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

Azadi Ka Amrit Mahotsav

Pradhan Mantri Gram Sadak Yojana

Full Depth Reclamation for Rehabilitation of Low Volume Roads

May 2022

Full Depth Reclamation for Rehabilitation of Low Volume Roads

May 2022

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

This document is for wide dissemination amongst the stakeholders connected with construction and maintenance of Rural (low volume) Roads, such as PTAs/STAs, Engineers, Quality Monitors, Contractors, Field Supervisors etc.

ग्रामीण विकास मंत्रालय राष्ट्रीय
ग्रामीण अवसरंचना विकास एजेंसी
भारत सरकार

Azadi Ka Amrit Mahotsav

प्रधान मंत्री
ग्राम सड़क योजना

साध्वी निरंजन ज्योति

मा० राज्यमंत्री ग्रामीण विकास एवं उपभोक्ता मामले, खाद्य और सार्वजनिक वितरण मंत्रालय, भारत सरकार

श्री गिरिराज सिंह

मा० मंत्री ग्रामीण विकास एवं पंचायती राज मंत्रालय, भारत सरकार

श्री फग्गन सिंह कुलस्ते

मा० राज्यमंत्री
ग्रामीण विकास एवं इस्पात मंत्रालय, भारत सरकार

के प्रेरणादायी और कुशल नेतृत्व एवं मार्गदर्शन में प्रधान मंत्री ग्राम सड़क योजना का सफल क्रियान्वयन हो रहा है।

यह योजना देश की ग्रामीण आबादी को सड़क संपर्क उपलब्ध करा कर उनके चहुंमुखी विकास में सहायक सिद्ध हो रही है।

इस प्रकार ग्रामीण विकास मंत्रालय राष्ट्र निर्माण के क्षेत्र में उत्तरोत्तर प्रगति के पथ पर अग्रसर है और निरंतर सफलता की नई ऊंचाइयों को छू रहा है।

Shri Nagendra Nath Sinha, IAS
Secretary
Ministry of Rural Development
Government of India

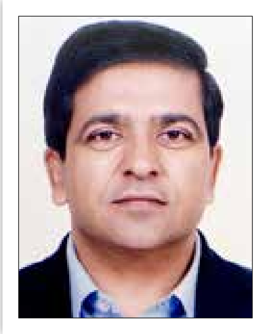
MESSAGE

Rural road connectivity is a key component of Rural Development for promoting access to economic and social services. Pradhan Mantri Gram Sadak Yojana (PMGSY) plays a vital role in this direction and the roads constructed under the programme are important part of the poverty reduction strategy. Their continued existence is absolutely essential to achieve the intended objective. Pradhan Mantra Gram Sadak Yojana (PMGSY) was launched in the year 2000 with an objective of providing all-weather road connectivity to all eligible unconnected habitations in rural areas of country.

Aiming to cover upgradation of existing selected rural roads based on their economic potential and their role in facilitating the growth of rural market centres and rural hubs, PMGSY-II and PMGSY-III schemes were launched in 2013 & 2019 respectively. In the last 21 years, more than 7 Lakh kms of rural roads have been constructed under the PMGSY. They have provided flip to the rural economy.

With a view to achieve optimal use of non-conventional materials and cost-effective environment friendly "Green Technologies" in the construction of PMGSY roads, the Ministry has fixed States specific targets for use of new Technologies in construction of PMGSY roads. Out of 112930 km road length sanctioned under new materials/ green technologies, 69278 km road length has been constructed till 31st March 2022.

Construction of conventional pavement adversly affects the environment in terms of use of natural resources, emission of greenhouse gases etc. Hence, there is a need to adopt innovative technologies which are not only cost effective but also make rural road construction more economical and environmental friendly. Full Depth Reclamation (FDR), being an innovative methology, will improve the quality of road works constructed and promote speedy construction. Cement treated base using FDR will be helpful in conservation of natural resources as this technology focuses on recycling of existing pavement materials. I am sure this document on FDR would help various stakeholders, such as state government departments, consultants, the field engineers, implementers etc. for effective use of FDR in the field.



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

FOREWORD

The Government of India, as a part of the poverty reduction strategy, launched the Pradhan Mantri Gram Sadak Yojana (PMGSY-I) on 25th December 2000 as a Centrally Sponsored Scheme to assist the states for construction of rural roads. The primary objective of the PMGSY was to provide all-weather road connectivity to the eligible unconnected habitations in the rural India. The mandate of PMGSY has been subsequently widened to include new interventions. PMGSY-II was launched in 2013, with a target to upgrade 50,000 km of the existing rural roads. Road Connectivity Project for Left Wing Extremism Affected Areas (RCPLWEA) was launched in 2016 for construction/upgradation of strategically important roads in the remote areas of the country. PMGSY-III was launched in 2019 for consolidation of 1,25,000 km through routes and major rural links connecting habitations to various socio-economic centres. Since inception till 31st March 2022, more than 7 lakh km road length has been completed under various verticals of PMGSY.

PMGSY has helped in better access of marketplace for the rural masses and generated employment in various forms. It has also helped in improving socio-economic condition of rural populace. An evaluation of Centrally Sponsored Schemes in Rural Development Sector, including Pradhan Mantri Gram Sadak Yojana was carried out by the Development Monitoring and Evaluation Office (DMEO) of NITI Aayog in 2020 and it was found that the scheme is well aligned with India's international goals and is seen to contribute to SDGs (Sustainable Development Goals) 2 & 9 as it addresses the issues of poverty, hunger and infrastructure for growth. Roads constructed under PMGSY have been observed to create positive impacts at the level of the household and community. Roads have impacted in increase access to market and livelihood opportunities, health and education facilities of people.

PMGSY has been pioneer in adopting new and green technologies in construction of rural roads. A new technology vision was formulated in 2013, and as a result more than 1 lakh km of roads have been sanctioned under PMGSY, which have adopted one or more new technologies. Recently, the adoption of new technology has seen an enhanced emphasis. A new Technology Vision 2022 is being adopted by the Ministry.

The Ministry has introduced this year in the State of Uttar Pradesh, one of the innovative methodologies in the field of road construction called as Full Depth Reclamation (FDR). FDR involves recycling existing bituminous pavement and its underlying layers into a new base layer through a prescribed process which is pulverizing existing pavement (wearing course, base, and sub-base), blending with cementitious agent, water, corrective aggregates (if needed) as per mix design to produce a cementitious stabilized base. It is a sustainable technology for pavement rehabilitation. It increases the structural capacity of new pavement by providing a stronger and more consistent base. In FY 2021-22, Ministry has sanctioned 695 roads of 5396 km length to the State of Uttar Pradesh under FDR.

This document has been prepared with contributions and suggestions of my NRIDA colleagues 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 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), Shri Pankaj Sharma, YCE, Shri Arun Kumar Patel, YCE and Shri Avinash Panda, YCE.

I also acknowledge the immerse contribution made by, Dr. U.K. Guruvittal, Chief Scientist, CRRI, Prof A. Veeraragavan, IIT Madras and Prof G.D. Ransinchung R.N, IIT Roorkee, without whose support and vital guidance, it would not have been possible for us to produce this document.

Finally, I am grateful to Hon'ble Minister, Rural Development, Shri Giriraj Singh Ji for his tremendous encouragement and mentorship of new technology. I am thankful to Hon'ble Minister of State, Rural Development Sadhvi Niranjan Jyoti and Shri Faggan Singh Kulaste. I am indebted to Shri Nagendra Nath Sinha, Secretary, Ministry of Rural Development for his constant guidance and support to various innovative approaches and new technologies in PMGSY.

CONTENTS

1. FULL DEPTH RECLAMATION FOR REHABILITATION OF LOW VOLUME ROADS 1

1.1 Introduction 1

1.2 Full Depth Reclamation (FDR) 3

1.2.1 Process Involved in FDR 4

1.3 Types of Full Depth Reclamation Stabilization 4

1.4 Full Depth Reclamation Specification 5

1.5 Applicability of FDR Process 6

1.6 Construction Process of FDR 6

2. MIX DESIGN AND QUALITY CONTROL FOR FDR 11

2.1 Mix Design of FDR 11

2.1.1 Steps in the Mix Design of FDR 11

2.1.2 Sampling from the Pavement for Design of Stabilized FDR Layer 12

2.1.3 Gradation of the Sample 13

2.1.4 Optimum Moisture Content and Maximum Dry Density 13

2.1.5 Unconfined Compressive Strength (UCS) Tests 14

2.1.6 Durability Test 14

2.1.7 Mix Design Report 15

2.2 Quality Control Tests 15

2.2.1 Strength of Subgrade 16

2.2.2 Pulverization 16

2.2.3 Evaluation of Strength 19

2.3 Quality Assurance Related Precautionary Measures 22

2.4 Test Frequency 22

2.5 Acceptance Criteria 23

2.6 Opening to Traffic 24

3. ADVANTAGES AND LIMITATION OF FDR 25

3.1 Advantages of Full Depth Reclamation 25

3.2 Limitation in Adopting Full Depth Reclamation 26

4. TEST FORMATS for FDR 27

5. REFERENCES 33

LIST OF ANNEXURES

Annexure I: Installation of GPS System in Key Machinery and Equipment 35

Annexure II: Mix Design for Cement Treated Base (CTB) using Cement and Additive (Zycobond & Terrasil 40

Annexure III: Cost Comparison between Conventional and FDR Technology 54

Annexure IV: Rate Analysis FDR 59

LIST OF TABLES

Table 1: Grading Limits of Soil Materials for stabilization with cement 13

Table 2: Permissible loss of mass in W-D durability test 15

Table 3: Tests recommended during construction 23

Table 4: Tests recommended after construction 23

LIST OF FIGURES

Figure 1: Full Depth Reclamation 2

Figure 2: FDR Process 3

Figure 3: Typical Pavement Sections for Rural Roads 3

Figure 4: Schematic view of a roadway Reclaimer during FDR Process 7

Figure 5: Application of dry cement powder to pulverized mix 8

Figure 6: Application of cement slurry to pulverized mix 8

Figure 7: Full-depth reclamation train with water truck (left) and reclaimer 9

Figure 8: Final compaction of FDR base with a tamping roller (*right*) and Smooth Wheel Roller 9

Figure 9: UCS after 7 days at varying cement content 14

Figure 10: Cement application rate verification 17

Figure 11: Phenolphthalein test at Site 18

Figure 12: Density Gauge 19

Figure 13: A Core taken from FDR Layer 20

Figure 14: Structural Evaluation using FWD 21

ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
CCS	Commercial Chemical Stabilizer
CTB	Cement Treated Base
DCP	Dynamic Cone Penetrometer
FDR	Full Depth Reclamation
FWD	Falling Weight Deflectometer
GPS	Global Positioning System
GSB	Granular Sub Base
IRC	Indian Road Congress
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PIU	Project Implementation Unit
PMGSY	Pradhan Mantri Gram Sadak Yojna
RAP	Recycled Asphalt Pavement
UCS	Unconfined Compressive Strength
WBM	Water Bound Macadam
WMM	Wet Mix Mecadam

1. FULL DEPTH RECLAMATION FOR REHABILITATION OF LOW VOLUME ROADS

1.1. INTRODUCTION

The objective of Pradhan Mantri Gram Sadak Yojna (PMGSY) has been to provide all-weather good connectivity to the desired habitations across the country by construction of new roads as well as upgradation of existing roads. Most of the rural roads are low volume roads.

Low volume roads carry a variety of farm to market and passenger vehicles, often with heavy load and high tyre pressure, and serve as lifeline for many villages and towns across the country. However, in most cases, such roads are surfaced with a thin layer of bituminous mix, which can easily be damaged under traffic and the impact of the environment, heat and moisture. In many cases, water enters the granular base underneath the thin surface layer and damages it and as a result, these pavements often suffer from premature distresses in the form of ravelling, cracking, rutting and in general loss of ride-ability, which cannot be addressed successfully by replacing the surface layer with another thin bituminous layer. Full depth reclamation (also can be termed as full depth recycling, FDR) of the existing pavement layer offers a significant cost-effective and sustainable rehabilitation method for such cases. Apart from rehabilitation of distressed pavement structure, FDR can be adopted for upgradation (and widening) of existing roads without requiring any structural overlaying of base layers while designing for same or higher order of traffic category.

The pavement problems may lie within the surface layer, but more often can be found in the layers beneath the surface. Base, Sub-base and subgrade layers can be held accountable for a majority of the problems we see in pavements. Full-depth reclamation of asphalt pavement is a rehabilitation method that involves recycling of the existing distressed bituminous layers of an existing asphalt pavement along with a predetermined thickness of the underlying granular (Water Bound Macadam or WBM, Wet Mix Mecadam or WMM and Granular Sub Base or GSB) layer(s) into a new base layer. The FDR process begins with using a road reclaimer to pulverize an existing asphalt pavement layer and a portion of the underlying base, sub-base, and/or subgrade. However, minimum height of embankment and subgrade should always be maintained. Usually, the pulverized material is uniformly blended with an additional stabilizing material such as Portland cement or bituminous emulsion/foamed asphalt or other Commercial Chemical Stabilizers (CCS), to provide an upgraded, homogeneous material.

With the use of FDR, a strong cemented stabilized layer is produced, which behaves like a semi rigid pavement. Such pavements will behave in a satisfactory manner if they are laid on a uniformly compacted and structurally sound underneath layers.

