Royal Government of Bhutan
Ministry of Works & Human Settlement
Department of Roads
Thimphu

Pavement Design Manual

First edition **June 2005**

Foreword

Well developed communication system is the life line of any country. In Bhutan road transport plays a vital role in smooth movement of men and materials from one location to another with acceptable level of comfort, safety & reliability with minimum incurrence of road user cost. With the rapid growth of traffic, road pavements are required to be designed for higher volume of traffic and heavier loads of the order of about 15 million standard axles for maximum gross weight of a truck up to 30 tonnes. The purpose of this publication is to assist engineers in the analysis, design and construction of road pavements in a professional and scientific manner. An attempt has been made to make this manual a comprehensive, user friendly, and simple reference document. This manual can be rightly termed as "The Living Document" for reference and up dates will be published to keep us abreast with the state of the art practices in pavement design and construction including case references of useful experiences gained.

A Technical Standard Committee had been formed in 2004 in the Department with Roads Director, Mr. Phuntsho Wangdi as the Chairman. The Technical Standard Committee is responsible for publishing technical manuals and standards of which this publication is one of the Technical Standard Committee's first modest contribution. The following are the members of the Technical Standard Committee:

Phuntsho Wangdi	Director	Chairman
Kunzang Wangdi	Suptdg. Engineer	Coordinator
Pravat Rai	Asstt. Engineer	Member
Karma Wangdi	Asstt. Engineer	Member
Karma Tenzin	Asstt. Engineer	Member
Tougay Choedup	Asstt. Engineer	Member

As this is the first edition of pavement design manual produced in-house by the Department, the users will have comments, criticisms and queries. We would highly welcome comments that will add value and substance for incorporation in the next edition

Thimphu
June 2005

Phuntsho Wangdi
Director/Chairma

Acknowledgement

As a member of Technical Standard Committee of the Department of Roads, I would like to thank our Director, Mr. Phuntsho Wangdi for his vision and conception to produce the "Pavement Design Manual" to be used by the Engineers of the Department of Roads to contribute to provide reliable, economical and better road riding quality.

I also would like to thank the Superintending Engineers of the Department of Roads, Mr. Kunzang Wangdi, Mr. Tshering Wangdi and Mr. M.N.Lamichaney for their painstaking efforts in editing and providing necessary corrections and guidance.

Thanks are also due to all the staff of Survey & Design Division for providing useful suggestions and views.

The prompt support and financial assistance rendered by the EFRC Support Project for the publishing of this manual is highly appreciated and acknowledged.

Tougay Choedup
Member
Technical Standard Committee
Department of Roads

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1.1 Introduction

With the rapid growth of traffic plying on our road network, the pavements are required to be designed for heavy volume of traffic. *An ideal pavement design procedure is one which will predict a thickness and composition which, without being conservative, ensures that the pavement will not deteriorate beyond a tolerable level of serviceability in less than the design period*.

1.2 Definition

Pavement design is defined as the process of developing the most economical combination of pavement layers in relation to both thickness and material type to suit the soil foundation and the cumulative traffic to be carried during the design life.

1.3 Pavement types

Flexible pavement
Rigid pavement
Interlocking block pavement etc.

A flexible pavement is a multilayered structure resting over the soil sub grade with the quality of material decreasing with depth. A rigid pavement is usually made up of cement concrete, occasionally over a base course. The fundamental difference between the rigid and flexible pavement is the manner in which the wheel load is transferred to the sub grade. In a flexible pavement the pavement structure is expected to deform in the same way as the sub grade through lateral distribution of the applied load with depth. As such the basic requirement in the design of flexible pavement is the layer of sufficient thickness to distribute the wheel load to the sub grade without causing over stressing in the sub grade. Thus the strength of sub grade plays an important role in design. On the other hand, the rigid pavement, because of its rigidity and high modulus of elasticity tends to distribute the load over a wide area of the soil by beam and slab action of the concrete and is able to bridge over local weak spots. In rigid pavement the structural capacity of the concrete is an important factor.

1.4 Components of a flexible pavement.

A flexible pavement consists of asphalt surface course built over a base course and sub base course resting on the sub grade soil.

Sub grade

The sub grade is normally the in-situ soil over which the pavement is being constructed. It can also refer to the top of embankment or fill over which the pavement is laid.

Sub base

The sub base usually consists of granular material either naturally occurring, stabilised or prepared from crushed aggregates. This can be considered as a layer of weaker quality and hence cheaper than base course, but in any case sufficiently stronger than sub grade to help the distribution of wheel load. In certain instances, sub base helps as a drainage layer.

Base course

The base course which is the main load bearing layer is normally the thickest layer of the flexible pavement underlying the surface course. The materials used in this layer are invariably of high quality. The base course can be constructed by well graded aggregates in order to provide mechanical interlocking action and properly compacted. This can be of wet mix macadam type, water bound macadam type or well graded dry aggregates. For the well graded dry aggregate base course, the prime coating should be should be applied 48 hours prior to laying of surface course so as to keep the finer aggregates intact.

Surface course

The main purpose of surface course is to provide a smooth, skid resistant riding surface which is of utmost importance from the user point of view. It protects ingress of water to the underlying pavement layers. The surface course must carry high stresses induced by the traffic without unacceptable deformation. Normally the surface course is formed by dense bituminous macadam, asphaltic concrete and premix carpet with seal coat.

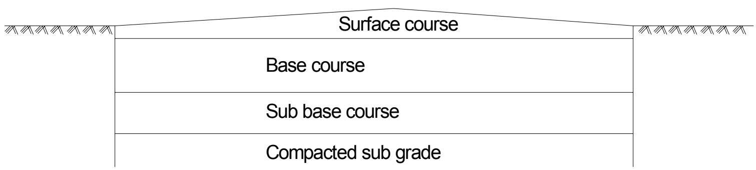


Fig. (a) Component of flexible pavement

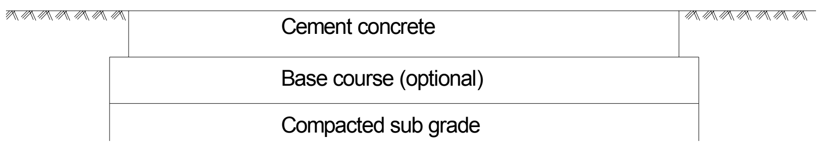


Fig. (b) Component of rigid pavement

1.5 Components of a rigid pavement.

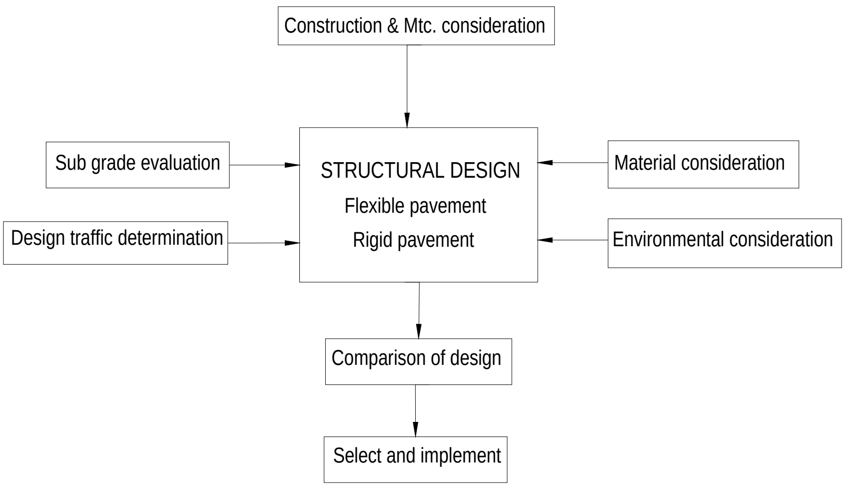
A “Rigid Pavement” is cement concrete pavement, plain or reinforced laid over a base course. Apart from expediting construction in case of weak sub grade, base course helps better drainage and consequently minimises volume changes and frost action. The base course is sometimes called as sub base and is not considered to be load carrying member, though it does lends support. While using plain concrete, some reinforcement becomes necessary at joints, provided to relieve stresses due to expansion, contraction, warping or to facilitate construction. On the other hand reinforcement may also be used to take due care of the stresses arising due to temperature fluctuation. In that case it is known as temperature reinforcement. Heavy reinforcement used without breaks or joints is usually known as continuously reinforced concrete where the reinforcement is expected to take care of both temperature stresses and also load stresses to some extent.

1 Flexible Pavement Design

1.6 Flow chart

The design of flexible pavement involves the interplay of following variables.

1 Construction and maintenance consideration
2 Environmental consideration
3 Sub-grade evaluation
4 Design traffic determination
5 Availability of pavement material and their properties.



1.7 Design Theory.

An analytical design of flexible pavement is based on layered structure as per the strain at critical locations as shown below.

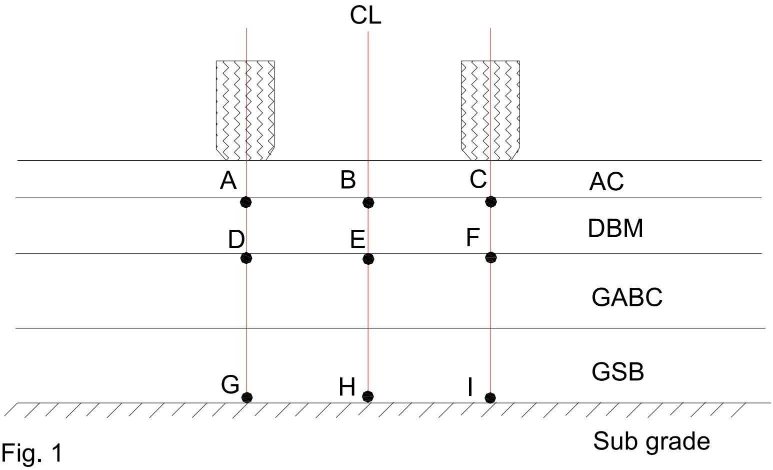


Fig. 1

A,B,C,D,E&F are the critical locations for horizontal tensile strain at the base of asphalt layer (ε_t). This is because the bottom of bound layers is in tension under load. Large tensile strains causes fracture of bituminous layer during the design life. The maximum value of strain is adopted for design.
G,H&I are the critical vertical compressive strain at the top of sub grade (ε_z) of which maximum value is taken for design. If the strain is excessive, the sub grade will deform resulting in permanent deformation at the pavement surface during the design life. No stress/strain analysis is required for granular/gravel layers. Such stress/strain analysis is computed by using computer software such as CIRCLY.

The pavement deformation within the bituminous layer can be controlled by meeting the asphalt mix design requirement (see asphalt mix design section)

Thicknesses of sub base, base and asphalt layers are selected using the analytical design approach such that strains at critical points are within the allowable limits for allowable number of load repetitions.

Based on the analytical design approach, simple design charts are developed to carry out the pavement design using the simple input parameter like traffic and soil strength.

1.8 Computation of Design Traffic (N_s)

The design traffic in terms of cumulative number of standard axles (8160kg) to be carried by the pavement during the design life is estimated by using the equation

$$N_s = \frac{365\left[(1+r)^n - 1\right]}{r} \times A \times D \times F \qquad \textbf{Eqn 1}$$

Where,

i) A = Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day and $A = P(1+r)^x$, Where

P = Number of commercial vehicles as per last count.

r = Annual growth rate of commercial vehicles. The growth rate should be estimated based on the past trends of traffic growth. If adequate data are not available, an average annual growth rate of 7 to 7.5% may be adopted. (for7%, r = 0.07)

x = Number of years between the last count and the year of completion of construction.

ii) n = Design life of pavement in years. Design load is defined in terms of cumulative number of standard axles that can be carried before strengthening of the pavement is necessary. The following design life is recommended for various types of roads.

Expressways and Urban Roads	20 years
National Highways and District Roads	15 years
Feeder Roads and others	10 years

iii) F = Vehicle damage factor (VDF). It is defined as equivalent number of standard axles per commercial vehicle. In other words it is a multiplier to convert the number of commercial vehicles of different axle load and axle configuration to the number of standard load repetition given in table 1.1

Table 1.1

Initial Traffic	VDF values recommended		
(CVD)	Unsurfaced	Thin surfacing	Thick surfacing
< 150	0.5	0.75	-
150 - 1500	-	1	1.25
> 1500	-	1.25	1.5

D = Lane distribution factor. The assessment of commercial traffic by direction and by lane is necessary as it directly affects thickness design.

The following values are recommended.
Single-lane roads = 1.00
Double-lane roads = 0.75

1.9 Sub-Grade Evaluation

The sub-grade strength is assessed in terms of California Bearing Ratio (CBR) of the sub-grade soil both in fill and cut section at the critical moisture conditions likely to occur in-situ. To weed out extreme CBR values, the outliers for high and low values should be compared with the critical values given

in table 1.2. If the computed outlier is greater than the critical value (r), it should be rejected.
Checking for extremely high values

$$r = \frac{CBR_{max} - CBR_{max-1}}{CBR_{max} - CBR_{min}} \qquad \text{Eqn 2}$$

where,

CBR_{max} = Highest CBR value
CBR_{max-1} = Second highest CBR value
CBR_{min} = Lowest CBR value

Checking for extremely low values

$$r = \frac{CBR_{min-1} - CBR_{min}}{CBR_{max} - CBR_{min}} \qquad \text{Eqn 3}$$

where,

CBR_{max} = Highest CBR value
CBR_{min-1} = Second lowest CBR value
CBR_{min} = Lowest CBR value

Table 1.2

n	3	4	5	6	7	8	9	10	11
r	0.941	0.765	0.642	0.560	0.507	0.468	0.437	0.412	0.392
n	12	13	14	15	16	17	18	19	20 or more
r	0.376	0.361	0.349	0.338	0.329	0.320	0.313	0.306	0.300

n = number of CBR values

r = statistical critical values

1.10 Design CBR

Design CBR can be calculated from one of the following methods.

A) Lower 10th percentile method
B) Section CBR method

A. Design CBR by lower 10th percentile method is given by the equation

$$CBR_{design} = CBR_{mean} - 1.3\sigma \qquad \text{Eqn 4}$$

where,

CBR_{design} = Design CBR

CBR_{mean} = Mean CBR

σ = Standard deviation

Standard deviation $\sigma = \sqrt{\dfrac{\sum(xi - mean)^2}{n-1}}$

where n= no. of results

The design CBR value should be rounded to nearest 0.5%

B. Section CBR method is given by the equation

$$CBR_{section} = CBR_{mean} - (CBR_{max} - CBR_{min})/C$$

Eqn 5

where, $CBR_{section}$ = Section CBR

CBR_{mean} = Mean CBR

CBR_{max} = Maximum CBR

CBR_{min} = Minimum CBR

C = Coefficient given in table 1.3

Table 1.3

No. of CBR values	2	3	4	5	6	7	8	9	10 or more
C	1.41	1.91	2.24	2.48	2.67	2.83	2.96	3.08	3.18

The design CBR by Section CBR method should be decided from the relationship in Table 1.4

Table 1.4

Section CBR	Design CBR	Section CBR	Design CBR
2 or more but under 3	2	8 or more but under 12	8
3 or more but under 4	3	12 or more but under 20	12
4 or more but under 6	4	20 or more	20
6 or more but under 8	6		

1.11 Thickness Design

In Bhutan majority of roads, but excluding Expressways and some feeder roads under the Department of Roads shall basically consist of 3 layer pavements, namely Granular Sub Base layer(GSB), Graded Aggregate Base Course layer(GABC) / Wet Mix Macadam (WMM) and bituminous layer. Having calculated the design CBR and cumulative number of standard axles, the thickness of sub base and base course layer can be directly read off from Fig.2. It is to note that the minimum thickness of sub base should not be less than 150mm for design traffic less than 10 msa and 200mm for design traffic of 10 msa and above. The recommended minimum thickness of granular base should be 200 mm for traffic up to 2 msa and 250mm for traffic exceeding 2 msa. For CBR value of 9% and above, the minimum thickness of base should be 200 mm. Where the CBR value of sub grade is 2 percent or less, a capping layer of 150mm thickness of material with minimum CBR of 10% shall be provided in addition to the sub base. However the thickness design shall not be based on the strength of capping layer and it should be based on the original sub grade CBR.

