Paper No. 564

GUIDELINES FOR LONG LASTING BITUMINOUS PAVEMENTS IN INDIA

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ABSTRACT

The MORTH Specifications for Road and Bridge Works (2001) for producing and placing dense-graded bituminous paving mixes have been reviewed in detail and recommendations made. The recommendations based on the current state-of-the-art technologies pertain to: selection of viscosity grade bitumen; amount of natural sand in fine aggregate; Marshall mix design procedures in the latest Asphalt Institute MS-2; mixing and compaction temperatures based on viscosity graded bitumen; minimum mat compaction density based on theoretical maximum specific gravity of loose mix; and quality acceptance criteria. It has been recommended to have only one specification each for all dense graded bituminous mixes used in base course, binder course, and wearing course. Together, all recommendations form guidelines for obtaining long lasting pavements in India.

1 INTRODUCTION AND BACKGROUND

At the present time bituminous paving mixes are generally produced and placed in India as specified in MORTH Publication, "Specifications for Road and Bridge Works", Fourth Revision, 2001[30]. There is a proliferation of bituminous paving mixes in India. Eight mixes (two gradings each of BM, DBM, SDBC and BC) are specified in the MORTH specifications. A case was made on detailed technical grounds in a recent Indian Roads Congress paper[10] by Kandhal, Sinha and Veeraragavan to essentially have only four dense graded mixes of different nominal maximum aggregate size (NMAS) in the specifications, as is the case in most countries of the world. The following four dense graded mixes were proposed along with their recommended rut resistant gradations as given in Table 1:

25 mm NMAS — Dense Bituminous Macadam (DBM) Base Course.

19 mm NMAS — Bituminous Concrete (BC) Binder Course.

12.5mm NMAS — Bituminous Concrete (BC) Wearing Course Grading 1 (for heavy traffic).

9.5 mm NMAS — Bituminous Concrete (BC) Wearing Course Grading 2 (for light to medium traffic, urban areas, and thin application).

It was also recommended to delete the open graded, highly porous Bituminous Macadam (BM) and the Semi Dense Bituminous Concrete (SDBC) mixes from the MORTH Specifications because both of these mixes have serious technical flaws and are not cost effective. A detailed technical and economical comparison of BM with DBM was made in the paper[10] in terms of permeability, structural strength, use as PCC (Profile Corrective Course), cost considerations, traffic conditions, and general statements. It was concluded with technical justifications that dense graded DBM should be used in lieu of highly porous, open graded, undrained BM especially to obtain long lasting pavements. However, despite many fundamental, technical flaws associated with BM as mentioned in the Paper, some engineers still advocate to retain it in the specifications. This is probably due to the following misconceptions:

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Table 1 Proposed Four Dense Graded Mixes for India

Grading →	Proposed DBM Base Course	Proposed BC Binder Course	Proposed BC Wearing Course Grading 1	Proposed BC Wearing Course Grading 2
Nominal → Aggregate Size	25 mm	19 mm	12.5 mm	9.5 mm
Lift Thickness →	75-100 mm	50-75 mm	30-50 mm	25-40 mm
Sieve Size, mm ↓	Percent Passing			
37.5	100	-	-	-
26.5	90-100	100	-	-
19	71-95	90-100	100	-
13.2	56-80	66-86	90-100	100
9.5	-	55-75	70-88	90-100
4.75	38-54	35-55	53-71	55-75
2.36	28-42	28-44	38-54	40-55
1.18	-	20-34	24-38	29-44
0.6	-	15-27	17-29	21-33
0.3	7-21	10-20	12-22	14-25
0.15	-	5-13	7-15	7-15
0.075	4-7	4-7	4-7	4-7
Bitumen Content	4.0-5.5	4.0-5.5	5.0-7.0	5.2-7.5

Note : Wearing course grading 1 is recommended for heavy traffic roads (more than 1500 commercial vehicles per day). Wearing course grading 2 is recommended for light to medium traffic roads, in urban areas, and for thin (25 mm) applications.

a) Dense graded DBM is not flexible enough to be placed directly on WMM and therefore a "flexible" BM course is necessary between the WMM and DBM. If the DBM was not flexible it would not rut at all. But that is not the case. If there is uneven settlement /consolidation of WMM, the DBM is flexible enough to deform and adjust similar to BM if that is what is desired. It is a common practice in most countries of the world to place DBM type bituminous base course directly on crushed stone base course (we call it WMM). That practice has resulted in durable long lasting pavements without any problems.

