of the mix can give a rough estimate of the ITS strength attained by the ETB layer. Dynamic Cone Penetration (DCP) test was conducted immediately after construction and also after 1 day, 4 days, 7 days and 14 days of construction. It is expected that DCP slope would reduce as the curing progresses and hence DCP slope can provide a rough estimate of the amount of curing and thereby ITS value attained by the ETB layer. Figure 9 and Figure 10 respectively shows the ETB Layer immediately after construction and also after 24 hours of curing. It can be inferred that an appreciable curing has occurred during the first 24 hours and hence colour of the ETB layer has slightly changed. Figure 11 and Figure 12 respectively shows the DCP test and ITS test conducted on the ETB layer.

Figure 9: ETB after construction

Figure 10: ETB after 24 hours curing

Figure 11: DCP Test

Figure 12: ITS test

2.4. Performance evaluation of emulsion treated base layers using FWD

The field performance of the six ETB test sections were evaluated by assessing the back calculated moduli of the layers after 1 year of service life and comparing with that of conventional unbound granular base layers. The deflection bowl data was captured using FWD and the moduli was back calculated using KGPBACK software, following the guidelines outlined in IRC 115 (2014). Figure 13 and Figure 14 respectively shows the loading unit and the geophones attached to the FWD. A load of 200 Kg was dropped from a pre-determined height to a loading plate of 300 mm diameter, so as to develop a load of 40 kN force. The machine automatically adjusts the height, such that the required force is developed on the plate. The deflections produced at radial distances are captured using geophones. This deflection data was further used for back calculating the moduli of each individual layers, using KGPBACK software. KGPBACK is a genetic algorithm based model for back calculation of layer moduli. Back calculation using genetic algorithm requires a moduli range as input and does not require any seed moduli (IRC 115, 2014). KGPBACK is the commonly used software in India for the back calculation of elastic properties of existing pavement layers. The elastic properties of the existing pavement layers evaluated using this software can be used as the input to forward calculation software like IITPAVE, which can assess the critical mechanistic parameters of the pavement.

Figure 13: FWD loading unit

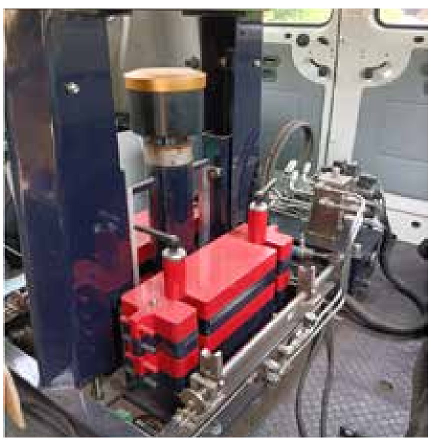


Figure 14: Loading plate and geophones

3. Results

3.1. DCP Slope and Indirect Tensile Strength of ETB mixes

In the present study, the immediate strength gain of ETB was evaluated in terms of reduction of DCP slope and increase in the ITS value of field cured samples. The percentage curing was also evaluated in terms of weight loss and the results obtained after 1 day, 4 days, 7 days and 14 days are summarised in Table 4. It can be inferred that the rate of curing will be faster during first 4 days and thereafter it slows down. It is expected that approximately 10% of the water will be taken up by the cement for the hydration process and hence the maximum curing in terms of weight loss, that can be expected from ETB is only around 90%. It was also inferred that major part of the curing process was completed after 7 days and there was no significant curing after that. This information will be extremely beneficial in deciding the minimum curing period required prior to the application of surface layer for ETB.

Table 4: Strength gain in ETB with 3% emulsion and 1% cement

No: of Days	Field density (g/cc)	Relative compaction	Percentage curing	DCP slope (mm/ blow)	ITS (kPa)
0	2.124	94.4%	10%	5.0	N.A.
1	2.140	95.1%	40%	4.0	114
4	2.156	95.8%	60%	3.5	188
7	2.162	96.1%	80%	2.5	208
14	2.187	97.2%	85%	2.4	220

Table 5: Climatic conditions at the test section

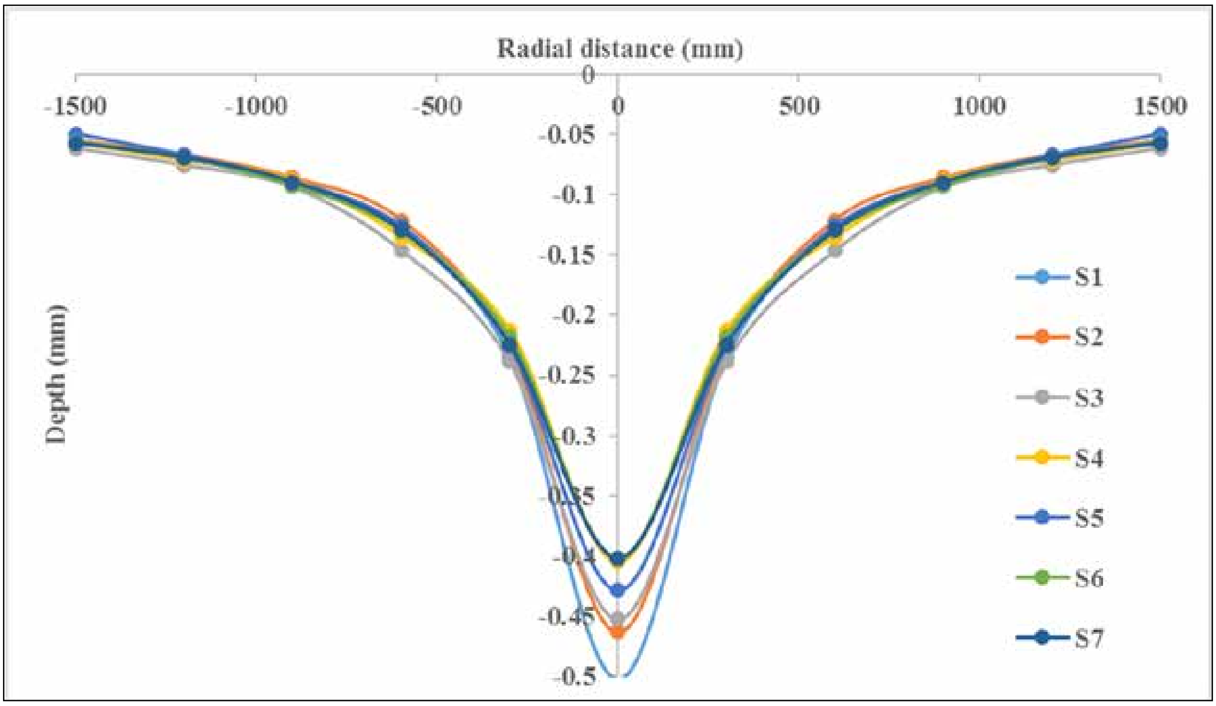
Parameter	Morning	Afternoon	Evening
Atmospheric temperature	24 °C	34 °C	26 °C
Humidity	99%	52%	88%
Probability of precipitation	1%	0%	0%
Wind speed	6 kmph	16 kmph	6 kmph