As most of the Rural Roads in India are confined to the agriculture fields, villages and remote areas with every possibility of water logging, there is a necessity of providing embankments for min. 0.60 m to 1.0 m above adjoining ground level, to circumvent the damages that can otherwise be caused due to capillary action of the low-lying water, rising to the pavement layers. Application of Cement Treated Base (CTB) Layer directly above a sub-grade shall only be considered if the road is in embankment, the subgrade is strong (CBR of ≥ 5%) and there are adequate provisions for drainage. Like all reconstruction methods, the FDR with cement/ Commercial Chemical Stabilizers (CCS) process requires an engineering pavement evaluation as a part of project selection, as well as implementation of established design practices and proper quality control during construction.

Full depth reclamation in particular has great advantages in terms of savings in time, energy, materials and costs. Generally, the existing layers of deteriorated pavements including old thin bituminous layers are recycled in-place by single or multiple passes of a specialized equipment, graded (with a grader) and compacted with a pad foot/sheep foot roller and pneumatic tyred rollers and static roller. During the reclamation operation, cutting, with/without adding of additional granular material, adding of cementitious/ stabilizing material at a specified rate and mixing are carried out simultaneously. The type and rate of application of the cementitious/stabilizing material and aggregates are determined through a mix design prior to the reclamation process which is governed as per existing soil/pavement materials as obtained after testing.

The key to successful FDR is a rational and effective combination of method and end result specification. The important items include mix design, quality control and training of personnel that are involved in the recycling operation. Key mix design tests should include those for selection of type and amount of stabilizing agent to cement ratio (if any), and the volumetric of the cold mix. The guidelines should be indicated for water application, mixing, curing, compaction, achievement of desired Unconfined Compressive Strength (UCS) value and checking of riding quality.

FIGURE 1: Full Depth Reclamation

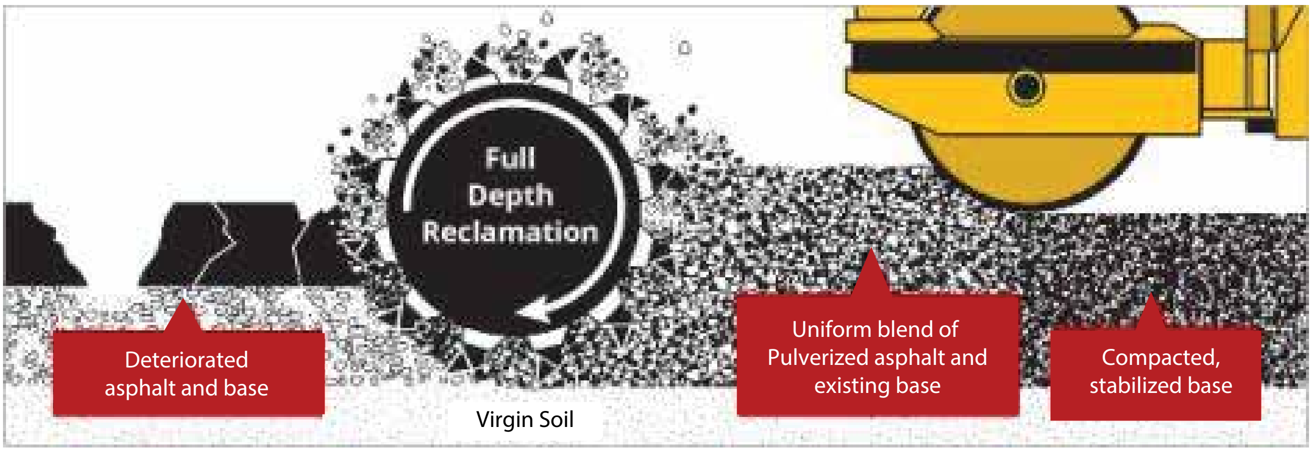
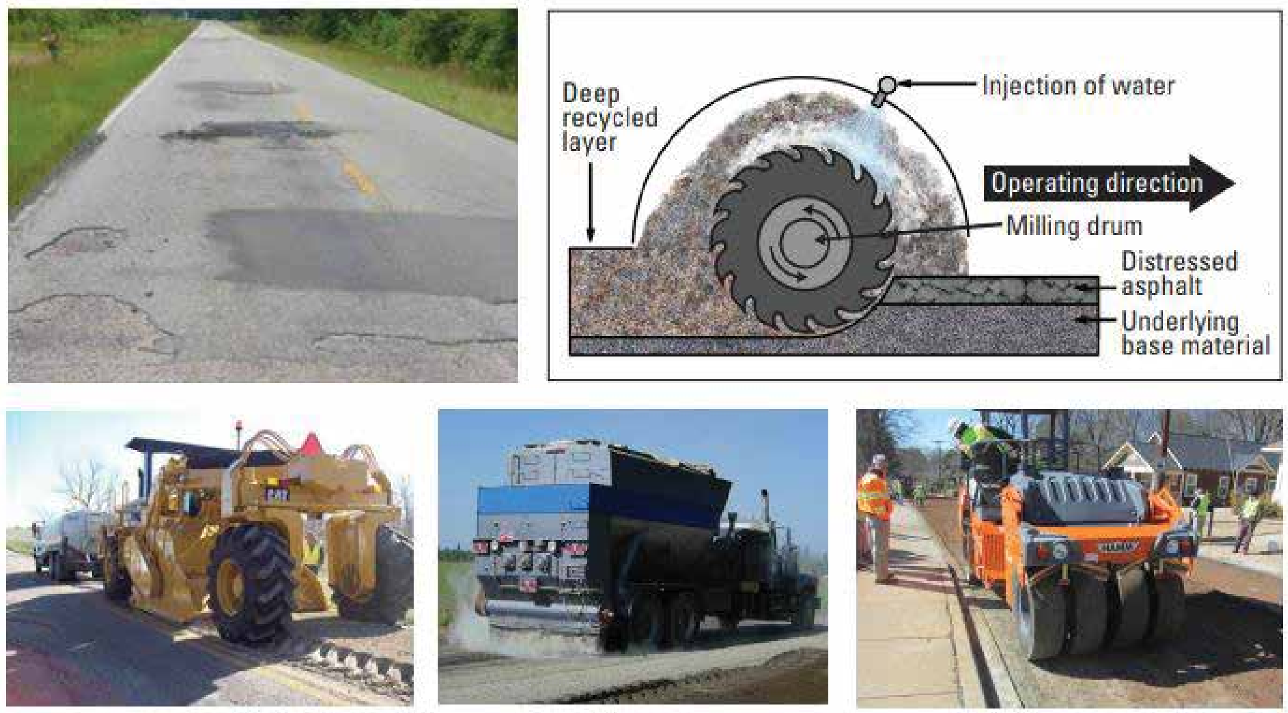


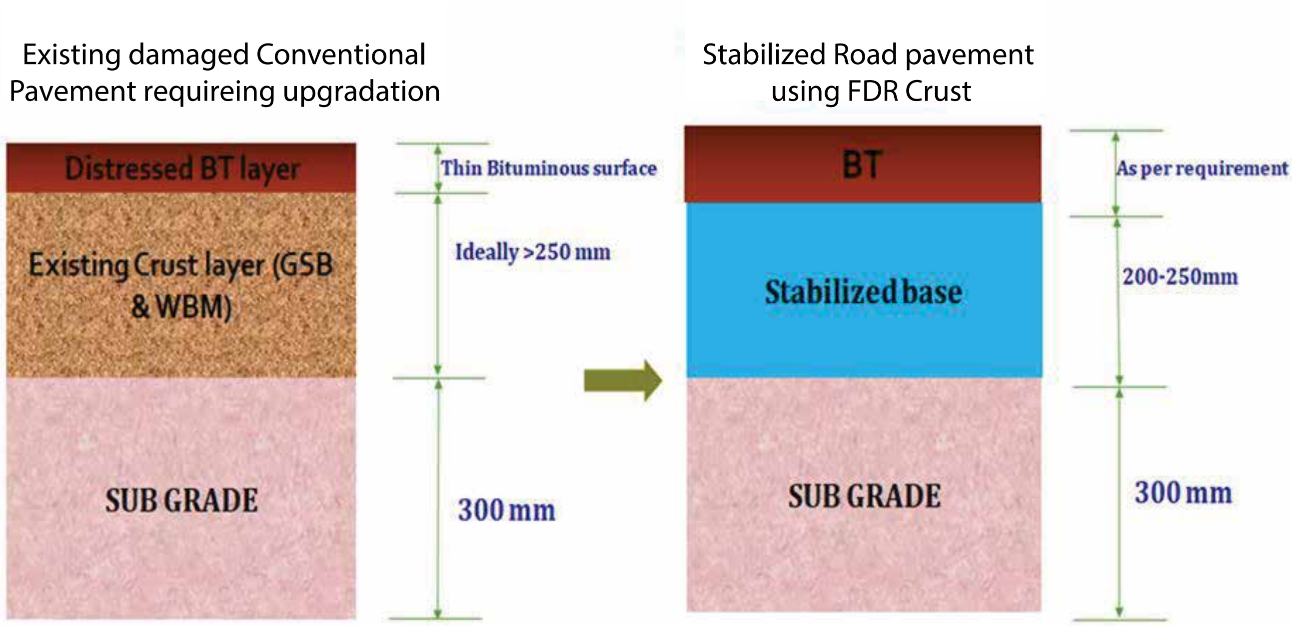
FIGURE 2: FDR Process



1.2. FULL DEPTH RECLAMATION (FDR)

Full-Depth Reclamation of an existing pavement is a rehabilitation method that involves recycling of an existing distressed bituminous surfacing course and its underlying layer(s) into a new base layer.

FIGURE 3: Typical Pavement Sections for Rural Roads



Note: Crack relief course with T6 and more traffic is recommended. It may be a SAMI Layer or 75 mm granular course

1.2.1. Process Involved in FDR

i. Use road reclaimer to pulverize an existing asphalt pavement and a portion of the underlying base, sub-base, and/or subgrade as required to meet the requirement of the designed stabilized and homogeneous base thickness depending upon the existing sub grade strength and designed traffic category.

ii. Blend the pulverized material uniformly with an additional stabilizing material such as cement/ cement with additives to provide an upgraded, homogeneous material.

iii. The stabilized material is compacted in- place with different compacting equipment.

iv. The result is a stiff, stabilized base that is ready for a new rigid or flexible surface course.

1.3. TYPES OF FULL DEPTH RECLAMATION STABILIZATION

Three different types of stabilization methods are associated with Full Depth Reclamation:

i. Mechanical stabilization (addition of aggregate)

ii. Chemical stabilization (addition of cement and stabilizing agent)

iii. Bituminous stabilization (addition of asphalt binder)

Mechanical stabilization is defined as mixing, and densification of reclaimed materials with the addition of granular materials, if necessary, to produce the required degree of structural support. Mechanical stabilization relies on particle interlocking between the pulverized mixture of existing asphalt and subsurface layers. The pulverized mixture is compacted after mixing to the specified density.

Chemical stabilization can be achieved by mixing the pulverized asphalt pavement and subsurface materials with a chemical stabilizing material. Materials that are commonly used with chemical stabilization include the following:

i. Portland cement

ii. Lime

iii. Fly ash

iv. Cement kiln dust (CKD)

v. Lime kiln dust (LKD)

vi. Stabilizing agent (patented and/or approved by the implementing authority)

vii. Stabilizing agent as approved by IRC

Bituminous stabilization can be achieved by mixing the pulverized asphalt pavement and subsurface materials with an emulsified asphalt or foamed (expanded) asphalt. Bituminous stabilization can be combined with other stabilizers such as Portland cement to achieve optimal FDR performance.

Of the three categories of stabilization, this document focuses on chemical stabilization with Portland cement, unless specifically stated otherwise. The FDR with cement process is an established engineered alternative for agencies seeking a cost-effective solution for roadway improvements, as estimated projects with adoption of FDR process can potentially save between 20 to 30 percent in costs over alternative reconstruction methods such as complete removal and replacement of existing pavement. In addition to the economic benefits, FDR with cement can be performed in a shorter time frame, saving weeks of labour and road closures and has benefits in terms of saving natural resources, reduction of Green House Gases, reducing carbon footprint.

1.4. FULL DEPTH RECLAMATION SPECIFICATION

The best specification is a set of easy to understand and implementable guidelines, based on existing standards that are familiar to the contractor, with end results that would allow the contractor the maximum flexibility and be innovative. An appropriate combination of method and end result specifications is the best approach for reclamation. The specification, for example, may allow any type of milling or pulverization equipment as long as the depth and width of the cut and the gradation of the material to meet the required specification within tolerance. Now a day many such equipment with different make having automatic control system is available for proper cutting and mixing (reclaiming). However, care should be taken that high quality equipment with microprocessor control should be preferred, as it has direct bearing on quality and resultant durability. To achieve good quality in construction of work, various kinds of equipment are used for which it is necessary that proper operation of equipment is maintained. To ascertain the quality, installation of a Global Positioning System (GPS) system is important through which monitoring of deployed equipment can be assured. In this regard a letter No. NRRDA-P017(25)/7/2021-Dir. (Tech), dated 31st Jan 2022 has been circulated among states to install GPS system in key machineries and equipment engaged in execution of road works. Copy of the letter is attached at **Annexure I**.

Standards for the type of stabilizing additives and the application rate (with tolerance) of the additive should be specified. Specifications should also spell out the responsibilities related to establishing the job-mix formula and the required sampling procedures, test methods and design criteria for the mix design. Properties of the reclaimed materials that are specified include gradation of the milled material, additive content and density. Generally, the type of rollers is specified, whereas the number of passes and rolling pattern need to be determined on a test strip.