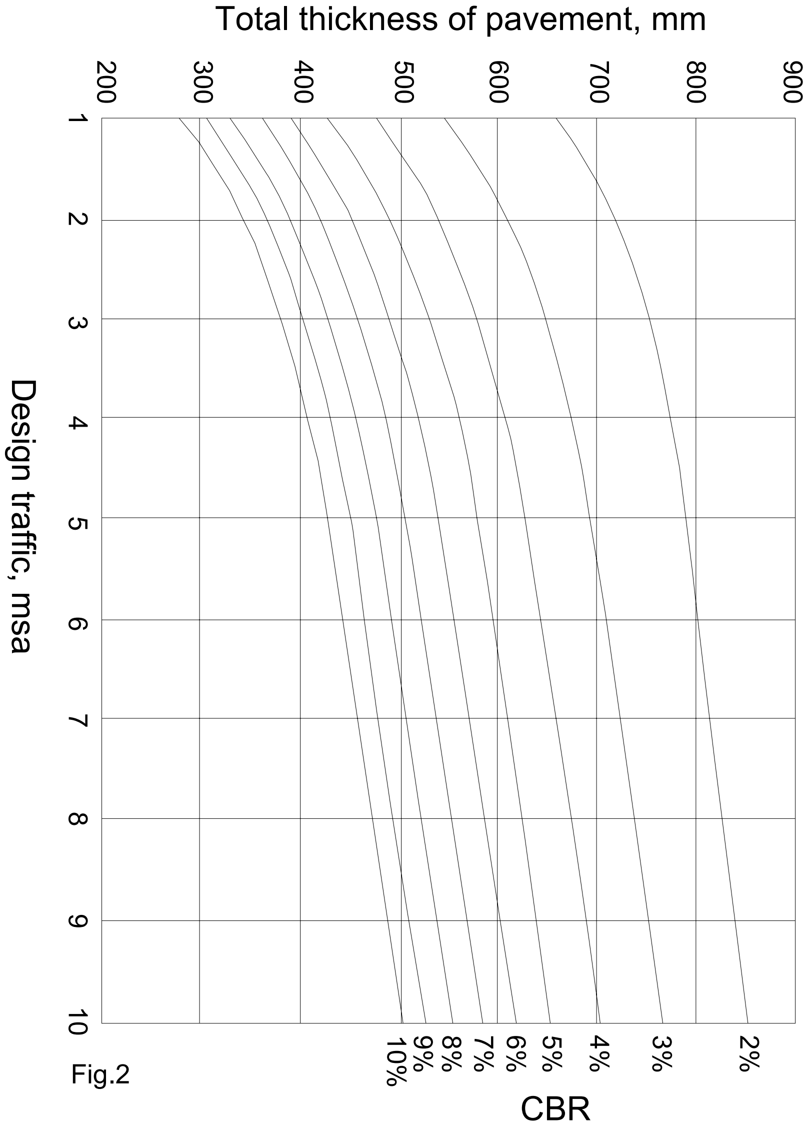

Total thickness of pavement, mm
200
300
400
500
600
700
800
900
Design traffic, msa
1
2
3
4
5
6
7
8
9
10
10%
9%
8%
7%
6%
5%
4%
3%
2%
CBR

Fig.2

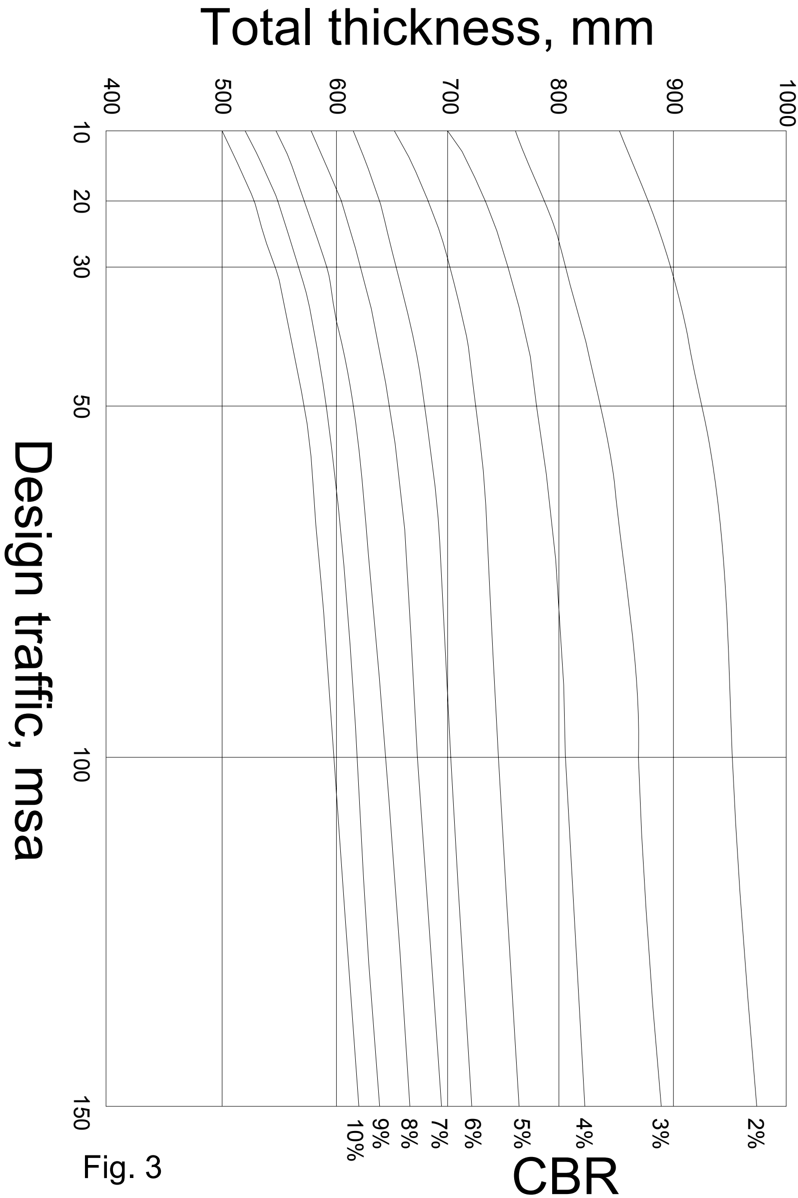

Total thickness, mm
400
500
600
700
800
900
1000
Design traffic, msa
10
20
30
50
100
150
10%
9%
8%
7%
6%
5%
4%
3%
2%
CBR

Fig. 3

1.12 Bituminous Layer Thickness

The minimum thickness of bituminous surface shall be as per Table 1.5 as shown below.

Table 1.5

Traffic (msa)	Wearing course	Binder course	Remarks
0 - 0.5	25 mm PMC/AC	-	Wearing course = surface layer
0.5 - 2	25 mm PMC/AC	-	Binder course = Bituminous course
2 - 5	25 mm AC	50 mm DBM	immediately below wearing course.
5 - 10	40 mm AC	60 mm DBM	PMC = Pre Mix Carpet
10 - 15	40 mm AC	65 mm DBM	AC = Asphaltic Concrete
15 - 20	40 mm AC	80 mm DBM	DBM = Dense Bituminous Macadam
20 - 30	40 mm AC	100 mm DBM	

1.13 Design Example

Traffic = 2 msa
Design CBR = 5%
Total pavement thickness = 490 mm from Fig 2.
Therefore pavement layer composition shall be:

Wearing course layer	= 25 mm premix carpet (PMC)
Dense bituminous macadam	= 50 mm
Base course layer	= 200 mm
Sub base layer (430-145)	=240 mm

Note : where PMC is adopted, seal is necessary and where AC is adopted, seal coat is not required.

1.14 Pavement Design Catalogue.

Table 1.6

CBR 2%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	660	-		25	PMC	200	460
2	715	50	DBM	25	PMC	200	465
3	750	50	DBM	25	PMC	250	450
4	780	50	DBM	25	PMC	250	480
5	790	60	DBM	40	AC	250	440
6	800	60	DBM	40	AC	250	450
7	810	60	DBM	40	AC	250	460
8	820	60	DBM	40	AC	250	470
9	830	60	DBM	40	AC	250	480
10	850	60	DBM	40	AC	250	500

Table 1.7

CBR 3%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	550	-		25	PMC	200	350
2	610	50	DBM	25	PMC	200	360
3	650	50	DBM	25	PMC	250	350
4	680	50	DBM	25	PMC	250	380
5	695	60	DBM	40	AC	250	345
6	710	60	DBM	40	AC	250	360
7	720	60	DBM	40	AC	250	370
8	740	60	DBM	40	AC	250	390
9	750	60	DBM	40	AC	250	400
10	760	60	DBM	40	AC	250	410

Table 1.8

CBR 4%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	480	-		25	PMC	200	280
2	540	50	DBM	25	PMC	200	290
3	580	50	DBM	25	PMC	250	280
4	610	50	DBM	25	PMC	250	310
5	620	60	DBM	40	AC	250	270
6	640	60	DBM	40	AC	250	290
7	660	60	DBM	40	AC	250	310
8	675	60	DBM	40	AC	250	325
9	690	60	DBM	40	AC	250	340
10	700	60	DBM	40	AC	250	350

Table 1.9

CBR 5%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	430	-		25	PMC	200	230
2	490	50	DBM	25	PMC	200	240
3	530	50	DBM	25	PMC	250	230
4	560	50	DBM	25	PMC	250	260
5	580	60	DBM	40	AC	250	230
6	595	60	DBM	40	AC	250	245
7	610	60	DBM	40	AC	250	260
8	620	60	DBM	40	AC	250	270
9	630	60	DBM	40	AC	250	280
10	650	60	DBM	40	AC	250	300

Table 1.10

CBR 6%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	390	-		25	PMC	200	190
2	450	50	DBM	25	PMC	200	200
3	490	50	DBM	25	PMC	250	190
4	520	50	DBM	25	PMC	250	220
5	540	60	DBM	40	AC	250	190
6	550	60	DBM	40	AC	250	200
7	570	60	DBM	40	AC	250	220
8	590	60	DBM	40	AC	250	240
9	600	60	DBM	40	AC	250	250
10	610	60	DBM	40	AC	250	260

Table 1.11

CBR 7%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	375	-		25	PMC	200	175
2	425	50	DBM	25	PMC	200	175
3	460	50	DBM	25	PMC	250	160
4	490	50	DBM	25	PMC	250	190
5	500	60	DBM	40	AC	250	150
6	515	60	DBM	40	AC	250	165
7	530	60	DBM	40	AC	250	180
8	550	60	DBM	40	AC	250	200
9	575	60	DBM	40	AC	250	225
10	580	60	DBM	40	AC	250	230

Table 1.11

CBR 8%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	375	-		25	PMC	200	175
2	425	50	DBM	25	PMC	200	175
3	450	50	DBM	25	PMC	250	150
4	460	50	DBM	25	PMC	250	160
5	470	60	DBM	40	AC	250	120
6	490	60	DBM	40	AC	250	140
7	500	60	DBM	40	AC	250	150
8	520	60	DBM	40	AC	250	170
9	530	60	DBM	40	AC	250	180
10	550	60	DBM	40	AC	250	200

Table 1.12

CBR 9 & 10%							
Traffic (msa)	Total Pavement Thickness (mm)	Pavement Composition					
		Bituminous Surfacing				Base Course (mm)	Sub Base (mm)
		Wearing Course		Binder Course			
		(mm)	Type	(mm)	Type		
1	350	-		25	PMC	200	150
2	400	50	DBM	25	PMC	200	150
3	400	50	DBM	25	PMC	200	150
4	420	50	DBM	25	PMC	200	170
5	450	60	DBM	40	AC	200	150
6	460	60	DBM	40	AC	200	160
7	470	60	DBM	40	AC	200	170
8	490	60	DBM	40	AC	200	190
9	505	60	DBM	40	AC	200	205
10	520	60	DBM	40	AC	200	220

2 Pavement Design at High Altitude

2.1 Phenomena of pavement at high altitude.

The road pavement in high altitude (above 2500m) is subjected to heavy snowfall, sub-zero temperature and frost action etc where road pavement requires special design consideration. Frost action is the singular most important factor which influences the design of pavement in high altitude areas. Due to fall in temperature, moisture at sub grade level freezes and it expands by about 9 % of its original volume which is known as frost heave. After the winter when atmospheric temperature increases above the freezing point, melting of ice in the soil starts. During the melting process, the ice lenses release excess water which tends to ooze upwards making the sub grade / sub base / base saturated which produces the weakest condition of the pavement. The water released by the melting of ice lenses can not drain downward because of the frozen sub soil and is impervious. Due to variation of temperature during day and night, such capillary action continues with alternate freezing and thawing actions.

2.2 Low atmospheric temperature.

In high altitude areas, flexible pavement becomes brittle and least ductile during the period of sub zero temperature when the greatest shrinkage and heave occur. Brittleness of pavement results in cracking of surface which provides a means for ingress of water. This offers a point where ravelling starts followed by surface cracks. The cracks further widen and intensify due to capillary action and ultimately the bituminous surface gets pealed off.

2.3 Frost susceptibility of soils

From the design and construction point of view it is important to set some criteria to distinguish whether a given soil is frost susceptible or not. If the soil is non frost susceptible the formation of ice by water during sub zero temperature can be minimised if not completely stopped. It is found that gravels, clean sands and highly plastic clays are not frost susceptible while silty sands, silt and lean clays are frost susceptible. While building a pavement structure at high altitudes, frost susceptible sub grade soil should be replaced by non frost susceptible material up to the maximum frost penetration depth. Moreover, frost susceptible materials should not be used in layer works. Table 1.11a gives grouping of soils based on frost susceptibility.

Table 1.11a Grouping of soils based on frost susceptibility.

sl	Grp.	Description	Characteristic
1	F1	Gravelly soils containing between 3 & 20% finer than 0.02 mm by weight	Least frost susceptible and least thaw weakening
2	F2	Sands containing between 3 and 15% finer than 0.02 mm by weight	Increased frost susceptibility and thaw weakening.
3	F3	a) Gravelly soil containing more than 20% finer than 0.02 mm by weight b) Sands, except fine silty sands containing more than 15% finer than 0.02 mm by weight. c) Clays with plastic indeces more than 12 d) Varved clays with uniform subgrade conditions	Frost susceptible and high thaw weakening
4	F4	a) all silts including silty clays b) Fine silty sands containing more than 15% finer than 0.02mm by weight. c) Lean clays with plastic index less than 12 d) Varved clays with non uniform sub grade conditions.	Frost susceptible and high thaw weakening

2.4 Pavement design against frost protection

The following guidelines may be followed for design of pavement against frost action.

a) The design will have to be related to the actual depth and severity of frost penetration.
b) Freezing conditions could develop within the pavement structure if water had a chance to ingress from above and hence has to be avoided.
c) Depth of structure (pavement) should not be less than depth of frost penetration and should compose of non frost susceptible materials. In any case the thickness should not be less than 450 mm
d) Crushed stone base is a non frost susceptible medium as it is free draining. It may be extended over full formation width.
e) Structurally strong courses like DBM against WBM/WMM is more suitable especially if heavy machineries are likely to be deployed for snow clearance.
f) Alternative designs that are not flexible may also be considered.
g) Binder to be used shall not be less than 80/100 penetration grade. Cut-backs and fluxed bitumen including cationic emulsion can be used if found suitable instead of straight run bitumen.
h) As high altitude areas are usually damp, antistripping agents for surface course should be used.

2.5 Design steps

Step1

Determination of frost penetration depth

In order to determine the depth of frost penetration, the freezing index is to be calculated which is defined as *"the product of monthly average temperature which fall below 0ºC and the total number of days in the month*". The relationship between freezing index and depth of frost penetration is given in fig.4.

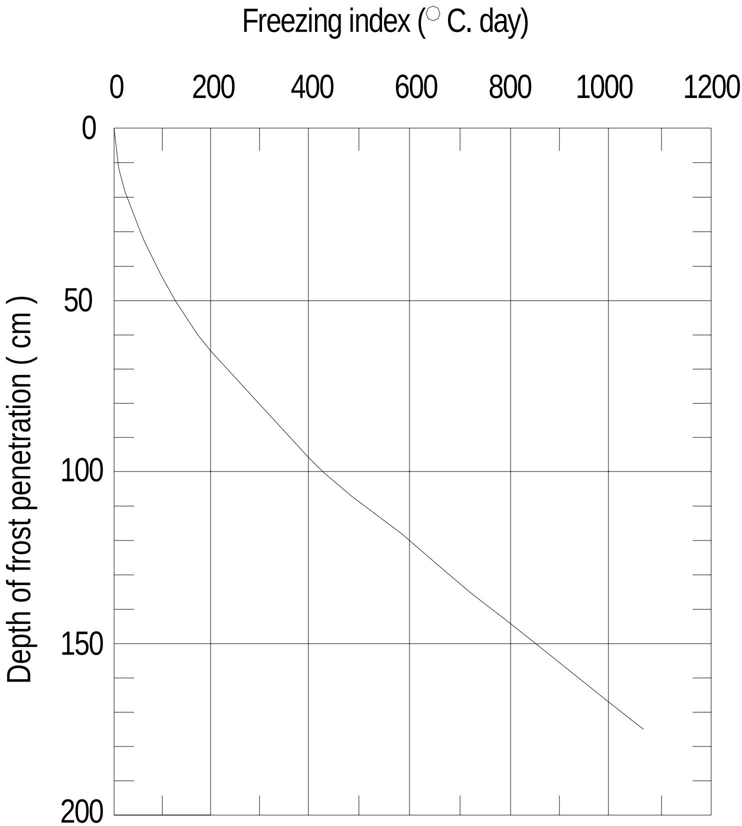


Fig. 4

Step 2
Design traffic and design sub grade CBR shall be in accordance with the criteria used for normal flexible pavement design.

Step 3
Subtract total pavement thickness from frost penetration depth which gives the thickness of replacement material. The pavement thickness shall not be based on the strength of replaced soil but it should be based on the strength (CBR) of the natural sub grade soil.

Step 4
Where PMC is specified for surface course in pavement design catalogue, it should be replaced by asphalt concrete to make the surface impervious. AC shall be produced using anti stripping agent.

2.6 Design example.

Frost index = 100 ºC day
Design traffic = 1 msa
Design CBR = 5%
From graph 1a, frost penetration depth = 50 cm
From graph 1 or table 1.9, total thickness = 40 cm

Granular sub base (GSB) = 26.5 cm
Base Course (GABC) = 13.5 cm
Surface course (AC) = 2.5 cm

The sub grade soil replacement with non frost susceptible material (if necessary)
= (50-40)
= 10 cm

Note: the materials for all the above layers should be non frost susceptible.

3 Flexible Pavement Overlay Design

3.1 Introduction

Performance of flexible pavement is closely related to the elastic deflection of pavement under the wheel load. The deflection of pavement depends upon sub grade soil type, moisture content, layer thickness and quality of pavement course, surface temperature etc. Deflection of pavement can be measured by Benkelman Beam Deflection (BBD) test, Standard Falling Weight Deflectometer (FWD), Light Falling Weight Deflectometer (FWD-light) etc.

The deflection value obtained from any of the above instrument can be used for overlay design of flexible pavement. Although the use of FWD Light would be more convenient and faster as compared to the other two, overlay design by BBD (Static Load Method) is described here. FWD can also be used.

3.2 Deflection measurement.

Prior to BBD test, pavement condition survey is to be conducted in order to identify a road section of uniform performance. Pavement condition survey consists primarily of visual observations supplemented by simple measurement of rut depth using a 3 m straight edge. The road length shall be classified into sections of equal performance in accordance with the criteria given in Table 2.1 below.

Table 2.1 : criteria for classification of pavement section

Classification	Pavement condition
Good	No cracking and rutting less than 10 mm
Fair	No cracking or cracking confined in the wheel track with rutting between 10-20mm
Poor	Sections with cracking exceeding 20% shall be treated as failed.

In each section of uniform performance of pavement a minimum of 10 points should be marked at equal distance for taking deflection measurement. The interval between the points should not be more than 50 m. The points for measurement should be 60 cm from the edge of the road for pavement width of 3.5 m and 90 cm for greater than 3.5m width. The deflection of pavement is influenced by pavement temperature and sub grade moisture content. Hence corrections are necessary.

3.3 Temperature correction

It is recommended that the deflection measurement be taken when the ambient temperature is greater than 20ºC. In this case temperature correction shall not apply. In any case temperature measurement is to be taken only for pavement of bituminous layer thickness ≥ 4cm. Pavement temperature is taken by making a suitable hole of 4 cm deep and filling it up with glycerine. Temperature is taken by inserting a thermometer and recording the temperature after 5 minutes. Temperature reading is to be taken after every one hour.