It should be noted that the strength gain reported in the present study may not be applicable for all pavements with ETB as it largely depends up on the environmental conditions prevailing at the construction site. The climatic conditions at the test section, during the period of construction is summarised in Table 5. It is practically difficult to collect field cured samples from each construction site and assess the minimum period after which the layer gains 90% of the design strength. Hence it is recommended to test the DCP slope and correlate that with the expected ITS of the ETB layer. As per TG 2 (2009), ETB can be considered under top most category when the DCP slope is less than 3.7 mm/blow. It is also possible to evaluate the expected ITS of the layer using percentage curing of the ETB mixes. However, this would give a realistic estimate only if the pavement is compacted to more than 97% of MDD.

3.2. Deflection bowl data

Data collection using FWD starts with the generation of a load pulse which is produced by dropping 200 kg weight from a predetermined height. The deflected shape of the pavement surface is measured by 9 geophones placed at radial distances of 0 mm, 200 mm, 300 mm, 450 mm, 600 mm, 900 mm, 1100 mm, 1300 mm and 1500 mm from the centre of the load. The duration of impulse load is maintained in the range of 25 to 30 ms, which is approximately equal to the time needed to traverse the length of a tyre imprint at a speed of about 60 kmph. As per the guidelines of IRC 115 (2014), the peak load was maintained as 40 kN. When the peak loads differ from 40 kN, the measured deflections were normalized to correspond to the standard load of 40 kN. The normalizations of deflections were done linearly since the entire analysis of pavement design is based on linear elastic layered theory. Before starting the testing procedure, FWD was positioned over the test location in such a way that the loading plate can be placed directly above the identified location. Since the pavement under consideration was a single-lane two-way carriageway, load was placed at 0.6 m from the outer edge of the pavement. Geophone frame is slowly brought down to the pavement surface, so that the probes of the geophones touch the ground. Loading plate now presses against the pavement and the wheels of the vehicle get slightly lifted up from the ground level. An initial drop is given as seating load to ensure conditioning of the test location. Then the mass is raised again and the process is repeated three times. The deflection bowl data obtained corresponding to the 7 test sections are illustrated in Figure 15. While the loading process takes place, the data acquisition software is triggered by a position sensor to record the output from the load cell and geophones. Data is processed by the software to determine the magnitude of the applied load and the surface deflections at different geophones. If the magnitude of deflection at the farthest geophone is not within the permissible range, the test was repeated. Air and pavement temperatures, as well as the load impulse time is measured at the time of drops. From Figure 15, it can be inferred that the deflection bowl of test section with WMM layer was much deeper than that of the pavements with ETB layer. The depth of the bowl is found to decrease with emulsion content, indicating the improved structural support from ETB with higher emulsion content.

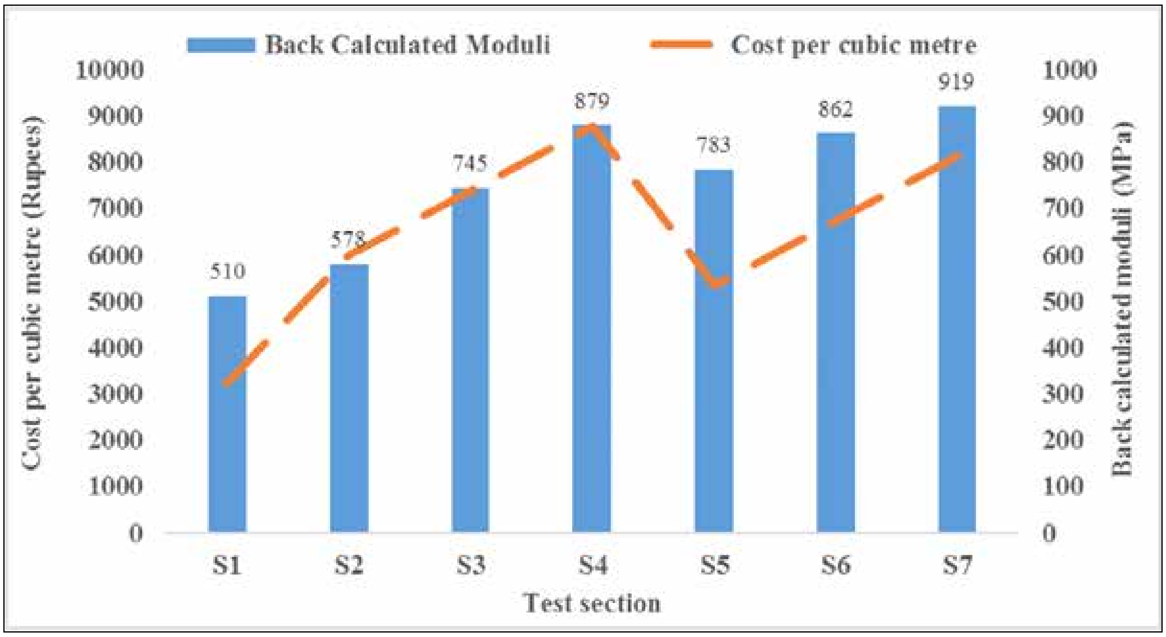
Figure 15: Deflection bowl data obtained from the 7 test sections