One of the key steps in the full depth recycling operation is the mix design. Once the mix design is completed, the results are utilized to provide treatment specifics for the different sections of the project. Such specific information generally includes data as follows:

i. Project extent (stations) containing geographical and topographical information, existing pavement details.

ii. Depth of reclamation (mm) as per design requirement.

iii. Sequence of execution process including choice of equipment.

iv. Application rate of stabilizing agent (%), only cement or with any additives as per mix design.

v. Minimum strength requirement (dry and/or wet) (MPa).

vi. Minimum density (% of modified AASHTOT-180).

The mix design must be developed in conjunction with the field investigation personnel to ensure that the recommendations are achievable in the field. A clause is generally inserted in the specification that requires the contractor to organize and execute the project in such a way that the specification is met in the reclamation operation. The existing material may not be sufficient to meet the mix requirements and/or the layer requirements, and new materials, in the form of aggregates, may be required to improve density and mechanical properties, meet gradation and/or level or grade the recycled layer. The specific reason for the addition of new materials must be clearly specified.

1.5. APPLICABILITY OF FDR PROCESS

FDR can be a cost-effective rehabilitation strategy for a number of scenarios including the following:

i. Flexural distresses in wheel lanes

ii. Asphalt distress due to low base failure (pavement condition index below 2 [poor condition])

iii. Excessive rutting or alligator cracking in the asphalt surface

iv. Excessive patching (20 percent or more)

v. Need to widen the roadway

vi. Need to increase structural design of the roadway

vii. Need to correct the asphalt pavement cross slope in conjunction with other needed distresses to be corrected

viii. Where the cost of overlaying granular material is high

Full-depth reclamation is an effective method of roadway rehabilitation and can be a cost-effective strategy for pavements that require patching in excess of 15 to 20 percent of the existing pavement area. Full-depth reclamation is also useful for pavements that have deflections or advanced pavement distress such as severe linear or block cracking, alligator cracking shoving, or rutting.

With regard to pavements that have reduced ride quality with significant bumps and dips, FDR can be used to improve these deficiencies. The existing pavement and underlying materials need to be pulverized and reshaped to a levelled base layer prior to the surface course is placed.

Full-depth recycling also allows the existing pavement cross section to be reshaped. The FDR mixture can be used to improve roadway geometrics, super elevation adjustments, or drainage issues. Full-depth recycling also allows agencies to widen their existing roadways to provide a consistent base with fewer environmental impacts and reduced cost compared with alternative remove-and-replace construction methods. These improvements are typically not cost effective with merely overlay projects, where the new surface course is limited to a defined thickness.

1.6. CONSTRUCTION PROCESS OF FDR

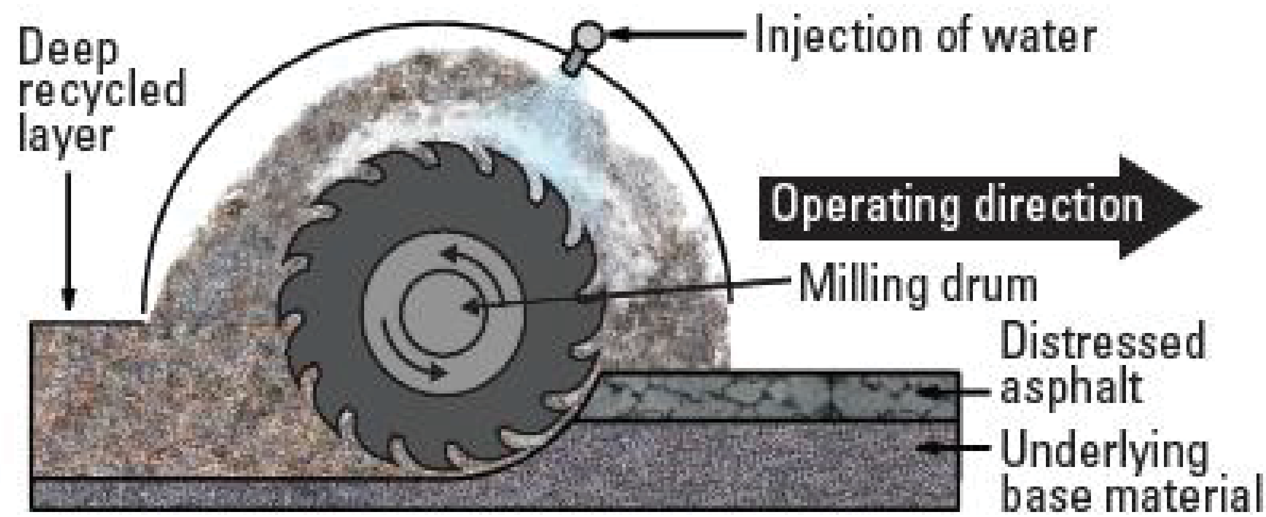
Full-depth reclamation is similar to other concrete pavement formation in which it relies on mechanical consolidation of materials and chemical hydration processes for its strength. The first step in the FDR process is using a roadway reclaimer to pulverize the existing pavement materials. As mentioned earlier, the depth of pulverization includes the asphalt pavement and a portion of the underlying materials including the base, subbase, and/or subgrade. Not only does pulverizing and blending the underlying materials with the existing asphalt layer provide a uniform mixture but cutting into the granular base and subgrade also keeps the cutting teeth of the reclaimer cooler. This increases the efficiency of the machine and reduces equipment maintenance costs.

A schematic view of how a roadway reclaimer works is shown in **Figure 4**. The cutting or milling drum on the roadway reclaimer rotates in an "up-cut" direction, opposite to the direction of the reclaimer's tyre rotation. The up-cut rotation of the cutting head improves pulverization and assists in reducing the size of the reclaimed asphalt materials. Modern reclaimers have the ability to add water or other fluid stabilizing agents during the reclaiming process with automatic control system. Some of the manufacturers of Recycler are as under:

Wirtgen, Germany	Carerpillar, USA
Sakai, Japan	Roadtech, USA
Bomag, Germany	Remi, China
XCMG, China	DGX, Chine

Note: The information indicated above is not exhaustive. There may be other manufacturers also. Agencies should explore the market to choose the best option.

FIGURE 4: Schematic view of a roadway Reclaimer during FDR Process



After the existing asphalt and underlying material have been pulverized and blended together, the mixture is graded to the desired typical section. If there is existing kerb and gutter that the new surface must match, some of the existing pulverized mixture may need to be removed to allow sufficient elevation difference for the new surface course. Milling some of the asphalt surface prior to pulverization may also be used to lower the grade.

Once the grading and shaping of the pulverized material is complete, cement is added to the mixture. Cement can be applied either as dry powder **(Figure 5)** or in slurry form **(Figure 6).** The cement application rate is usually specified in terms of weight per area. It should be noted that cement can be added to the asphalt surface prior to pulverization, thereby eliminating the need for an additional pass of the reclaimer. This option should be evaluated on an individual project basis to ensure proper pulverization of the existing pavement is achieved.

FIGURE 5: Application of dry cement powder to pulverized mix

FIGURE 6: Application of cement slurry to pulverized mix

The pulverized material and cement are mixed by another pass of the roadway reclaimers **(Figure 7).** Water is typically added to the mixture through on-board applicators in the mixing chamber of the roadway reclaimer to achieve the appropriate moisture content for compaction and hydration. After the cement and water have been thoroughly mixed with the pulverized base material, the mixture is ready for compaction. Compaction can be accomplished with a variety of equipment including pad foot/sheep foot rollers, smooth-wheeled vibrating rollers (**Figure 8**), and pneumatic tire rollers. Finally, the completed FDR base is moist cured or sealed with a bituminous curing seal.

FIGURE 7: Full depth reclamation train with water truck (left) and reclaimer

FIGURE 8: Final compaction of FDR base with a tamping roller *(right)* and Smooth Wheel Roller

2. MIX DESIGN AND QUALITY CONTROL FOR FDR

2.1. MIX DESIGN OF FDR

The FDR mix design process includes sampling the materials from existing carriageway to determine the thickness of the existing asphalt and aggregate base and sub-base layers and classifying the types of existing pavement materials that will be incorporated into the FDR base layer. The reclaimed sampled material is tested in a laboratory where an appropriate cement content, optimum moisture content, and maximum density are determined to achieve the desired strength and durability for long-term performance of the pavement to be constructed using the material. One element that can affect the overall FDR mix design is the amount of the base or sub-base material that will be incorporated in the FDR layer.

The mix design should account for variances in reclaimed material types and thicknesses throughout the length of the road to be reclaimed. It is recommended that the mix design be changed when the material types and thicknesses significantly change over the length of road. Thorough sampling of the existing carriageway will assist in determining if multiple mix designs are required over the length of the project. Adequate sampling of the roadway is important to ensure a safe mix design for entire length of road to be reconstructed through FDR.

2.1.1. Steps in the Mix Design of FDR

The correct proportioning of materials is important for the production and quality of FDR mixes. The mix design should be carried out with a scientific and systematic approach that balances the existing and desired engineering properties, constructability, durability, and economics. The following general steps may be followed for the mix design:

i. Obtain the field samples from every 1 km for determining the variability in the material for deciding the number of mix designs to be carried out.

ii. Determine the gradation of the reclaimed sample.

iii. If necessary, additional materials may be added to satisfy the gradation requirements.

iv. For mix design, three different cement contents testing may be selected.

v. Determine optimum moisture content and maximum dry density of mix using each estimated cement/CCS content.

vi. For each cement content, 150 mm cubical specimen may be prepared at maximum density and optimum moisture content for determination of unconfined compressive strength (UCS) at 28 days. Cylindrical specimen of 100 mm Diameter and 200 mm height can also be used for determination of UCS value, but the results are to be converted to 150 mm cube by multiplying the result with a correction factor of 1.25. Other combinations of height to diameter as per IRC: SP:89 (Part II): 2018 can also be adopted.

vii. 12 cycles of Wet-dry durability test on each specimen at the estimated cement content to be conducted.

viii. Plot the unconfined compressive strength and wet-dry durability test results on a graph to determine the desired cement content.

ix. Create a mix design report with the established cement content/CCS content and moisture/density information.

2.1.2. Sampling from the Pavement for Design of Stabilized FDR Layer

To properly design an FDR mixture, a thorough understanding of the existing asphalt pavement and underlying granular layers is necessary. To understand the types and characteristics of the materials that will be incorporated into the FDR mix, sampling of the existing roadway should be performed. The samples should be examined throughout their full depth to determine the physical properties of the proposed FDR mix. The samples should be measured, inspected, and tested for mix design purposes.

During field sampling operations, the sampling team should make visual observations of the existing roadway to determine if areas of major distress, such as excessive patching or severely rutted areas, warrant additional material samples, particularly if the subgrade/sub-base is considered to be wet or unstable. If the project evaluation determines that material types and/or thicknesses change throughout the roadway, samples should be taken at each varying material location, with a minimum of one sample from every one km length. All material samples should be kept separate with their locations recorded in a core log. If sample gradation and material type vary significantly along the project length, several mix designs may be required. To prevent this, engineering judgment should be used to determine the representative case. It is up to the engineer to understand the worst case condition and make a decision on how to handle the situation.

It is recommended that samples be obtained at varying offsets along the roadway alignment. Samples can be taken at the pavement edge, between wheel paths, and near the centreline to get a thorough representation of the carriageway. The existing roadway should be sampled with a staggered approach. A variety of methods can be used to obtain material samples. Examples of these methods include auger sampling, block samples (open pits), or a combination of these methods.

In addition to the material sampling, testing of the subgrade is essential to ensure that there is solid foundation beneath the proposed FDR layer. Evaluation of the subgrade includes identifying weak areas that will require additional strengthening. The subgrade should be able to withstand construction traffic during the FDR process and should have sufficient strength to limit excessive deflection. Deflecting subgrades will require improvement or stabilization to ensure adequate compaction of the reclaimed mixture. A dynamic cone penetrometer (DCP) can be used to determine the in-situ strength of the subgrade that will ultimately support the FDR layer.

2.1.3. Gradation of the Sample

After the samples have been obtained and delivered to the laboratory, the materials will need to be blended in a manner that will replicate the reclaiming operations during construction. The recycled asphalt pavement (RAP) will be combined with the appropriate proportions of underlying base and sub-base materials and any additional material as needed. A well graded mixture is critical to ensure the FDR layer will be strong and durable with the minimum amount of cement.

Full-depth reclamation relies on fine aggregate and non-plastic fines being mixed with the pulverized asphalt and cement/CCS to get adequate compaction. The roadway reclaimer will not always break down the existing asphalt pavement into material that is small enough to provide adequate fine aggregate content in the mix. To obtain enough fine aggregate in the mix to achieve compaction, a portion of the underlying sub-base normally is incorporated into the FDR or additional material of requisite gradation can be added.

The gradation of the in-situ pulverized materials should meet the criteria given in MoRD specifications as presented in Table 1. However, if the gradation obtained is different, then additional material of desired sizes shall be mixed and mix design can be done subjected to meet the desired gradation, strength and durability criteria. For improving the gradation of retrieved material and to reduce the plasticity index, apart from conventional materials, waste materials like construction and demolition (C&D) waste, brick bat aggregates, iron and steel slag, copper slag, zinc slag, fly ash etc. can also be considered for the purpose of mixing.

