

# CONSTRUCTION AND QUALITY CONTROL OF FLEXIBLE AND RIGID PAVEMENTS

## Construction and Quality control of Subgrade and Granular layers

National Rural  
Infrastructure Development  
Agency



Ministry of Rural  
Development

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Technology



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# Lecture 2

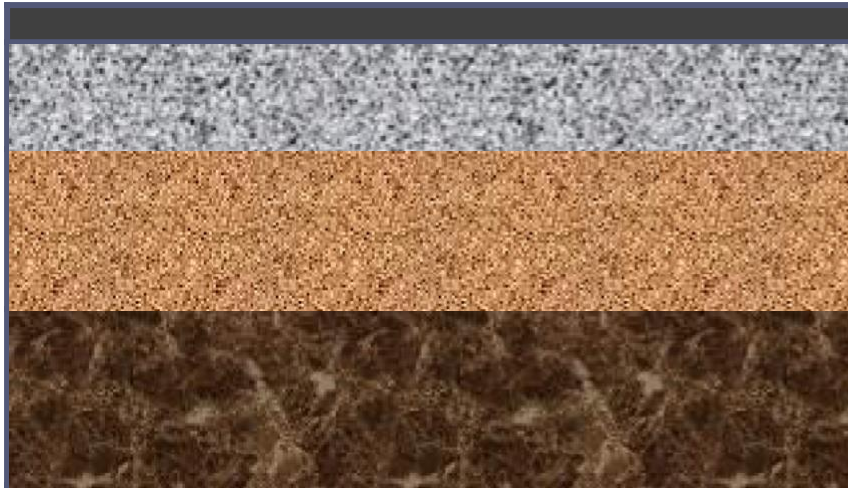
- ▶ **Construction and Quality control of Subgrade and Granular layers**

# Background knowledge which is important

- What are the modes in which low volume roads fail?
- What are the mode in which unbound subgrade soil or granular materials will fail?
- Why shall the specifications for low volume roads and high volume roads differ?
- What would be parameters which influences the strength of the subgrade and granular layers?
- How shall the specification values appear as we move from one layer to another

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# Typical failures



A test pit taken in a low volume road exhibiting rutting



A test pit taken in a high volume road exhibiting rutting

# Typical failures

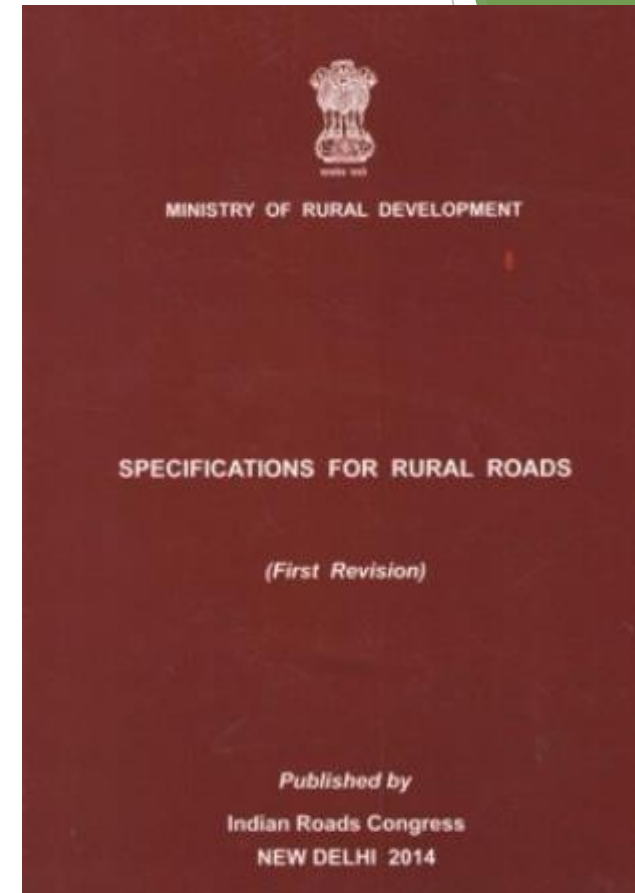
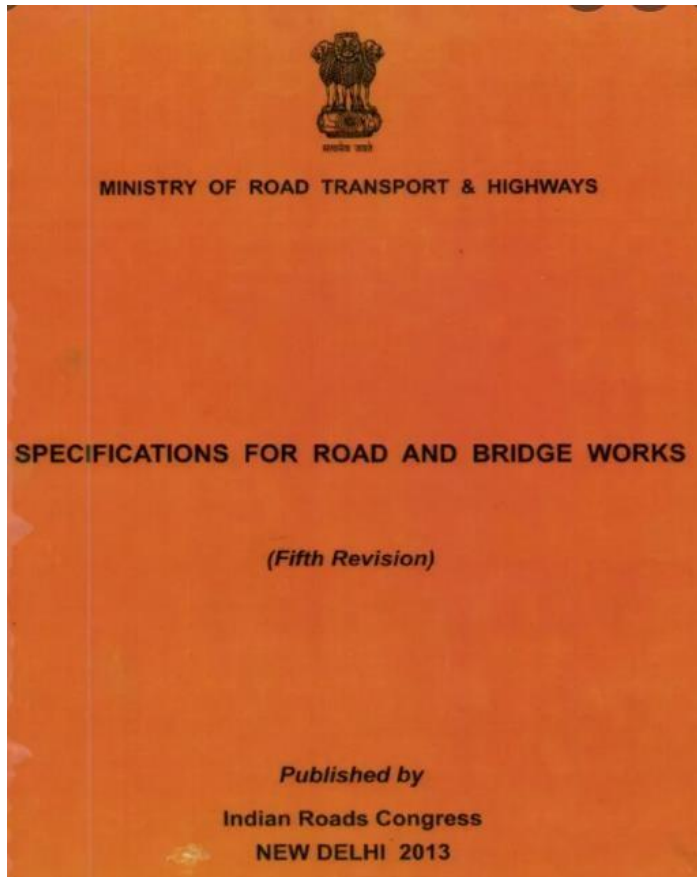