3.3. Comparison of Back Calculated Moduli and Construction Cost

For back calculating the layer moduli using KGPBACK software, the user has to input upper and lower limits of the moduli value, along with other information like peak load applied, Poisson's ratio, layer thickness, observed deflections and position of geophones. Back calculation using KGPBACK software was be done by considering the pavement as a three-layer system. 20 mm thick surface layer and the 150 mm base layer were combined together as the top most layer. Similarly, granular materials consisting of the sub base layer was considered as the middle layer and subgrade was considered as the bottom most layer. According to the recommendations of IRC 37 (2018), a value of 0.35 was assumed as the Poisson's ratio for bituminous layer, granular layer and subgrade. The moduli range recommended by IRC 115 (2014) for thick bituminous layer is 750- 3000 MPa. Since the top layer in this analysis is assumed to be a combination of 20 mm OGPC and 150 mm base, 600-1200 MPa was assumed as the input moduli range for the top most layer. However, the range of input moduli value was suitably adjusted depending upon the expected output moduli value. Although the recommended range of granular layer moduli is 100-500 MPa, a slightly higher range of 200-600 MPa was used in this analysis, since it was suspected that the moduli of sub base at some location was more than 500 MPa. Generally, it is recommended to select 5 to 20 times CBR as the moduli range for subgrade. In the present study, it was decided to select 50-200 MPa as the moduli range for subgrade. The back calculated moduli obtained corresponding to the 7 test sections are summarised in Figure 16. The cost of each test sections, calculated based on estimate data available in PRICE software, is also reported along with the back calculated moduli. It can be inferred that benefit of using ETB can be significantly improved when RAP is incorporated to the ETB mix.

Figure 16: Comparison of back calculated moduli and construction cost



4. Discussion

The major findings of the present study are summarised as follows:

- Considering the limited availability of fund allocated to individual road construction projects, field engineers often hesitate to use ETB, due to its increased material cost. Based on the back calculated moduli obtained from the present study, it can be inferred that the increased cost of construction material can be compromised by suitably designing the layer thickness, based on the appropriate moduli value of ETB layer.

- The current method of ETB mix preparation imposes additional financial burden on the contractors. Moreover, the ETB mix produced using conventional concrete mixers are found to undergo segregation, which may severely affect the uniformity of the ETB mix. The current issues can be resolved by suitably modifying the WMM mixing plant to incorporate facilities for blending aggregate with the design emulsion content, pre-mixing water content and active filler.
- The rate of strength gain of emulsion depends primarily on the breaking and curing process of bituminous emulsion. Breaking is not a major concern under normal circumstances, since the emulsions can be customized for a given aggregate type. However, curing can be a major concern when the atmospheric conditions does not favour evaporation of water from the surface. In the present study, the climatic conditions were favourable to facilitate curing and hence the ETB layer gained sufficient strength within 7 days of curing. It is strongly recommended that the ETB layer construction should be done only when the environmental conditions facilitate curing of emulsion.
- The surfacing of ETB layer should be done only when the ETB material gains at least 90 percent of its design strength. This can be ensured by conducting DCP test on ETB layer, or by checking the percentage curing of the mix, when the mix is compacted to more than 97% of MDD. However, exposing the ETB layer to more than 14 days should also be avoided, as it may result in loss of aggregates from the ETB layer.
- Construction of base layers using conventional unbound granular materials such as the WMM possess the threat of loss of aggregates due to construction traffic and the resulting air pollution. This condition can be eliminated by the use of ETB, which can act as a partially bound layer.
- Although ETB materials require sufficient time to gain initial strength, its performance at the end of 1 year was found to be much better than the conventional unbound granular base layers. The moduli of ETB at the end of 1 year service period was found to be 1.5 to 2 times that of WMM layer, depending on the dosage of emulsion used. Considering the shortage for virgin aggregates, use of ETB with improved moduli value is highly appreciable to reduce the requirement of virgin aggregates for pavement construction.
- Although ETB layer ensures much improved structural support, the cost of ETB construction still remains as a matter of concern. ETB layer can be economical only when it is used along with RAP materials. In addition to material savings, RAP materials are found to facilitate improved binding of the ETB material, which was reflected in its back calculated moduli. However, extreme care should be taken while fixing the proportion of RAP to be used, so that the combined aggregate gradation lies within the specified range recommended for ETB.
- One of the most important advantages of using ETB in LVR is that it opens up the possibility of applying BC layer without a binder course. As per the present guidelines, BC can be applied only along with a binder course and it is not possible to apply a dense bituminous layer directly over the unbound granular layer. But since ETB exhibits a moduli value very close to that of the binder course, it is possible to apply BC layer directly over the ETB layer. In effect, ETB layer is capable enough to replace both the WMM layer and BM layer, thereby making it possible to have an economical construction practise for LVR.

5. Conclusion

From the present study, it was inferred that the ETB layer has a huge potential in pavement construction, especially for LVR. Considering the improved field performance of ETB, it is possible to reduce the need for virgin aggregates and also facilitate the use of RAP materials. Moreover, the use of ETB in LVR brings in the possibility of using BC surfacing in LVR, without the additional cost of binder courses. However, there are a few challenges that need to be addressed. The construction of ETB layer can be done economically only if suitable batch mixing plants are made available to contractors. The early age strength still remains a matter of concern due to the uncertainty associated with the immediate strength gain. The DCP slope, field density and percentage curing can be considered as the indicators for evaluating the strength gain of ETB layer. ETB layers for LVR can be constructed economically only when it is used along with limited proportion of RAP materials. RAP materials have huge potential in pavement construction, as they reduce the need for virgin aggregates and facilitate the binding of ETB mixes. Full Depth Reclamation (FDR) can be one of the best options to be adopted along with emulsion stabilisation, as it reduces the need for virgin aggregates and help to reduce the construction cost by a substantial amount.

6. Acknowledgement

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Performance Evaluation of Cold Bituminous Mix Thin Surfaced Rural Roads

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Abstract

Conventionally, hot bituminous mix is used is the construction of wearing course for rural roads in India, which is energy and emissions intensive involving on-site heating. As an eco-friendly solution, recently cold bituminous mix (CBM) technology is becoming popular for thin surfacing in rural roads. Thousands of kilometres of rural roads have been constructed using CBM across the country under the famous rural connectivity programme, PMGSY. Taking up an initiative from National Rural Infrastructure Development Agency (NRIDA), twenty-seven rural roads constructed using cold mix technology in the state of Odisha were evaluated during pre- and post-monsoon seasons. The test tracks are located in different geographical locations in the state of Orissa and catering to different traffic levels. A few conventionally surfaced roads were also evaluated for comparison purpose. It was observed that raveling and potholes are major distresses and monsoon has significant impact on the pavement condition index (PCI) of the CBM roads. Roads constructed using CBM were found to be comparable with hot bituminous mix roads under similar conditions, however considering the environmental benefits, CBM technology can be considered sustainable in a long run.