b) BM is cheaper than DBM and that is why it is good for a developing country like India. A detailed, comparative cost analysis given in the Paper shows that the DBM is cheaper than the BM by 15 to 21 per cent if the relative structural strengths are considered. Only when the BM is used as PCC to correct camber/super elevation it is cheaper than the DBM. But the problem still remains that the undrained BM PCC would trap moisture/water creating a "bath tub" within the pavement and thus will be potentially detrimental to the pavement.

Some engineers have suggested retaining the BM but providing outlet for the water trapped in the open graded BM. To do this, the BM has to be extended all the way to the edge of the embankment (that is, day lighted) or pavement edge drains have to be constructed to drain the BM. Both of these solutions are very expensive propositions.

If BM is used as PCC for correcting camber, it may not be possible to drain the BM wedge (triangle) especially if it is towards a raised median. Moreover, rainwater falling in the raised median may also enter sideways into the porous BM wedge and cause stripping and potholes. Such a case has been observed on a national highway in India.

As mentioned in that Paper, it is time to move on from open graded "cheaper" mixes to dense graded, durable mixes if the objective is to have long lasting pavements both for low-volume and high-volume roads.

If the dense graded 9.5 mm NMAS wearing course as recommended in Table 1 is adopted, there is no need for the "semi-dense" SDBC, which is technically flawed due to pessimum voids as explained in the IRC Paper. The recommended dense graded mix (which can also be used in thin 25 mm applications) will be more durable and cost effective than the SDBC, because the former is only about 5 per cent costlier than the latter.

Some discussion of how the recommended base course, binder course, and wearing course mixes (Table 1) should be used in new pavements as well as in overlays follows.

Base course mixes, which use relatively larger size aggregate, are not only stiff/stable but also are economical because they use relatively lower bitumen contents. Surface or wearing course mixes with smaller aggregate on the other hand have relatively higher bitumen contents, which not only impart high flexibility but also increase their durability. The binder (intermediate) course mix serves as a transition between the base course and wearing course. Several studies[3,30,34] have shown that permanent deformation (rutting) within flexible pavement is usually confined to the top 100 to 150 mm of the pavement. This means both the binder and wearing course mixes should be designed to be resistant to rutting. That is why in extreme cases of heavy traffic loads and high tyre pressures, it is considered prudent to use Stone Matrix Asphalt (SMA) mix in which due to stone-on-stone contact the load is carried directly by the coarse aggregate skeleton.

It is not necessary to use all three bituminous courses (base, binder, and wearing) in a new flexible pavement unless the traffic is very high. For example, the following combinations can be used depending upon the total thickness of the bituminous course(s) required as per structural design based on IRC:37:

a) WMM + DBM Base Course + BC Binder course + BC Wearing Course.

b) WMM + BC Binder Course + BC Wearing Course.

c) WMM + BC Wearing Course only.

For low-volume roads only a granular base and a bituminous wearing course may suffice based on structural requirements. Some examples are given below for suggested bituminous courses for total required bituminous layer thickness considering the recommended lift thicknesses for the four mixes (given in Table 1):

Required Total Bituminous Layer Thickness	**Use**
Less than 50 mm	BC Wearing Course only (Grading 1 or 2)
75 mm - 125 mm	BC Binder Course + BC Wearing course
150 mm or more	DBM Base Course + BC Binder Course + BC Wearing Course

If the total design bituminous layer thickness falls between 50 mm and 75 mm, or between 125 mm and 150 mm, use the higher thickness.

It has been surmised by some that a BC wearing course is too stiff and will crack if placed directly over WMM. This is not correct because the BC wearing course has relatively lower stiffness due to its lower NMAS (12.5 or 9.5 mm) and high bitumen content. This combination is being used in other countries including Australia and South Africa. Similarly, a bituminous overlay required for strengthening flexible pavement can consist of the following depending upon the required thickness as per IRC:81:

a) BC Binder Course + BC Wearing Course.

b) BC Wearing Course only.