# Typical failures



# MoRTH and MoRD specification manuals- Specification for Road and Bridge work



# Subgrade construction -General requirements

- The Contractor shall submit following test data, prior to 7 days of commencement of subgrade construction
- Soil Classification test data
- Moisture content-Dry density relationship of each
- CBR test results

# Acceptance criteria for Soil used in Subgrade

- The following type of soils/materials are considered unsuitable for embankment/**subgrade** construction
  - Materials from swamps, marshes and bogs (wetland)
  - Organic soils - OL, OI and OH
  - Materials susceptible to spontaneous combustion
  - Materials in frozen condition
  - Clays having  $LL > 70$  and  $PI > 45$
  - Expansive soils, with swell index  $> 50\%$
  - **Materials with salts that results in leaching of embankment**
  - Materials with Sulphate ( $SO_2$ ) exceeding 0.5% by mass
  - The size of coarse materials in the mixture shall not exceed 75 mm for embankments and 50 mm when placed in subgrade

# Assessment of soil used for

Division	Sub-Division		Group letter symbol	Typical names	Value as Subgrade when not subject to frost action	Unit Dry Weight g/cm <sup>3</sup>	CBR Value percent
<b>Coarse-Grained Soils</b> More than half of material is larger than 75 micron IS Sieve Size (The 75 micron IS Sieve size is about the smallest particle visible to the naked eye)	<b>Gravels</b> More than half of coarse fraction is larger than 4.75 mm IS Sieve size	Clean gravels (little or no fines)	GW	Well graded gravels, Gravel - sand mixtures; little or no fines	Excellent	2.00-2.24	40-80
			GP	Poorly graded gravels or gravel sand mixtures; little or no fines	Good to excellent	1.76-2.24	30-60
		Gravels with fines (appreciable amount of fines)	GM	Silty gravels, poorly graded gravel - sand silt mixtures	d <sup>+</sup> - good to excellent u <sup>+</sup> - good	2.00-2.32 1.84-2.16	40-60 20-30
			GC	Clayey gravels, poorly graded gravel - sand clay mixtures	Good	2.08-2.32	20-40
	<b>Sands</b> More than half of coarse fraction is smaller than 4.75 mm IS sieve size (For visual classification the 5 mm size may be used as equivalent to the 4.75 mm IS Sieve size)	Clean sands (little or no fines)	SW	Well graded sands, gravelly sands; little or no fines.	Good	1.76-2.08	20-40
			SP	Poorly graded sands or gravelly sands; little or no fines	Fair to good	1.68-2.16	10-40
		Sands with fines (appreciable amount of fines)	SM	Silty sands, poorly graded sand silt mixtures	d <sup>+</sup> - fair to good u <sup>+</sup> - fair	1.92-2.16 1.60-2.08	15-40 10-20
			SC	Clayey sands, poorly graded sand clay mixtures	Poor to fair	1.60-2.16	5-20