3.4 Moisture correction

It is best that deflection measurements are made when the pavement is at its weakest condition, i.e. immediately after monsoon. Since this is not always feasible, corrections to moisture contents are applied when the measurement is done in during other seasons. The recommended factors are 1.2 for sandy/gravely sub grade and 1.5 for clayey sub grade. The soil sample for moisture determination should be taken from the soil beneath the carriageway at a depth 5 to 10 cm below the bottom of sub base layer.

3.5 Overlay design life.

Overlay design life shall be minimum of 5 years and maximum of 10 years.

3.6 Traffic determination

Traffic load in terms of million standard axles of commercial vehicle of laden weight of 3 tons and more shall be considered for overlay design. The design traffic shall be determined from equation 1 used for flexible pavement design but the design life will be different.

3.7 Deflection measurement

Equipment required.

1. Loaded truck producing 8170 kg at the rear axle of dual wheels with tyre pressure of 5.6kg/cm^2 made up of 10 x 20, 12 ply tyre.
2. Benkelman Beam (calibrated)
3. Dial gauge
4. measuring tape, markers etc

3.8 Test procedure

1. Place the dual wheels of loaded truck on the test point
2. Place the Benkelman Beam probe between the dual wheels placed on the test point
3. Level the beam ensuring that probe and dial gauge touch the pavement and the beam respectively.
4. Take the initial reading d1.
5. Move the truck to 2.7 m and take the intermediate reading, d2.
6. Further move the truck to 9 m and take the final reading, d3.
7. The readings are recorded in standard formats given in Table 2.2

Table 2.2 Proforma for recording pavement deflection data.

Name of road:	Date & time of observation :	
	Climatic condition (hot/humid/cold) :	
Section :	Ambient temperatire :	
	Annual rainfall, mm :	
Traffic :	Temperature correction :	yes/no
Proposed overlay = AC	Seasonal correction :	yes/no
	Sub grade soil type :	

Location of test point (Chainage)	Dial gauge reading			Difference				Measured deflection (mm)	Temp factor	Moisture factor	Corrected deflection (mm)
	Initial d1	I/mediate d2	Final d3	if (d1-d3)	ii (d1-d2)	itf (d2-d3)	if-ii				

3.9 Calculation of rebound deflection

From the set of reading d1, d2 and d3, if both the values of (d1 – d3) and (d1 – d2) are within 0.025mm, true pavement deflection $d_t = 2(d1 - d3)$. But, if the difference is more than 0.025mm, the true pavement deflection is calculated as below.

$d_t = 2(d_a + 2.91 d_x)$

d_t = true/rebound deflection
$d_a = (d1 - d3)$
$d_x = (d2 - d3)$.

3.10 Analysis of test data

Pavement deflection from individual test points for particular section is corrected for moisture and temperature before calculation of mean deflection, standard deviation and characteristic deflection.

Mean deflection, $d_m = \frac{\Sigma d_t}{n}$

d_t = individual true pavement deflection
n = no. of deflection measurements.

Standard deviation, $\sigma = \frac{\sqrt{\Sigma (d_t - d_m)^2}}{n-1}$

Characteristic deflection, $D_c = d_m + 2\sigma$

From the characteristic deflection and design traffic, the overlay thickness in terms of bituminous macadam is read off from fig 5. For asphalt or granular overlay, the following equivalency factor may be applied.

1 cm of bituminous macadam = 1.5 cm of WBM or Wet Mix Macadam
1 cm of bituminous macadam = 0.7 cm of DBM or Asphaltic Concrete.

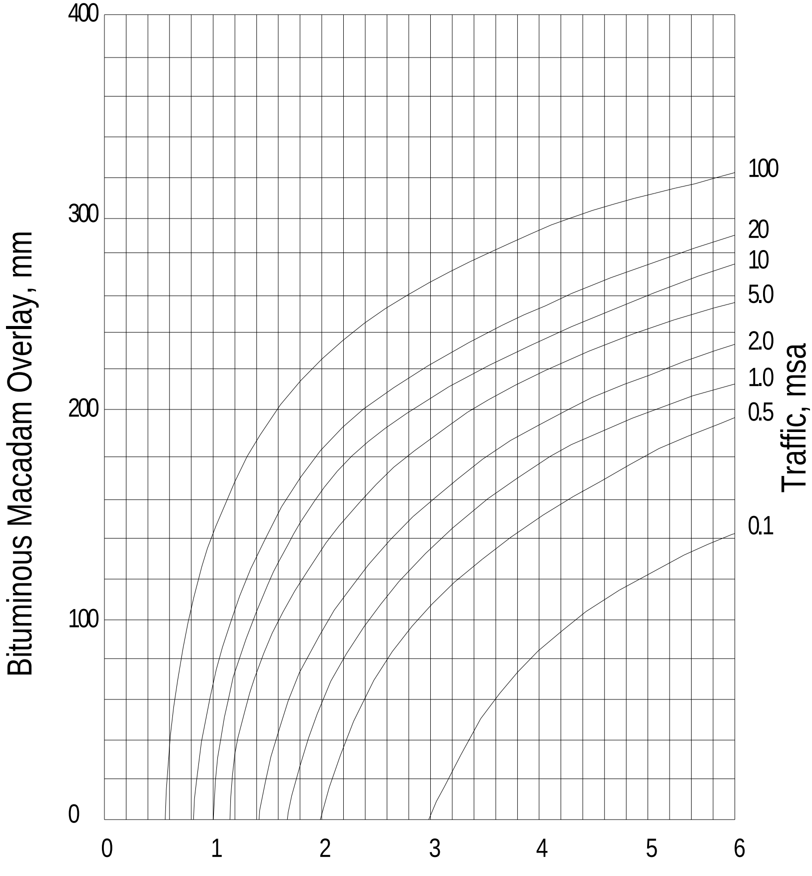

400
300
200
100
0
Bituminous Macadam Overlay, mm
100
20
10
5.0
2.0
1.0
0.5
0.1
Traffic, msa
0
1
2
3
4
5
6
Characteristic deflection, mm

Fig. 5

3.11 Worked example

								Annual rainfall, mm :	687 mm			
Traffic :	456 CVD (S/Lane)							Temperature correction :	NO			
Proposed overlay = AC								Seasonal correction :	Yes			
								Sub grade soil type :	Sandy gravel			
Location of test point (Ch. m)	Dial gauge reading			Absolute difference				Measured deflection (mm)	Temp Factor	Moisture Factor	Corrected deflection (mm)	
	Initial d1	Inter d2	Final d3	if (d1-d3)	ii (d1-d2)	itf d2-d3	if-ii					
0.00	11.00	10.79	10.76	0.24	0.21	0.03	0.33	0.65	No	1.2	0.79	
50.00	11.00	10.78	10.77	0.23	0.22	0.01	0.01	0.46	No	1.2	0.55	
100.00	11.00	10.78	10.77	0.23	0.22	0.01	0.01	0.46	No	1.2	0.55	
150.00	11.00	10.62	10.61	0.39	0.38	0.01	0.01	0.78	No	1.2	0.94	
200.00	11.00	10.70	10.70	0.31	0.30	0.00	0.00	0.61	No	1.2	0.73	
250.00	11.00	10.58	10.55	0.45	0.42	0.03	0.54	1.07	No	1.2	1.29	
300.00	11.00	10.42	10.38	0.62	0.58	0.04	0.74	1.47	No	1.2	1.77	
350.00	11.00	10.42	10.42	0.58	0.58	0.00	0.00	1.16	No	1.2	1.39	
400.00	11.00	10.69	10.68	0.32	0.31	0.01	0.01	0.64	No	1.2	0.77	
450.00	11.00	10.73	10.71	0.29	0.27	0.02	0.02	0.58	No	1.2	0.70	
500.00	11.00	10.59	10.58	0.43	0.41	0.02	0.02	0.85	No	1.2	1.02	
550.00	11.00	10.20	10.19	0.82	0.80	0.01	0.01	1.63	No	1.2	1.96	
600.00	11.00	10.83	10.81	0.19	0.17	0.02	0.02	0.38	No	1.2	0.46	
650.00	11.00	10.68	10.68	0.32	0.32	0.00	0.00	0.65	No	1.2	0.78	
700.00	11.00	10.53	10.52	0.48	0.47	0.01	0.01	0.96	No	1.2	1.15	
										Total	14.83	
										Mean	0.99	
		D_c	1.43							σ	0.44	

Traffic forecast is calculated as usual method.

$$N_s = \frac{365\left[(1+0.075)^{10} - 1\right]}{0.075} \times 456 \times 1 \times 1.25$$

N_s = 3.2 msa

For characteristic deflection of 1.43mm and design traffic of 3.2 msa, the bituminous overlay thickness from fig 5 = 57 mm

For the proposed overlay of Asphaltic concrete (AC), the thickness of AC is

0.7 * 57 = 39.9 mm
= say 40 mm thick AC

(*Note: the overlay thickness of 40 mm AC has already been constructed along Norzin Lam in Thimphu in 2003)*

4 Sprayed Seal Design

4.1 Introduction

The general aim in design of single application of spread seal is to achieve a single layer of aggregate particles in continuous, partly interlocked, contact with sufficient binder to hold the aggregate in place without the binder filling surface voids and reducing surface texture. In the second application, the spaces between the aggregate particles of first applications are filled up. Usually the size of aggregates used for the second application is half the size of first application and the rate of application of binder and aggregate in the later case should be less than that of the first application.

4.2 Aggregate quality and size used for sprayed sealing.

The best shape is cubical and single sized. Aggregate is single sized when 2/3 of whole material passes one sieve and retained on second sieve having an opening of 70% of the top sieve. The flakiness index and Los Angeles Abrasion Values (L.A) of the aggregate is vital for sprayed sealing works. The flakiness index of the aggregate should not exceed 35% while the requirement for Los Angeles Abrasion Value is given below in Table 3.1

Table 3.1: L.A. Values

Expected traffic	Maximum L.A Value
> 1500 VPD	18%
300 - 1500	27%
< 300	30 - 35%

Various sizes of aggregates and their uses are given in Table 3.2

Table 3.2

Aggregate size	Uses
10 - 20 mm	Heavy traffic
< 10 mm	Light traffic
2 - 5 mm	for hard surface where embedement is not possible

4.3 Choice of binder and application

Choice of binder depends on aggregate type and climate. Binder should be 2/3 of Average Least Dimension (ALD) of aggregates. Amount of residual bitumen depends of ALD. For the porous surface the amount of bitumen should be increased and decrease for prime surfaces. Choice of binder and conditions for their use are given in Table 3.3

Table 3.3

Sl.No	Binder type	Condition for use	Advantages
1	Cut back bitumen with conventional cutter oil	Pavement surface temperature above 10ºC and raising if below 15ºC	Earlier stone retention than emulsion. Less cost than emulsion
2	Cut back bitumen with fast evaporating cutter oil	Work carried out during cooler months of the year. Pavement surface temperature above 10ºC and raising if below 15ºC	Reduce the chance of cutter oil remaining in the seal and causing bleeding during the following summer.
3	High bitumen content emulsion (67% or higher)	Pavement surface temperature above 10ºC	May be used in damp condition Aggregate size 5, 7, 10 and 14mm.
4	High bitumen content emulsion (67% or higher) with polymer additive	Pavement surface temperature above 5ºC	Gives better early aggregate retention than emulsion without polymer additive. May be used in damp conditions. Aggregate sie 5, 7, 10 and 14mm
5	80/100 penetration grade bitumen	Pavement surface temperature above 10ºC	Can be used with large aggregates upto 20 mm in cold climate.

4.4 Design procedure.

Choose aggregate size from Table 3.2.
Choose appropriate binder from Table 3.3
Determine Average Least Dimension (ALD) form graph 1b. In order to use ALD Fig 6, we have to know the mean size and flakiness of the aggregate to be used. Alternatively, ALD can be measured directly by averaging the least dimension of 200 representative chippings.
Choose basic void factor from Table 3.4

Table 3.4 Basic void factor

Traffic (AADT)	Void factor BV_f (L/m^2 /mm)
< 70	0.20 - 0.24
70 - 200	0.18 - 0.21
200 - 300	0.16 - 0.19
300 - 600	0.15 - 0.17
600 - 1250	0.14 - 0.16
1250 - 2500	0.13 - 0.15
> 2500	0.12 - 0.14

Calculate adjustment required for BV_f from Table 3.5, 3.6 and 3.7

Table 3.5

Aggregate quality void factor adjustment		
Aggregate type	Aggregate shape	void factor adjustment (L/m2 /mm)
Rounded	NA	+ 0.01
Partly crushed	NA	+ 0.005
Crushed	Flaky	- 0.01
	Angular average	0.0
	Angular good	+ 0.005
	Cubic	+ 0.01

Table 3.6

Aggregate size void factor adjustment	
Nominal size, mm	void factor adjustment (L/m2 /mm)
5, 7 and 10	0.0
14	+ 0.01

Table 3.7

Traffic void factor adjustment	
Traffic effect	void factor adjustment (L/m2 /mm)
15% to 30% heavy vehicles	- 0.01
More than 30% heavy vehicles	- 0.02
Slow moving traffic in climbing lane	- 0.01
Fast moving cars. (overtaking lanes of rural roads) Channelisation	+ 0.01
Slight confining of wheel path	0.0

Calculate design void factor (DV_f) = BV_f + table 3.5 + 3.6 + 3.7
Calculate basic binder application (A)
A = ALD * DV_f (L/m^2)
Add for aggregate absorption (C) = 0.01
Surface texture allowance (B) = 0.0 to 0.3 is added
Allow for embedment allowance (E) = 0.0 for traffic <1250 vpd, - 0.1 for 1250 – 2500 vpd.
Residual binder application = A + C + B + E
(If emulsion is used, residual binder application will be + quantity of water)
Determine basic aggregate spread rate from Fig. 7.
Deduct 5% for whip-off and 5% for stockpile wastage.

4.5 Binder and aggregate application for two application seals.

Where the second application is to be applied sometime after the first, eg after several months of opening to traffic both applications should be designed as single application seal except that the binder and aggregate application rates may be reduced to the minimum basic rate in order to fill the void spaces in the first application only.

Where the second application is to be applied immediately after the first, having exposed to little or no traffic, the following design procedure may be used.

a) Design the first application using the procedure for single application seals except reduce the basic void factor by 0.02 L/m^2 /mm. Aggregate should be applied without any allowance for whip-off.
b) Design the second application as for single application seal but without the addition of any allowances for surface texture. Aggregates in the second application are normally no more than half the size of the first and spread at the rate sufficient to fill the voids in the first application.

Note 1: The above designs are only for guide to designers. The actual design may be modified by construction trials and actual analysis.

Note 2 : Emulsion application rate of > 1.3 L/m^2 will cause run off at steep gradient and super elevated sections. In such cases, emulsion may be replaced by other suitable binder.

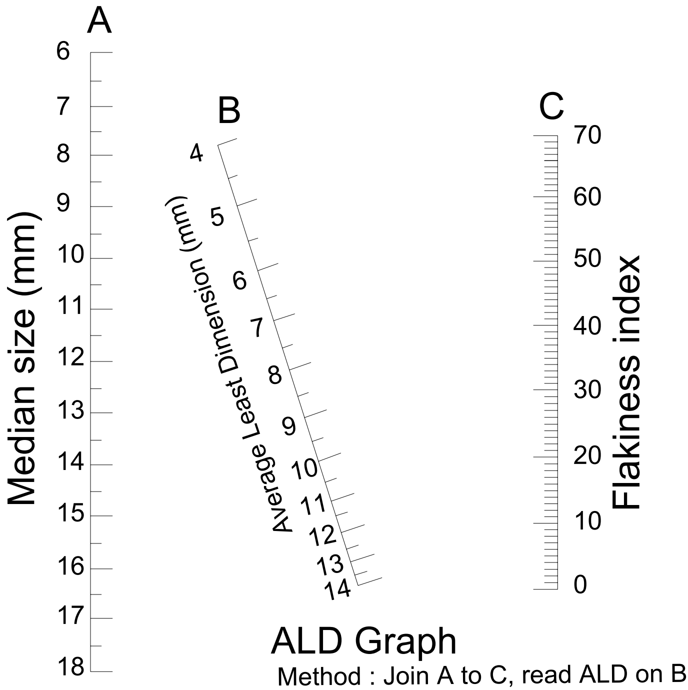

A
Median size (mm)
6
7
8
9
10
11
12
13
14
15
16
17
18
B
Average Least Dimension (mm)
4
5
6
7
8
9
10
11
12
13
14
C
Flakiness index
70
60
50
40
30
20
10
0
ALD Graph
Method : Join A to C, read ALD on B

Fig. 6

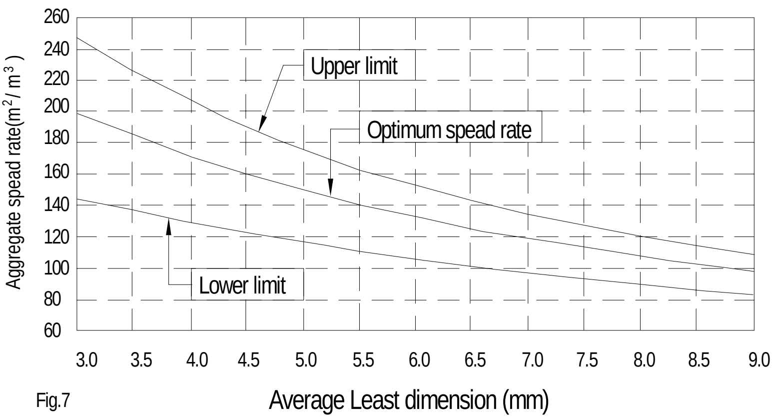

Aggregate spead rate(m2 / m3)
260
240
220
200
180
160
140
120
100
80
60
Upper limit
Optimum spead rate
Lower limit
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Average Least dimension (mm)

Fig.7

4.6 Worked example

Job : Sprayed sealing of Simtokha – Dochula Highway.
(Single application)

Binder : High bitumen content emulsion (70% bitumen)

Aggregate : Nominal Maximum size = 10 mm
Mean size = 10 mm
Flakiness index = 25%
L.A. value = 22%
Traffic = < 300vpd
Air temperature 13ºC (10 am to 3pm)

ALD from Fig. 6 3 = 7 mm
Basic void factor from table 3.4 = (0.16 – 0.19 = 0.175
Adjustments from table 3.5, 3.6 and 3.7 = -0.01+0.0+-0.01 = -0.02
Design void factor = 0.075 + (-0.02) = 0.155

Basic binder application = 7 * 0.155 = 1.085 L/m^2

Add aggregate absorption + surface texture + embedment = 0.01+0.15+0 = 0.16

Residual binder application = 1.085 + 0.16 = 1.245 L/m^2
Add 30% due to water in emulsion = 1.245 +30% = 1.62 L/m^2

Aggregate spread rate from Fig. 7 = 120 m^2 / m^3

Deduct 10% for whip-off and stockpile wastage
= 120 - 10% = 108 m^2 / m^3

5 Asphalt Mix Design

5.1 Introduction

Any asphalt or bituminous mix is designed to achieve the desirable properties of asphalt mix, which are used as road and runway surface layer. Some types of bituminous mixes are also used as base course. Asphalt mix design is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure. When these selected and proportioned materials are mixed with optimum bitumen content it should be able to resist the design traffic load provided it is properly constructed.