Unlike most developed countries, overloading is a major concern in India. On very heavily trafficked road with severe overloading problem, it is recommended to modify the BC wearing course and BC binder course (that is, the top 100 mm of the pavement only, which is likely to rut) as follows:

a) Ensure to use viscosity graded VG-30 grade bitumen as per latest IS 73:2006[4], which is significantly more rut resistant than the old 60/70 penetration bitumen.

b) Use Polymer Modified Bitumen (PMB).

c) Use Stone Matrix Asphalt (SMA) as per IRC Specifications approved recently.

Critical review of the bituminous paving mixes and their specifications is warranted considering less than expected durability of bituminous mixes in India especially after monsoon rains. This Paper can be considered as a continuation of the IRC Paper referred above, which reviewed the proliferation of bituminous mixes in India and recommended desirable mixes along with their gradations. This Paper reviews the specifications for producing and placing the selected four dense graded bituminous mixes to obtain long lasting bituminous pavements. Both reviews are expected to be helpful to the contractors who are currently designing their own projects (including bituminous mix selection) under the Public-Private-Partnership (PPP) programme.

Revisions to the current MORTH Specifications have been suggested as follows in terms of materials; design of mix; construction operations; and quality control and acceptance. Only the suggested changes to the MORTH Specifications have been given in this paper. It has been recommended to have only one Specification for all dense graded bituminous mixes used in base course, binder course, and wearing course.

2 MATERIALS

2.1 Bitumen

Indian Standard Specification for Paving Bitumen IS 73:2006[3] must now be used for all bituminous mixes. This revised standard issued in July 2006 specifies Viscosity Graded Bitumen only such as VG-30 and VG-10. It replaced Penetration Graded Bitumen, such as, 60/70 and 80/100. The new Viscosity Graded (VG) bitumens, which will provide consistent resistance to rutting at high pavement temperatures must be specified in MORTH Specification by issuing a corrigendum, and implemented as soon as possible so that the use of substandard Penetration Graded Bitumen is discontinued.

Tables 2, 3, and 4 give the standard Viscosity Grades (VG), their general applications, and selection criteria. The viscosity grades are readily available now in India with no extra cost. The contractors especially those with PPP or BOT projects must use VG grades only to ensure adequate rut resistance and durability of their projects.

Since all types of modified bitumen (Table 4) are not considered equal in performance, the type of modifier should be specified for each contract. Polymer modified bitumen is suitable for highly-trafficked roads. Testing of modified bitumen at the point of delivery should be specified in the contract since phase separation during transport is quite common. Polymer can also be added at the hot mix plant site to avoid phase separation and/or degradation. However, it is necessary to have appropriate blending equipment and a testing laboratory to conduct all tests required in the specification.

Table 2 Viscosity Graded (VG) Bitumens and their General Applications

Viscosity Grade (VG)	General Applications
VG-40 (40-60 penetration)	Use in highly stressed areas such as those in intersections, near toll booths, and truck parking lots in lieu of old 30/40 penetration grade
VG-30 (50-70 penetration)	Use for paving in most of India in lieu of old 60/70 penetration grade
VG-20 (60-80 penetration)	Use for paving in cold climatic, high altitude regions of North India
VG-10 (80-100 penetration)	Use in spraying applications and for paving in very cold climate in lieu of old 80/100 penetration grade

Table 3 Selection Criteria for Viscosity-Graded (VG) Paving Bitumens Based on Climatic Conditions

Lowest Daily Mean Air Temperature, º C	Highest Daily Mean Air Temperature, ºC: Less than 20º C	20 to 30º C	More than 30º C
More than -10º C	VG-10	VG-20	VG-30
-10ºC or lower	VG-10	VG-10	VG-20

Table 4 Selection Criteria for Grade of Modified Bitumen

	Highest Daily Mean Air Temperature, º C: Less than 20º C	20 to 30º C	More than 30º C
Lowest Daily Mean Air Temperature, º C	Grade of Modified Bitumen	Grade of Modified Bitumen	Grade of Modified Bitumen
More than -10º C	PMB/NRMB 120 CRMB 50	PMB/NRMB 70 CRMB 55	PMB/NRMB 40 CRMB 60
-10º C or lower	PMB/NRMB 120 CRMB 50	PMB/NRMB 120 CRMB 50	PMB/NRMB 70 CRMB 55