Source: IRC 36-2010

# Assessment of soil used for

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Division	Sub-Division	Group letter symbol	Typical names	Value as Subgrade when not subject to frost action	Unit Dry Weight g/cm <sup>3</sup>	CBR Value percent
Fine-Grained Soils More than half of material is smaller than 75 micron IS Sieve Size. (The 75 micron IS Sieve size is about the smallest particle visible to the naked eye)	Sils and clays with low compressibility and liquid limit less than 35	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with none to low plasticity	Poor to fair	1.44-2.08	15 or less
		CL	Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of low plasticity	Poor to fair	1.44-2.08	15 or less
		OL	Organic silts and organic silty clays of low plasticity	Poor	1.44-1.68	5 or less
	Sils and clays with medium compressibility and liquid limit greater than 35 and less than 50	MI	Inorganic silts, silty or clayey fine sands or clayey silts of medium plasticity	Poor to fair	1.44-2.08	15 or less
		CI	Inorganic clays, gravelly clays, sandy clays, silty clays, lean clays of medium plasticity	Poor to fair	1.44-2.08	15 or less
		OI	Organic silts and organic silty clays of medium plasticity	Poor	1.44-1.68	5 or less
	Sils and clays with high compressibility and liquid limit greater than 50	MH	Inorganic silts of high compressibility, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	1.28-1.68	10 or less
		CH	Inorganic clays of high plasticity, fat clays	Poor to fair	1.44-1.84	15 or less
		OH	Organic clays of medium to high plasticity	Poor to very poor	1.28-1.76	5 or less
	Highly organic soil		Pt	Peat and other highly organic soils with very high compressibility	Not suitable	-

Source: IRC 36-2010

# Performa for presenting

Name of the Laboratory.....	Date .....			
Reference (Data concerning location of sample, etc)				
Test information (Origin of soil sample, etc)				
No. of Samples tested..... 2.00 mm IS Sieve 425 micron IS Sieve 75 micron IS Sieve				
Liquid Limit				
Plastic Limit				
Plasticity Index				
Shrinkage Limit				
Free Swelling Index				
Maximum Dry Density (Standard Proctor's/Modified Proctor's test) Optimum Moisture Content.....				
Soil Classification as per IS:1498				
CBR (For subgrades)				
General Remarks (i.e. suitability of embankment material, safe side slopes, etc)				

# Preparing the foundation supporting the subgrade

- The surface receiving the subgrade material shall be compacted to a minimum of 98% of MDD
- When the difference between the top of subgrade and ground level is less than 0.3 m, and if the ground is not compacted to 100% relative density, then the ground shall be loosened upto a level of 0.3 m below the subgrade level, watered and compacted to achieve a relative density of 100%
- Subgrade work shall not commence until the density of top 300 mm of embankment is verified by the engineer



# Construction of Subgrade

- Spreading and Moisture control
- Compaction
- Compaction Equipments
- Control strips-Roller passes

# Density requirement of Embankment and Subgrade soil

Sl No	Type of work	For NH/SHs/MDRs Maximum dry density (as per BIS 2720 -Part 8)	For rural roads, Maximum dry density (as per BIS 2720 - Part 7)
1	Embankments upto 3 m height, not subjected to extensive flooding	Not less than 15.2 kN/ cu.m	Not less than 14.4 kN/ cu.m
2	Embankments exceeding 3 m height/embankment of any height subject to long period of inundation	Not less than 16.0 kN/cu.m	Not less than 15.2 kN/ cu.m
3	Subgrade and earthen shoulder	Not less than 17.5 kN/ cu.m	Not less than 16.5 kN/cu.m

# Field compaction

**PROCESS** Field compactors are differentiated by the nature of force applied and duration of these forces

- The methods include
  - Kneading compaction
    - Static compaction
    - Dynamic/impact compaction
    - Vibratory compaction



# Guideline for selecting a compaction equipment

Sl no	Type of material	Compaction type	Remarks
1	Rock fill (except soft material)	Vibratory roller	
2	Broken concrete, brick, flyash	Vibratory roller, Smooth wheeled static roller, Pneumatic tyred roller	Pneumatic tyred roller shall be used for flyash only
3	Coarse grained soil	Vibratory roller, pneumatic roller, smooth wheeled rollers	
4	Fine grained soils	Sheep foot rollers, smooth wheeled rollers, pneumatic rollers, vibratory rollers, vibro rammers, plate compactors, power rammer	Sheep foot rollers are most suitable for clayey soil