5.2 Desirable properties of asphalt mix:

1. Resistance to permanent deformation: The mix should not distort or be displaced when subjected to traffic loads. It is more important at high temperatures. Selection of bitumen type is important.
2. Fatigue resistance: the mix should not crack when subjected to repeated loads over a period of time
3. Durability: aggregates should be adequately coated and should not have very high air voids, which accelerates the aging process.
4. Skid resistance: mix should have good skid resistance.
5. Workability etc

5.3 Marshall Method of mix design

The asphalt mix is designed by various methods.

1. Marshall method
2. Hveem stabilometer method

Usually Marshall Method of mix design is followed. In this method, the resistance to plastic deformation of compacted cylinder specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate of 50 mm per minute. There are two major features of Marshall Method of mix design.

1. density-void analysis
2. stability-flow tests

The Marshall stability of mix is defined as the maximum load carried by the specimen at standard temperature of 60 deg C. The flow value is the deformation that the specimen undergoes during the loading up to the maximum load. In this method of mix design, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

Marshall Apparatus

Set of IS sieves

Marshall test

Digital balance

5.4 Steps of design

1. Select aggregate quality and grading limits
2. Aggregate gradation/blending
3. Determine specific gravity of each aggregate and asphalt and calculate maximum theoretical density
4. Prepare test specimen as per requirement
5. Determine apparent density of compacted specimen
6. Calculate binder volume, air void, porosity and VFA
7. Perform stability-Flow test
8. Plot density, stability, flow, void and VFA against asphalt content used
9. Evaluate the design with its requirement.

The aggregates are tested for Aggregate Crushing Value (ACV), Los Angeles Abrasion (LAA), Stripping, Shape etc and grading range is selected from standard specification given in this manual

5.5 Aggregate gradation/blending

The grading of aggregates should fall within upper and lower of gradation curve which are plotted using the following equation.

Upper Limit = $\left(\frac{d}{D}\right)^{0.6} * 100$ (%passing)

d = sieve opening

Mid point = $\left(\frac{d}{D}\right)^{0.5} * 100$ (%passing) D = maximum agg. size

Lower limit = $\left(\frac{d}{D}\right)^{0.4} * 100$ (%passing)

In case of asphalt with top size of 10mm, standard aggregate mix is produced by blending 13mm aggregate, 5mm aggregate, coarse sand, fine sand and filler of varying proportions. Excessive of filler material > 10% will make the asphalt mix weak and uneconomical. It will also consume more binder due to increase in surface area. On the other hand, absence of filler material will result in excessive void in the mix which reduces the strength and stability.

The actual aggregate gradation is blended by trial and error method or graphical method as convenient to the designers. Simple excel based computer programs are very useful. In this particular case, sieving of all aggregates intended for use should be carried out. The computer can immediately plot the graph after feeding the required data. The percentage proportion may be changed to achieve the best possible grading curve. One can develop one's own suitable program in the excel sheet. Prepare the aggregate mix as per the proportions so determined to give total weight of 1200g. Combined sieving shall be done and % passing is compared with required specification and the gradation curve plotted. The % passing from combines sieving should fall inside the upper and lower limit of the gradation curve, if not, the proportion % is adjusted and the trial is repeated until the target curve is inside the specified limit. Tolerance of about ± 2 to 5% may be allowed.

5.6 Determination of specific gravity

Specific gravity of each aggregate including filler material should be determined as per normal standard. The specific gravity of bitumen should be obtained from the supplier or can be determined. It is roughly 1.02 ~ 1.036 for 80/100 grade bitumen. Specific gravity is required to calculate maximum theoretical density of specimen. Water absorption of aggregates can also be determined.

Specific gravity test for coarse aggregates can be calculated as follows.

GA = A/(A-C)

Where GA = specific gravity g/cc

A= dry weight in air

C = Weight in water

B = Weight of surface dry aggregate

5.7 Water absorption calculation

Total weight of saturated surface dry sample should be 1kg. Before aggregate is surfaced dried, sample of roughly 5kg should be soaked in water for 24 hours. Two samples are tested for taking average.

Water absorption (%) = [(B-A)/A] x 100

Specific gravity test for fine aggregates.

GF = W6/(A-W5-W7)

Gf = specific gravity

A = flask capacity = 500cc

W1 = surface dry sample weight (take 500g)

W2 = flask weight

W3 = flask+sample weight

W4 = weight of flask+sample+water (remove air)

W5 = weight of added water = W4-W3

W6 = weight of sample after drying

W7 = water content = W1-W6

Water absorption (%) = (W7/W6) x 100

5.8 Maximum theoretical density calculation

About 500g of saturated surface dry sample should be taken. Before aggregate is surfaced dried, sample of roughly 3kg should be soaked in water for 24 hours. Two samples are tested for taking average.

Example

1	2	3	4 vol
Aggregate	Composition	Sp.gr	(2/3)
13mm	55	2.707	20.318
C.sand	45	2.701	16.660
		Total (A)	36.978

5	6	7	8	9	10	11
Asphalt	sp.gr	asphalt vol	agg. Vol	total vol	max.density	agg vol
%		(5/6)	11(100-6)/100	(7+8)	100/9	(A)
4.5	1.036	4.344	35.314	39.658	2.522	36.978
5	1.036	4.826	35.129	39.955	2.503	36.978
5.5	1.036	5.309	34.944	40.253	2.484	36.978
6	1.036	5.792	34.759	40.551	2.466	36.978

5.9 Prepare test specimen

Aggregate proportions as obtained from aggregate mix design are used.

E.g. 13mm = 55%
Coarse sand = 45%
No. of specimen to be prepared = 25
With bitumen content 4.5% = 5 nos.
With bitumen content 5% = 5 nos.
With bitumen content 5.5% = 5 nos.
With bitumen content 6% = 5 nos.
With bitumen content 6.5% = 5 nos.

5.10 Specification for compacted Marshall Specimen

For a mix of particular asphalt content, the result of any two-test piece with extreme values if any should be deprived from inclusion in averaging the result.

Height = 6.35cm (6.3cm ~ 6.4cm)
Diameter = 10.16cm (it is fixed by mould)
For a well graded aggregate mix, about 1200g of aggregate will produce a compacted Marshall specimen of height of 6.35cm. If not, we have to adjust it. As per above example, take aggregate = 1200g for 4.5% bitumen
i.e. 13mm = 55% = 660g
Crushed sand = 45% = 540g
Bitumen = (Agg. * bitumen) / (100 - bitumen)
= (1200 * 4.5) / 100- 4.5) = 56.54g

5.11 Temperature range

Before mixing, aggregate and bitumen should be heated to required temperatures separately.

Aggregate temperature = 165 ~ 175 deg.C
Bitumen temperature = 137 ~ 141 deg.C
Compaction temperature = 137 ~ 141 deg.C

It is better to preheat the aggregates in a temperature controlled oven. Other heating devices like gas and stove are also required. Bitumen is added to the aggregates and mixed thoroughly at the above specified temperature. Temperature should be controlled at compaction temperature before the mix is put in to Marshall mould for compaction. After putting the mix in the mould, 25 times tampering should be given in such a way that a heap is formed in the middle. 50 times compaction is given at both ends by standard Marshall compactor either by automatic or manual hammer. The specimen is taken out from the mould using sample extractor. The height of the sample is checked using vernier calliper. If it is between 6.3cm ~ 6.4 cm, then it is ok and the first Marshall sample is ready. Exact specified height of specimen is very important for Marshall test. The rest of the samples are prepared similarly.

5.12 Adjustment of specimen height.

Example 1

Measured specimen height = 6.8cm
Extra height = (6.8 _ 6.35) = 0.45cm
Weight of specimen which produced that extra 0.45cm is
Vol * density(D)
PI * R^2 * H * D
3.141 * (10.16/2)^2 * 0.45 * 2.242 (D=2.242 e.g. only)
81.78g (excess)

Density (D) of the sample so prepared can be measured.
D = W1/W3
W1 = Weight of sample in air
W2 = weight of sample in water
W3 = W1_W2 (volume)
So reduce the mix quantity by 81.78g
ie 1200_81.78 =1120g

Now with this new quantity, recalculate the aggregate and bitumen content. As the quantity reduced is from the asphalt mix, new quantity shall be

Bitumen = 1120 * 0.045 = 50.4g
13 mm = 1120 * (0.55*0.945) = 582.12g
Crushed sand = 1120 * (0.45*0.945) = 476.28g

With these new calculated quantities of aggregate and bitumen content, the sample is prepared again. If the prepared sample is again out of the permissible limit, adjustment is done again. Usually it should be OK. Or one easy way is to prepare the specimen of 1200g of any height but the stability value should be corrected by stability correlation ratio so that the value is reduced to 63.5mm height. Correlation ratio table is given below.

Stability Correlation Ratios*

Vol of Specimen (cm3)	Thickness (mm)	Correlation Ratio
393 to 405	49.2	1.56
406 to 420	50.8	1.47
421 to 431	52.4	1.39
432 to 443	54.0	1.32
444 to 456	55.6	1.25
457 to 470	57.2	1.19
471 to 482	58.7	1.14
483 to 495	60.3	1.09
496 to 508	61.9	1.04
509 to 522	**63.5**	**1.00**
523 to 535	64.0	0.96
536 to 546	65.1	0.93
547 to 559	66.7	0.89
560 to 573	68.3	0.86
574 to 585	71.4	0.83
586 to 598	73.0	0.81
599 to 610	74.6	0.78
611 to 625	76.2	0.76

*The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 63.5 mm specimen.

5. Determine apparent density of compacted specimen

The density of compacted specimen should be determined after the sample is extracted.

D = W1/(W1~W2)

D = density

W1 = weight of sample in air

W2 = weight of sample in water

5.13 Calculate binder volume, air void, porosity and VFA

Binder volume % = (bit. content * mix density)/sp.gr of asphalt

Air void % = [1-(mix density/max. theoretical density)] * 100

Porosity = Binder volume + air void

VFA = (binder volume/porosity) * 100

5.14 Perform stability-Flow test

For conducting stability test, the specimen is immersed in water bath at a temperature of 60˚∓1˚C for a period of 30 minutes. It is then placed in the Marshall Stability testing machine and loaded at a constant rate of 5mm per minute until failure. The total maximum load that causes failure of the specimen is taken as Marshall Stability. The value so obtained is multiplied by dial gauge factor. The total amount of deformation at the time of maximum load is recorded as Flow value. The total time between removing the specimen from water bath and completion of the test should not exceed 30 seconds. Plot density, stability, flow, void and VFA against each asphalt content. Five separate smooth curves are drawn with percentage of asphalt on x-axis and density, Marshall Stability, Flow, VFA and Air void on the y-axis.

5.15 Evaluate the design with its requirement.

Optimum bitumen content (OBC): OBC should be the average binder content for maximum density, maximum stability, specified air void, specified flow value and specified VFA.
The overall objective of the mix design is to determine an optimum blend of different components (aggregate + asphalt) that will satisfy the specified requirements.

The mixture should have:

- Adequate amount of asphalt to ensure a durable pavement
- Adequate stability to withstand traffic load
- Adequate voids that will accommodate small amount of compaction by traffic load without bleeding and loss of stability.
- Adequate workability to facilitate placement without segregation

If the mix design for OBC does not satisfy all the requirements, it is necessary to adjust the original blend of aggregates.

If low stability: low quality of aggregates and poor gradation

If high voids: increase fines or filler content

If low voids: increase coarse aggregates

6 Rigid Pavement Design

6.1 Introduction

In this manual only plain concrete pavement with dowelled joints will be considered. As the stresses induced in concrete pavements are mainly flexural, the concrete pavements fail due to bending stress. Hence the 28 day flexural strength is the key parameter in predicting concrete pavement performance. For the durability of concrete wearing surface, 28 day characteristic flexural strength should not be less than 4 Mpa and cement content should not be less than 350kg per cu.m of concrete. The slump value of concrete should be between 30 to 60 mm. Where there are no facilities for testing beam samples for determining flexural strength, the mix design may be carried out using equivalent compressive strength values. The following equation may be used for relating flexural strength with compressive strength.

The target compressive strength at 28 days is given by

$$f_c = 7.63 * f_{ct} + 2.58 * \sigma \qquad \text{Eqn 6}$$

Where f_{ct} = flexural strength at 28 days (Mpa)
f_c = characteristic compressive strength (Mpa)
σ = standard deviation (see Table 5.1)

Table 5.1

Grade of concrete	Standard deviation for compressive strength in Mpa (σ)		
	Very good	Good	Fair
M30	5.0	6.0	7.0
M35	5.3	6.3	7.3
M40	5.6	6.6	7.6
M45	6.0	7.0	8.0

6.2 Design procedure

The design procedure involves checking for load and temperature stress at the edge region and load stress at the corner region after having analysed for sub grade, traffic, environment and material properties.

6.3 Sub grade characterization.

The modulus of sub grade reaction (k value) determined by plate load test is used for rigid pavement design. However an approximate k value may be obtained if the sub grade CBR is known as shown in Table 5.2. The design CBR should be estimated in the same way as in the flexible pavement.

Table 5.2

Soaked CBR value (%)	2	3	4	5	7	10	15	20	50	100
k-value $Kg/cm^2/cm$	2.1	2.8	3.5	4.2	4.8	5.5	6.2	6.9	14	22.2

The sub base layer of usually lean concrete is provided below the concrete slab in order to provide a working platform over weak sub grade and to protect concrete slab from freezing & thawing and pumping action of water. If the modulus of sub grade reaction is less than 6 kg/cm^3, use sub base thickness of 10cm lean concrete. The design shall then continue with k-value of 6 kg/cm^3.

6.4 Traffic characterization.

The design traffic for commercial vehicle is estimated from the equation given below. The design wheel load of commercial vehicle shall be 4100 kg with tyre pressure of Kg/cm^2.

$$N_s = A * \left[1 + \frac{r}{100}\right]^{n+x} \qquad \textbf{Eqn 7}$$

Where, A = Initial traffic

r = Annual growth rate of commercial vehicles. The growth rate should be estimated by the past trend of traffic growth. If adequate data is not available, an average annual growth rate of 7% may be adopted.
(for7%, r = 0.007)

x = Number of years between the last count and the year of completion of construction.

n = Design life of pavement in years. Design life of rigid is 20 years.

N_s = Commercial vehicle per day

For rigid pavement design, one more type of traffic classification is required, given in Table 5.3.

Table 5.3

Classification	Commercial vehicles per day
A	0 - 15
B	15 - 45
C	45 - 150
D	150 - 450
E	450 - 1500
F	1500 - 4500
G	above 4500

6.5 Environmental conditions

For realistic estimation of temperature stress, the maximum temperature difference between the top and bottom of slab should be determined at the place where rigid pavement is going to be constructed. If the data can not be collected due to some reasons, the following approximate values given in Table 5.4 may be adopted.

Table 5.4

Altitude	Temperature difference in various slab thickness (deg C)				
	10cm	15cm	20cm	25cm	30cm
200 - 1000m	14	15.6	16.4	16.6	16.8
1000 - 2000m	15	16	17	18	19
2000 - 3000m	16	17	18	19	20
above 3000m	17	18	18	20	21

6.6 Material characterization

For economical design, the recommended minimum flexural strength of rigid pavement is 4 Mpa. In such case the modulus of elasticity equal to 3 x 10^5 Kg/cm^2 and Poisson's ration of 0.15 can be used. The coefficient of thermal expansion α will be 10 x 10^{-6} ºC.

6.7 Spacing and lay out of rigid pavement

Joints are very crucial for rigid pavement to allow its contraction and expansion. If the lane width $\leq$ 3.5m, longitudinal joints are not required. Apart from facilitating lane construction, longitudinal joints are also required to allow for transverse contraction and warping of the slab which will minimise cracking along the centre line of the pavement. Such joints are reinforced by tie bars which are used to tie two slabs together to ensure that the abutting slabs do not separate and to resist tensile forces.

Transverse joints are very important for rigid pavement. The transverse joints are reinforced by dowel bars which help to transfer 40% of the load and to relieve the stress at edge and corner. The surface of the joints shall be sealed to avoid penetration of water. The dowel bars are not provided for slab thickness less than 15 cm. The transverse joints are provided to a maximum spacing of 4.5m. In a dowel group action, the capacity of dowel bar beneath the load is full (one) and capacity decreases to zero at a distance of 1.8 times radius of relative stiffness. The capacity variation between these two limits is linear. The maximum joint width is 20mm. The requirement of dowel bars and tie bars are given in Table 5.5 and Table 5.6 respectively. However the engineers should design their own dowel and tie bar systems. An illustrative example is given.

Table 5.5 Recommended dimensions of dowel bars

Slab	Dowel bar details (deformed bars)		
thickness	diameter (mm)	Length (mm)	Spacing (mm)
20	25	500	250
25	25	500	300
30	32	500	300
35	32	500	300

Table 5.6 (Recommended dimension of tie bars)

Slab thickness (cm)	Tie bar details				
	Diameter (mm)	Maximum spacing (cm)		Minimum length (cm)	
		deformed bars	plain bars	deformed bars	plain bars
15	8	33	53	44	48
	10	52	83	51	56
20	10	39	62	51	56
	12	56	90	58	64
25	12	45	72	58	64
	16	80	128	72	80
30	12	37	60	58	64
	16	66	106	72	80
35	12	32	51	58	64
	16	57	91	72	80

6.8 Thickness design steps

Step 1
Determine traffic intensity and modulus of sub grade reaction as explained earlier guess slab thickness.

Step 2
Calculate maximum temperature stress at the edge region. The Bradbury's coefficient (C) to be used are given in Table 5.7 which are derived from L/*rl* or W/*rl* ratios. Use larger of the two values. Using Bradbury's Coefficient and temperature differential, estimate edge temperature stress from Fig. 8.