PMB = Polymer Modified Bitumen, NRMB = Natural Rubber Modified Bitumen and CRMB = Crumb Rubber Modified Bitumen

2.2 Coarse Aggregate

The stripping test IS 6241 has been specified for coarse aggregate in the present MORTH Specifications. This test, which is conducted on coarse aggregate only, is antiquated and proven to be inadequate based on research conducted in the past. Most mixtures pass this easy static-immersion test and, therefore antistripping agents are not used when actually needed resulting in stripping problems. In many cases, the fine aggregate is hydrophilic and causes stripping, which can be worse than that from the coarse aggregate. Many of the stripping problems (especially potholes after monsoons) in India are potentially due to reliance on this antiquated test. There is a need to use the Water Sensitivity or Moisture Susceptibility Test AASHTO T 283, which is conducted on the whole bituminous mix. This test, which is most commonly called Moisture Susceptibility Test, is also used in the Superpave mix design. This test is already in the MORTH Specifications Section 800 as a "water sensitivity" test and therefore it is recommended to make it mandatory to be conducted on all bituminous mixes at the time of mix design and once a week during mix production. IS 6241 can be retained only as a screening test for the coarse aggregate.

The recommended revised physical properties of coarse aggregate are given in Table 5.

Table 5 Physical Properties of Coarse Aggregate

Property	Test	Requirement	Test method
Cleanliness	Grain size analysis	Max. 5% passing 0.075 mm	IS 2386 Part I
Particle Shape	Flakiness and Elongation Index (combined) Heavy traffic (more than 1500 commercial vehicles/day) Light traffic (less than 1500 commercial vehicles/day)	 Max. 35% Max. 40%	IS 2386 Part I
Strength *	Los Angeles Abrasion Value	Binder and wearing course: Max. 30%	IS 2386 Part IV
		Base course: 35%	
	Aggregate Impact Value	Binder and wearing course: Max. 24%	IS 2386 Part IV
		Base course: 27%	
Polishing **	Polished Stone Value	Min. 55	IS 2386 Part IV
Durability	Soundness (either Sodium or Magnesium Sulphate) - 5 cycles		
	Sodium Sulphate	Max. 12%	IS 2386 Part V
	Magnesium Sulphate	Max. 18%	IS 2386 Part V
Water Absorption	Water Absorption	Max. 2%	IS 2386 Part III
Stripping ***	Coating and Stripping of Bitumen Aggregate Mixtures	Min. Retained Coating 95%	IS:6241

Notes:

* The aggregate may satisfy either of the two tests.

** Only for wearing courses

*** This test shall be conducted as a screening test for coarse aggregate only. It is mandatory to conduct AASHTO T 283 (Annex A), which is conducted on the whole bituminous mix as specified in Table 6.

Consideration should be given to increase the maximum Los Angles abrasion values by 5 per cent because the presently specified values are too stringent and may necessitate transport of aggregates over long distances at high costs. The State of Georgia in the US has the best roads in the US. It has granite as the predominant aggregate type with high LA abrasion values. Georgia specifies[6] maximum LA abrasion of 50 per cent for granite aggregate. Whereas, very high LA values beyond a threshold value are not desirable, very low values do not necessarily mean it is a better aggregate[16].

Consideration should also be given to delete the Aggregate Impact Value (AIV) test because the LA Abrasion test subjects the aggregate to both impact and abrasion (from steel balls and aggregate to aggregate contact, when the drum is rotated). Unlike AIV, LA Abrasion simulates the processing of aggregate in a drier drum. Most countries in the world including the US specify LA Abrasion test only.

Not all tests specified in Table 5 need to be conducted very frequently. Tests such as Polished Stone Value and Soundness need to be conducted at the time of source (quarry) approval and less frequently thereafter.

Kandhal *et al*[16,17,23] and others[7] have conducted research and reported on several new test methods for testing and characterizing coarse aggregates for bituminous mixes. The new test methods pertain to particle shape, angularity and surface texture (such as uncompacted void content) and soundness & durability (such as Micro-Deval test). The new improved test methods have been adopted by AASHTO and need to be considered by the Bureau of Indian Standards (BIS), IRC, and MORTH to enhance the quality of bituminous mixes in India.