# Compaction requirement of embankment and subgrade material

Sl No	Type of work/Materials	Relative compaction as percentage of <b>max laboratory dry density</b> as per IS 2720 (Part 7 or 8)
1	Subgrade and earthen shoulders	Not less than 97%
	Embankment	Not less than 95%
	Expansive Clays (Soils having a free swell index greater than 50%) a) Subgrade b) Embankment (allowed after suitable treatment)	Not allowed Not less than 95%

# Compaction of expansive soils

- Expansive soils - such as black cotton soil (have montmorillonite clay mineral) exhibits extreme hardness and deep cracks when dry, and a tendency to heave when wet.
- In semi-arid region, with pronounced short wetting and drying, volumetric changes in subgrade resulting in pavement distortion, cracking and general unevenness
- The amount of volume change in expansive soil depends on
  - The dry density of the compacted soil
  - The moisture content
  - Structure of soil and method of compaction
- Expansive soils swell very little when compacted at low density and high moisture content (wet side of optimum, +2% than OMC, determined in a field trial)
- Field moisture-density relationships have to be obtained at different moisture contents and same number of roller passes
- Provision of 0.6m - 1m height buffer layer (non expansive soil) above expansive soil
- Blanket course - impermeable layer - comprised of coarse/medium sand (well graded sand or non-plastic moorum ( $PI < 5$ ) to serve as an effective intrusion barrier

# Construction of Subgrade



# Quality control tests and

their frequency for borrow

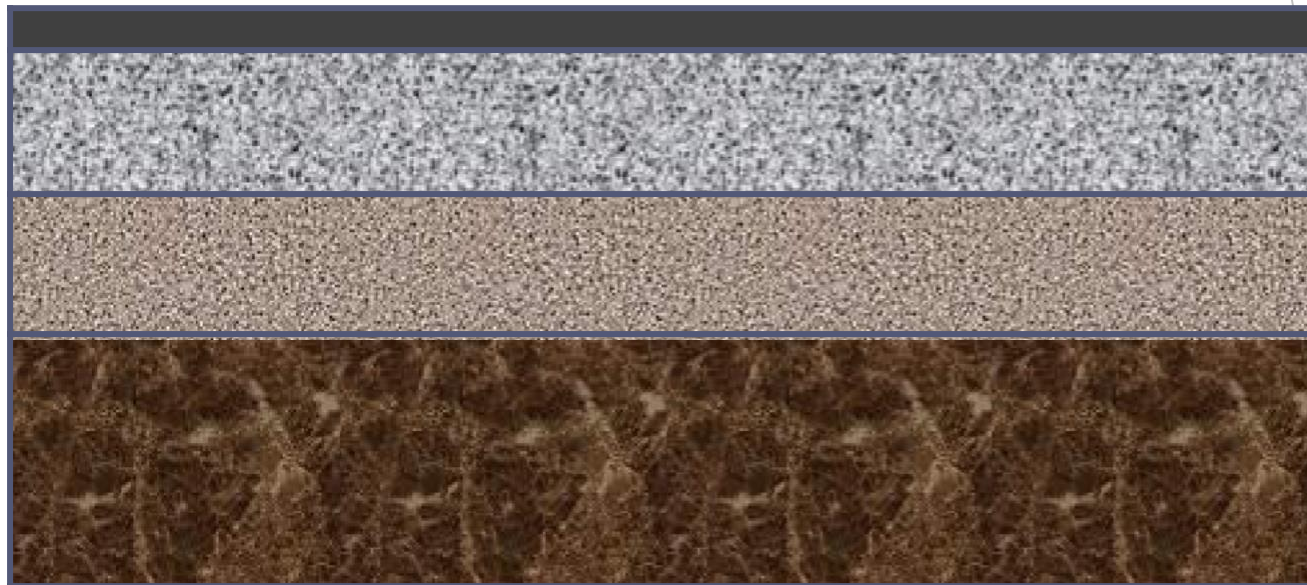
Type of Test	Frequency
1. Soil Classification as per BIS 1489 1) Sieve Analysis (Wet sieve analysis except for cohesionless soils)  II) LL, PL, and PI as per IS2720	One test from each source for one km length or part of
2. Standard Proctor Compaction test	-do-
3. Free Swell Index test	-do-
4. Deleterious Content 1) Organic matter content by loss on ignition method ii) Total soluble sulphate content	-do-
5. CBR test (soaked or unsoaked) as specified	One test per km: this will comprise testing of 3 specimens and CBR value has to be reported as the average of three test results