Where L = slab length
W = width of slab
rl = radius of relative stiffness of concrete

$$rl = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}} \qquad \text{Eqn 8}$$

E = modulus of elasticity (3 x 10^5 Kg/cm^2)
μ = Poisson's ratio (0.15)
k = modulus of sub grade reaction (Kg/cm^2/cm)
h = estimated slab thickness

Table 5.7

L/rl or W/rl	Bradbury's coefficient, C
1	0.000
2	0.040
3	0.175
4	0.440
5	0.720
6	0.920
7	1.030
8	1.075
9	1.060
10	1.075
11	1.050
12 and above	1.000

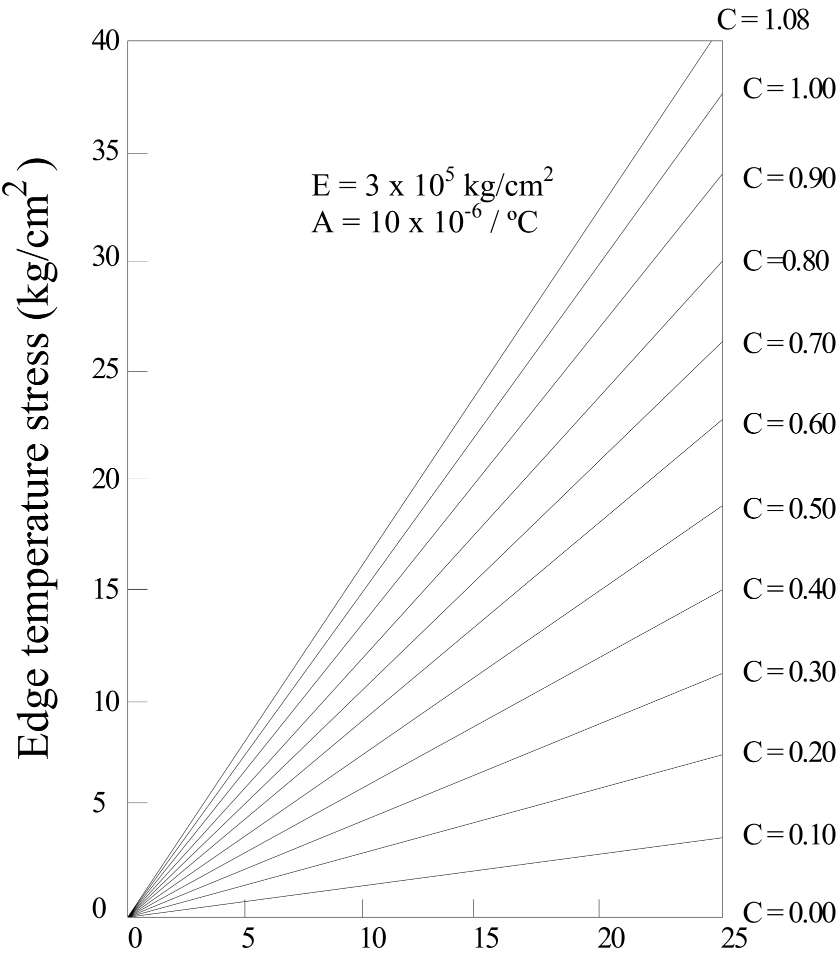


Fig.8 Temperature differentials (ºC)

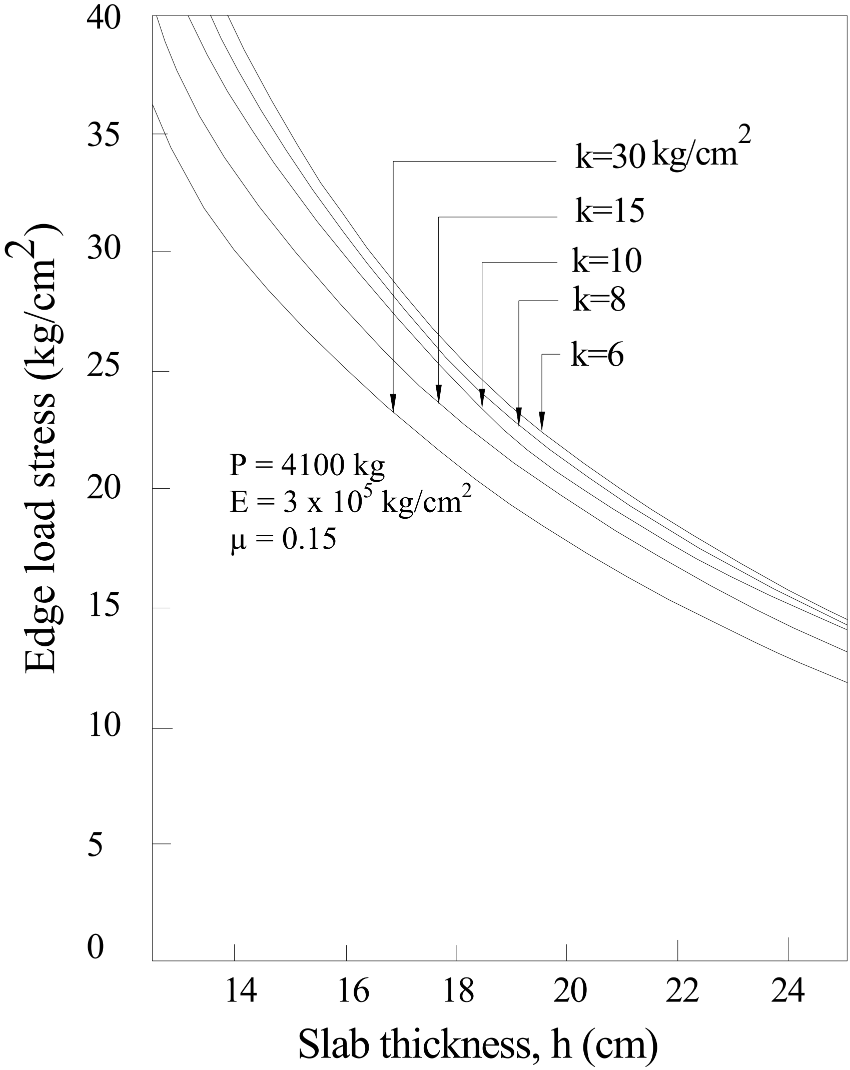

40
35
30
25
20
15
10
5
0
Edge load stress (kg/cm2)
k=30 kg/cm2
k=15
k=10
k=8
k=6
P = 4100 kg
E = 3 x 10^5 kg/cm2
μ = 0.15
14
16
18
20
22
24
Slab thickness, h (cm)

Fig.9

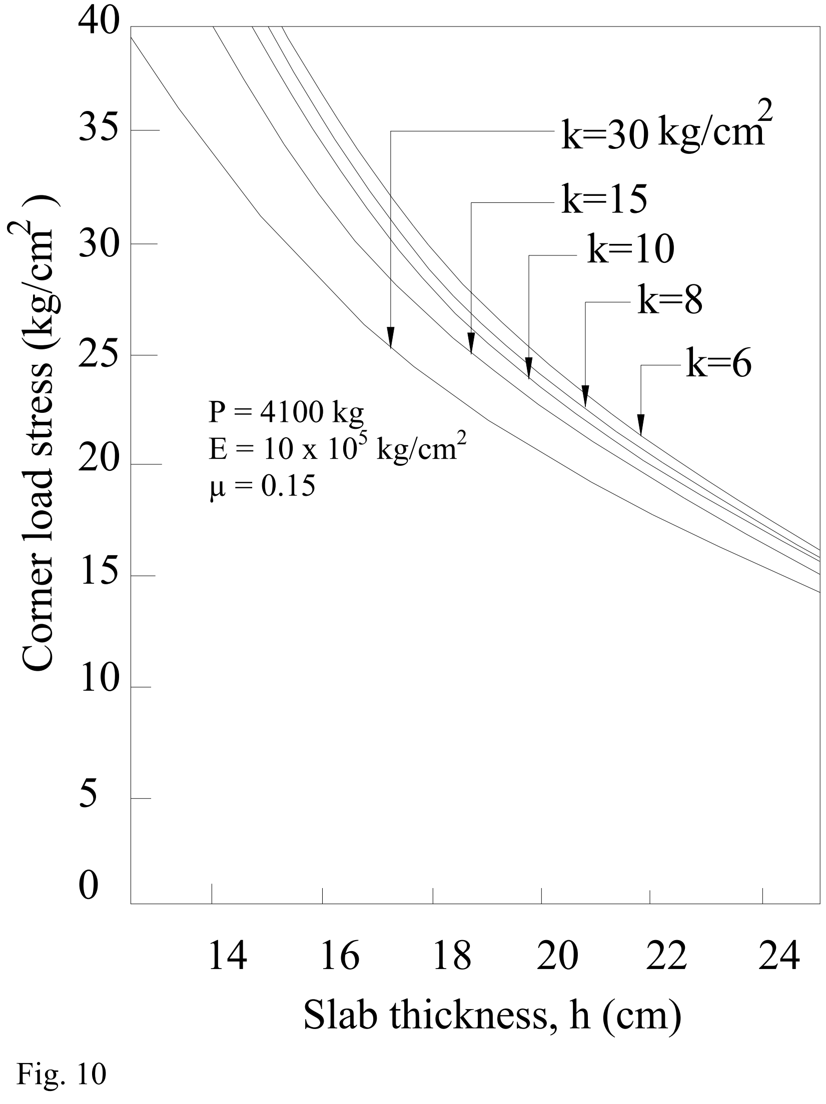

40
35
30
25
20
15
10
5
0
Corner load stress (kg/cm2)
k=30 kg/cm2
k=15
k=10
k=8
k=6
P = 4100 kg
E = 10 x 10^5 kg/cm^2
μ = 0.15
14
16
18
20
22
24
Slab thickness, h (cm)

Fig. 10

Step 3
Subtract the edge temperature stress from the allowable flexural strength to obtain available residual strength of concrete to support traffic load.

Step 4
Estimate the stress due to wheel load placed at the edge using Fig. 9 for the values of known sub grade modulus of reaction and slab thickness.

Step 5
Calculate the factor of safety by dividing residual stress from step 3 by edge stress obtained from step 4. In case the factor of safety is too low or far in excess of unity, adjust the slab thickness accordingly and repeat design step 1 to 4. The factor of safety should be 1 or slightly more.

Step 6
Estimate the stress due to wheel load placed at the corner region using Fig.10. The corner stress should be less than allowable flexural strength. If not, repeat the design from step 1 to 5 by increasing the slab thickness to meet the requirement.

Step 7
From the design traffic calculation, classify the traffic from A to G. Adjust the slab thickness as per traffic classification given below in Table 5.8.

Table 5.8

Traffic classification	Slab thickness correction (cm)
A & B	-5.00
C & D	-2.00
E & F	0.00
G	2.00

6.9 Design example

Design a concrete pavement for flexural strength of 40 Kg/cm^2 for double lane road having total carriage way width of 6m having traffic intensity of 1500CVD. The pavement should be in service for a minimum of 20 years before it is rehabilitated. The transverse joints shall be after every 4.5m with a maximum opening of 20mm joint gap. The traffic growth is 8% per annum. The CBR values from ten locations are 14.5%, 24%, 18%, 19%, 16%, 15%, 10%, 13%, 12%, and 17%. The road is likely to be opened to traffic after 3 years since the time of traffic count?

Solution

1. Design traffic determination (from Eqn 7)

$$N_s = 1500 * \left[1 + \frac{8}{100}\right]^{20+3} = 8810 \text{ CVD}$$

2. Design CBR determination

CBR values

24 19 18 17 16 15 14.5 13 12 10

Check for outliers (for large value from Eqn 2)

$r = \dfrac{24-19}{24-10}$ = 0.357 < 0.412 from table 1.2 (hence CBR value 24 is accepted)

Check for outliers (for small value from Eqn 3)

$r = \dfrac{12-10}{24-10}$ = 0.143 < 0.412 from table 1.2, hence o.k

Calculate section CBR

Mean CBR = 15.85%

$CBR_{section} = 15.85 - (24-10)/3.18$ (from Eqn 5)

= 11.45%

from Table 1.4, design CBR = 8%, therefore k-value = 5
(so use k-value =6 for design after providing 10cm thick lean concrete sub base)
3. Guess slab thickness = 200mm
4. Calculate maximum temperature stress at edge region
Temperature difference from table 12 = 16.4 deg C

$$rl = \sqrt[4]{\frac{3x10^5 x20^3}{12(1-0.15^2)6}} \qquad \text{(from Eqn 8)}$$

= 76.42
Length of slab L = 4.5m
Width of slab W = 6/2 = 3m
Therefore L/rl = 4.5/0.7642 = 5.89
W/rl = 3/0.7642 = 3.92

Use 5.89 to find out C
From table 14, C = 0.69
With the values of C, slab thickness and temperature differential known, estimate temperature stress at the edge from Fig. 8 = 17 Kg/cm^2

5. Available residual strength of concrete to support traffic load = 40 – 17 = 23 kg/sq.cm.
6. Estimate stress due to wheel load at the edge from Fig. 9 = 22 kg/sq.cm.
7. Calculate factor of safety = 23/22 = 1.05 (hence O.K)
8. Estimate stress due to wheel load placed at the corner region from Fig.10 = 25 kg/cm^2 < 40 kg/cm^2. Hence the design is safe.
9. Adjustment for traffic intensity of 8810 CVD. As per table5.8, it is G-type traffic. Therefore, as per table5.8, add 2cm to above slab thickness.
10. Final pavement thickness = 20+2 = 22 cm thick with 10cm lean concrete sub base.

6.10 Design of dowel bar system

Design parameters
Slab thickness = 22 cm
Design single wheel load = 4100 kg
Permissible shear stress in dowel bar (f_s') = 1000 kg/cm^2
Permissible flexural stress in dowel bar (f_s) = 1400 kg/cm^2
Permissible bearing in concrete = 100 kg/cm^2
Joint width (z) = maximum 20mm
Load transfer = 40% of 4100 kg = 1640 kg

$$rl = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$$

Where *rl* = radius of relative stiffness of concrete
E = modulus of elasticity (be 3 x 10^5 Kg/cm^2)

$$rl = \sqrt[4]{\frac{3x10^5 x22^3}{12(1-0.15^2)6}}$$

μ = Poisson's ratio (0.15)

= 82.08

k = modulus of sub grade reaction (Kg/cm^2/cm)
h = calculated slab thickness

Assumptions
Length of dowel bar (L) = 50 cm
Diameter of dowel bar (Ǿ) = 20 mm
Spacing of dowel bar (S) = 40 cm

a) Load transfer capacity in shear = 0.785 * Ǿ^2 * f_s' Eqn 9
= 0.785 * 2^2 * 1000
= 3140 kg

b) Load transfer capacity $= \dfrac{f_c * L^2 * \phi}{12.5[L + (1.5 * z)]}$ Eqn 10

in bending

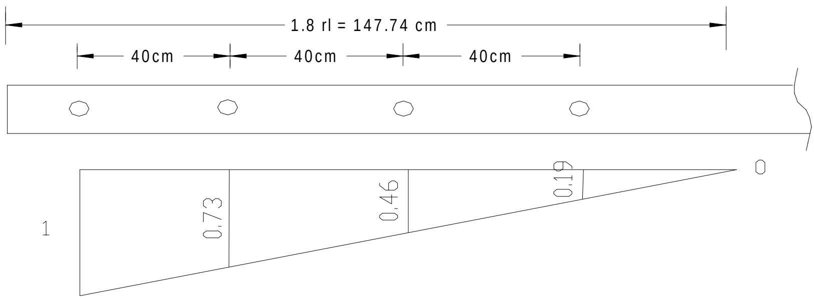
$$= \frac{100 * 50^2 * 2}{12.5[50 + (1.5 * 2)]}$$

= 754.72 kg

Take the lower value from a and b to compute capacity factor
Capacity factor required = single wheel load / load transfer capacity

= 1640kg/754.72
= 2.173

Load transfer capacity available is the function of radius of relative stiffness and dowel bar spacing. If the capacity of dowel bar directly under the wheel load is 1, the capacity decreases to zero at a distance of 1.8*rl* . Therefore the available load capacity factor is calculated as shown below.



1 - 40/147.74 = 0.73
1 - 80/147.74 = 0.46
1 - 120/147.74 = 0.19

Available capacity factor = 1 + 0.73 + 0.46 + 0.19 = 2.38
As the available capacity factor 2.38 > 2.173 of required capacity factor, the length, diameter and spacing of dowel bar assumed are safe.

Details dowel bars
Length = 50 cm + 2cm joint width = 52 cm
Diameter of dowel bar = 20 mm
Spacing of dowel bar = 40 cm

The first dowel bar should be placed at a distance of 15 cm from either edge of the slab and adjust the spacing for next dowel with a provision of 40 cm spacing for the rest.
(See fig.1)

6.11 Tie bar design

Slab width (W)= 3m
Slab thickness = 22cm
Coefficient of friction (f) = 1.5
Allowable bond stress of deformed tie bar (f_b) = 24.6 kg/cm^2
Density of concrete = 2400 kg/m^3
Permissible flexural stress in tie bar (f_s) = 1400 kg/cm^2

Weight per m^2 of slab (W_t) = 0.22 x 2400
= 528 kg

Area of steel required (A_S) $= \dfrac{W_t * W * f}{f_s}$ Eqn 11

$= \dfrac{528 * 3 * 1.5}{1400}$

= 1.70 cm^2 per m

Assume diameter (Ǿ) of tie bar = 16 mm

Cross sectional area (A) = $\dfrac{\pi\phi^2}{4} = \dfrac{\pi 1.6^2}{4}$ = 2.0 cm^2

No. of tie bars required per m = A_S /A = 1.70/2.0 = 0.85

Spacing of tie bar = 100 cm / 0.85 = 117.6 = say 120 cm

Length of tie bar = $\dfrac{f_s * \phi}{f_b} = \dfrac{1400 * 1.6}{24.6} = 91 cm$ say 100 cm

Tie bar details = 100 cm long, 16mm dia, 120cm c/c
See dowel bar and tie bar arrangement in fig 2 as per above design.