2.3 Fine Aggregate

Fine aggregate is defined as material passing either 4.75 mm or 2.36 mm sieve. Right now, the MORTH Specification is not clear in terms of crushed sand versus natural sand used as a fine aggregate. One can use 100 per cent natural sand (which tends to contain rounded particles) in all bituminous courses, which increases the potential for rutting problems. Many agencies in the world limit the amount of natural sand to 50 per cent in the DBM type base courses and 10 per cent in the BC binder and wearing courses (layers within 100 mm of the road surface) to minimize rutting problem. This requirement should also be included in the MORTH specifications.

Kandhal *et al*[15,16,17,21,25] and others[8] have also researched and reported on new improved test methods for testing and characterizing fine aggregates for bituminous mixes. The new test methods pertain to particle shape (such as fine aggregate angularity or FAA test) and plastic fines (such as Methylene Blue test). These new test methods have been adopted by AASHTO and need to be considered by BIS, IRC and MORTH.

2.4 Filler

Many highway engineers in India like to specify adding mineral filler to the bituminous mix even if there is no deficiency of fines in the aggregates used. This is not justified. All asphalt plants in India are required to have baghouses to collect the fines from the dryer. These "baghouse fines" should be incorporated back into the mix in a controlled manner through a screw conveyer. Many studies[9,16] in the US have shown that the baghouse fines (which are same as stone dust or mineral dust resulting from the aggregate crushing operation) are good mineral fillers. Portland cement does not have any advantage over stone dust and therefore its use is not cost effective. However, if the designed mix fails the Moisture Susceptibility test (AASHTO T 283) then addition of 1-2 per cent hydrated lime is desirable. Hydrated lime is not only a good antistripping agent, it can also retard the oxidation or aging of the bitumen during service.

In regions of India where hydrophilic aggregates such as quartzite and granite are used in mixes, it should be made mandatory to add hydrated lime in every ton of hot mix produced in the whole region. For example, in and around Jaipur only quartzite aggregate is used in bituminous mixes and, therefore, this requirement if implemented will be very helpful.

Unfortunately, there is no Indian standard for hydrated lime to be used in bituminous mix (there is for building lime). Therefore, a reference needs to be made to AASHTO M 303, "Lime for Asphalt Mixtures", which specifies active lime content ($CaOH_2$ + CaO) above 90 per cent.

Kandhal *et al*[14,16] have reported on new test methods (such as Rigden voids) for testing and characterizing mineral fillers, stone dust, and baghouse fines. BIS, IRC and MORTH should consider these test methods.

2.5 Aggregate Gradation

Aggregate gradations for DBM base course, BC binder course, and two BC wearing courses were discussed earlier. The final recommended gradations for use in India are given in Table 1. Justification for adopting these mixes and their respective revised gradations is given in detail in the IRC Paper[10] mentioned earlier.

3 DESIGN OF MIX

At the present time, all bituminous mixes are designed with Marshall Method using 75 blows regardless of traffic. MORTH Specifications should be able to be used on all types of roads: NH, SH, MDR, and ODR. So 50-blow Marshall Design must be used for low to medium traffic roads such as ODR. It is neither technically correct nor desirable to design all roads with 75 blows as stipulated in the present MORTH Specifications because it will give undesirably low bitumen contents for low to medium traffic roads, which will reduce the durability of such roads. Low road durability is a severe problem in India. Only high-volume roads (carrying more than 1500 commercial vehicles per day) should use 75-blow Marshall Design like it is done in most countries of the world[33]. Even in the Superpave mix design there are 4 levels of lab compaction depending on traffic. In Superpave, there is a compaction level in terms of gyrations, which is equivalent to 50-blow Marshall and is used on most roads with light to medium traffic. Continuing to use 75 blows for all roads in India will reduce the design bitumen content of roads with light to medium traffic by as much as 0.5 per cent resulting in lower service life.

Quite often, it is argued that the traffic will increase on existing low to medium trafficked roads in a few years. However, by that time the bitumen would get oxidized and therefore get stiffened to counteract the effect of slightly higher bitumen content.