# Quality control test during

Sl No	Type of Test	Frequency
1	Placement Moisture content	At least 3 tests daily
2	In-situ Density measurement	At least 3 test daily (i) Average of 3 test results shall not be less than the specified degree of compaction (ii) Individual test values of degree of compaction shall not be less than 1% of specified value of degree of compaction. (For example, for the specified value of 100% Proctor density, the individual test value shall not be less than 99% of Proctor density and average of the three tests carried out shall not be less

# Granular layers in Pavement



Bituminous layer

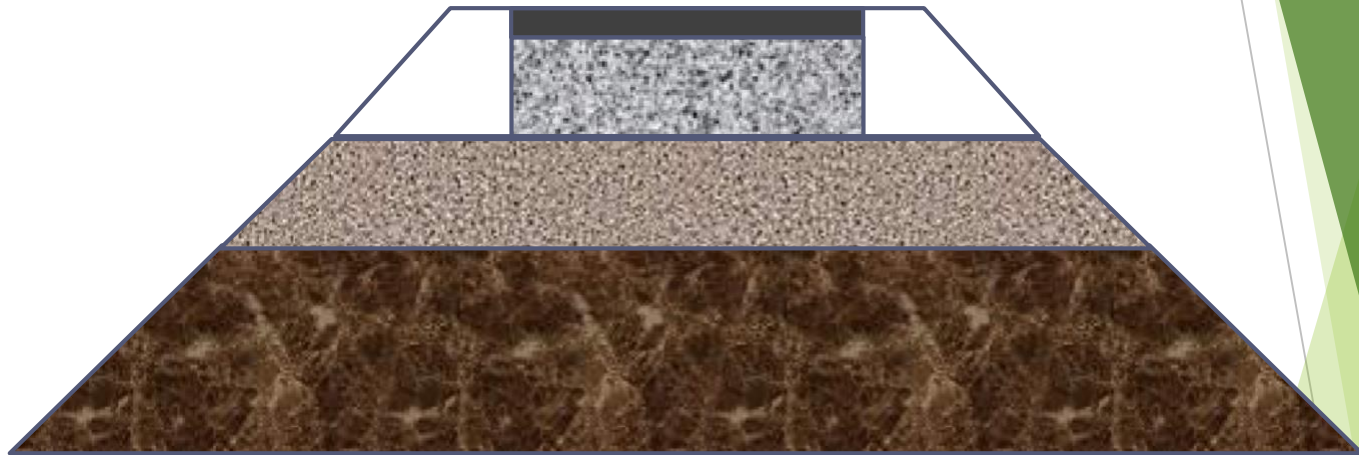
Granular Base

Granular  
Subbase

Subgrade

# Granular Subbase (GSB)

- Intended purpose - Subsurface Drainage



- Material permitted to be used - Natural sand, moorum, gravel, crushed stone, crushed slag, brick metal, kankar or a combination

# Aggregate Gradation for GSB

IS Sieve Size	Percentage by weight passing IS Sieve		
	Grading 1	Grading 2	Grading 3
75 mm	100		
53 mm		100	100
26.5 mm	55-75	50-80	
9.50 mm			
4.75 mm	10-30	15-35	25-45
2.36 mm			
0.425 mm			
0.075 mm	<15	<15	<15

# Grading for Gravel Subbase

IS Sieve size (mm)	Percentage of weight passing IS Sieve	
	Grading 1	Grading II
53	100	-
37.5	100	-
26.5	75-95	-
19	80-100	-
9.5	40-75	55-80
4.75	30-60	40-60
0.425	15-30	15-30
0.075	<15	<15

The Gravel subbase shall have a minimum soaked CBR value of 20

# Physical properties requirements of materials in GSB

- Liquid limit and Plasticity Index requirement

Climate	LL	PI	Remarks
Areas with annual rainfall > 1000 mm	< 35	< 10	Design traffic upto 1 msa
Areas with annual rainfall < 1000 mm	< 40	< 15	Design traffic upto 1 msa
All areas irrespective of rainfall	< 25	< 6	Design traffic > 1 msa