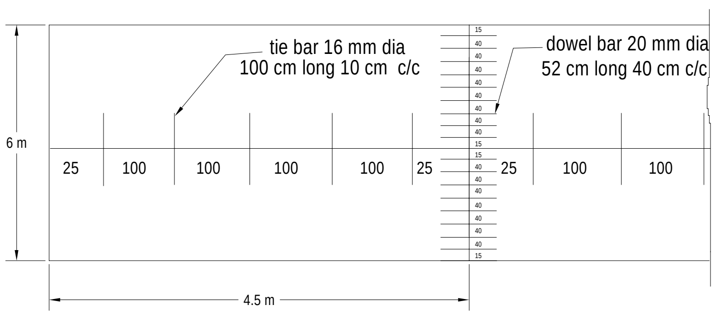


Fig. 11

7 Concrete Mix Design

7.1 Data required

The concrete mix design steps along with an example are listed below.

Specified data :
Minimum cement content = 350 kg/m^3
Maximum aggregate size = 20 mm
Slump value = 35 mm
Minimum flexural strength of concrete = 4 N/mm^2 or 40 kg/cm^2
Type of cement = OPC
Maximum aggregate = 20mm crushed.
Relative density of aggregate (SSD) = 2.7 (should be determined)
% passing 600µm sieve for fine aggregate = 70% (should be determined)

7.2 Design steps

Step 1

Calculate 28 day target compressive strength from Eqn 6

$$f_c = 7.63 * f_{ct} + 2.58 * \sigma$$

$$f_c = 7.63 * 40 + 2.58 * 7.3$$

= 324 kg/cm^2
say 325 kg/cm^2 or 32.5 N/mm^2

Step 2

Find out free water cement ratio using table 16 and Fig.12.
From table 16, 28 days compressive strength is 49 N/mm^2
On the Fig.12, draw a temporary graph line on the starting line against 49 N/mm^2

Using newly drawn graph line, read off free water cement ratio against the required compressive strength. For 32.5 N/mm^2 compressive strength, free water cement ratio = 0.64

Step 3
Determine free water content from table 17.
Free water content = 210 kg/m^3

Step 4
Calculate cement content
Cement content = free water content/free water cement ratio
= 210/0/64
= 328.125 kg/m^3
Note: the calculated cement content 328.125 kg/m^3 is less than specified minimum cement content of 350 kg/m^3. So use specified minimum cement content of 350 kg/m^3

Step 5
Recalculate free water cement ratio due to change in cement content.
Modified free water cement ratio = free water content / minimum cement content.
= 210/350
= 0.6
Note: If the cement content calculated in step 4 is ≥ minimum specified cement content, step 5 is not required.

Step 6
Determine concrete density from Fig.13 corresponding to relative density of aggregates and free water content.
For relative density of aggregate = 2.7 and free water content = 210 kg/m^3 (from step 3),
Density of concrete from graph 7 = 2390 kg/m^3

Step 7

Calculate total aggregate content.
= (density of concrete – cement content – free water content)
= 2390 – 350 – 210
= 1830 kg/m^3

Step 8

Determine fine aggregate content using % passing 600µm sieve and slump value specified.
% passing 600µm sieve = 70%
Slump value specified = 35mm
Maximum aggregate = 20mm crushed
Water cement ratio = 0.6 (from step 5)
From Fig.15, fine aggregate required = 32%
Fine aggregate content = total aggregate content * 32%
= 1830*.32
= 586 kg/m^3

Step 9

Calculate coarse aggregate content
= total aggregate content – fine aggregate content
= 1830 – 586
= 1244 kg/m^3

Step 10

Calculate individual quantities per m^3 of concrete mix

Quantities	Cement (kg)	Water (kg or litre)	Fine aggregate (kg)	Coarse aggregate (kg)
per m^3	350	210	586	1244

Ratio by weight = cement : fine agg. : coarse agg
= 1 : 1.7 : 3.6 W_c = 0.6

Ratio by volume
50 kg of cement = 0.035 m^3
= 1.235 cft.
For 1 bag of cement
Fine aggregate = 1.7*1.234 = 2 cft
Coarse aggregate = 3.6*1.235 = 4.5 cft
Water = 30 litres

Approximate compressive strength (N/mm^2) of concrete mixes made with a free water cement ratio of 0.5 is given in Table 6.1

Table 6.1 (compressive strength N/mm^2)

Type of cement	Type of coarse aggregate	Compressive strength (N/mm^2 age (days)			
		3	7	28	91
Ordinary Portland Cement (OPC)	Crushed	27	36	49	56
	Uncrushed	22	30	42	49
Rapid setting OPC	Crushed	34	43	55	61
	Uncrushed	29	37	48	54

Approximate free water content (kg/m^3) required to give various level of workability is given in Table 6.2

Table 6.2 (Free water content (kg/m^3)

Slump value in (mm)		0 - 10 (mm)	10 - 30 (mm)	30 - 60 (mm)	60 - 180 (mm)
Maximum aggregate size	Type of aggregate				
10	Crushed	180	205	230	250
	Uncrushed	150	180	205	225
20	Crushed	170	190	210	225
	Uncrushed	135	160	180	195
40	Crushed	155	175	190	205
	Uncrushed	115	140	160	175

7.3 Water – Cement ratio graph

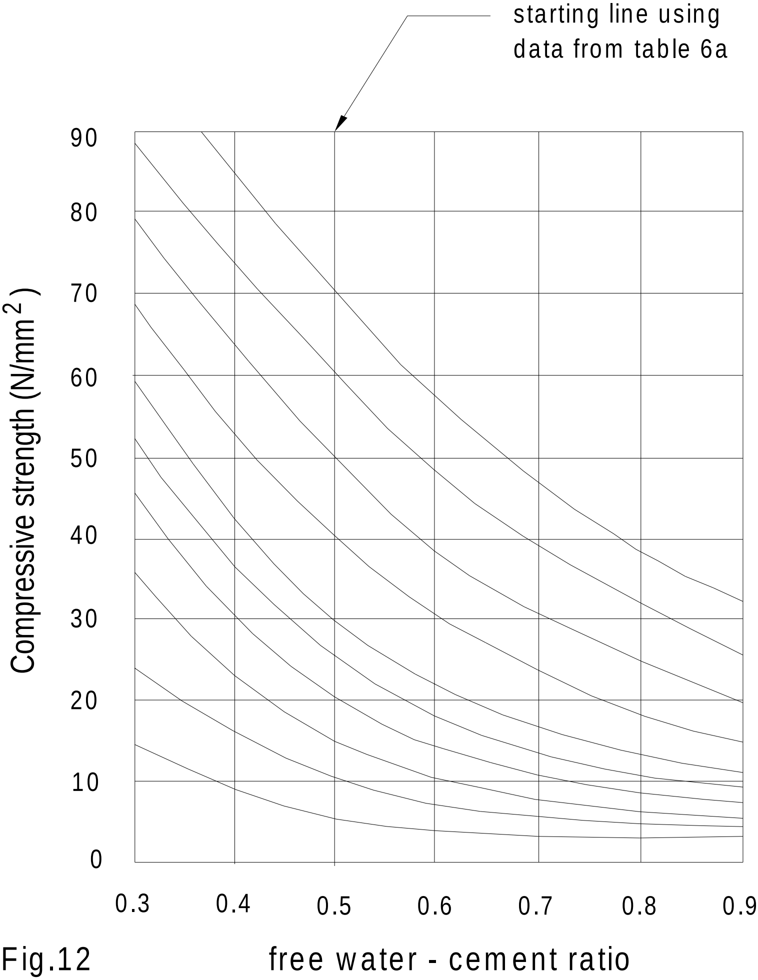


Fig.12

7.4 Density estimation graph

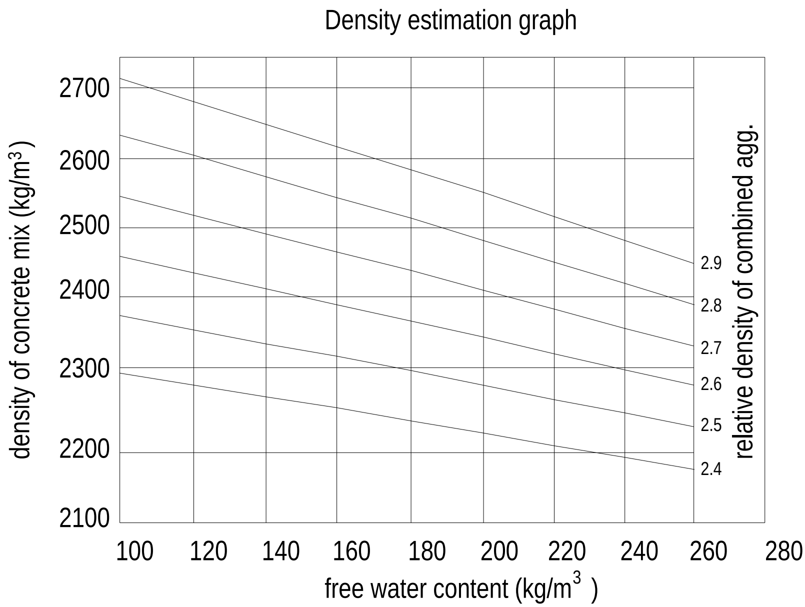


Fig.13

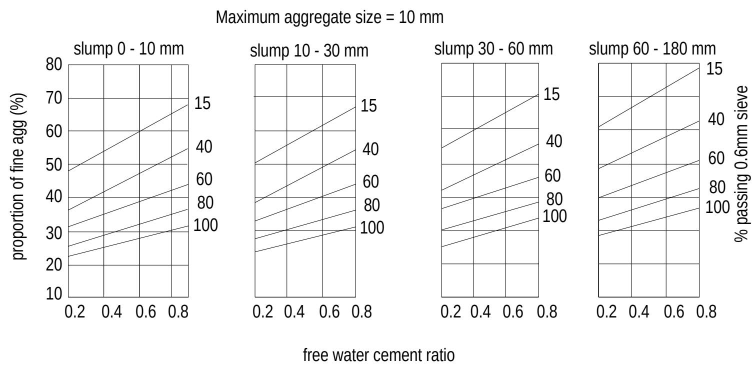


Fig.14

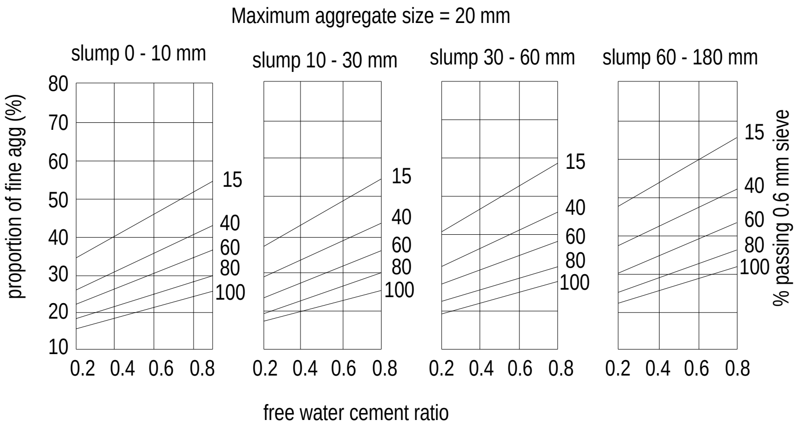

Maximum aggregate size = 20 mm
slump 0 - 10 mm
slump 10 - 30 mm
slump 30 - 60 mm
slump 60 - 180 mm
proportion of fine agg (%)
% passing 0.6 mm sieve
free water cement ratio

Fig.15

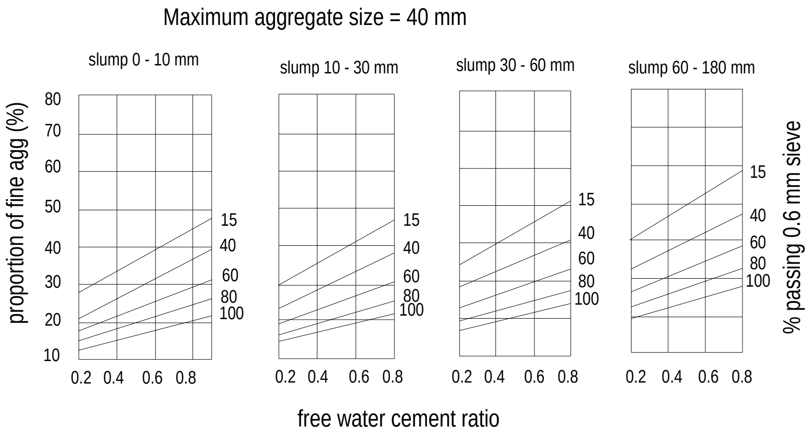

Maximum aggregate size = 40 mm
slump 0 - 10 mm
slump 10 - 30 mm
slump 30 - 60 mm
slump 60 - 180 mm
proportion of fine agg (%)
% passing 0.6 mm sieve
free water cement ratio

Fig.16

8 Pavement Material Specification

8.1 Quality of Materials and Workmanship

The materials and workmanship shall be of the best of their respective kinds and shall be to the approval of the Employer or his representative on site. In reading these Specifications, the words to the approval of the Engineer shall be deemed to be included in the description of all materials incorporated in the works, whether manufactured or natural, and in the description of all operations for the due execution of the works.

8.2 Preparation of sub-grade:

The surface of the formation for a width of sub-base, which shall be 15 cm more on either side of base course, shall first be cut to a depth equal to the combined depth of sub-base and surface courses below the proposed finished level (due allowance being made for consolidation). It shall then be cleaned of all foreign substances. Any ruts or soft yielding patches that appear due to improper drainage conditions, traffic hauling or from any other cause, shall be corrected to the finished profile.

If sub-grade is composed of clay, fine sand or other soils that may be forced up into the coarse aggregate during rolling operations, an insulation layer of granular materials (selected material) shall be provided for blanketing the sub-grade.

In slushy soil or in areas that are water logged, special arrangements shall be made to improve the sub-grade and the total pavement thickness shall be designed after testing the properties of the sub-grade soil. Necessary provision for the special treatment required shall be made.

8.2.1 Consolidation:

The sub-grade shall be consolidated with a power road roller of 8 to 12 tonnes. The roller shall run over the sub-grade till the soil is evenly and densely consolidated to required density. (The roller shall pass a minimum of 5 runs on the sub-grade). All the undulations in the surface that is developed due to rolling shall be made good with material or quarry spoils as the case may be and the sub-grade is re-rolled.

8.2.2 Surface Regularity:

The finished surface shall be uniform and conform to the lines, grades and typical cross-sections shown in the drawings. When tested with the template and straight edge, the variation shall be within the tolerances specified in the Table 7.1 below:

Table 7.1 : Permissible Tolerances of Surface Regularity

Longitudinal Profile	Cross Profile
Maximum permissible undulation when measured with a 3m straight edge	Maximum permissible variation from specified profile when measured with camber plate
24 mm	15 mm

When the surface irregularity of the sub-grade falls outside the specified tolerances, it shall be rectified with fresh material or quarry spoils as the case may be, and the sub-grade re-rolled to the satisfaction of the Engineer.

In the case of earthwork consolidated under optimum moisture conditions, each layer of earth shall be carefully moistened to give field moisture content in the range of +1% to -2% of the optimum moisture content (OMC). Each layer of uniform thickness not exceeding 200mm shall then be compacted by rolling with 8 to 10 tonnes power road roller and a sheep-foot roller if required. The required amount of water shall be added during consolidation to keep the moisture content of the soil at the optimum as per test. The density to be achieved shall not be less than 95% of the density obtained in the laboratory.

Each compacted layer shall be tested in the field for density and accepted before the operations for the next layer are begun. Control on compaction in the field shall be exercised through frequent moisture content and density determinations. A systematic record of these shall be maintained. At all times during construction the top of the embankment shall be maintained at such cross fall as will shed water and prevent ponding.

8.2.3 Compaction test and acceptance Criteria:

One measurement of density shall be made for each 500 sq.m of compacted area or for a smaller area as directed by the Engineer. Each measurement shall consist of at least 5 density determinations and the average of these 5 determinations shall be treated as the field density achieved. In general the control at the top 40 cm thickness of the formation shall be more strict with density measurements being done at the rate of one measurement for 250 sq.m of compacted area. Further for the determination of the mean density the number of tests in one measurement shall not be less than 10 and the work will be accepted if the mean dry density equals or exceeds the specified density.

When density measurements reveal any soft areas in the embankment, it shall be compacted further. If in spite of that the specified compaction is not achieved the material in the soft areas shall be removed and replaced by approved materials and compacted to the satisfaction of the Engineer. Should circumstances arise owing to wet weather the moisture content cannot be reduced to the required amount by above procedure, compaction work shall be suspended.

Soil suitable for consolidation under O.M.C. conditions should preferably have the following characteristics:

(a)	Minimum percentage of clay	10%
(b)	Liquid Limit	14
(c)	Plasticity index	4
(d)	Percentage of silt should not exceed	5%
(e)	Peat, muck and organic soils are unsuitable.	

The Engineer, may, however, relax these requirements taking into account availability of materials, cost of transportation and other relevant factors. Various tests required to be conducted on the borrow material with their recommended frequency are indicated below. All the tests need not be stipulated for every project. Depending upon site conditions etc. only some may be found necessary at a particular project. The frequency of testing indicated refers generally to the minimum number of tests to be conducted. The rate of testing must be stepped up as found necessary depending upon the variability of the materials and compaction methods employed at a project.

(a) Gradation: At least one test for each kind of soil. Usual rate of testing shall be 1 to 2 tests per 8000 cu.m of soil.
(b) Plasticity: At least one test for each kind of soil. Usual rate of testing shall be 1 to 2 tests per 8000 cu.m of soil.
(c) Proctor Tests: At the rate of 1 to 2 per 8000 cu.m of soil.
(d) Deleterious Contents: As required.
(e) Moisture Contents: One test for every 250 cu.m of soil.

8.2.4 Measurement:

The length and width shall be measured correct to a centimetre. The area shall be worked out in square metre, correct to two places of decimal.

8.3 Granular Sub-base

Providing and laying granular sub-base course (GSB) to the required degree of compaction with proper formation of cross fall using motor grader for laying and compacted to required density as per material gradation and aggregate quality specified.

8.3.1 Scope:

This work shall consist of laying and compacting well-graded material on prepared sub grade in accordance with the requirements of these specifications. The material shall be laid in one or more layers as sub-base or lower sub-base and upper sub-base (termed as sub-base hereinafter) as necessary according to lines, grades and cross-sections shown on the drawings or as directed by the engineer.

8.3.2 Materials:

The material to be used for the work shall be natural sand, gravel, crushed stone, or combination thereof depending upon the grading required. The material shall be free from organic or other deleterious constituents and conform to one of the three gradings given in Table 7.2 or Table 7.3.