MORTH mix design requirements for all dense graded mixes need to be revised as shown in Table 6. The minimum stability, range of flow, and VFB values for both 50 and 75 blow Marshall designs have been taken from the latest sixth edition[2] of the Asphalt Institute MS-2, which is widely used successfully worldwide and has been referred to in MORTH Specifications at several places. These values have been used in very hot climate areas such as in Arizona in the US and other hot, tropical countries successfully.

It should also be ensured that the ratio by weight of fines (material passing 0.075 mm sieve) and effective bitumen content (fines/bitumen ratio) in the bituminous mix is between 0.6 to 1.2 as included in Table 6. This way there are some minimum fines to stiffen the bitumen and not too much fines which will make the mortar too brittle (dull) and less cohesive and will also reduce the VMA more than desired.

Some values in Table 6 are based on some research done in India. It had also included criteria for heavy rainfall areas. There is no sound technical reason whatsoever for having a different Marshall stability and flow criteria for heavy rainfall areas. It is the pavement temperature and not the amount of rainfall, which affects these properties. Therefore, rainfall has not been considered in Table 6. High rainfall can potentially increase the moisture damage in the mix. For that AASHTO T 283 is enough with 80 per cent minimum retained tensile strength requirement. It has worked very well in hot and heavy rainfall area of the US (rainfall significantly more than India). Since there is AASHTO T 283, which has been specified now and it requires 60°C water-bath conditioning, there is no need to have Retained Marshall stability after 24 hours in water at 60ºC, which is less severe than AASHTO T 283.

Extensive research has shown that the air void range of 3 to 5 per cent applies to all courses, which is also reflected in the latest Asphalt Institute MS-22. In fact some states in the US specify even lower air voids 2 to 4 per cent for the base courses, which do not get further compaction from traffic. This is unlike past practice when higher air voids were specified for base courses compared to binder and wearing courses.

Table 6 Requirement of the Dense Graded Bituminous Mix when using Unmodified Bitumen

Specification	**Requirements**
Compaction level (Number of blows)	75 blows on each face of the specimen for heavy traffic and 50 blows on each face for light to medium traffic
Minimum stability (kN at 60ºC) AASHTO T 245	9.0 for heavy traffic roads* (75-blow Marshall specimen) 5.3 for light to medium traffic roads (50-blow Marshall specimen)
Minimum flow (mm) AASHTO T 245	2
Maximum flow (mm) AASHTO T 245	4
Ratio of fines to effective bitumen content	0.6 - 1.2
% Air Voids (MS-2 and ASTM D 2041)	3 - 5
% Voids filled with bitumen (VFB) Asphalt Institute MS-2	65 - 75 for heavy traffic* (75-blow Marshall specimen) 65-78 for light to medium traffic (50-blow Marshall specimen)
Marshall Quotient. kN /mm (stability/flow)	2 to 5
Tensile Strength Ratio (minimum), %, AASHTO T283 (with freeze & thaw option) (see Annex A for the outline of this test method)	80

% Voids in Mineral aggregate VMA					
Nominal Maximum Particle size (mm) **	Min % VMA related to designed % air voids***				
	3	4	5		
9.5	14	15	16		
13.2	13	14	15		
19.0	12	13	14		
26.5	11	12	13		
37.5	10	11	12		

* Heavy traffic roads are those roads carrying more than 1500 commercial vehicles per day (CVD).

** The nominal maximum particle size is one size larger than the first sieve, which retains more than 10% material.

*** For intermediate value of designed percentage air voids interpolate the VMA.

Although the latest MS-2 (sixth edition at the present time) should be used for Marshall Design, many contractors do not follow it completely. For example, the maximum specific gravity of the bituminous mix (Gmm) should not be calculated by a formula from the specific gravity values of individual aggregates and bitumen. Rather, it should be measured directly[39] by using ASTM D 2041, which determines the weight and volume of loose, voidless mix to calculate the maximum specific gravity of the mix. Volume of the voidless mix is determined after submerging it in water and removing all air bubbles by applying vacuum. An outline of ASTM D 2041 is given in Annex B. Also, the bulk specific gravity of the coarse aggregate and the fine aggregate should be measured by using ASTM C 127 and ASTM C 128, respectively, rather than the Indian Standards IS 2386 (Part III), which are outdated and suitable for concrete mixtures only and not for bituminous mixes. The procedures for obtaining the saturated surface dry (SSD) condition of coarse and fine aggregates in the Indian Standards are not correct for bituminous mixes. Both ASTM tests give specific instructions to obtain SSD condition of the aggregate. For example, in case of fine aggregate (ASTM C 128) sand cone method should be used to obtain SSD condition. Unless these three test methods: ASTM D 2041, C 127 and C 128 are used, the calculated values of air voids and VMA can be highly erroneous because the actual amount of bitumen absorbed by the aggregate will not be obtained and considered These three ASTM standards should be incorporated in the MORTH Specifications.