- Wet aggregate impact value  $\leq 50$
- Soaked CBR at field density (100% MDD) shall be minimum 20%
- MoRD also permits utilization of sub-base material having a CBR value of not less than 15%, if the requisite material is not available within the economic lead

# Construction operation of GSB

- Preparation of Subgrade
  - Removing of any vegetation if any, and other extraneous matter, lightly sprinkle water, if necessary, and rolled by two passes of 80-100 kN static smooth wheel rollers
- Spreading and compacting
  - Material shall be spread using a tractor towed appliances to the required slope and grade
  - Blended material can be procured. Gradation of this shall be ensured. In-place mixing shall be done by tractor-towed rotovator. Manual mixing is only permitted for small scale jobs
  - Moisture content shall be ensured, Have to consider evaporation loss
  - Compaction shall be carried out using an approved roller
    - For a compacted layer thickness of 100 mm - a static smooth wheel rollers of 80-100 kN shall be used
    - For a compacted layer thickness of 225 mm, the compaction shall be done by means of vibratory roller of minimum 80-100 kN static weight

# Construction operation

- Rolling operation
  - In locations with unidirectional slope/super elevation, rolling shall commence at lower edge and proceed towards the upper edge
  - In other conditions, rolling shall commence at the edge and progress towards the crown for portions having cross-slope in both the directions
  - Each roller pass shall uniformly overlap not less than  $1/3^{\text{rd}}$  of the track made in the preceding pass. The speed of the roller shall not exceed 5 kmph
  - Desired density after rolling - 100% of MDD



# Gravel/Soil Aggregate Subbase, Base and Surface course

- This section provides gradation and material specification for laying and compacting well-graded gravel/soil- aggregate mixtures in sub-base, base or surface course
- Materials - Natural gravel/soil-aggregate/Blended material with aggregates fractions such as gravel, moorum, sand

# Gravel/Soil Aggregate Subbase, Base and Surface course

- Physical property requirements
  - Wet aggregate impact value shall not exceed 40 and 30% for use in sub-base, base and surfacing course
  - Flakiness index shall not exceed 25 and 20% for base and surfacing respectively (*This requirement is applicable only to crushed aggregates*)
  - If water absorption is greater than 2%, Soundness test shall be carried out
    - Loss in mass - Sodium sulphate solution - 5 cycles - Max 12%
    - Loss in mass - Magnesium sulphate solution - 5 cycles - Max 18%
  - If crushed gravel is used - not less than 90% by weight of particles shall have 2 fractured face

# Gravel/Soil Aggregate Subbase, Base and Surface course

Sieve Size (mm)	Percentage by weight passing		
	A	B	C
53	100		
37.5	97-100	100	
26.5		97-100	100
19	67-81		97-100
9.5		56-70	67-79
4.75	33-47	39-53	47-59
0.425	10-19	12-21	12-21
0.075	4-15	4-15	4-15

**Grading requirements for sub-base /base course**

# Gravel/Soil Aggregate Subbase, Base and Surface course

Sieve size, mm	Percentage by weight passing IS designation Nominal Maximum aggregate size		
	80 mm	60 mm	20 mm
80	100		
40	80-100	100	
20	60-80	80-100	100
10	45-65	55-80	80-100
4.75	30-50	40-60	50-75
2.36		30-50	35-60
0.6	10-30	15-30	15-35
0.075	5-15	5-15	5-15

Grading requirements for sub-base /base course, based on NMA S

# Gravel/Soil Aggregate Subbase, Base and Surface

IS Sieve, mm	% Passing
26.5	100
19	97-100
4.75	41-71
0.425	12-28
0.075	9-16

Grading requirement for Gravel for  
Surface course

IS Sieve, mm	% Passing
10	100
4.75	80-100
2.36	50-80
1.18	40-65
0.6	
0.3	20-40
0.075	10-25

Grading requirement for Soil-aggregate  
mixture for Surface course

# Gravel/Soil Aggregate Subbase, Base and Surface course

- Plasticity characteristics
  - For gravel surfacing, the PI of material used in subbase/base layer shall not exceed 10
  - For gravel/soil aggregate used in surface course

Climate	Liquid limit (Max)	PI
High rainfall areas (Annual rainfall > 1500 mm)	35	4-9
Medium rainfall areas (Annual rainfall 750-1500 mm)	40	6-15
Low rainfall areas (Annual rainfall < 750 mm)	55	15-30