Keywords: Cold mix technology, Performance Evaluation, Rural Roads, Pavement Condition Index

1. Introduction

Road infrastructure development is an integral part of socio-economic development of the country. Traditionally hot bituminous mixture has been used for construction of surfacing of rural roads, which is both energy and emissions intensive as it involves on-site heating to produce the mix. A study by Olsen et al (2021) showed that there is increased risk of reduced lung function and lung cancer among the labours working with hot mix asphalt. Considering the issues associated with the environmental impact of conventional methods, there was a need to develop alternate technologies, which can provide a balance between environment impact and long term performance. Therefore, more recently, cold mix technology has become popular for the construction of thin surfacing in rural roads. In case of CBM, the production of bituminous mixture is done at ambient temperature without application of heat. The application of CBM in rural roads in lieu of hot bituminous mixes provides some benefits as listed below:

- Environmental impact is lower in CBM as compared to hot mix
- Less dependence on the construction equipment for heating the aggregates and bitumen
- Creation of employment opportunities for rural dwellers

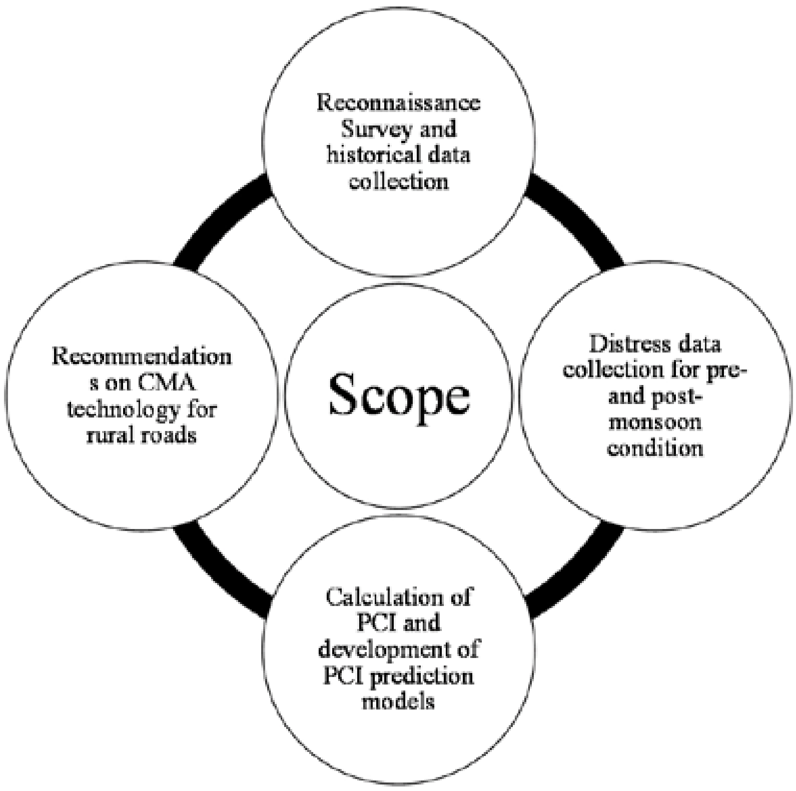
- Easiness in implementing in difficult terrains, where carrying equipment for hot mix will be difficult
- Less impact on the health of the occupational workers
- Reduced ageing of the mixtures

Thousands of kilometers of rural roads have been constructed using CBM across the country, under the Pradhan Mantri Gram Sadak Yojana (PMGSY). Taking up an initiative from NRIDA, twenty-seven rural roads constructed in the state of Odisha using cold mix technology were evaluated by IIT Bhubaneswar. A few conventionally surfaced roads using hot mix were also evaluated for comparison purpose. The primary objective of the present study was to conduct the performance evaluation of CBM rural pavements constructed in the state of Odisha.

2. Methodology

The scope of the study is presented in Figure 1. Rural Roads constructed using CBM with varying age, soil and traffic conditions were taken up for this study. The CBM and conventional sections selected had similar traffic and environmental conditions. Structural and functional condition evaluations were conducted during pre and post monsoon seasons and pavements were rated as per the guidelines given in IRC:82 (2015) and ASTM D6433 (2020). Environmental impact assessment of the road projects with conventional hot mix and CBM was also conducted to quantify the environmental benefits of the new technology.

Figure 1: Scope of the Research Study

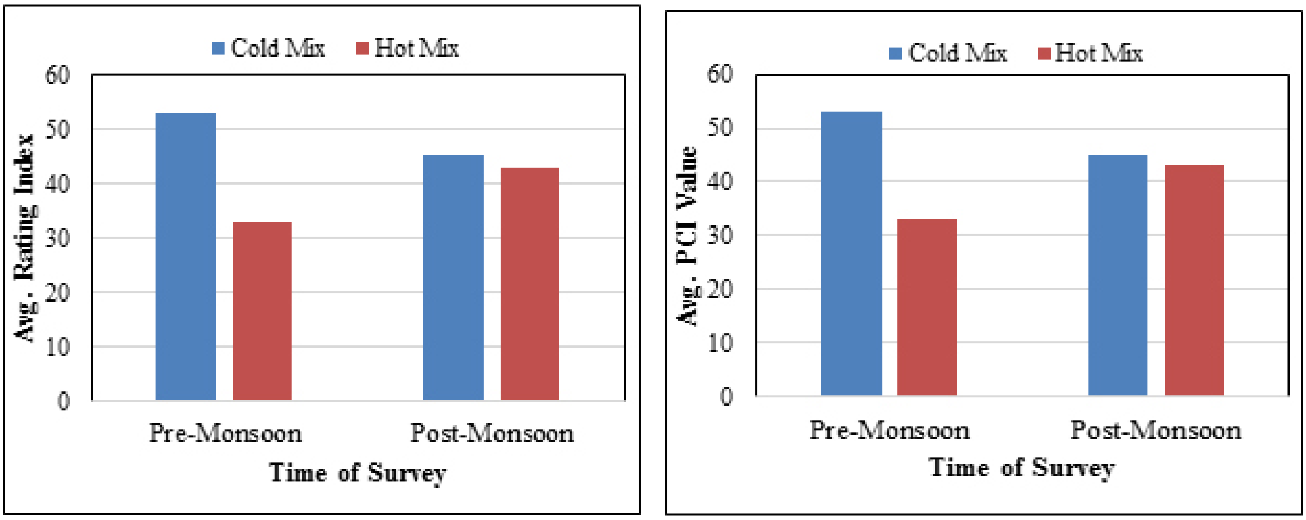


3. Performance Evaluation

3.1. Rating Indices

Performance indices in terms of rating index as per IRC and PCI as per ASTM method were estimated from the pavement condition survey data. The average rating indices for all the roads are presented in Figure 2.