Table 7.2 Grading for close graded GSB material

IS sieve designation	% by weight passing IS sieve		
	Grading 1	Grading 11	Grading 111
75.0 mm	100	-	-
53.0 mm	80 – 100	100	-
26.5 mm	55 – 90	70 – 100	100
9.50 mm	35 – 65	50 – 80	65 – 95
4.75 mm	25 – 55	40 – 65	50 – 80
2.36 mm	20 – 40	30 – 50	40 – 65
0.425 mm	10 – 25	15 – 25	20 – 35
0.075 mm	3 – 10	3 – 10	3 – 10
Min. CBR Value	30	25	20

Table 7.3 – Grading for coarse graded GSB materials

IS sieve designation	% by weight passing IS sieve		
	Grading 1	Grading 11	Grading 111
75.0 mm	100	-	-
53.0 mm		100	
26.5 mm	55 – 75	50 – 80	100
9.50 mm			
4.75 mm	10 – 30	15 – 35	25 - 45
2.36 mm			
0.425 mm			
0.075 mm	<10	<10	<10
Min. CBR Value	30	25	20

Note: Material passing 425 micron sieve shall for all the three gradings when tested shall have liquid limit and plasticity index not more than 25 and 6 % respectively.

While the gradings in Table 7.2 are in respect of close-graded granular sub-base materials, one each for maximum particle size of 75 mm, 53 mm and 26.5 mm. The corresponding grading for the coarse graded materials for each of the three maximum particle sizes are given at Table 7.3. The grading to be adopted for the project shall be as specified.

Physical Requirements:
The materials shall have a 10 percent fines value of 50 KN or more (for sample in soaked condition) when tested. The water absorption value of the coarse aggregate shall be determined; if this value is greater than 2 percent, soundness test shall be carried out. For grading II and III materials, the CBR shall be determined at the density and moisture content likely to be developed in equilibrium conditions which shall be taken as being the density relating to a uniform air voids content of 5 percent.

8.3.3 Strength of sub-base:

It shall be ensured prior to actual execution that the material to be used in the sub-base satisfies the requirements of CBR and other physical requirements when compacted and finished.
When directed by the Engineer, this shall be verified by performing CBR tests as required on specimens remoulded at field dry density and moisture content and any other tests for the "quality" of the materials, as may be necessary.

8.3.4 Construction operations

Spreading and Compacting: The sub-base material of the specified grading shall be spread on the prepared sub grade with the help of a motor grader of adequate capacity, its blade having hydraulic controls suitable for initial adjustment and for maintaining the required slope and grade during the operation or other means as approved by the engineer.

When the sub-base materials consist of combination of materials mentioned above, mixing shall be mechanically done by the mix-in place method.

Manual mixing shall be permitted only where the width of laying is not adequate for mechanical operations, as in small sized jobs. The equipment used for mix-in-place construction shall be such that it is capable of mixing the material to the desired degree. If so desired by the Engineer trial runs with the equipment shall be carried out to establish its suitability for the work.

Moisture content of the loose material shall be checked and suitably adjusted by sprinkling additional water from a truck mounted or trailer mounted water tank and suitable for applying water for uniformly and at controlled quantities to variable widths of surface or other means approved by the Engineer so that, at the time of compaction, it is from 1 percent above to 2 percent below the optimum moisture content. While adding water, due allowance shall be made for evaporation losses. In the absence of mixing plant the mixing may be done by pay-loader, excavator etc but it should be ensured that a uniform mix is obtained.

Laying & rolling of sub base layer

Mixing of sub base material

8.3.5 Rolling/compaction

The mix should be laid and rolling shall start immediately. If the thickness of the compacted layer does not exceed 100 mm, a smooth wheeled roller of 80 to 100 KN weight may be used. For a compacted single layer up to 225 mm the compaction shall be done with the help of a vibratory roller of a minimum 80 to 100 KN static weight with plain drum or pad foot drum or heavy pneumatic tyred roller of minimum 200 to 300 KN weight having a minimum tyre pressure of 0.7 MN/m2 or equivalent capacity roller capable of achieving the required compaction. Rolling shall commence at the lower edge and proceed towards the upper edge longitudinally for portions having unidirectional cross fall and super-elevation and shall commence at the edges and progress towards the centre for portions having cross fall on both sides. Each pass of the roller shall uniformly overlap not less than one third of the track made in the preceding pass. During rolling, the grade and cross fall (camber) shall be checked and any high spots or depressions, which become apparent, corrected by removing or adding fresh material. The speed of the roller shall not exceed 5 Km per hour. Rolling shall be continued till density is at least 98% of the maximum dry density is achieved. The surface of any layer of material on completion of compaction shall be well closed, free from movement under compaction equipment and from compaction planes, ridges, cracks or loose material. All loose, segregated or otherwise defective areas shall be made good to the full thickness of layer and re-compacted.

8.3.6 Measurements for payment:

GSB shall be measured as finished work in position in cubic metres. The protection of edges of granular sub-base extended over the full formation as shown in the drawing shall be considered incidental to the work of providing granular sub-base and as such no extra payment shall be made for the same.

8.4 Wet Mix Macadam

Providing and laying wet mix macadam (WMM) graded aggregate base course to required degree of compaction with proper formation of cross fall by using well graded crushed aggregates premixed using suitable mixer, motor grader as per material gradation and aggregate quality specified.

8.4.1 Scope:

This work shall consist of laying and compacting clean, crushed, graded aggregate and granular material, premixed with water, to a dense mass on a prepared sub grade/sub-base/base or existing pavement as the case may be in accordance with the requirements of these specifications. The material shall be laid in one or more layers as necessary to lines, grades and cross-sections shown on the approved drawings or as directed by the engineer.

The thickness of a single compacted (WMM) layer shall not be less than 75 mm. When vibrator or other approved types of compacting equipment are used, the compacted depth of a single layer of the sub-base course may be increased to 200mm upon approval of the engineer.

8.4.2 Materials:

Aggregates:

Physical Requirements: Coarse aggregates shall be crushed stone. If Gravel/shingle is used, not less than 90% by weight of the gravel/shingle pieces retained on 4.75mm sieve shall have at least two fractured faces. The aggregate shall conform to the physical requirements set forth in the Table 7.4 below.

Table 7.4: Physical; requirements of coarse aggregate for WMM for the sub-base base course

Test	Requirement
Los Angeles Abrasion Value OR	40% maximum *
Aggregate Impact Value	30% maximum *
Cobined flakiness and elongation indices	30% maximum **

* Aggregates may satisfy the requirement of either of the two tests.

** To determine this combined proportion, flaky stones from a representative sample should first be separated out. Flakiness index is weight of flaky stone divided by weight of stone sample. Only the elongated particles are separated out from the remaining non-flaky stone metal. Elongation index is the weight of elongated particles divided by total non-flaky particles. The value of flakiness index and elongation index so found are added up.

If the water absorption value of the coarse aggregates is greater than 2 percent, soundness test shall be carried out on the material delivered in the site.

Grading Requirements: The aggregates shall conform to the grading given in the Table 7.5 or Table 7.6 given below.

Table 7.5: Grading requirements of aggregates for WMM

IS sieve Designation	% 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 micron	8 – 22
75 micron	0 – 8

Materials finer than 425 micron shall have plasticity index (PI) not exceeding 6.

Table 7.6 Grading requirements of aggregates for WMM

Sieve size (mm)	Nominal maximum particle size (% passing)		
	37.5 mm	28 mm	20 mm
50	100		
37.5	95 - 100	100	
28			100
20	60 - 80	70 - 85	90 - 100
10	40 - 60	50 - 65	60 - 75
4.75	25 - 40	35 - 55	40 - 60
2.36	15 - 30	25 - 40	30 - 45
0.425	7 - 9	12 - 24	13 - 27
0.075	5 - 12	5 - 12	5 - 12

Note : for paver laid materials, lower fines content may be accepted.

The final gradation approved within these limits shall be well graded from coarse o fine and shall not vary from the low limit on one sieve to the high limit on the adjacent sieve and vice-versa.

8.4.3 Construction Operations

Preparation of Base: The base of the sub-grade/sub-base/base shall be prepared to the specified lines and cross fall (camber) and made free of dust and other extraneous material. Any ruts or soft yielding places shall be corrected in an approved manner and rolled until firm surface is obtained if necessary by sprinkling water.

Preparation of lateral confinement of aggregates: While constructing WMM, arrangement shall be made for the lateral confinement of the wet mix. This shall be done by laying materials in the adjoining shoulders along with that of WMM layer.

Preparation of Mix: WMM shall be prepared in an approved mixing plant of suitable capacity having provision for controlled addition of water and forced/positive mixing arrangement like pug mill or pan type mixer of concrete batching plant. For small quantity of wet mix work, the engineer may permit the mixing to be done in concrete mixers.

Optimum moisture for mixing shall be determined after replacing the aggregate fraction retained on 22.4mm sieve with material of 4.75mm to 22.4mm size. While adding water, due allowance should be made for evaporation losses. However, at the time of compaction, water in the wet mix should not vary from the optimum value by more than the specified limits. The mixed material should be uniformly wet and no segregation should be permitted.

Mixing of materials by machine

Laying of base course layer

Compaction of base course

Finished surface of base course

8.4.4 Spreading of mix:

Immediately after mixing, the aggregates shall be spread uniformly and evenly upon the prepared sub-grade/sub-base/base in required quantities. In no case should these be dumped in heaps directly on the area where these are to be laid nor shall their hauling over a partly completed stretch be permitted. The mix may be spread by motor grader. For portions where mechanical means cannot be used, manual means as approved by the engineer shall be used. The motor grader shall be capable of spreading the material uniformly all over the surface. Its blade shall have hydraulic control suitable for initial adjustments and maintaining the same so as to achieve the specified slope and grade.

The surface of the aggregate shall be carefully checked with templates and all high or low spots remedied by removing or adding aggregate as may be required. The layer may be tested by depth blocks during construction. No segregation of larger and fine particles should be allowed. The aggregates as spread should be of uniform gradation with no pockets of fine materials.

8.4.5 Compaction:

After the mix has been laid to the required thickness, grade and cross fall/camber the same shall be uniformly compacted, to the full depth with suitable roller. If the thickness of single compacted layer does not exceed 100 mm, a smooth wheel roller of 80 to 100 KN weight may be used. For a compacted single layer up to 200 mm, the compaction shall be done with the help of vibratory roller of minimum static weight of 80 to 100 KN or equivalent capacity roller. The speed of roller shall not exceed 5km/h. In portions having a unidirectional cross fall/super-elevation, rolling shall commence from the lower edge and progress gradually towards the upper edge. There

after, roller should progress parallel to the centre line of the road, uniformly overlapping each preceding track by at least one-third width until the entire surface had been rolled. Alternate trips of the roller shall be terminated in stops at least 1 m away from any preceding stop.
In portions in camber, rolling should begin at the edge with the roller running forward and backward until the edges have been firmly compacted. Rolling shall then progress gradually towards the centre parallel to the centreline of the road uniformly overlapping each of the preceding track by at least one third width until the entire surface has been rolled.
Any displacement occurring as a result of reversing of the direction of a roller or from any other cause shall be corrected at once as specified and/or removed and made good.
Along forms, kerbs, walls or other places not accessible to the roller, the mixture shall be thoroughly compacted with mechanical tampers or a plate compactor. Skin patching on an area without scarifying the surface to permit proper bonding of the added material shall not be permitted.
Rolling shall not be done when the sub grade is soft yielding or when it causes a wave like motion in the sub-base/base course or sub grade. If irregularities develop during rolling which exceeds 123 mm when tested with a 3 m straight edge, the surface should be loosened and premixed material added or removed as required before rolling again as to achieve a uniform surface conforming to the desired grade and cross fall. In no case should the use of unmixed materials be permitted to make up the depressions.
Rolling shall be continued till the density achieved is at least 98% of the maximum dry density for the material.

Nuclear densometer (Troxler)

After completion, the surface of any finished layer shall be well-closed, free from movement under compaction equipment or any compaction planes, ridges, cracks and loose material. All loose, segregated or otherwise defective areas shall be made good to the full thickness of the layer and re-compacted.

8.4.6 Setting and Drying:

After final compaction of wet mix macadam course, the road shall be allowed to dry for 24 hrs.
Opening to traffic: No vehicular traffic of any kind should be allowed on the finished wet mix macadam surface till it has dried and the wearing course laid.

8.4.7 Measurement for payment

WMM shall be measured as finished work in position in cubic metres.

8.5 Dense Bituminous Macadam (DBM)

Providing and Laying Dense Bituminous Macadam (DBM) to the required degree of compaction based on mixture design approved by the supervising engineer including preparation of surface with road broom, application of prime coat @ 0.75kg/sq.m by mechanized method using asphalt plant, paver, steel roller, tyre roller etc complete.

8.5.1 Scope:

This clause specifies the construction of DBM, for use mainly but not exclusively, in base/binder and profile corrective courses. DBM is also intended for use as a road base material. This work shall consist of construction in a single or multiple layers on a previously prepared base or sub-base. The thickness of a single layer shall be 50mm to 100 mm

8.5.2 Materials

Bitumen: The bitumen shall be paving bitumen of specified Penetration Grade.

Coarse Aggregates: The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. They shall be clean, hard, durable, of cubicle shape, free form dust and soft or friable matter, organic or other deleterious substances. Where crushed gravel is proposed for use as aggregate, not less than 90% by weight of the crushed material retained on 4.75 mm sieve shall have at least two fractured faces.

Table 7.7: Physical requirements for coarse aggregate for DBM.

Property	Test	Specification
Cleanliness (dust)	Grain size analysis	Max. 5% passing 0.075 mm sieve
Particle shape	Flakiness & Elongation index	Max. 30% (combined)
Strength	Los Angeles Abrasion Value	Max. 35%
	Aggregate Impact Value	Max. 27%
Durability	Sodium sulphate	Max. 12%
(soundness)	Magnesium sulphate	Max. 18%
Water absorption	Water absorption	Max. 2%
Stripping	Stripping test	Min. 95% retained
Water sensitivity	Retained tensile strength	Min. 80%

Fine Aggregates: Fine aggregates shall consist of crushed or naturally occurring mineral material or a combination of the two, passing 2.36 mm sieve and retained on 75 micron sieve. They shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter. The plasticity index of the fraction passing 0.425mm sieve shall not exceed 4 when tested. The plasticity index of the fraction passing 0.425 mm sieve shall not exceed 4 when tested.

Filler: Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the engineer. The filler shall be graded within the limits specified below.

Table : 7.8 Grading requirements for mineral filler

IS Sieve(mm)	Cumulative % by weight of total aggregate
0.6	100
0.3	95-100
0.75	85 – 100

The filler shall be free from organic impurities and have a plasticity index not greater than 4. The plasticity requirement shall not apply if the filler is cement or lime. When the coarse aggregate is gravel, 2% by weight of the total aggregate, shall be Portland Cement or hydrated lime and the percentage of the fine aggregate reduced accordingly. Cement or hydrated lime is not required when the limestone aggregate is used. Where the aggregates fail to meet the requirements of the water sensitivity test in Table 7.7 then 2% by total weight of aggregate, of hydrated lime shall be added without additional cost.

8.5.3 Aggregate Grading :

The combined grading of the coarse and fine aggregates and added filler for the particular mixture shall fall within the limits shown in the Table 7.9, for DBM grading 1 or 2 as specified in the contract. The type and quantity of bitumen, and appropriate thickness, are also indicated for each mixture type.

Table 7.9: Composition of DBM pavement layers.

Grading	1	2
Nominal aggregate size	40 mm	25 mm
Layer thickness	80 ~ 100 mm	50 ~ 75 mm
Sieve size mm	Cumulative % passing by weight	
45	100	
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55 – 75	56 – 80
4.75	38 – 54	38 – 54
2.36	28 – 42	28- 42
0.3	7 – 21	7 – 21
0.075	2 - 8	2 – 8
Bitumen content %	Min 4.0	Min 4.5

8.5.4 Mixture Design

Requirement for the mixture: Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table 7.10

Table 7.10: Requirements for dense graded bituminous macadam

Stability at 60 degrees	350 kg or more
Flow value (1/100) cm	20 ~ 40
Percent air void	3 ~ 7
Voids filled with bitumen (VFB)	65 ~ 85
Compaction level	50 blows on each face
Percent air void in mineral agg.	See table 7.11

The requirements for minimum percent voids in mineral aggregate (VMA) are set out in Table 7.11

Table 7.11: Minimum percent voids in mineral aggregate (VMA)

Nominal maximum	Minimum VMA, Percent related to Design Air Voids.		
particle size (mm)	3	4	5
9.5	14	15	16
12.5	13	14	15
19	12	13	14
25	11	12	13
37.5	10	11	12

Notes:

1. The nominal maximum particle size is one size larger than the first sieve retaining more than 10 percent.

2. Interpolate minimum voids in the mineral aggregate (VMA) for design air voids values between those listed.

Binder Content:
The Marshall method for determining the optimum binder content shall be adopted as described in Section 4, replacing the aggregates retained on 26.5 mm sieve by the aggregates passing 26.5 mm sieve and retained on 22.4 mm sieve, where approved by the engineer.

Job mix formula:
The job mix formula should be submitted in writing the engineer in writing, at least 20 days before the start of the work. While establishing the job mix formula, it should be ensured that it is based on a correct and truly representative sample of the materials that will actually be used in the work and that the mixture and its different ingredients satisfy the physical and strength requirements of these specifications.
Approval of the job mix formula shall be based on the independent testing by the engineer for which samples of all ingredients of the mix shall be furnished by the contractor as required by the engineer.
The approved job-mix formula shall remain effective until and unless a revised job mix formula is approved. Should a change in the source of materials be proposed, a new job mix formula shall be forwarded to the engineer for approval before placing of the material.

8.5.5 Plant trials

Once the laboratory job mix formula is approved, the plant trials should be carried out to establish that the plant can be set up and produce a uniform mix conforming to the approved job mix formula. The permissible variations of the individual percentages of the various ingredients in the actual mix from the job mix formula to be used shall be within the limits as specified in the Table 7.12.

Table 7.12: Permissible variations from the job mix formula.