# Construction operation

- Preparation of Surface
- Spreading of gravel/soil aggregate mixture
  - Mixing -plant mixing, mechanical in-place mixing, **Manual mixing permitted only for small-sized jobs**
  - Moisture content - determined from Dry density - Moisture content relationship - Account for evaporation loss
  - Rolling by approved roller weight - For a compacted layer thickness of 100 mm - static steel wheel rollers of 80-100 kN capacity; for compacted layer thickness above 100 mm and upto 225 mm - vibratory rollers are recommended
  - Compaction commences from the edge to interior- Grade shall be checked
  - Desired density -100% MDD

# Water Bound macadam - Sub-base, Base- Surfacing

- The work primarily consist of constructing a layer of crushed aggregates mechanically interlocked by rolling and bonding together with screening, binding material where necessary
- Materials - Coarse aggregates- Crushed /Broken stone, crushed slag, over-burnt (Jama) bricks
- 90% of particles retained on 4.75 mm sieve shall have at least 2 fractured faces
- Water absorption less than 2%

Test	Sub-base	Base	Surfacing
Aggregate Impact Value	Less than 50	Less than 40	Less than 30
Flakiness Index	Less than 30	Less than 25	Less than 20
Soundness test			
- Loss with Sodium Sulphate	Less than 12%	Less than 12%	Less than 12%
-Loss with Magnesium Sulphate	Less than 18%	Less than 18%	Less than 18%



# WBM Coarse aggregate grading requirement

	Size range	IS sieve, mm	% passing
1)	90 to 45 mm	125	100
		90	90-100
		63	25-60
		45	0-15
		22.4	0-5
2)	63 to 45 mm	75	100
		63	90-100
		53	25-75
		45	0-15
		22.4	0-5
3)	53 to 22.4 mm	63	100
		53	90-100
		45	65-90
		22.4	0-10
		11.2	0-5



- Grading 1 shall be restricted only to subbase
- The aggregate grading are to be met befo compaction, after compaction the grading may vary. The allowable tolerance is 5% from the specified upper and lower limits excluding the first and last sieve

# Water Bound Macadam aggregate gradation

Grading Classification	Size of Screenings	IS Sieve Designation	Percent by Weight Passing the Sieve
A	13.2 mm	13.2 mm	100
		11.2 mm	95 – 100
		5.6 mm	15 - 35
		180 micron	0 – 10
B	11.2 mm	11.2 mm	100
		9.5 mm	80 – 100
		5.6 mm	50 – 70
		180 micron	5 – 25

Screening gradation



# Water Bound Macadam - Approximate quantities of coarse aggregates and screenings required for 75 mm compacted thickness of WBM for 10 m<sup>2</sup> area

Classification	Size Range	Compacted Thickness	Loose Qty.	Screenings			
				Stone Screening		Crushable Type Such as Moorum or Gravel	
				Grading Classification & Size	For WBM Sub-base/ Base Course (Loose Quantity)	Grading Classification & Size	Loose Qty.
Grading 1	63 mm to 45 mm	75 mm	0.91 to 1.07 m <sup>3</sup>	Type A 13.2 mm	0.12 to 0.15 m <sup>3</sup>	Not uniform	0.22 to 0.24 m <sup>3</sup>
-do-	-do-	-do-	-do-	Type B 11.2 mm	0.20 to 0.22 m <sup>3</sup>	-do-	-do-
Grading 2	53 mm to 22.4 mm	75 mm	-do-	-do-	0.18 to 0.21 m <sup>3</sup>	-do-	-do-

# Construction procedure

- Preparation of surface to receive the WBM material
  - Any ruts/yielding material shall be corrected
  - Surface has to be rectified to the required grade and camber
  - Laying WBM layer above existing bituminous layer shall be avoided
- When WBM is placed above subgrade - provision of inverted choke (100 mm coarse sand)



# Construction procedure

- Provision of lateral confinement - by building adjoining shoulders
- Spreading of coarse aggregates - followed by rolling - static/Vibratory rollers. Rolling shall continue until aggregates are keyed (interlocked). Transverse profiles are to be checked using straight edge
- Spreading of fine screening material - mechanical brooms/hand brooms - Dry rolling with light vibration cause them to settle in the interstices of coarse aggregates
- After screening is applied, surface is spread with water with additional spreading of screening material if reqd
- **No traffic is permitted until the road has set**

# Water Bound Macadam - Construction procedure



Spreading of aggregates using a grader



Ensuring that sufficient loose qty of material is spread - checking with string lines