TABLE 1: Grading Limits of Soil Materials for stabilization with cement

IS Sieve	Percent by wt. Passing within the Range
53.0 mm	100
37.5 mm	95-100
19.0 mm	45-100
9.5 mm	35-100
4.75 mm	25-100
600 micron	8-65
300 micron	5-40
75 micron	0-10

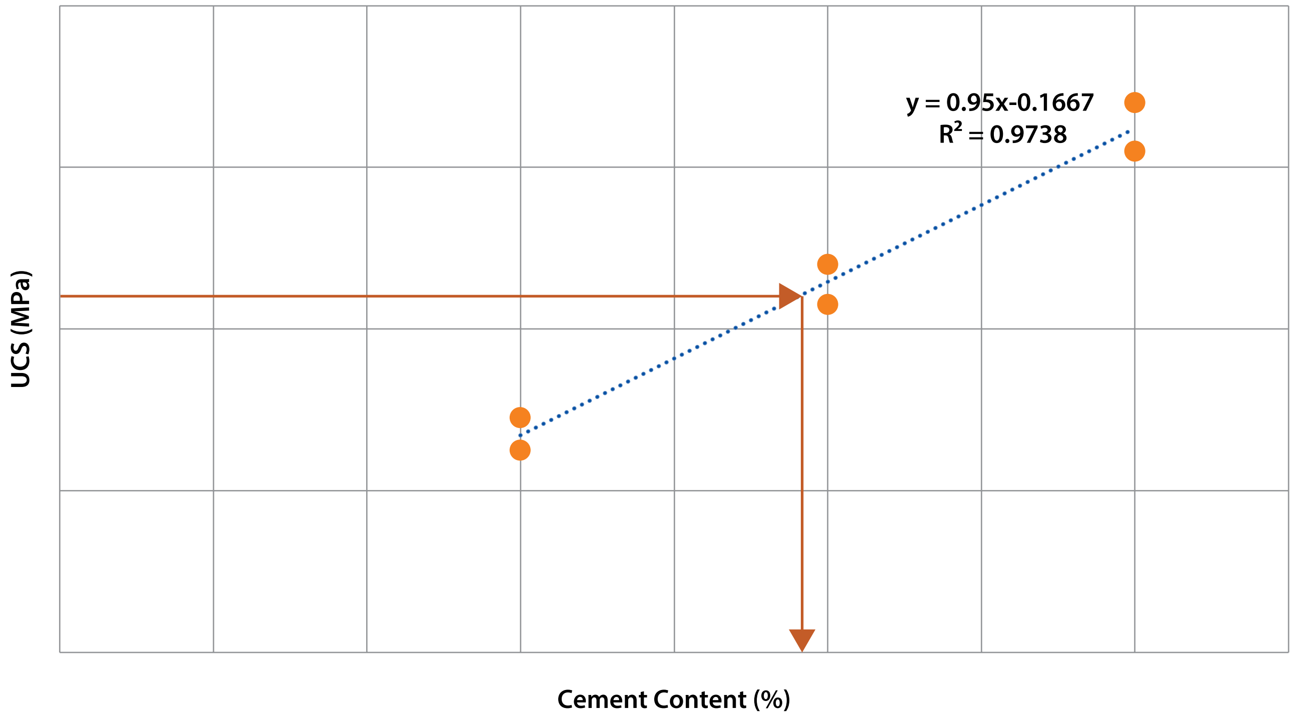
2.1.4. Optimum Moisture Content and Maximum Dry Density

After the material has been analysed in the laboratory and three trial cement contents have been established, the optimum moisture content (OMC) and maximum dry density (MDD) should be calculated. Determining the adequate amount of water and cement for the FDR layer is critical in obtaining the desired moisture and density of the FDR mix. This information is also critical for quality control purposes during construction. Research has shown that cement-stabilized materials have better strength and performance when they are properly compacted. Therefore, determining maximum density and optimum moisture content is an important step in the mix design process.

2.1.5. Unconfined Compressive Strength (UCS) Tests

Based on the optimum moisture content test results of the cement/CCS treated FDR samples that were determined earlier, specimens should be prepared at each estimated cement content (e.g., 3%, 5%, and 7%) for unconfined compressive strength testing. A minimum of two specimens be prepared for each cement content. The unconfined compressive strength (UCS) cubes or cylinders should be made in accordance with IRC: SP: 89:2018 (Part II). After curing the specimens for seven days in the moist curing room, the specimens should be removed and taken for the unconfined compressive strength testing. A graph of 7-day UCS with varying cement content is plotted as shown in **Figure 9**. The optimum cement or CCS content is determined corresponding to the target UCS value from this relationship chart.

FIGURE 9: UCS after 7 days at varying cement content



2.1.6. Durability Test

In addition to meeting the desired unconfined compressive strength, the mix design should also pass wet-dry durability testing to ensure that it will be a long-lasting pavement base solution. The wet dry brushing test consists of 12 cycles of wetting, drying and brushing of the samples (carried out as per ASTM D 559). Wet dry (W-D) cycles results in carbonation of the exposed surface of stabilized specimens and materials are brushed off causing loss of mass.

FDR with use of cementitious/CCS materials can improve the resistance of the reclaimed base to loss in strength due to submergence and drying. Loss of mass after 12 cycles of W-D test is used as a design criterion for stabilized materials towards durability consideration (Table 2).

TABLE 2: Permissible loss of mass in W-D durability test

ASTM Soil Classification	Maximum Allowable Weight Loss (%)
GW, GP, GM, SW, SP, SM	14
GM, GP, SM, SP	14
GM, GC, SM, SC	14
SP	14
CL, ML	10
ML, MH, CH	10
CL, CH	7
OH, MH, CH	7

2.1.7. Mix Design Report

The report should contain the following minimum information:

i. Gradation of combined mixture (including Recycled Asphalt Pavement or RAP)

ii. Liquid limit, PL, and PI of combined material (if applicable)

iii. Maximum dry density and Optimum Moisture Content (OMC) of the FDR mixture

iv. Unconfined compressive strength at each trial cement content

v. Wet density of UCS test specimens before and immediately after moist curing period

vi. Recommended cement content as a percentage of dry materials

vii. Recommended CCS content as per mix design

viii. Material certifications and source information for Portland cement

In addition to these items, the graph of unconfined compressive strength versus the percent of cement in the mixture (as shown in **Figure 9**) should be provided. The moisture/density curve should also be provided for the recommended cement content. A graph should also be generated that shows the average moisture-conditioned UCS and wet-dry durability for each mixture versus the percentage of cement in the mixture. The recommended spread rate specified in kg/sqm for the cement should be provided so that a correct amount of cement is applied during construction.

A sample Mix design for Cement Treated Base (CTB) using cement and additive (Zycobond & Terrasil) prepared by IIT – Roorkee is attached at **Annexure II**.

2.2. QUALITY CONTROL TESTS

The successful construction of FDR with cement/CCS relies on the control of depth and uniformity of pulverization, strength of compacted subgrade, cement content and placement moisture content of reclaimed mix, and compaction of reclaimed layer. If the sub-base/subgrade material below the FDR layer is soft, it will not adequately support the FDR equipment and/or layer, construction personnel should halt construction until a solution is determined. This situation can often be corrected by blading the pulverized material to one side of the roadway and removing the poor soils under the proposed FDR layer. The excavated area should be filled with suitable fill and compacted before moving the pulverized material back to the roadway and before adding cement.

The following tests should be conducted in case of FDR with cementitious/CCS materials:

i. Strength of subgrade
ii. Pulverization and Gradation
iii. Cement content/Admixture content
iv. Mixing uniformity
v. Moisture content and Density of FDR base layer
vi. Strength of FDR base layer
vii. Stiffness of FDR base
viii. Thickness of the FDR layer base layer

The tests and checks given in this section are exclusively for FDR layer. For other layers including top bituminous layer and other works of the project, quality assurance/quality control is to be exercised as given in MoRD Specifications for Rural Roads and relevant contract document of the project.

2.2.1. Strength of Subgrade

In-situ strength of the subgrade can be determined using a dynamic cone penetrometer (DCP). The following relationships as given in ASTM D 6951 (2009) may be used to predict the in-situ CBR value of the soil:

For all soils, except for CL with CBR<10 and CH soils	$CBR = 292/DCP^{1.12}$
For CL soils with CBR<10:	$CBR = 1/(0.07019 \times DCP)^2$
For CH soils:	$CBR = 1/(0.002871 \times DCP)$

Where DCP value is in mm/blow.

Sufficient strength of the subgrade as per IRC guidelines should be ensured before going ahead with the FDR construction.

2.2.2. Pulverization

Pulverization of the existing asphalt pavement and underlying material is important in achieving a homogenous mix for cement stabilization. The pulverization of the existing material can be improved by the following:

i. Slower forward speed of the mixing machine
ii. Additional passes, if using a multiple pass mixing machine
iii. Replacing worn mixer teeth
iv. Pre-wetting and premixing the soil at optimum moisture content before processing begins

The depth of pulverization should be verified by inspection personnel to ensure construction operations are meeting the project specifications. If the pulverized material does not meet the consistency of the material samples used in the mix design, construction and inspection personnel should notify the engineer before adding cement. This situation would likely be observed when the gradation is verified following pulverization. The engineer should determine whether the mix design is still applicable based on the pulverized material on site. Additional testing of the pulverized material may be performed, and revised cement content requirement should be worked out.

2.2.2.1. Cement Content

During cement application operations, cement spreaders should be operated at a constant slow rate of speed. A consistent level of cement should be kept in the hopper to obtain a uniform cement spread. String line or other edge markers should be used to obtain the true edge of pavement. When cement is placed using bulk cement spreader, the check on the accuracy of the cement spread can be done through spot check and overall checks.

Spot check—In this, a sheet of canvas, usually 1 m^2 in area, is placed ahead of the cement spreader. After the spreader has passed the canvas, the cement is carefully picked up and weighed (**Figure 10**).

Overall check—The distance or area is measured over which a truckload of cement of known weight is spread. This actual area is then compared with the theoretical area, which the known quantity of cement should have covered.

FIGURE 10: Cement application rate verification

2.2.2.2. Moisture Content

An important factor in a successful FDR mix is moisture content. The FDR mix should be at the optimum moisture content throughout mixing and compaction for the entire treatment depth. It is not recommended to determine the moisture content by nuclear gauge, since the moisture reading with this method can be unreliable. The moisture content of the mix during construction can be determined either by ASTM D4643 (microwave oven) or ASTM D4959 (direct heating). Throughout the FDR work, the placement moisture content should be maintained slightly above (+2%) its specified value of moisture content. Therefore, rapid determination of the in-situ moisture content periodically, during the laying the FDR base layer is necessary to allow adjustments to be made so as to bring the moisture content of the stabilized material to the required value.

2.2.2.3. Mixing Uniformity

When cement is added to the soil material, the resultant mixture experiences an increase in pH value, usually into the moderate to strongly alkaline range from 8.0 to 9.0. This is a measurable difference from the untreated soil which commonly has a lower pH. A hole dug through the completed FDR work can be tested at various depths to determine at what point the pH increase ceases, thereby indicating the depth of treatment. The most accurate method is determining the pH value by a pH meter. A second method, which is simple and easy but less accurate than using a pH meter, consists of using certain indicators or dyes. This method is accurate enough for most purposes. A commonly used chemical to determine the presence of calcium in cement-stabilized materials is phenolphthalein. A chemical reaction between the phenolphthalein and cement in the FDR mixture produces a pinkish-red colour, indicating the presence of cement (**Figure 11**). If the pinkish-red colour extends to the bottom of the specified FDR depth, adequate mixing has been achieved. However, if the pinkish-red colour does not extend to the full depth of the FDR layer, mixing operations should be modified to ensure cement is evenly mixed throughout the FDR depth.

FIGURE 11: Phenolphthalein test at Site

2.2.2.4. Density

Immediately after final rolling is completed, in-place density tests should be performed at several locations on the first few sections completed. A density (**Figure 12**) gauge can be used to determine the degree of compaction obtained in the field to avoid disturbance in the stabilized layer. It should be noted that density gauges should be properly calibrated, operated, and maintained to ensure that results are accurate. In the absence of density gauge, Sand replacement method or determination of density of extracted core by wax coating method may be used. The density of the layer should not be less than 100% of the maximum density of the cement-treated mix as determined in the laboratory.

FIGURE 12: Density Gauge

2.2.2.5. Thickness of Stabilized Layer

Compacted thickness of FDR layer is usually checked by digging small holes in the fresh cement stabilized layer to determine the bottom of treatment. Thickness can also be checked by coring (150 mm dia. samples) the hardened FDR layer. This provides a small-diameter core for measuring thickness and for unconfined strength testing if required. Cores should be taken after seventh day of laying of the FDR layer, for in-place compressive strength testing and determination of thickness of layer.

2.2.3. Evaluation of Strength

Continuous monitoring of the strength of processed material is required to ensure that the specified strength is being achieved. Representative samples of the full depth of mixed material should therefore be taken from the site immediately prior to compaction of the FDR layer material. As per IS:516 (1959), cubical specimens (150 mm size) may be prepared. Cylindrical test specimens may also be prepared having length equal to twice the diameter. Cylindrical specimen of 100 mm dia. and 200 mm height can also be used for determination of UCS value, but the results are to be converted to 150 mm cube by multiplying the result with a correction factor of 1.25. Other combinations of height to diameter as per **IRC: SP:89(Part II):2018** can also be adopted. Preparation of the test specimens should be completed within two hours of mixing. The density at which the test specimens are to be compacted depends on the density requirements of the specification and various methods which are in use. The test specimens should be prepared at the same density as the compacted material in the field.

A core specimen for the determination of compressive strength shall have a diameter at least three times the maximum nominal size of the coarse aggregate used in the stabilized layer, and in no case shall the diameter of the core specimen be less than twice the maximum nominal size of the coarse aggregate. The length of the specimen, when capped, shall be as nearly as practicable twice its diameter. Therefore, it is recommended that not less than 150 mm diameter core should be obtained from the FDR layer for verification purposes (**Figure 13**). Cores should be taken on the seventh day after completion of the FDR layer for in-place compressive strength testing.