Description	Permissible variation	
	course	course
Aggregate passing 19 mm sieve or larger	± 8%	± 7%
Aggregates passing 13.2 mm, 9.5 mm	± 7%	± 6%
Aggregate passing 4.75 mm	± 6%	± 5%
Aggregate passing 2.36 mm, 1.18 mm, 0.6 mm	± 5%	± 4%
Aggregate passing 0.3 mm, 0.15 mm	± 4%	± 3%
Aggregate passing 0.075 mm	± 2%	± 1.5%
Binder content	± 0.3%	± 0.3%
Mixing temperature	± 10ºc	± 10ºc

Asphalt plant

Laying by paver

8.5.6 Laying Trials:

Once the plant trials have demonstrated the capacity of the plant, laying trials should be demonstrate that the proposed mix can be successfully laid, and compacted as per required specifications. The laying trial shall be carried out on a suitable area which is not to form part of the works, unless specifically approved in writing, by the Engineer. The area of the laying trials shall be a minimum of 100 sq.m. of construction similar to that of the project road, and shall be in all respects, particularly compaction, the same as the project construction, on which the bituminous material is to be laid. The density of the finished paving layer shall be determined by taking cores, no sooner than 24 hours after laying, or by other approved method.

Once the laying trials have been approved, the same plant and methodology shall be applied to the laying of the material on the project, and no variation of either shall be acceptable, unless approved in writing by the Engineer, who may at his discretion require further laying trials.

8.5.7 Construction Operations

The methodology and plant to be used for the whole project should be best arrived after conducting and laying trials for the job mix ratio, which should be based on a correct and truly representative sample of the materials that will actually be used in the work, and that its different ingredients satisfy the physical and strength requirements of these specifications.

8.5.8 Weather and Seasonal Limitations:

Laying shall be suspended while free standing water is present on the surface to be covered, or during rain, fog and dust storms. After rain, the bituminous surface, prime or tack coat shall be blown off with high pressure air jet to remove excess moisture, or the surface left to dry before laying is started. Laying of bituminous mixture shall not be carried out when the air temperature at the surface on which it is laid is below 10ºC, or when the wind speed at any temperature exceeds 40 km/h at 2m height unless specifically approved by the engineer.

8.5.9 Preparation of Base, prime coat and tack coat:

The base on which the dense graded bituminous material is to be laid shall be thoroughly swept clean by a mechanical broom and dusts removed by compressed air. In locations where mechanical broom cannot access, other approved methods shall be used as directed by the engineer. The prime coat and tack coat as per requirements shall be applied in accordance with their respective specifications, or as directed by the engineer.

8.5.10 Mixing and Transportation of the mixture:

The premixed bituminous material for DBM shall be prepared in a hot-mix plant of adequate capacity and capability of yielding a mix of proper and uniform quality with thoroughly coated aggregates at appropriate mixing temperatures; the difference in temperature between the binder and the aggregate at no time should exceed 14ºC. The hot mix plant should be calibrated from time to time in order to ensure the uniform quality of the mix and better coating of aggregates.

The bituminous material should be transported in clean insulated vehicles, and unless otherwise agreed by the engineer, shall be covered while in transit or waiting for tipping. Subject to the approval of the Engineer, a thin coating of diesel or lubricating oil may be applied to the interior of the vehicle to prevent sticking and to facilitate the discharge of the material.

8.5.11 Laying and rolling:

Except in areas where a mechanical paver cannot access, bituminous materials shall be spread, levelled and tamped by an approved self-propelled paving machine. As soon as possible after arrival at site, the materials shall be supplied continuously to the paver and laid without delay. The rate of delivery of material to the paver shall be regulated to enable the paver to operate continuously. The travel rate of the paver, and its method of operations, shall be adjusted to ensure an even and uniform flow of bituminous material across the screed, free from dragging, tearing and segregation of the material. In areas with restricted space where a mechanical paver cannot be used, the material shall be spread, raked and levelled with suitable hand tools by experienced staff, and compacted to the satisfaction of the engineer. The minimum thickness of material laid in each paver pass is to be determined based on compaction coefficient. Bituminous material shall be kept clean and uncontaminated. The only traffic permitted to run on bituminous material to be overlaid shall be that engaged in laying and compacting the next course or, where a binder course is to be sealed or surface dressed, that engaged on such surface treatment. Should any bituminous material become contaminated it shall be made good to the satisfaction of the engineer. Binder course shall not remain uncovered by either the wearing course or surface treatment, whichever is specified in the contract, for more than three consecutive days after being laid. The Engineer may extend the period by minimum amount of time necessary, because of weather conditions or for any other reason.

Bituminous materials shall be laid and compacted in layers which enable the specified thickness, surface level, regularity requirements and compaction to be achieved. Compaction of bituminous materials shall commence as soon as possible after laying. Compaction shall be substantially completed before the temperature falls below the minimum rolling temperature

Table 7.13 Manufacturing and rolling temperature

Bitumen penetration	Bitumen (ºC)	Aggregate (ºC)	Mix (ºC)	Laying (ºC)	Rolling (ºC)
35	160 -170	160 -170	170 max.	130 min.	100 min.
65	150 - 165	150 - 170	165 max.	125 min.	90 min.
90	140 - 160	140 - 165	155 max.	115 min.	80 min.

Rolling of the longitudinal joints shall be done immediately behind the paving operation. After this, rolling shall commence at the edges and progress towards the centre longitudinally except that on super-elevated and uni-directional cambered portions, it shall progress from the lower to the upper edge parallel to the centre line of the pavement. Rolling shall continue until all roller marks have been removed from the surface. All deficiencies in the surface after laying shall be made good by the attendants behind the paver, before initial rolling is commenced. The initial or breakdown rolling shall be done with 8-10 tonnes dead weight smooth wheeled rollers. The intermediate rolling shall be done with 8 – 10 tonnes dead weight or vibratory roller or with a pneumatic tyred roller of 12 to 15 tonnes weight having nine wheels, with a tyre pressure of at least 5.6 kg/sq.cm. The finish rolling shall be done with 6 to 8 tonnes smooth wheeled tandem rollers. Bituminous materials shall be rolled in a longitudinal direction, with the driven rolls nearest the paver. The roller shall first compact material adjacent to joints and then work from the lower to the upper side of the layer, overlapping on successive passes by at least one-third of the width of the rear roll or, in the case of a pneumatic-tyred roller, at least the nominal width of 300 mm. Rollers shall move at a speed of not more than 5km/h. The roller shall not be permitted to stand on pavement which has not been fully compacted, and necessary precautions shall be taken to prevent dropping of oil, grease, petrol or other foreign material on the pavement either when the rollers are operating or standing. The wheels of the rollers shall be kept moist with water, and the spray system provided with the machine shall be in good working order, to prevent the mixture form adhering to the wheels. Only sufficient moisture to prevent adhesion between the wheels of the rollers and the mixture should be used. Surplus water shall not be allowed to stand on the partially compacted pavement.

Where longitudinal joints are made, the materials shall be fully compacted and the joint made flush. All joints shall be offset by at least 300 mm from parallel joints in the layer beneath or as directed, and in a layout approved by the engineer. Joints in the wearing course shall coincide with either the lane edge or the lane marking, whichever is appropriate. The rolling shall be continued till the density achieved is at least 95% of the maximum dry density.

8.5.12 Opening to traffic:

The newly laid surface shall not be open to traffic for at least 24 hrs after laying and completion of compaction, without the express approval of the Engineer in writing.

8.5.13 Measurement for payment:

The finished work shall be measured in cu.m at a specified thickness correct to two places of decimal.

8.6 Asphalt/ Bituminous Concrete

Providing and laying Asphalt/Bituminous Concrete to the required degree of compaction based on the job mixture design approved by the supervising engineer using asphalt plant, paver, steel roller, tyre roller etc. as per material gradation and aggregate quality specified.

8.6.1 Scope:

This clause specifies the construction of Bituminous Concrete, for use in wearing and profile corrective courses. This work shall consist of construction in a single or multiple layers of bituminous concrete on a previously prepared bituminous bound surface. A single layer shall be 25 mm to 100 mm in thickness.

8.6.2 Materials

Bitumen: The bitumen shall be paving bitumen of penetration grade as specified

Coarse aggregates: The coarse aggregates shall be generally as specified for DBM, except that the aggregates shall satisfy the physical requirements specified in Table 7.14

Table- 7.14: Physical Requirements for coarse aggregate

Property	Test	Specification
Cleanliness(dust)	Grain size analysis	Max 5% passing 0.075 mm sieve.
Particle shape	Flakiness and Elongation Index	Max 30%(Combined)
Strength	Los Angeles Abrasion Value	Max 30%
	Aggregate Impact Value	Max 24%
Polishing	Polished Stone Value	Min 55
Durability	Sodium Sulphate	Max 12%
(soundness)	Magnesium Sulphate	Max 18%
Water Absorption	Water Absorption	Max 2%
Stripping	Stripping test	coating
Water Sensitivity	Retained tensile strength	Min. 80%

Fine Aggregates: The fine aggregates requirement shall be same as that for DBM.

Filler: Filler shall be generally as specified for DBM.

8.6.3 Aggregate grading and binder content:

The combined grading of the coarse and fine aggregates and added filler shall fall within the limits shown in Table 7.15 for grading 1 to 2 as specified in the contract.

Table 7.15 Composition of Bituminous Concrete Pavement Layers

Grading	1	2
Nominal aggregate size	19 mm	13 mm
Layer thickness	50 ~ 65 mm	30 ~ 45 mm
Sieve size mm	Cumulative % passing by weight	
45		
37.5		
26.5	100	
19	79-100	100
13.2	59-79	79-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10 - 20	18-28
0.15	13-May	12 - 20
0.075	2 - 8	4 - 10
Bitumen content %	5.0-6.0	5.0-7.0
Bitumen Grade (pen)	65	65

8.6.4 Mixture Design

Requirements for the mixture: Apart from the conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table 7.16.

Binder Content: The binder content shall be optimized to achieve the requirements of the mixture set out in Table 7.16 and the traffic volume as specified in the contract.

Table- 7.16: Requirements for bituminous pavement layers

Stability at 60 degrees	350 kg or more
Flow value (1/100) cm	20 ~ 40
Percent air void	3 ~ 7
Voids filled with bitumen (VFB)	65 ~ 85
Compaction level	50 blows on each face
Percent air void in mineral agg.	See table 7.11

The Marshall method for determining the optimum binder content shall be adopted, replacing the aggregates retained on 26.5 mm sieve and retained on 22.4 mm sieve, where approved by the Engineer.

8.6.5 Job mix formula:

The procedure for formulating the job mix formula shall be generally as specified in DBM and the results of tests enumerated.

8.6.6 Plant trials and laying trials

They shall be same as described for DBM works.

8.6.7 Construction operations

The methodology and plant to be used for the whole project should be based arrived after conducting plant and laying trials for the job mix ratio, which should be based on a correct and truly representative sample of the materials that will actually be used in the work, and that its different ingredients satisfy the physical and strength requirements of these specifications.

8.6.8 Weather and seasonal limitations:

The provisions as in DBM shall apply.

8.6.9 Preparation of base:

The surface on which the bituminous concrete is to be laid shall be prepared as that specified for DBM construction or as directed by the Engineer. The surface shall be thoroughly swept clean by mechanical broom and dusts removed by compressed air. In locations where a mechanical broom cannot access, other approved methods shall be used as directed by the Engineer.

8.6.10 Mixing and transportation of the mixture:

The provisions as specified for DBM construction shall be applied.

8.6.11 Spreading:

The general provisions as specified for DBM work shall apply, as modified based on trial laying.

8.6.12 Measurement for payment:

The measurement shall be as specified for DBM work.

Finished asphalt surface

8.6.13 Quantity of various materials used in Bitumen emulsion work.

Item for 10 sq.m	Aggregate/sand	Emulsion requirement
Premix carpeting		
20 mm thick		
Tack coat		7.50 kg
Premix	10mm = 0.21 cu.m	30.80 kg
Seal coat	Sand = 0.030 cu.m	5.30 kg
25mm thick		
Tack coat		7.50 kg
Premix	10mm = 0.27 cu.m	40.20 kg
Seal coat	Sand = 0.045 cu.m	5.30 kg
50mm thick		
Tack coat		7.50 kg
Premix	10mm = 0.54 cu.m	51.60 kg
Seal coat	Sand = 0.045 cu.m	5.30 kg
Pothole/patch repair		
Tack coat		5.50 kg
Premix	As required	22.0 kg
Surface dressing		
Single coat	10mm agg = 0.02 cu.m	23.0 kg
Double coat		
First coat	12mm = 0.10 cu.m	12.0 kg
second coat	10mm = 0.06 cu.m	16.0 kg
Seal coat	10mm agg = 0.08 cu.m	13.0 kg

For premix seal coat, the aggregates shall be first made wet with water and thereafter shall be mixed with emulsion until the aggregates are well saturated.

8.7 Premix carpet

8.7.1 General:

This type of treatment is normally applied on roads where the motor traffic of medium intensity. This treatment consists of applying a tack coat on the prepared base followed immediately by spreading aggregates pre-coated with specified binder, to camber and consolidated.

8.7.2 Materials:

The specifications given above (painting two coat) shall apply except that for the specified consolidated thickness of premix carpet viz. 20mm or 25mm or 50mm, the quantities of bitumen for tack coat and pre-coating the stone grit as well as the size and the quantity of stone grit shall be as given in the table below, unless otherwise directed by the Engineer.

Sl.No	Consolidated thickness of premix carpet	Tack coat (kg/sq.m)	Bitumen (kg/cu.m)	Aggregate quantity (cu.m/100 sq.m)
1	20 mm	0.75	64	10mm = 2.4
2	25 mm	0.75	64	10mm = 3.0
3	50 mm	0.75	96	10mm = 6.0

8.7.3 Preparation of mix and laying:

The stone grit (aggregate) shall be surface dry and contain not more than 2 percent moisture before use. It shall be first screened of dust and measured in boxes and then loaded into the drum mixer according to the capacity of the mixing drum in the proportion given in the table above. The aggregate shall be heated to facilitate mixing with the binder in cold weather, where so directed by the Engineer.

The binder heated in boilers to the temperature 149-degree C. to 177 degree C. and maintained at that temperature shall be drawn off from the boiler into a suitable container or in bucket gauged to show the weight of bitumen in it. This shall then be poured over the aggregate into the mixer @ 64 kg per cu.m of aggregate or as directed and mixing started and continued till aggregate is uniformly coated with bitumen. The hot mix shall be discharged from the mixer, carried to the road surface and spread to levels immediately after applying the tack coat, to a thickness sufficient to achieve after consolidation the specified thickness. The consolidated thickness shall in no place be less than the specified thickness by more than 25%. Rakes and drag spreaders shall be used for spreading the mixture.

8.7.4 Consolidation of premix:

The specifications shall be as specified under "painting two coats" above except the number of trips of the roller shall not be less than five times. Any high spot or depressions, which become apparent, shall be corrected by addition or removal of premix materials.

Further the prepared finished surface shall be protected from traffic for 24 hours or such period as may be specified by the Engineer.

8.8 Bitumen grade and their use:

Suggested bitumen grades for various paving uses.

Paving uses	Bitumen grade	
	Hot climate	Cold climate
Airfields		
Runways	60 - 70	120 - 150
Taxiways	60 - 70	85 - 100
Parking aprons	60 - 70	85 - 100
Highways		
Heavy traffic	60 - 70	85 - 100
Medium & light traffic	85 - 100	120 - 150
Streets		
Heavy traffic	60 - 70	85 - 100
Medium & light traffic	85 - 100	85 - 100
Driveways		
Industrials	60 - 70	85 - 100
Service stations	60 - 70	85 - 100
Residentials	60 - 70	85 - 100
Parking lots		
Industrial	60 - 70	60 - 70
Commercial	60 - 70	85 - 100
Recreational		
Tennis Courts	85 - 100	85 - 100
Playgrounds	85 - 100	85 - 100
Curbing	60 - 70	85 - 100

9 Terminology

Aggregate
Aggregate retained on 2.36mm sieve is called coarse aggregate and passing 2.36mm is called fine aggregates.

Aggregates, dense graded
Aggregates uniformly graded from the maximum size down to and including filler to make a dense mixture

Asphalt
A dark brown to black cementitious material solid or semi solid in consistency, in which the predominating constituents is bitumen which occur in nature as such or obtained as a residue in refining petroleum.

Base course
That layer of pavement immediately below the surface or wearing course resting on the sub base. It may be composed of granular material like crushed stone, crushed or uncrushed gravel and sand or combination of these materials. It can also be with bituminous mixes.

Binder course
An intermediate course of bituminous mixes between the base and the wearing course.

Bitumen
A non-crystalline solid or viscous material, black or brown in colour having adhesive properties and soluble in carbon disulphate / trichloro ethylene. It is usually the end product in the distillation of crude petroleum

Bitumen emulsion
It is a liquid product in which substantial amount of bitumen is suspended in finely divided condition in an aqueous medium and stabilised by means of one or more suitable reagents.

Bituminous / Asphaltic concrete
A well graded mixture of high quality aggregates with designed bitumen content hot mixed and hot rolled to a uniform dense mass with specific design criteria without any seal coat. It is also termed as asphaltic concrete.

California Bearing Ration (CBR)
It is the measure of shearing resistance of a soil to penetration under carefully controlled density and moisture conditions. The ratio is expressed as percentage of the unit load required to force a standard piston into the soil at a rate of 1.25 mm per minute divided by the unit load required to force the same piston the same depth at the same rate into a standard sample crushed stone.

Coarse aggregate
It is a relative term to denote the larger mineral fragments usually limited to a size greater than 4.75 mm.

Pavement
It is the structure consisting of superimposed layers of selected and processed materials placed on a sub grade to support the applied traffic loads and distribute them to the soil foundation.

Prime coat
It is the single coat application of a binder of low viscosity to an absorbent granular surface preparatory to any superimposed bituminous treatment or construction. If over non bituminous surfaces it also arrests dust and fill capillary voids.

Primer
A low viscous binder made from bitumen usually by mixing it with light diesel oil or kerosene oil and is applied over non bituminous surface. Emulsion can be also a primer.

Resurfacing
Resealing a paved road or re-gravelling an unpaved road to preserve its structural integrity and riding quality. It is a complete renewal of an old wearing surface by a new layer of surfacing.

Sub Base course
The layer of pavement material placed between sub grade and base course. It may be composed of granular material like crushed stone, naturally occurring materials, crushed or uncrushed gravel and sand or combination of these materials.

Sub grade
A natural formation or embankments on which the pavement layers rests. It is prepared to proper shape and well consolidated. Weak and un-compactable sub grade soil should be replaced by better soil which may be termed as soil replacement or capping layer.

Tack coat
A bituminous coat which ensures a bond between an existing surface and the superimposed layer.

Wearing course
The top or surface course of bituminous pavement over which the traffic rides.

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