Figure 2: (a) Rating index as per IRC:82-2015; (b) PCI as per ASTM D6433



It may be seen from Figure 2 that in the pre-monsoon condition, the rating indices for CBM pavements are found to be higher compared to conventional pavements, however, the difference is less in post monsoon season. But in both the conditions, the CBM pavements depicted better rating than conventional pavements.

3.2. Performance Modeling

The performance of CBM pavements was modeled using the distress data collected during this study from five districts, (i.e. Puri, Ganjam, Kendujhar, Balasore and Cuttack) encompassing twelve test sections. The performance model developed is given by Eq. 1.

$$PCl_t = PCl_0 - 15.553 - 0.697(t - t_0) \quad (1)$$

Where,

PCI_t = Pavement condition index at any age 't'

PCL_0 = Pavement condition index measured during last survey

t = Age of pavement in months corresponding to PCI_t

t_0 = Age of pavement in months corresponding to PCI_0

This model can be used to assess the change in the PCI as a function of the age of the pavement. The predicted change in the PCI for future years are shown in Figure 3. It may be seen that to reach a PCI of 55 (that corresponds to poor condition), most of the sections may take about 4-5 years. Further, if the present age of individual sections are added, the life of CBM roads may be between 6-8 years necessitating major rehabilitation.

Figure 3: Performance of CBM sections

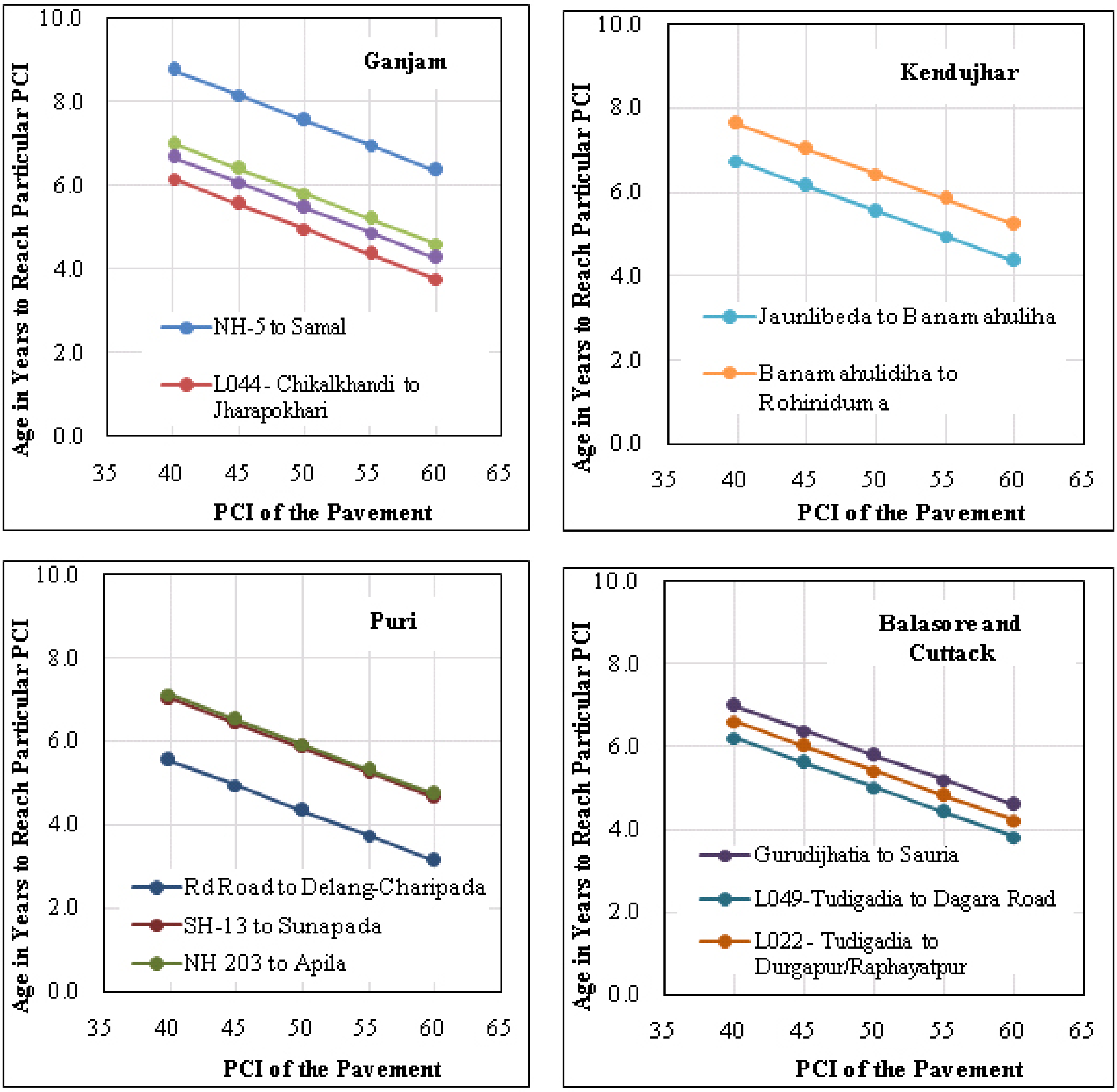
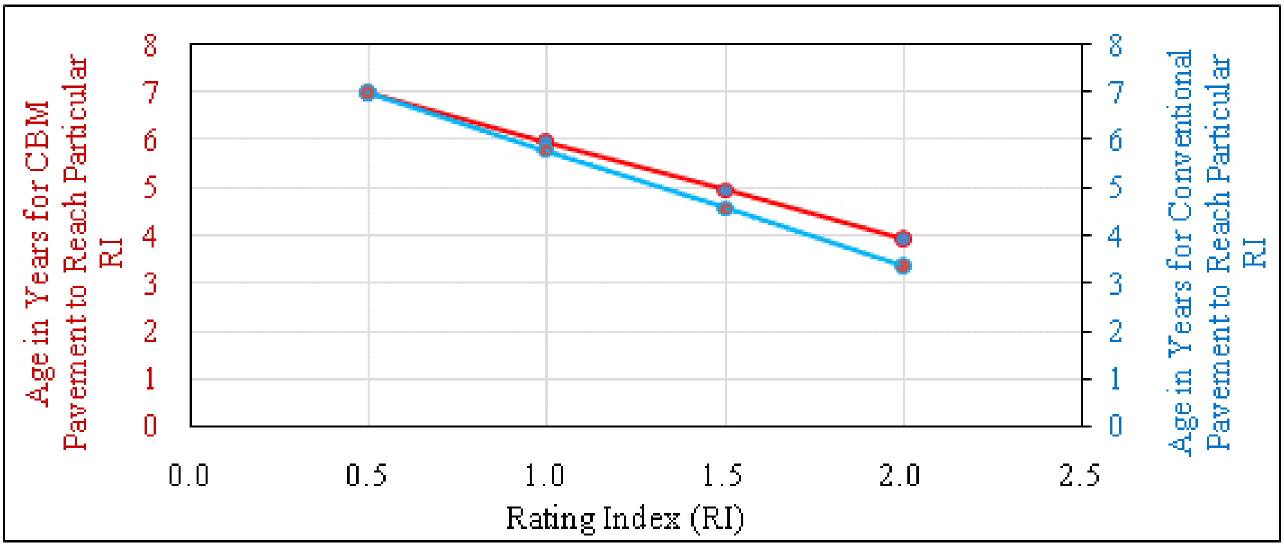