FIGURE 13: A Core taken from FDR Layer

The cores can be used to verify FDR layer thickness. However, it is not recommended to use compressive strength results from core samples alone as an acceptance criterion. Unlike concrete, issues with the lower-strength FDR and coring method may cause internal damage to the core, resulting in reduced strength results. Although compressive strength results from cores should not be used as an acceptance criterion, the results can be a good indicator of whether the FDR layer is hardening properly. The strength test results obtained from the cubes or cylinders prepared at the time of laying of the FDR layer as well as the strength test results from core samples must satisfy the strength requirements.

Falling Weight Deflectometer (FWD) test should be conducted for evaluation of in-situ modulus during currency of work and as well as after completion of the entire road. FWD is a non-destructive field technique for the pavement. FWD is used for performing structural evaluation of the pavement by applying load to the pavement and measures the response in terms of stress, strain, or defection. The FWD generates a load pulse by dropping a weight in the range of 50 to 350 kg. Load is dropped from a height of fall in the range of 100 to 600 mm. This load pulse is transmitted to the pavement through a circular load plate of diameter

300 mm. The load pulse generated by the FWD under the load plate momentarily deforms the pavement into a bowl shape. Being a non-destructive technique, FWD provides ease in collecting large amount of data with lesser time required and lesser labour requirements with respect to the conventional methods. Therefore, FWD test should be encouraged, and it should be conducted with the help of STA/PTA and any other reputed consultancy firm.

2.2.3.1. Evaluation of in-situ Modulus

The resilient modulus (M_R) of an FDR layer is a measure of the stiffness of the FDR layer. M_R can be determined from UCS values (after 7 days curing) by using the following relationship developed by Sullicon et al (208) for cement treated bases.

$$M_R = 3032 \text{ x } UCS^{0.5}$$

Where M_R and UCS are expressed in MPa.

Alternatively, in-situ resilient modulus of the FDR layer can be evaluated through measurement of deflection using a Falling Weight Deflectometer (FWD) and then back calculating the resilient modulus. The in-situ resilient modulus will be compared with the resilient modulus as determined using above equation. **Figure 14** shows structural evaluation of a stabilized pavement using FWD.

FIGURE 14: Structural Evaluation using FWD

2.2.3.2. Storage and Handling of the Cement/CCS

Unless cement and cementitious admixtures are properly stored and used in a fresh condition the quality of the pavement layer will be substantially reduced. Cement must be stored in a sound water-tight building and the bags stacked as tightly as possible. The stock should be verified by the concerned authority before use. The storage of admixture at site shall be done as per standard instructions of manufacture. PIU shall obtain original purchase vouchers/GST invoice from the contractor. Also, all mandatory tests required for the acceptance of material brought at site shall be carried out from IITs/NITs/PTA/STA before incorporation in the work.

2.3. QUALITY ASSURANCE RELATED PRECAUTIONARY MEASURES

The following quality checks should also be taken up for successful implementation of the FDR work:

(i) Ensure that clearing and grubbing have been performed satisfactorily and the road section has been prepared for FDR work.

(ii) In case embankment widening or subgrade works are involved, ensure that these activities are carried out as per MoRD Specifications for Rural Roads.

(iii) Inspect and ensure that pavement section of the existing carriageway matches with pavement section shown in DPR at various chainage and it is in uniformity with sections considered for mix design in DPR.

(vi) If additional aggregate materials are required, ensure that they are properly stacked in such a manner that they do not obstruct the FDR works and are not getting contaminated with any foreign matter.

(v) The machinery (Road reclaimer, cement spreader, rollers, etc.) proposed to be used should be checked to ensure that they meet contract requirements.

(vi) Inspect and ensure that the road safety measures are in place and alternate route arrangements are available for traffic movement when existing carriageway is taken up for FDR.

(vii) Quality tests on materials to be incorporated in FDR should be completed and they should conform to MoRD specification requirements for base course before starting the works. Quality control laboratory must have been set up as per Contract document.

(viii) As part of the quality control and in order to make a final decision on moisture content and stabilizer content, the information gained in the laboratory tests should be related to a preliminary field trial. At least 10 days before the main work begins, Test strip/Control strip of minimum 100 m length (on the road alignment) should be constructed to decide about the methodology to be adopted for the works. An engineer should be present at site during test strip construction. After construction, test strip shall be evaluated as per quality tests as given in Section 6 and approved by the Engineer.

2.4. TEST FREQUENCY

It is prudent to conduct periodic testing during construction to confirm that the properties of materials being used are within the range of value anticipated during the design. Quality control tests and their minimum desirable frequency are as given in Table-3 and 4 for tests to be conducted during and after construction respectively. Tests indicated here are minimum number of tests to be conducted in any project. However, PIU or Contractor may carry out a greater number of tests if they so desire. Tests to be conducted by State Quality Monitors (SQMs) and National Quality Monitors (NQMs), departmental senior officers during their inspections will be in addition to these tests. All these quality tests/checks are to be considered incidental to works, and no separate payment shall be made. Contractor's laboratory must be well equipped to carry out these tests.

TABLE 3: Tests recommended During Construction

Test	Test Method	Min. Desired Frequency
Quality of Cement/Hydraulic binder and additives	As per relevant IS specifications or as per the Supplier Guidelines	Once initially for approval of the source of supply and later for each consignment of the material
Depth of Pulverization	pH meter or Phenolphthalein Test	One test per 250 m length
Thickness of Stabilized Layer	Coring/digging holes of 100 mm diameter	One test per 250 m length
Gradation of Pulverized materials	Mix Design	One test per 250 m length
Cement Content	Spot Check	One test per 500 m length
Mixing uniformity	Visual	Regularly
Moisture content	IS 2720 (Part-2)	One test per 250 m length
Density	IS 2720 (Part- 28)	One test per 250 m length
UCS Test (from cubes)	IS: 516 -1959 or IRC: SP: 89:2010	One test per 250 m length

TABLE 4: Tests recommended After Construction

Test	Test Method	Min. Desired Frequency
Core Strength	IS: 1199 -1959	One test per 250 m length
Stiffness of the Layer	IRC: 115: 2014	One test per 250 m length

Note: In addition to the tests specified above, compulsory random field testing of UCS and density shall be conducted from a reputed Government Institute like IITs/NITs/PTAs/STAs etc. to ascertain the quality of work executed on ground.

2.5. ACCEPTANCE CRITERIA

Gradation	Tolerance of up to 5% on intermediate sieves, except the first and last sieve
UCS value	As per Mix Design (Average value should be more than 4.5 MPa after 7 days curing with a minimum individual value of 4.0 MPa)
Stiffness (MPa)	Min 90% of the design modulus values as per IRC:37-2018 for Cement Stabilized Base Layer (Average. Modulus should be more than 5000 MPa subjected to a Minimum 4500 MPa after 28 days of curing; Average. Modulus should be more than 3500 MPa subjected to a Minimum 3000 MPa after 7 days of curing)
Compaction (%)	100 % of the MDD using heavy compaction method
Tolerance of the Surface Level (%)	± 10 mm

In case of variation from the design UCS, in-situ value obtained from cubes or cores (any one of these), being on lower side, prior to proceeding with laying of base/surface course on it, matter shall be referred to the technical experts like STA/PTA and whatever additional pavement layer and any other work required from the sound engineering practice that shall be constructed by the Contractor at his own cost.

2.6. OPENING TO TRAFFIC

The completed FDR with cement layer can be opened for light traffic after three days of curing if adequate stiffness is developed in the cement-stabilized FDR layer to low-speed local traffic and to construction equipment traffic. The stiffness of the cement-stabilized FDR layer should be estimated over the entire depth of treatment by using the DCP tests. A DCP index of less than or equal to 10 mm/blow after three days curing of the cement-stabilized FDR layer should be considered acceptable for construction of the subsequent pavement layer. The FDR layer can be opened to all traffic after the 7-day moist curing period, provided the FDR layer has hardened sufficiently to prevent permanent deformation.

3. ADVANTAGES AND LIMITATION OF FDR

3.1. ADVANTAGES OF FULL DEPTH RECLAMATION

i. Most pavement distress can be treated satisfactorily with desired strength requirement.

ii. Significant structural improvements to the pavement crust (specially in base course).

iii. Stronger base results in better performance requiring less maintenance.

iv. Shortened construction schedule due to mechanized construction.

v. Cost effectiveness due to no/minimal use of additional costly granular material because of higher cartage. Tentative cost comparison between Conventional and FDR Technology with various Lead distances of Aggregate for different traffic category and carriage way width is attached at **Annexure III**. Rate analysis of FDR for the states of Bihar and Uttar Pradesh is attached at **Annexure IV.**

vi. Early opening to traffic.

vii. Improves Riding Quality due to use of mechanized grader and proper compaction with appropriate compacting equipment.

viii. Hauling cost minimized due to use of locally available marginal material or minimal use of granular material (stone aggregate) of higher lead.

ix. Eliminates material disposal problem as the existing and damaged asphalt binder materials are reclaimed and reused.

x. Results in conservation of natural resources due to no/minimal use of stone aggregates to construct the stabilized base course.

xi. Minimal air quality problem and reduction in carbon footprint due to minimizing the different construction activities like quarrying and processing of stone material, carrying of stone aggregates to construction site with longer lead.

xii. Reduce impact on the communities during construction due to reduction in construction time.

3.2. LIMITATION IN ADOPTING FULL DEPTH RECLAMATION

Although there are significant advantages in adopting Full Depth Recycling into a roadway rehabilitation Project, certain aspect of the roadway project must be considered.

i. If there are areas with drainage problems such as saturated sub grade or inadequate drainage system to direct water away from the pavement structure, FDR alone will not be able to rectify this issue. For such cases, the existing pavement materials need to be dismantled and stacked outside the roadway and redress the drainage issue including laying, compacting of sub-grade layer before going for laying of recycled base course.

ii. Modern Pulverizing equipment can exceed 300-450 mm in depth and as with all pavement reconstruction method, the elevation of existing utilities should be checked and documented before selecting Full Depth Recycling as rehabilitation method.

iii. Full depth recycling is not the solution of all pavement distress, agencies should consider the condition of the existing pavement and reason of distress.

iv. Like all reconstruction methods, the Full Depth Reclamation with adoption of stabilizing agent and cement to achieve the required strength of the pavement requires an engineering pavement evaluation as a part of project selection as well as implementing of established quality control practice during construction.

4. TEST FORMATS FOR FDR

Gradation Test

Road Name:

Test Ref. No.: **Date:**

Sieve Size (mm)	Percentage Passing	Limit as per Specifications	Deviation (%)
53.0		100	
37.5		95-100	
19.0		45-100	
9.5		35-100	
4.75		25-100	
0.600		8-65	
0.300		5-40	
0.075		0-10	

Remarks:

Cement Spreading Rate

Road Name:

Test No.: **Date:**

Sl. No.	Area of Sheet (sqm)	Amount of Cement (kg)	Rate of Spreading (kg/m^2)	Avg. Rate of Spreading (kg/m^2)

Remarks:

Test for Depth of Mixing

Road Name:

Test No.: **Date:**

Location:

Sl. No.	Depth of Core (mm)	pH Value	Phenolphthalein Test Result	Depth of Mixing (mm)

Remarks:

Determination of Cube Strengths

Road Name:

Location:

Test No.: **Date:**

Curing Period:

Specimen No.	Size of Cube (mm)	Plan Area (mm^2)	Maximum Load at Failure (kN)	UCS (MPa)

Remarks:

Correction Factors as per IRC SP-89-2010 for Various Size and Shape of Test Specimens		
Sl. No.	Specimen Size	Correction factor
1	150 mm cube	1.00
2	100 mm cube	0.96
3	200 mm × 100 mm diameter cylinder	1.25
4	115.5 mm × 105 mm diameter cylinder	1.04
5	127 mm × 152 mm diameter cylinder	0.96

Field Density using Sand Replacement Method

Road Name:

Test No.: **Date:**

Location:

Weight of Soil (gm)	Volume of Soil (cc)	Bulk Density (gm/cc)	Moisture Content (%)	Dry Density (gm/cc)

Remarks:

Field Density using Density Gauge

Road Name:

Test No.: **Date:**

Location:

Sl. No.	Bulk Density (gm/cc)	Moisture Content (%)	Dry Density (gm/cc)

Remarks:

Thickness of Layer and Strength of Cores

Road Name:

Location:

Test No.: **Date:**

Age of Layer:

Sl. No.	Core Diameter (mm)	Core Height (mm) or Depth of Layer	UCS (MPa)	Corrected UCS (MPa)

Remarks:

Layer Stiffness Evaluation using DCP

Road Name:

Test No.: **Date:**

Number of Blows	DCP Reading (mm)	Difference	Depth	DCP Index (mm/blow)

Comment:

Layer Stiffness Evaluation using FWD

Road Name:

Test No.: **Date:**

No. of Days after Construction:

Temperature:

Load	Deflection (mm)						
	D_0	D_{300}	D_{600}	D_{900}	D_{1200}	D_{1500}	D_{1800}

Back-calculated Modulus:

Comment:

5. REFERENCES

1. Mihai Marasteanu, 'Full-Depth Reclamation (FDR) for Suburban/Urban and Local Roads Application', Minnesota Department of Transportation, Research Services & Library, 2016
2. Hernán Gonzalo-Orden, et.al., 'Advances in the Study of the behaviour of Full-Depth Reclamation(FDR) with Cement', University of Burgos, Spain, Published online in Applied Sciences Journal, 2019(www.mdpi.com/journal/applsci)
3. Design and construction guidelines for full depth reclamation of asphalt pavement, Geotechnical Engineering Manual GEM-27, Department of Transportation, New York, 2015
4. Recommended Mix Design Guidelines for Full Depth Reclamation (FDR) Using Cementor Cement Kiln Dust (CKD) Stabilizing Agent (FDR202), Asphalt Recycling & Reclaiming Association, Illinois, (www.ARRA.org), 2016
5. Guide to Full-Depth Reclamation (FDR) with Cement, PCA and IOWA State University, 2019
6. Full Depth Reclamation by Mt Carmel Stabilization Group Inc (www.arra.org)
7. Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-14), US Department of Transportation, Federal Highway Administration, 2014
8. Recommended Construction Guidelines For Full Depth Reclamation (FDR) Using Cementitious Stabilization (FDR102), www.arra.org, 2015.
9. Rajib B. Mallick, Prithvi S. Kandhal, Elton Ray Brown, Richard L. Bradbury, Edward J. Kearney, Development of a Rational and Practical Mix Design System for Full Depth Reclaimed (FDR) Mixes, The Recycled Materials Resource Center (RMRC) at the University of New Hampshire, 2002
10. Basic Asphalt Recycling Manual, ARRA and US Department of Transportation, Federal Highway Administration, 2001
11. Material Properties of Cold In-Place Recycled and Full-Depth Reclamation Asphalt Concrete, NCHRP Research Report 863, Transportation Research Board, 2017 (http://nap.edu/24902)
12. Recycling and Reclamation of Asphalt Pavements Using In-Place Methods, NCHRP Synthesis 421, Transportation Research Board, 2011

13. Brian K. Diefenderfer and Alex K. Apeagyei, In-Place Pavement Recycling Project, Virginia Department of Transportation, Federal Highway Administration, 2014

14. Photos and Notes made available by M/s Wirtgen Group India

15. IS2720-Part 4 "Methods of test for soils: Grainsize analysis". Published by Bureau of Indian standard, New Delhi, India

16. IS4332-Part 5 "Methods of test for stabilized soils: Determination of unconfined Compressive Strength of stabilized soils". Published by Bureau of Indian standard, New Delhi, India

17. IRC: SP:89-2010 "Guidelines for soil and granular material stabilization using cement, lime and fly ash". Published by Indian Roads Congress, New Delhi, India

ANNEXURE I

INSTALLATION OF GPS SYSTEM IN KEY MACHINERY AND EQUIPMENT

Dr. Ashish Kumar Goel, IAS

Additional Secretary, MoRD
Director General, NRIDA

राष्ट्रीय ग्रामीण अवसंरचना विकास एजेंसी
(ग्रामीण विकास मंत्रालय, भारत सरकार)

National Rural Infrastructure Development Agency
(Ministry of Rural Development, Govt. of India)
5th Floor, 15-NBCC Tower, Bhikaji Cama Place, New Delhi-110066

DO No. NRRDA-P017(25)/7/2021-Dir.(Tech) 31 January 2022

Sub: Installation of GPS system in key machinery and equipment engaged during execution of road works under PMGSY & RCPLWEA.

Dear Madam/Sir,

During the construction of PMGSY roads, many construction equipment like tippers, rollers, excavators, motor graders, etc are used. Proper operation of equipment/ machinery for the specified period is essential to achieve quality as per the specifications during the execution of roads. But, there is no mechanism to monitor the operation of the deployed equipment by the PIUs/ SRRDAs, other than manual inspection. It is not possible that PIU engineer can be present at the site all the time. Hence, a tool for monitoring the deployed equipment is required for ensuring proper quality.

1. In this context, to enhance transparency during road construction and maintenance, it has been decided to implement the GPS enabled VTS (Vehicle Tracking System) on the equipment/ vehicles which are used during road construction such as tippers, rollers, excavators, motor grader, etc. GPS-enabled VTS (Vehicle Tracking System) will be instrumental in enhancing productivity during construction and in improving the quality of work.

2. Detailed guidelines for implementation of GPS enabled VTS (Vehicle Tracking System) are enclosed. States are requested to implement the GPS enabled VTS (Vehicle Tracking System) on all the important construction vehicles/ machinery/ equipment deployed by the contractor/ PIUs for execution of PMGSY (including RCPLWEA) works.

3. The VTS system for road construction should be made functional **latest by 1st May 2022 for all the ongoing road works of PMGSY-III.** Payments to contractors will only be possible once VTS system is established on construction related vehicles and VTS reports are uploaded on OMMAS. SRRDAs should start the process of selecting the vendor and establishing the control room immediately. SRRDAs are free to decide as to which activities/ infrastructure they want to purchase, and which they want to hire from the market. It is advisable that those equipment/ infrastructure which are prone to become obsolete very fast should be taken on hire basis so as to keep pace with emerging technology and bring economy in cost.

With regards,

Yours sincerely,

(Dr. Ashish Kumar Goel)

To,

1. Additional Chief Secretaries/ Principal Secretaries/ Secretaries in-charge of implementing PMGSY & RCPLWEA (All States/UTs).

2. CEO /E-in-C /Chief Engineers of SRRDAs/RCPLWEA (All States/UTs)

Annexure

Detailed guidelines for the implementation of the GPS enabled VTS (Vehicle Tracking System)

GPS enabled VTS (Vehicle Tracking System) is nowadays being quite prevalent and also very economical. Many Government organizations are already using GPS System for enhancing transparency in their operations, such as NHAI, FCI, NDMC, Municipal Corporations, health departments (ambulances), etc. Features of GPS System are as follows:

- The GPS signal is available anywhere on the globe. Hence users will not be deprived of GPS facilities anywhere (even if mobile signal is not present).
- The GPS system gets calibrated on its own and hence it is easy to be used by anyone.
- It provides users with location-based information. This will provide location, movement, speed, etc related data which can be monitored at the control room, or on mobile/ tablet devices by SRRDA, PIU, contractors, etc.

2. Advantages of GPS enabled VTS (Vehicle Tracking System) are as follows:

Tracking - Vehicles that are on the system are displayed in tracking. The tracking status is categorized into Running, Idle, Halt.

Live Maps - The movement of all the running vehicles can be seen on map at a time.

Tracking Vehicles list- List of all vehicles in the fleet which are in running status with the latest tracked time

Passive and Active Tracking - Active systems will collect and send information in real-time whilst passive systems will collect and save all the data, which will be made available to be retrieved later. When a mobile signal isn't available, the information will be saved to the device and will be sent once it is possible to do so.

Less Paperwork: While everything goes digital, there is less paperwork for the division to handle.

Improved Administration: Vehicle tracking systems facilitate administration. All of the time saved on admin can be used for other processes that need more attention and this can lead to greater efficiency and transparency in the system.

3. Further, in this context, the Ministry of Road Transport and Highways has also provided the list of approved vehicle location tracking device manufacturers at their official website (for details please refer to https://morth.nic.in/list-approved-vehicle-location-tracking-device-manufacturers for the same). This list is only indicative. There are other vendors available in the open market. The SRRDA should follow a transparent and competitive process to select the most suitable vendor of their work.

4. **Scope of work:**

The Scope of Work should broadly comprise the following activities:

- Ability to locate a vehicle at a given time.

- Facility to auto-generate routes for the vehicles based on origin and destination point.
- Facility to track defined vs. actual movement of vehicles, capture deviations if any.
- Facility to view vehicle movements real-time on digital maps and provide information on current location on demand.
- Facility to view vehicle details of a particular vehicle on an interactive GIS Map supporting latitude, longitude location records generated by GPS device. This should include all possible types of map view like a roadmap, terrain, and other applicable views.
- Facility for users to access and view position/location information on GIS maps near real-time through a web interface with historic data displayed on maps.
- Facility for playing back the recorded details of the vehicle movement along the authorized route.
- The system should have analytics features as per requirements.
- Web-based Vehicle Tracking Software and customize the same as per the requirements to operate and maintain the GPS-based Vehicle Tracking devices installed in Vehicles.
- It is assumed that the entire route of a vehicle is covered by GPS and a leading mobile network. But there might be some parts of the route where there is no network coverage. So the system must work in off-line mode too for these areas and will provide the data once the vehicle enters the mobile network zone.
- The Bidder shall be responsible for updating and upgradation (if required) of all Software and Hardware for the successful operation of the project during the contract period.
- All data generated during the operation period shall be the property of the SRRDA & NRIDA. The vendor is also required to submit the data every 3-5 days, this data will be submitted on GeoSadak i.e. https://geosadak-pmgsy.nic.in/ a web-based GIS application of NRIDA.
- The successful bidder has to share the API/data/ specific MIS as per the requirements of SRRDA / NRIDA without any additional charges.
- All the supporting accessories and associated software, monitoring dashboard will be provided by the bidder, and apart from the quoted in the financial proposal, no other cost will be entertained by the SRRDA thereafter.
- Dynamic reporting system. Provide the following customized MIS report as per requirements of SRRDA/NRIDA. Some of the reports are as follows:
    - Live location of the Vehicle
    - Working Hour/ Efficiency reports
    - Detailed Activity reports
    - Vehicle Summary
    - History Report (showing path taken by vehicle)
    - Trip-wise Report
    - Vehicle stoppage report.
    - Monthly monitoring summary etc.

- Management Dashboard and Analytics: Bidder shall be responsible for developing a management dashboard with key performance indicators in easy to view graphical and colorful format depending on user credentials. The dashboard shall be supported with analytical reports in terms of machine levels, system failure trends, etc.
- Training Design & Execution of Training to the stakeholders for successful implementation and operation.
- The application should provide the location and history of the vehicles in the GIS map. The tracking data will be kept live in the system for at least 6 months. There will be a provision to support archive and restore functions for older data.
- The setup Control room at SRRDA level for live tracking of the vehicles
- Provide a graphical interface to make quick position-related assessments. The application shall support dynamic monitoring of vehicles moving out of their defined routes and be able to raise alerts to the control station.

Note: SRRDAs are free to define scope of work for purchase and for hire separately.

5. GPS Vehicle Tracking System Workflow

A GPS-enabled vehicle tracking device is installed on each vehicle such as like excavators, motor graders, dozers, etc. to collect and transmit tracking data via a cellular or satellite network. A GPS tracking system uses the Global Navigation Satellite System (GNSS) network. This network incorporates a range of satellites that use microwave signals that are transmitted to GPS devices to give information on location, vehicle speed, time, and direction. So, a GPS tracking system can potentially give both real-time and historic navigation data on any kind of vehicle journey.

The tracking hardware is installed inside the vehicle in such a manner that it is not visible from outside the vehicle. Hence, it works as a secret unit that continuously sends the coordinates to the monitoring center. GPS tracking unit is a device that uses the Global Positioning System to determine the precise location of a vehicle to which it is attached.

A vehicle tracking system combines the installation of an electronic device in a vehicle with purpose-designed software to allow the user to monitor the vehicle, collecting data in the process from the field and delivering it to the base of operation. The system consists of a GPS receiver that provides the real-time location of the vehicle. This real-time data is stored in the database.

The vendor will setup a GPS Device on the vehicle and this device will provide the live location of the vehicle and mapped the data on Google MAP. The vendor does have their own GPS Vehicle Tracking System wherein the following three types of users which will use this system:

(i) NRIDA Level User

(ii) SRRDA Level User

(iii) PIU Level User

Above mentioned users are having different rights to view the live tracking or history of the vehicles :-

- NRIDA level user will have all the rights he/she can view the live tracking of the vehicle PAN India level
- SRRDA level users will have all the rights he/she can view the live tracking of the vehicle at their State level only
- PIU level users will have all the rights he/she can view the live tracking of the vehicle at their PIU level only

The System Administrator will provide these rights, therefore the user will enter the system through proper Authorization and Authentication. Following features will have in the GPS Vehicle Tracking System:

- In case if the GPS Device may be tweaked/altered, alert SMS will be sent at users registered Mobile No. or at Mobile App.
- Through the Vehicle Tracking System, users are able to track the live location of the vehicles, print reports at any time. Users are also able to see the historic data later on. Further, this data will be ported on GIS Web-based application Geo Sadak through Web API.
- A control room will be set up at the SRRDA level so that SRRDA is able to monitor the system at the PIU level and take decisions accordingly.

MIX DESIGN FOR CEMENT TREATED BASE (CTB) USING CEMENT AND ADDITIVE (ZYCOBOND & TERRASIL)

Transportation Engineering Group
Department of Civil Engineering
Indian Institute of Technology, Roorkee
Roorkee- 247 667
E-mail: gdranfce@iitr.ac.in/
gdranjan@gmail.com
(O): +91-1332-285584
(M): +91-8126924834

Dr. G.D. Ransinchung R.N.
Professor
Coordinator, Transportation Engineering Group
Chairman, ISC
Coordinator, STA, PMGSY, NRIDA, Govt. , India.
Standing Committee Member, AKC50, Transportation Research Board, Washington D.C., U.S.A.
National Advisory Committee Member on Self-Healing Roads, TIFAC, DST, New Delhi.
B-8 Committee Member, Indian Roads Congress, New Delhi.
Formerly, H-3 & H-6 Committee Members, Indian Roads Congress, New Delhi.

Dated: 13.01.2022

M/s Blacklead Infratech Pvt Ltd.,
902, Tower-I, Parsvnath Planet,
Vibhuti Khand, Gomti Nagar,
Lucknow-700013.