In accordance with the latest (sixth edition) of the Asphalt Institute Manual MS-2 as well as Superpave mix design method, the design bitumen content should be selected to correspond with 4.0 per cent air voids for all types of mixtures. The selected binder content must satisfy all other Marshall and void properties. The current practice of determining the optimum bitumen content by averaging the bitumen contents corresponding to highest stability, highest density, 4 per cent air voids, etc, should be discontinued. This is because (a) some of the curves are not well defined in terms of their peak and (b) air void content is the most important parameter for selecting the design bitumen content as it affects both rut and fatigue resistance of the bituminous mixes.

Minimum tensile strength ratio using AASHTO T 283 has been specified in Table 6 to test the designed mix for moisture susceptibility. The AASHTO T 283 test method involves: preparation of two subsets of Marshall specimens with 6 to 8 per cent air voids; testing one subset in dry condition for indirect tensile strength (Marshall testing machine can be used for this in conjunction with 12.5 mm wide steel strip at top and bottom); conditioning the other subset by vacuum saturating with water, one freeze & one thaw cycle (in 60ºC water bath) to cause potential stripping and then testing for indirect tensile strength; and calculating the retained tensile strength from test data on dry and conditioned subsets. AASHTO T 283 has worked very well in hot and heavy rainfall areas of the US (rainfall significantly more than India). It is also used in the Superpave mix design. AASHTO T 283 should replace the presently specified ASTM D 1075, which determines retained Marshall stability. An outline of AASHTO T 283 is given in Annex A.

Where maximum nominal size of the aggregate is more than 25 mm, modified Marshall method developed by Kandhal[19,26] using 150 mm (6-inch) diameter specimen as described in the Asphalt Institute Manual MS-2 (Sixth Edition) and ASTM D 5581 should be used. This test method requires modified equipment (which is commercially available) and modified procedure. When the modified Marshall test is used, the specified minimum stability values and the specified flow values given in Table 6 should be multiplied by 2.25 and 1.5, respectively.

Kandhal *et al*[20,22] and others observed that the bituminous pavements in the US were achieving densities under heavy truck traffic with high tyre pressures significantly higher than those obtained in the laboratory using 75-blow Marshall compactor. In other words, the pavement density after 2-3 years' traffic was greater than 75-blow Marshall laboratory design density. Increasing the number of blows above 75 did not help because it simply caused aggregate breakdown (degradation) under the impact type Marshall hammer compaction. That is why; Superpave Gyratory Compactor (SGC) was developed and made part of the Superpave mix design method.

When a bituminous mix needs to be designed in India for very heavy truck traffic, the following option should be considered in a decreasing order of preference for mix design/adjustments:

a) Superpave mix design. This mix design method is fully developed in the US and manuals similar to MS-2 are available for Superpave. Superpave mix design method can be adopted in India or at least allowed for major projects with minor adjustments. It uses a gyratory compactor, which can provide the needed compaction effort based on design traffic without significant aggregate degradation. Optimum bitumen content is selected at 4.0 per cent air void content.

b) Use a Rotating Base, Slanted Foot Marshall Hammer. This automated, mechanical Marshall compactor has been used in the US effectively[20,22] to achieve high laboratory density using 75 blows. Its foot has a 1-degree bevel or slant. Every time the hammer is lifted, the base supporting the Marshall mould rotates automatically so that the slanted foot falls at different places in the mould causing a kneading action. This standard mechanical Marshall compactor is available commercially from at least three equipment suppliers in the US and if needed, can be fabricated in India. Again, design bitumen content is selected at 4.0 per cent air void content.

c) Use a Marshall Hammer with Hugo Foot. Prof. Hugo of South Africa developed the Hugo foot. This foot also causes some kneading action during compaction because it has indents on its face and is also rotated. It is not known whether it is available commercially.

d) Adjustment to Bitumen Content. Conduct the conventional Marshall Mix design with 75 blows and determine the bitumen content at 4.0 per cent air void content. Reduce this bitumen content by 0.2 to 0.3 per cent and adopt the reduced bitumen content in the job mix formula. This adjustment is based on the fact that the design bitumen content obtained by the Superpave volumetric mix design is generally less than that obtained by conventional Marshall design by 0.2 to 0.3 per cent.