Figure 4 shows the performance comparison of CBM and conventional pavement sections in terms of duration in years, which is required to reach a particular rating index. It may be seen that, if the terminal rating index is 1.0, both the CBM and conventional pavements reach this condition at almost similar time and therefore, the maintenance requirements will be similar.

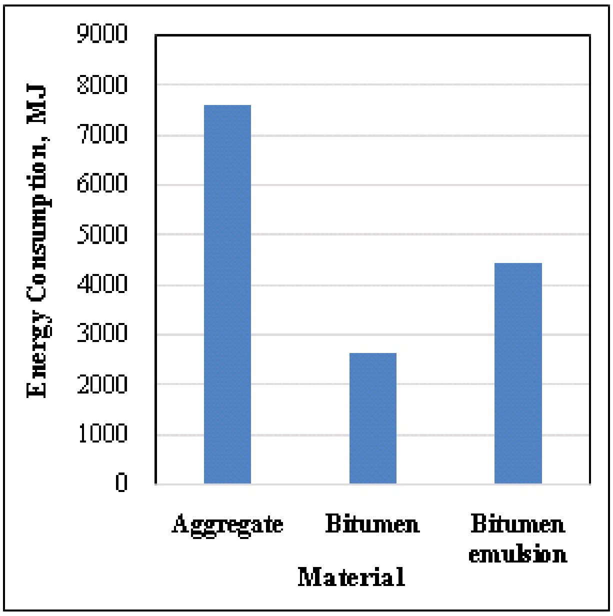
Figure 4: Rating of Pavement Sections to Reach a Particular PCI



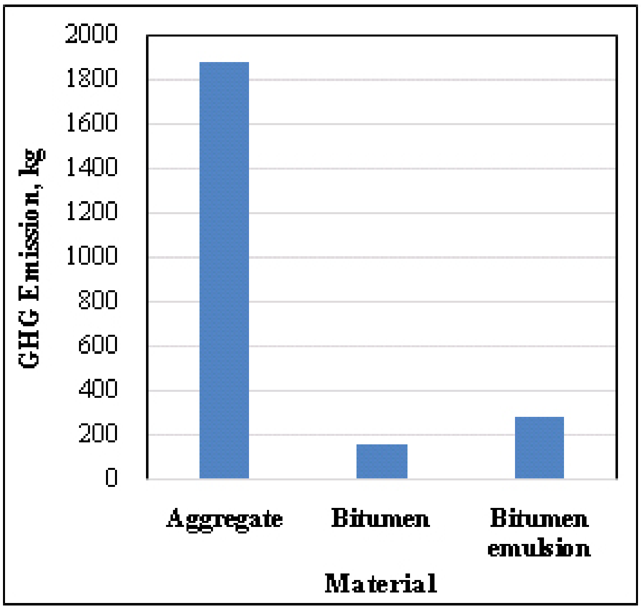
4. Environmental Impact Assessment(EIA)

The EIA was performed by comparing energy consumption and GHG emission for individual materials production and production of mixtures. The functional unit of 1.0 km and 3.5 m wide road was considered. The energy consumption factors were adopted from the study by Chehovits and Galehouse (2010). The energy consumption and GHGs under different stages are shown in Figure 5.