IITR/CED/TEG/CTB Design Mix/1312022

DESIGN MIX REPORT

Sub: Preparation of Job Mix Design for Roads under Full Depth Reclamation/In-situ Stabilization with Cement and Additive Package UDFDR-01.
Name of Road: T05 Archha Barehi Kamsin Road Distt: Chitrkoot PKG UP 1985.

Project No.: CED-6346/21-22

Sir,

As discussed, the design mix report of above cited subject is being enclosed herewith for your ready reference and office record.

Receipt of the same may kindly be acknowledged.

(G.D. Ransinchung R.N.)

Prof. G. D. Ransinchung R. N.
Dept. of Civil Engineering
IIT Roorkee-247 667
Ph.:+91-8126924834
Email: gdranfce@iitr.ac.in

1

Report on

MIX DESIGN FOR CEMENT TREATED BASE (CTB) LAYER FOR CONSTRUCTION & MAINTENANCE OF ROADS UNDER FULL DEPTH RECLAIMATION/IN-SITU STABILIZATION WITH CEMENT AND ADDITIVE PACKAGE UPFDR-01- T05 ARCHHA BAREHI KAMSIN ROAD DISTT: CHITRKOOT PKG UP 1985

PROJECT NO.: CED-6346/21-22

Submitted to

M/S. BLACKLEAD INFRATECH PVT LTD. 902, TOWER-I, PARSVNATH PLANET, VIBHUTI KHAND, GOMTI NAGAR LUKNOW – 700013

BY

DR. G.D. RANSINCHUNG R.N., PROFESSOR (P.I.)
COORDINATOR, TRANSPORTATION ENGINEERING GROUP
DR. PRAVEEN KUMAR- PROFESSOR (CO-PI)

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE
ROORKEE-UTTARAKHAND-247667

JANUARY, 2022

CONTENT

S.No.	Description	Page No.
1	Cover letter	1
2	Front page of report	2
3	Content	3
4	Introduction	4
5	Details of laboratory studies	4
6	Materials used	4
7	Combined Gradation of RPM	5
8	Atterberg limits	6
9	Proctor compaction test	6
10	California Bearing Ratio (CBR) test	6
11	Unconfined compressive strength (UCS)	6-7
12	Relavent photographs collected during lab investigation	7-10
13	Concluding remarks based on the lab studies	10-11
14	Construction Methodology for CTB	10-11
15	Construction of Trial Section for CTB	11-12
16	Disclaimer	12-13
17	Acknowledgement	13-14

1. INTRODUCTION

M/s Blacklead Infratech Pvt. Ltd., requested Dr. G.D. Ransinchung R.N., Professor, Department of Civil Engineering, Indian Institute of Technology Roorkee for establishing design mix for cement treated base (CTB) for construction of roads under Full Depth Reclamation/In-situ Stabilization with Cement and additive. Dr. G.D. Ransinchung R.N. apprised his willingness to take-up the work.

The main objective of the present job is to establish the most economical and practical combination of supplied Reclaimed Pavement Materials (RPM) in conjunction with cement and Terrasil & Zycobond to suit the road construction employing Full Depth Reclamation Technique. Design mix was established in accordance with IRC: SP: 89-Part-II, 2018. Gradation of the RPM was carried out in the laboratory keeping the requirements of grading as specified in MORTH clause Table 400-4.

2.0 DETAILS OF LABORATORY STUDIES

2.1 Materials

Reclaimed Pavement Materials (RPM) was supplied by the client to the testing laboratory of Transportation Engineering Group, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee. After ensuring proper quartering of the samples, materials were subjected to the gradation and durability tests so as to evaluate the suitability of the RPM for road construction with cement and stabilizers (Terrasil & Zycobond). In the current laboratory investigation, no conventional aggregates were incorporated since the main motive behind employing Full Depth Reclamation (FDR) concept in the road construction is to build road without procuring additional conventional aggregates atleast at the stage of unbound base course construction.

2.1.1 Materials Used:

(i) Existing crust materials collected from the site by the client.

(ii) Ordinary Portland cement (OPC) of grade 43 conforming to IS: 8112 was used for the stabilization of existing crust materials.

(iii) Terrasil & Zycobond stabilizer which was made available to our Laboratory by the client.

Table 1 below presents the gradation of the existing crust materials and Fig.1 shows the gradation envelope of the existing crust materials.

Table 1: Combined Gradation of Existing Crust Materials

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
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

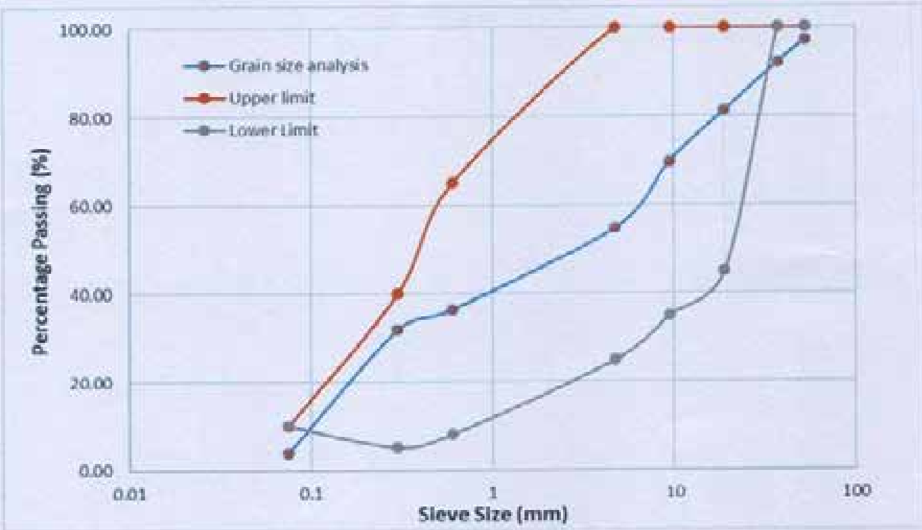


Fig.1 Gradation envelope of existing crust materials.

Note: It is not necessary that the existing crust pavement materials must conform to the specification limits of the specified grading but for the current project. the material collected from the sits is found to conform to the specified specification limits. Even if the gradation of RPM is not conforming to the specification limits, the aforesaid crust pavement material's mix should be able to produce desirable CBR value, UCS value, and must satisfy the durability tests.

5

2.1.2 Atterberg Limits:

Test was conducted in accordance with IS: 2720 (Part-5). Material passing 425 microns was found to be non-plastic.

2.1.3 Proctor Compaction test:

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 Fig. 2. Graphical plot has been prepared with water content in x-axis and dry density (g/cc) in y-axis. The optimum moisture content is 9.20% and corresponding maximum dry density is 2.120g/cc.

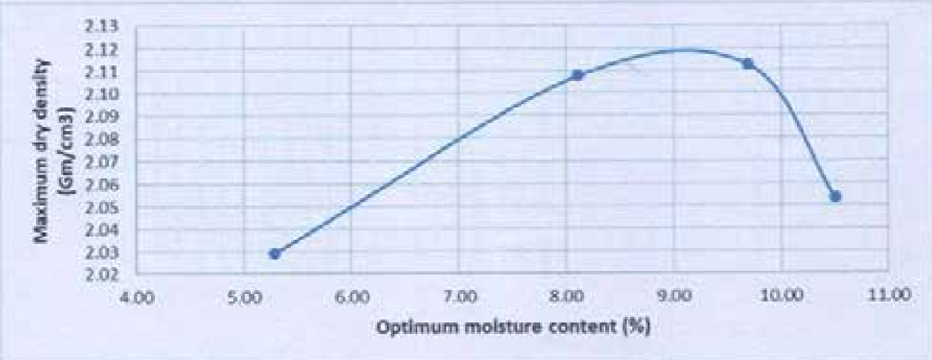


Fig.2 Proctor compaction curve of existing crust materials.

3 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. 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+ Terrasil & Zycobond 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 exiting 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.

Cube ID	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 day UCS = 4.77 MPa	
4	25.12.2021	22.01.2022	28	Due
5	25.12.2021	22.01.2022	28	Due
6	25.12.2021	22.01.2022	28	Due
7	25.12.2021	22.01.2022	28	Due
8	25.12.2021	22.01.2022	28	Due
9	25.12.2021	22.01.2022	28	Due

FEW PHOTOGRAPHS CAPTURED DURING LABORATORY INVESTIGATION

Fig.3 Preparation of cylindrical molds for determining optimum moisture content & maximum dry density.

7

Fig. 4 Removing oversize aggregates. **Fig.5** Weighing sieved materials.

Fig. 6. Sieving of materials

Fig. 7. Quartering materials

8

Fig.8. Preparation of mixture proportions for sample preparation.

Fig.9. Weighing and batching RPM and additives for preparation of mixture proportions for sample preparation

Fig.10. Cube molds for determining UCS and durability tests.

Fig.11. Cube molds for determining UCS and durability tests.

4 Concluding Remarks based on the Laboratory studies:

Existing crust pavement 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 for the construction of CTB layer. However, it is strongly recommend to validate the same in the field trial section prior taking to the main work areas.

(i) **The approximate quantity of cement, Zycobond, Terrasil, Water etc. for 1 m³ of RPM material are as follows:**

(a) Weight of RPM = 2120 kg

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

(c) Terrasil @ 0.85 kg/m³ {(2120 x 0.85x 1000)/2120}=850 gm.

(d) Zycobond @0.85 kg/m³ {(2120 x 0.85 x 1000)/2120} = 850 gm.

Total weight = 2227.7 kg.

(d) Quantity of water to be added = 204.95 kg

Adjustment in quantity of water may be needed to produce cohesive RPM mixture and this will depend upon the prevailing weather condition.

6.0 Construction Methodology for Cement Treated Base (CTB)

(i) Since the current project shall be executed with the concept of Mix-in place stabilization, hence it is mandatory to employ stabilization machinery.
The stabilization machinery used shall be capable of providing in-situ rock/boulder crushing-cum-pulverising-cum-homogenizing features and for a constant pre-determined depth/uniform operation.

(ii) Initially the existing pavement crust as specified in the contract shall be milled & crust and the same shall be spread across the widening portions of the road so as to maintain a proper level and thereafter the entire carriageway width has to be reclaimed lane by lane till the full carriageway width is achieved. Manual mixing methods using labour/agriculture based methodology should not be permitted.

(iii)Immediately desired dosage of cement as recommended in the design mix has to be spread across the width of the pavement followed by stabilizer and thereafter crushing-cum-pulverising-cum-homogenizing operations shall be carried out.

(iv)Proper road profile and uniformity in layer thickness shall be monitored employing suitable level instrument and thickness gauge.

(v) Initial compaction shall be done using static roller by giving 2-3 passes. Intermediate rolling shall be done with steel drum vibratory roller by giving 3-4 passes with vibration. The final rolling and finish rolling shall be done with static three-wheel roller and the rolling activity shall be continuing until the roller tire impressions on the surface is completely eliminated. Loose thickness of the layer shall be adjusted to achieve desired compacted thickness by keeping surcharge percentage of about 20-22% depending upon the compressibility of the materials.

(vi) In order to ensure quality of construction, it is mandatory to cast 150 mm cubes of at least six samples so that 3 cube samples each are available for 7 days & 28 days testing to ascertain Unconfined Compressive Strength (UCS) and validate with the laboratory results.

(vii) Curing shall be done for 3 to 4 days continuously by just moistening the stabilised RPM road surface for ensuring proper hydration of cement grains and stabilizers preferably 7 days moist curing is recommended.

(viii) The wearing course shall be laid after 3 to 4 days of laying of CTB layer but prolonged exposure to traffic may results in damage to CTB layer.

(ix) Tack coat shall be applied suitably to provide a firm adhesion at the interface of previously laid surface and newly laid mix.

12

7.0 Construction of Trial Section for CTB

It is strongly recommended to construct trial section of at least 50 m stretch road prior to construction of main project to validate the proposed design mix. It is also required to re-establish the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of RPM at site. In addition to these information, it is also suggested to ascertain the Unconfined Compressive Strength (UCS) from the samples collected from trial section. The final data retrieve from this exercise, shall be considered as final for main project execution.

DISCLAIMER

The design report is solely intended for the sponsoring agency. If you are not the intended recipient of the report, please be aware that you are not authorized in any way to read, forward, print, retain a copy or disseminate any part of it. The technical data provided in the report pertains to the specific work site, aggregate-mixtures, and testing was conducted in accordance with relevant Indian Standard Codes and design mix was done keeping the specifications of IRC: SP:89-Part-2, 2018. The opinion shared in this report is purely based on personal professional experience only. The responsibility of Indian Institute of Technology Roorkee is limited to only on the calculated design parameters and test results. All procedural, legal or operational matters will be the responsibility of the party using this report.

ACKNOWLEDGEMENTS

Investigator is thankful to M/s Blacklead Infratech Pvt. Ltd. for referring this project to the Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee. I would also like to acknowledge with much appreciation the crucial role imparted by the laboratory staff and research scholars, Transportation

Engineering Group, Department of Civil Engineering, IIT Roorkee during laboratory test.

SUBMITTED

(G.D. RANSINCHUNG R.N.)
PROFESSOR
&
PRINCIPAL INVESTIGATOR

Prof. G. D. Ransinchung R. N.
Dept. of Civil Engineering
IIT Roorkee-247 667
91-8126924834
Email: gdranfce@iitr.ac.in

14

COST COMPARISON BETWEEN CONVENTIONAL AND FDR TECHNOLOGY (Rates based on SoR 2021 UP)

These calculations are only indicative. Actual cost will vary on the basis of choice of technology/methodology as per site requirement, SoR of the state, location and various other factors. These calculations should not be treated as recommendations for a particular chemical/proprietary item.