Ensuring the levels



Compacting coarse aggregates using a static/vibratory roller

# Water Bound Macadam - Construction procedure



Screening materials



Spreading of screening materials



Packing/brooming of screening materials into the  
46 voids of coarse aggregates

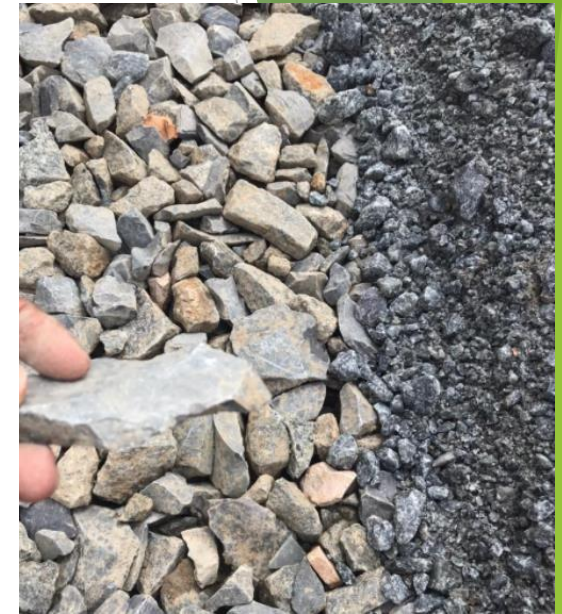


Applying vibration in-order to ensure packing of  
screening into coarse aggregates

# Aggregate Physical requirement

## Aggregate physical requirement for WMM

Test	Test Method	Specification
Aggregate Impact Value	IS2386	Max 40
Flakiness Index	IS2386	Max 25



- Aggregate water absorption should not exceed 2%
- Aggregates also needs to pass the soundness test (BIS 2386-Part 5)
- Aggregate physical requirement for GSB

Aggregate Impact Value (AIV)	IS:2386 (Part 4) or IS:5640	40 maximum
Liquid Limit	IS:2720 (Part 5)	Maximum 25
Plasticity Index	IS:2720 (Part 5)	Maximum 6
CBR at 98% dry density (at IS:2720-Part 8)	IS:2720 (Part 5)	Minimum 30 unless otherwise specified in the Contract



# Water Bound Macadam - Construction procedure

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Rolled finished surface



# Quality control test for WBM

## QC test before construction

Type of test	Frequency
1 Aggregate impact value	One test per source
2 Aggregate Water absorption	-do-
3 Soundness of aggregates (where water absorption > 2%)	-do-
4 Grading, LL and PI of screening	-do-
5 LL and PI of binding material when used	-do-

## QC test after construction

Type of test	Frequency
1 Aggregate grading	At least 2 test for a day's work
2 Flakiness Index of stone aggregates	-do-
3 PI of crushable screening and binding material	-do-
4 Aggregate Impact Value	One random test
5 Thickness of compacted layer	Random

# Wet Mix Macadam- Aggregate gradation and Production Plant



IS Sieve Designation	Percent by weight passing the IS Sieve
53.00 mm	100
45.00 mm	95-100
26.50 mm	-
22.40 mm	60-80
11.20 mm	40-60
4.75 mm	25-40
2.36 mm	15-30
600.00 micron	8-22
75.00 micron	0-5

# Water content in WMM

- **Mix design steps**
  - Determining blending proportions
  - Determination of OMC
- In field, gate opening, belt speed and production per hour is synchronized in-order to achieve the desired gradation

# WMM plant operation



# Construction operation

- Preparation of surface to receive the WMM material
- Provision of lateral confining
- Preparation of WMM mix - pugmills/pan-type mixers of concrete batching plant - OMC - allowance for moisture loss due to evaporation
- Spreading of the mix - Using WMM pavers
- Compaction - static/vibratory rollers

# Quality control test for WMM

## QC test before construction

Sl No	Type of Test	Frequency
1	Aggregate Impact Value	One to two test per source
2	Flakiness index test	-do-
3	Water Absorption test	-do-
4	Soundness test	-do-
5	Grading	-do-
6	Attemberg limits for particles passing 425 micron	-do-
7	Proctor compaction test	-do-

## QC test after

Type of test		Frequency
1	Aggregate grading	At least 1 test for a day's work
2	Placement moisture content	-do-
3	Density of compacted layer	-do-
4	Aggregate Impact Value	One random test
5	Thickness of compacted layer	Random