Figure 5: Energy Consumption and GHG Emission Comparison

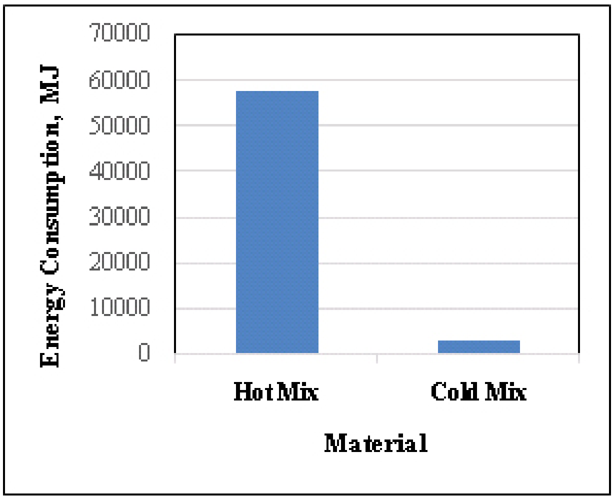


(a) Energy Consumption for Producing Individual Materials

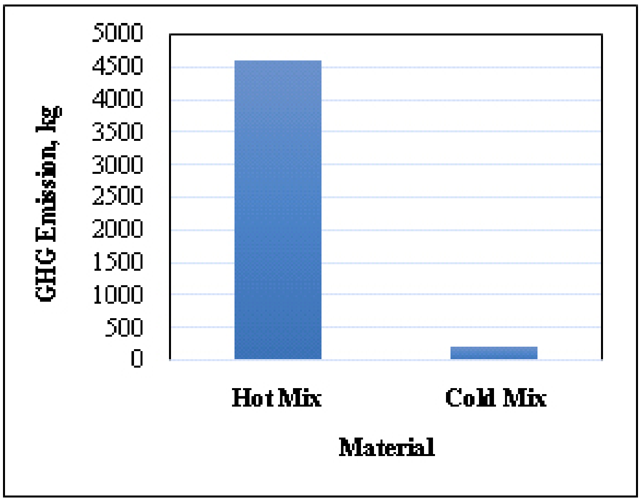


(b) GHG Emission associated with Production of Individual Materials

Figure 5: Contd...



(c) Energy Consumption from Different Layers



(d) GHG Emissions from Different Layers

Figure 5 shows that at the production stage, the energy consumed by bitumen emulsion is almost twice of that required for hot bituminous mix production. This is due to the fact that bitumen has to be heated and further processed to manufacture bitumen emulsion, which includes energy consumed for heating, energy consumed by the colloidal mill, and energy consumption associated with emulsifiers, stabilizers, etc. However, in the mix production stage, the energy consumed by cold mix is significantly lower than that required for hot mix. On the other hand, hot mix requires almost 20 times more energy than that required for cold mix. This energy is predominantly consumed in the form of fossil fuels required to heat the aggregates and bitumen. Further, the GHG emissions from cold mix production are significantly lower than hot mix, by 22 times. All these results indicate that CBM is a sustainable pavement material with significantly lower impact on the environment.

5. Conclusions

Based on the limited field studies conducted in the state of Odisha, the following conclusions could be made:

- Performance of roads with CBM is comparable with the conventional hot bituminous mix surfacing for rural roads
- The study found that an average period of 6-8 years is required to reach PCI value 55 for low volume rural roads with CBM surfacing. A similar duration was also observed for the conventional hot mix surfaced pavements, which indicates similar performance characteristics.
- The energy consumption and GHG emissions during the production of CBM was found to be considerably lower than the hot bituminous mixtures. Moreover, large scale implementation of this technology will decrease the carbon footprint of rural roads significantly.

Further studies taken up in other parts of the country will provide a more generalized conclusion on the use of cold bituminous mixes for construction of low volume road surfacing.

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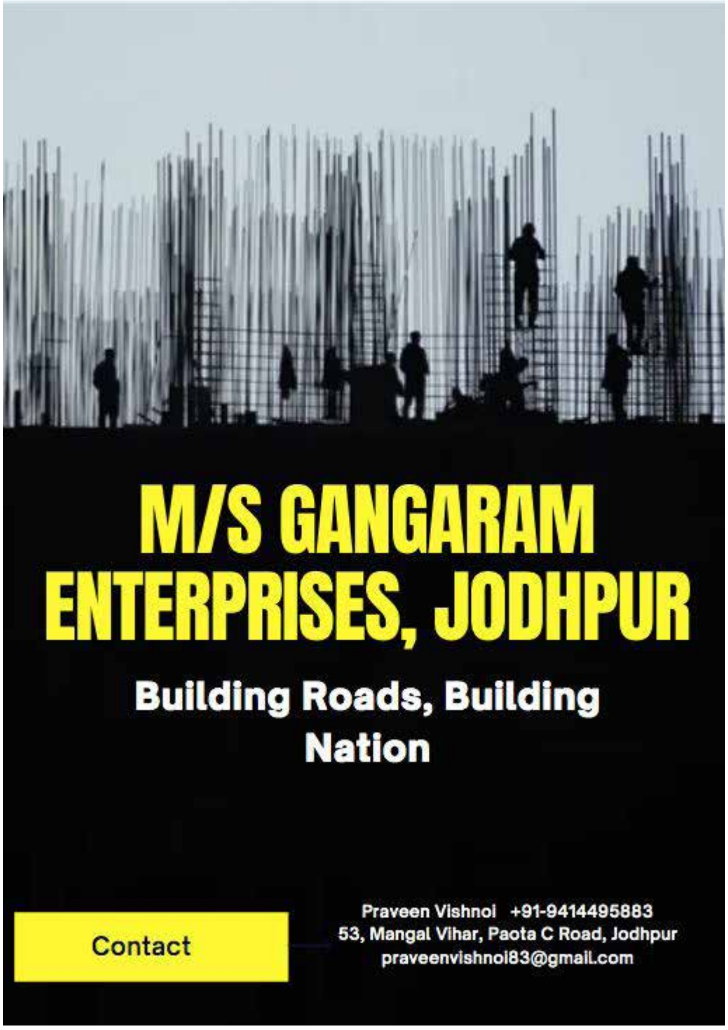

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Rapid Roads (Precast) System for Rural Roads

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Abstract

In India, over 67% population still lives in rural areas. Most of rural areas in India do not have access to all-weather roads and have tough times during monsoons. India has grown rapidly and providing access to all villages with all-weather roads has become a challenge and a matter of concern.

Identification of Problem

- Rural Poverty is often a product of poor infrastructure that hinders development and mobility. Rural areas tend to lack sufficient roads that would increase access to agriculture inputs and markets.
- Without roads, the rural poor are cut off from technological development and emerging markets in more urban areas.
- It also linked to poor health and low school enrolment, Rural isolation can imprison the elderly and people with disabilities.

1. Introduction

Today, world of roads mostly practicing heritage method of construction worldwide, however, flexible pavements are taken over by conventional rigid pavements to some extent. But it is fact that, nothing has been changed in the technology except mechanization. Today long span bridges, flyovers, high rise buildings, industrial complexes, tunnels, railways project etc., all experiencing the advent of precast/prefab technologies. It is unfortunate that, the road sector still struggling largely with bitumen as a road material which is highly reactive/sensitive to all type of weathers (summer, winter & rains). Thus, bitumen roads have got very less life. The stakeholders never changed their mind-set to perceive alternate methods/technologies which go with today modern world. However, ***Rapid Roads (Precast) System*** is an attempt to change the method of road construction to begin with rural or low volume roads and can be extended to medium to high volume roads with suitable changes as desired.