Lead	200 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
Case I a	**With T5 and less Traffic Category (3.75 m C/W) without surfacing**	WBM G-3 Overlay	**25.00**	Stabilized Base (FDR)	**29.00**
b	**With T5 and less Traffic Category (3.75 m C/W widening from 3.0 m C/W) without surfacing**	GSB in Widening	**31.00**	Stabilized Base (FDR)	**29.00**
		WBM G-3 Overlay			
Case II a	**With T5 and less Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**31.00**	Stabilized Base (FDR)	**35.00**
		1st Coat Surface Dressing (SD)		1st Coat Surface Dressing (SD)	
		2nd Coat SD		2nd Coat SD	
b	**With T5 and less Traffic Category (3.75 m C/W widening from 3.0 m C/W)**	GSB in Widening	**37.00**	Stabilized Base (FDR)	**35.00**
		WBM G-3 Overlay			
		1st Coat Surface Dressing (SD)		1st Coat Surface Dressing with Pre-Coating aggregate	
		2nd Coat SD		2nd Coat Surface Dressing with Pre-Coating aggregate	
Case III a	**With T6 to T8 Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**36.00**	Stabilized Base (FDR)	**52.00**
		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	

Lead	200 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
b	With T6 to T8 Traffic Category (3.75 m C/W widening from 3.0 m C/W)	GSB in Widening	44.00	Stabilized Base (FDR)	52.00
		WBM G-3 Overlay			
		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	
c	With T6 to T8 Traffic Category (5.5 m C/W widening from 3.75 m C/W)	GSB in Widening	69.00	Stabilized Base (FDR)	76.00
		WBM G-3 Overlay			
		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	
Case IV	With T9 Traffic Category (3.75 m C/W)	WBM G-3 Overlay	53.00	Stabilized Base (FDR)	55.00
a		Prime Coat			
		BM		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI/WMM (75 mm)	
		Seal Coat		BC (40 mm)	
b	With T9 Traffic Category (3.75 m C/W widening from 3.0 m C/W)	GSB in Widening	61.00	Stabilized Base (FDR)	55.00
		WBM G-3 Overlay			
		Prime Coat			
		BM		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI/WMM (75 mm)	
		Seal Coat		BC (40 mm)	
c	With T9 Traffic Category (5.5 m C/W widening from 3.75 m C/W)	GSB in Widening	94.00	Stabilized Base (FDR)	82.00
		WBM G-3 Overlay			
		Prime Coat		Prime Coat	
		BM		Tack Coat	
		Tack Coat		SAMI/WMM (75 mm)	
		OGPC		BC (40 mm)	
		Seal Coat			

Lead	250 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
Case I	**With T5 and less Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**34.00**	Stabilized Base (FDR)	**35.00**
		1st Coat Surface Dressing (SD)		1st Coat SD	
		2nd Coat SD		2nd Coat SD	
Case II a	**With T6 to T8 Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**39.00**	Stabilized Base (FDR)	**52.00**
		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	
b	**With T6 to T8 Traffic Category (5.5 m C/W widening from 3.75 m C/W)**	GSB in Widening	**75.50**	Stabilized Base (FDR)	**76.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		Tack Coat		SAMI	
		OGPC		BC (30 mm)	
		Seal Coat			
Case III	**With T9 Traffic Category (5.5 m C/W widening from 3.75 m C/W)**	GSB in Widening	**100.50**	Stabilized Base (FDR)	**82.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		BM		SAMI	
		Tack Coat		BC (40 mm)	
		OGPC			
		Seal Coat			

Lead	300 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
Case I	**With T5 and less Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**38.00**	Stabilized Base (FDR)	**35.00**
		1st Coat Surface Dressing (SD)		1st Coat SD	
		2nd Coat SD		2nd Coat SD	

Lead	300 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
Case II	**With T6 to T8 Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**43.00**	Stabilized Base (FDR)	**52.00**
a		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	
b	**With T6 to T8 Traffic Category (5.5m C/W widening from 3.75 m C/W)**	GSB in Widening	**79.00**	Stabilized Base (FDR)	**76.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		Tack Coat		SAMI	
		OGPC		BC (30 mm)	
		Seal Coat			
Case III	**With T9 Traffic Category (5.5 m C/W widening from 3.75 m C/W)**	GSB in Widening	**107.00**	Stabilized Base (FDR)	**82.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		BM		SAMI	
		Tack Coat		BC (40 mm)	
		OGPC			
		Seal Coat			

Lead	350 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
Case I	**With T5 and less Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**42.00**	Stabilized Base (FDR)	**35.00**
		1st Coat Surface Dressing (SD)		1st Coat SD	
		2nd Coat SD		2nd Coat SD	
Case II	**With T6 to T8 Traffic Category (3.75 m C/W)**	WBM G-3 Overlay	**47.00**	Stabilized Base (FDR)	**52.00**
a		Prime Coat		Prime Coat	
		Tack Coat		Tack Coat	
		OGPC		SAMI	
		Seal Coat		BC (30 mm)	

Lead	350 km	Conventional Technology		FDR Technology	
Cases Detail		Items- Conventional Technology	Tentative Average Cost/ km (Lakhs)	Items- FDR Technology	Tentative Average Cost/ km (Lakhs)
b	**With T6 to T8 Traffic Category (5.5 m C/W widening from 3.75 m C/W)**	GSB in Widening	**88.00**	Stabilized Base (FDR)	**76.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		Tack Coat		SAMI	
		OGPC		BC (30 mm)	
		Seal Coat			
Case III	**With T9 Traffic Category (5.5 m C/W widening from 3.75 m C/W)**	GSB in Widening	**116.00**	Stabilized Base (FDR)	**82.00**
		WBM G-3 Overlay		Prime Coat	
		Prime Coat		Tack Coat	
		BM		SAMI	
		Tack Coat		BC (40 mm)	
		OGPC			
		Seal Coat			

RATE ANALYSIS FDR

UTTAR PRADESH
Stabilisation 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 in mix design in accordance with IRC-SP-72-2015, I RC-37-2012 & 2018 and IRC SP 89 (part-II) 2018. Cementitious additive @ rate of a minimum of 5 - 7% and CCS/CS additive should be spread on the existing pavement using a mobile truck mounted containerized cement/additive spreader with microprocessor controlled weighing and spreading system. The additive spreader shall have variable working width sufficient to cover whole pavement lane. The in-situ stabilization process shall be carried out by a mobile and self-propelled stabilizer/reclaimer of working width of 2.4 m and with minimum engine horsepower 440 kw with a variable working depth up to 50 cm. The resultant stabilized mix then would be profiled to the required grade, level and thickness using motor grader and the mix would be compacted using 20 tonne pad foot roller in combination with smooth wheel roller to achieve desired proctor density as per IRC 37-2012 & 2018 and complete in all respect and curing with water as required including all materials, labour and machinery etc. The entire in-situ process would be carried out in single pass with milling and pulverising of damaged asphalt pavement/soil/ aggregates/soi1-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 tandem roller should be followed by Pneumatic Tyre Roller. The minimum unconfined compressive strength (UC'S) of' stabilized subbase/base should be 4.5 to 7 MPa after 7/28 days of curing as per IRC-SP-72-2015, IRC-37-2012 & 2018 Also durability aspects (wet-dry cycles) of stabilized subbase should be satisfied as per IRC 37-2012 & 2018 and IRC SP 89 (part II) 2018. The gradation mixes and materials should be as per IRC 37-2012 & 2018 and IRC SP 89 (part II) 2018. The train of equipment to be used are binder spreader- water Tanker - Additive Truck - Recycler - Padfoot Roller (20 Tonne) + Single Drum Compactor- Grader- Tandom Roller- Pneumatic Tyre Roller (20 Tonne)

Rate for the technology layer (Taking Daily average output of 625 cum (1375 tonne)/2500 sq. per for 0.25 m depth					
S. No.	**Description**	**Unit**	**Quantity**	**Rate**	**Amount**
1	2	3	4	5	6
1.	**Labour (Mazdoor)**	**Day**	**20**	**325.00**	**6500.00**
2.	**Machinery**				
i	Recycler Machine	hour	8	30277.00	242216.00
ii	Cement Spreader	hour	8	7905.00	63240.00
iii	Additive Spreader	hour	8	1750.00	14000.00
iv	Vibratory Pad Foot Roller (20 tonne)	hour	8	4200.00	33600.00
v	Vibratory Roller Smooth Drum	hour	8	2429.00	19432.00
vi	Motor Grade 150 HP	hour	8	5419.00	43352.00
vii	Pneumatic Tyre Roller (PTR)	hour	8	2440.00	19520.00

S. No.	Description	Unit	Quantity	Rate	Amount
1	2	3	4	5	6
viii	Front end/back toe loader 2.1 cum capacity	hour	8	2515.00	20120.00
ix	Bulker for cement handling for uploading to cement spreader, 6 units daily for 8 hours/bulker	hour	48	1370.00	65760.00
x	Water tanker 24KL Capacity, 4 number for 10 hours/each	hour	40	1270.00	50800.00
3.	**Materials**				
i	Cement at site @ 5% by weight of soil treated @ Rs. 6500 per ton in	tonne	62.5	6000.00	375000.00
ii	Additive per square meter@ Rs 450 per square meter	sq.m	2500	450.00	1125000.00
iii	**Cost of Water**	KL	180	60.00	10800.00
4	**Total**				2089340.00
5	Overhead & C P @ 12.5%				261167.5
	Cost for 625 cum				2350507.5
	Rate per cum				3760.81

BIHAR

Stabilisation of in-situ (existing pavement crust) or soil or otherwise subbase/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 in mix design in accordance with IRC-SP-72-2015, I RC-37-2012 & 2018 and IRC SP 89 (part-II) 2018. Cementitious additive @ rate of a minimum of 5–7% and CCS/CS additive should be spread on the existing pavement using a mobile truck mounted containerized cement/additive spreader with microprocessor-controlled weighing and spreading system. The additive spreader shall have variable working width sufficient to cover whole pavement lane. The in-situ stabilization process shall be carried out by a mobile and self-propelled stabilizer/reclaimer of working width of 2.4 m and with minimum engine horsepower 440 kw with a variable working depth up to 50 cm. The resultant stabilized mix then would be profiled to the required grade, level and thickness using motor grader and the mix would be compacted using 20 tonne pad foot roller in combination with smooth wheel roller to achieve desired proctor density as per IRC 37-2012 & 2018 and complete in all respect and curing with water as required including all materials, labour and machinery etc. The entire in-situ process would be carried out in single pass with milling and pulverising of damaged asphalt pavement/soil/ aggregates/soi1-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 tandem roller must be followed by Pneumatic Tyre Roller. The minimum unconfined compressive strength (UC'S) of' stabilized subbase/base should be 4.5 to 7 MPa after 7/28 days of curing as per IRC-SP-72-2015, IRC-37-2012 & 2018 Also durability aspects (wet-dry cycles) of stabilized subbase should be satisfied as per IRC 37-2012 & 2018 and IRC SP 89 (part II) 2018. The gradation mixes and materials should be as per IRC 37-2012 & 2018 and IRC SP 89 (part II) 2018. The train of equipment to be used are binder spreader- water Tanker-Additive Truck- Recycler- Padfoot Roller (20 Tonne) +Single Drum Compactor- Grader- Tandom Roller- Pneumatic Tyre Roller (20 Tonne)

Rate for the technology layer (Taking Daily average output of 625 cum (1375 tonne)/2500 sq. per for 0.25 m depth

S. No.	Description	Unit	Quantity	Rate	Amount
1	2	3	4	5	6
1.	**Labour (Mazdoor)**	**Day**	**20**	**325.00**	**6500.00**
2.	**Machinery**				
i	Recycler Machine	hour	8	30277.00	242216.00
ii	Cement Spreader	hour	8	6912.00	55304.00
iii	Additive Spreader	hour	8	1750.00	14000.00
iv	Vibratory Pad Foot Roller (20 tonne)	hour	8	4200.00	33600.00
v	Vibratory Roller Smooth Drum	hour	8	1998.00	15904.00
vi	Motor Grade 150 HP	hour	8	5450.00	43600.00
vii	Pneumatic Tyre Roller (PTR)	hour	8	1996.00	15968.00
viii	Front end/back toe loader 2.1 cum capacity	hour	8	2033.00	16264.00

S. No.	Description	Unit	Quantity	Rate	Amount
1	2	3	4	5	6
ix	Bulker for cement handling for uploading to cement spreader, 6 units daily for 8 hours/bulker	hour	48	1370.00	65760.00
x	Water tanker 24 KL Capacity, 4 number for 10 hours/each	hour	40	1270.00	50800.00
3.	**Materials**				
i	Cement at site @ 5% by weight of soil treated @ Rs. 6500 per ton in	tonne	62.5	5156.00	322250.00
ii	Additive per square meter@ Rs 450 per square meter	sq.m	2500	450.00	1125000.00
iii	**Cost of Water**	KL	180	40.00	7200.00
4	**Total**				2014366.00
5	Overhead & C P @ 12.5%				251795.75
	Cost for 625 cum				2266161.75
	Rate per cum				3625.86

NOTES

NOTES

Pradhan Mantri
Gram Sadak Yojana

National Rural Infrastructure Development Agency
15 NBCC Tower, 5th Floor, Bhikaji Cama Place
Rama Krishna Puram, New Delhi-110066
Tel: 011-26716930, 011-26716933, 011-26716936, 011-26716939 | Fax: (91)-011-26179555
Email: nrrda@pmgsy.nic.in | Web: www.pmgsy.nic.in