2. What is Rapid Roads System?

Rapid Roads System defines, *that the precast technology in which the pavements(panels) are manufactured at factories as per design, lane widths with varied thickness by using greener materials like flyash/ggbs as permitted. These pavements are transported to site, assembled and post-tensioned along the length of the road. This enables to complete roads faster, such roads become durable, long lasting, maintenance free, thus become sustainable.*

Rapid Roads System (RRS) are designed & manufactured to suits the required soil strengths and traffic capacities. The joints are designed, made easy to handle/assemble and taken care of contraction/expansion as well as construction requirements. These pavements come with details procedure for installations, precaution, and warranty et. complete.

The surface finish can be varied depend upon the usages like all type of roads, cycle/jagging tracks and foot path for pedestrians. RRS can be applied to railway platforms, industrial floors, plinth floors etc…

3. Relook at Bitumen Roads- Why?

- As most of the roads are of bitumen (flexible), the failure of flexible pavements is perennial due to increase in traffic and climatic conditions, thus, these pavements are non-sustainable against weathering.
- The bitumen, however, as a binding material is sensitive & reactive to weather(seasons) – during summer, bitumen pavement will expand too much, starts to crack, (sometimes melts), eventually allow water to seep-in leads to sag and form depression, may worsen to potholes.
- During winter, the temperature drops again, the water freezes and expands, pushing the crack outward also leads to distress & failure of pavement.
- More so bitumen pavements are vulnerable to rains & floods results, giveaway the surface, thus, exposing aggregate or base material for traffic leads to complete failure.
- Hence, with bitumen as a binding material, one can't build all weather roads or long-lasting sustainable pavements.
- Bitumen road requires maintenance of every 1-2 years and resurfacing/strengthening every 5 years.
- The very significant finding for Indian conditions where overloading is common in rural areas for want of river sand/other natural resources. The bitumen roads are bound fail under such loading condition.
- Bitumen roads usually requires more layers of base granular materials and require large quantities of natural resources. Soil treatment, stabilisation/mixing techniques are also unsustainable against life of pavements.

4. Features of Rapid Roads System

Rapid Roads System has following key features.

- Panels are casted for single, double lane widths with designed thickness at factory.
- Use of Smart Dynamic Concrete –SDC (Low Flow SCC) in place of Bitumen or PQC for panels casting.
- Use of greener/cementitious materials like fly ash & ggbs extensively in the production of SDC.
- Panels are textured, cured, coloured (if required) and tested for quality at factory.
- Panels are transported, assembled, post-tensioned & grouted at site as specified.

5. Advantages of Rapid Roads System

- Rapid Roads System can enable to open to traffic immediately after installation.
- Rapid Roads System save time & user cost.
- Rapid Roads System can enable to construct the roads at all seasons.
- Rapid Roads System allow to lift & transport roads to remote places.
- Rapid Roads System can withstand overloads and resist against deflections.
- Rapid Roads System offer long life and maintenance free roads.

- Rapid Roads elements can be easily replaceable if required.
- Rapid Roads System allow to take up any CD works by releasing the cable, remove panels and re use same panels after completion of CD works without any damage.
- Rapid Roads System empower to retrieve the panels during heavy floods/washed away roads and same panels can be used for immediate restoration of roads.

6. Stages of Construction (RRS)

For new roads (with Subgrade + GSB)

- Surface preparation for bedding.
- Placing of Polythene sheet.
- Placing of DLC for bedding/levelling course.
- Installation/assembly of panels (tong & groove).
- Post-tensioning of panels at regular intervals.
- Grouting as desired.
- Open to traffic.

7. For Existing Bitumen Roads

- Milling of top surface.
- Cleaning of milled surface.
- Installation/assembly of panels (tong & groove).
- Post-tensioning of panels at regular intervals.
- Grouting under panels to establish the proper contact.
- Curing of grout.
- Open to traffic.

8. Rapid Roads System - Project @ Bangalore






9. Conclusion

- The adaptation of new technologies like Rapid Roads System, 3D Printed Roads will lead to efficient and long-lasting solution to gigantic problem of connecting all the villages with all-weather roads.
- To overcome problems associated with bitumen roads, adaption of Rapid Roads System will be a game changer, revolutionary technology, provided all the stake holders embrace developments and work further in this direction.
- There is an urgent need to further refine engineering and technical guidelines for the planning and execution of rural or low volume road construction and maintenance, so that the infrastructure created under such programs is sustainable, context sensitive, and compliant with liveability principles.
- Provide more transportation choices. develop safe, reliable, and economical solutions to decrease household transportation costs, reduce nation's dependence on foreign oil, improve air quality, reduce GHG emissions, and promote public health and education.

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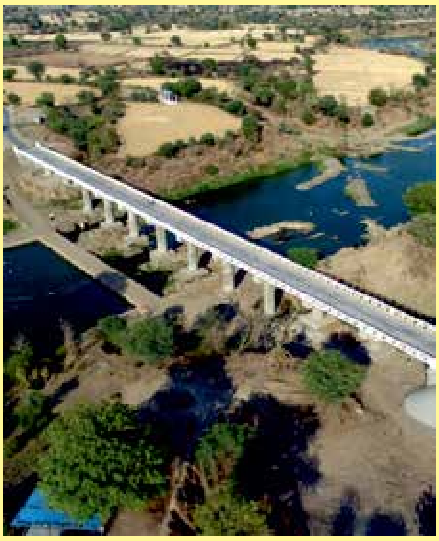

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- Efficient maintenance system for DLP & Post DLP roads including renewal.
- Transparent and quick tendering process.
- Development of e-Marg concept for monitoring of maintenance.
- Development of software (SAMVEG) for technical and administrative sanctions of maintenance work.

Department of Panchayat and Rural Development

Designed by M.P. Madhyam/2022

NOTES

MUGRODY CONSTRUCTIONS

Civil Engineers, Builders & Class I Contractors

Managing Partner

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