The preceding changes in the mix design procedures should at least be permitted to be used by PPP or BOT contractors to ensure rut resistant bituminous pavements subjected to very heavy truck traffic.

The concept of refusal density has been suggested by some researchers[32]. However, the increased number of blows (such as 300 or 400) on each side of the specimen used in this test can cause significant breakdown of the aggregate in the mix while the mix is also cooling fast. The degraded mix in the laboratory has no resemblance to the actual mix used on the road, which hardly degrades under rollers and traffic. As mentioned in MORTH Manual for Construction and Supervision of Bituminous Works[31], any conclusions drawn from a severely degraded mix in this test may become invalid. Moreover, the extent of degradation varies from aggregate to aggregate depending on their toughness, which is another variable.

Since the Marshall stability cannot be completely relied upon to ensure a rut resistant bituminous mix, it is recommended to consider a loaded wheel tester such as Asphalt Pavement Analyzer and Hamburg Wheel Tester to "proof test" the final Marshall mix design as is done by Georgia DOT. This is especially necessary for very heavy traffic and/or important highway projects. The technology of loaded wheel testers and related acceptance criteria are fully developed and documented by Kandhal *et al*[4,5,11,12,13] and others. It will be in the interest of PPP or BOT contractors to "proof test" their Marshall designed mixes.

4 CONSTRUCTION OPERATIONS

4.1 Mixing and Laydown

The existing MORTH table for mixing, laying and rolling temperatures for all dense mixes need to be revised, since viscosity grade bitumens have now replaced penetration grade bitumen. Table 7 should be used now. For mixtures containing modified bitumen binders, the supplier's recommendations should be followed. Normally, the mixing, laying and rolling temperatures for modified binders are increased by as much as 15ºC compared to unmodified binders. The control of volumetric properties of bituminous mixes[18] during production at the plant needs to be made more specific in the specifications.

Table 7 Mixing, Laying and Rolling Temparatures for Dense Mixtures (Degrees Celcius)

Bitumen Viscosity Grade	Bitumen Temperature	Aggregate Temperature	Mixed Material Temperature	Laying Temperature	*Rolling Temperature
VG-40	160-170	160-175	160-170	150 Min	100 Min
VG-30	150-165	150-170	150-165	140 Min	90 Min
VG-20	145-165	145-170	145-165	135 Min	85 Min
VG-10	140-160	140-165	140-160	130 Min	80 Min

* Finish rolling must be completed before the mat cools to these minimum temperatures.

4.2 Compaction

The intial or breakdown rolling should be done with a vibratory roller (8 to 10 tonnes dead weight), unless the mix is tender requiring initial two passes in a static mode (vibration turned off). The intermediate rolling should be done with a pneumatic tyred roller of 12 to 15 tonnes weight having nine wheels with a tyre pressure of at least 5.6 kg/cm^2. The finish rolling should be done with 6 to 8 tonnes smooth wheeled tandem rollers. It is a common practice in the US to use the vibratory roller in vibratory mode for initial or breakdown rolling. This way, the best packing of aggregates and high density is achieved with the vibrations while the mix is still very hot. If a static mode is used first for initial or breakdown rolling, it orients the aggregate particles in a certain manner but that orientation is disturbed again due to vibrations applied later. The vibratory roller should be used in static mode (vibrations turned off) for the first 2 passes only if the mix is tender and unstable to sustain vibratory compaction.

The density of finished paving layer should not be less than the 92 per cent and not more than 97 per cent of the average theoretical maximum specific gravity of the loose mix (Gmm) obtained on the day of paving following ASTM D 2041 (see outline in Annex B). Research by Kandhal and Koehler[27,28] and others has indicated that premature distress of pavement can take place if the air void content in the constructed mat exceeds 8 per cent (Fig. 1).

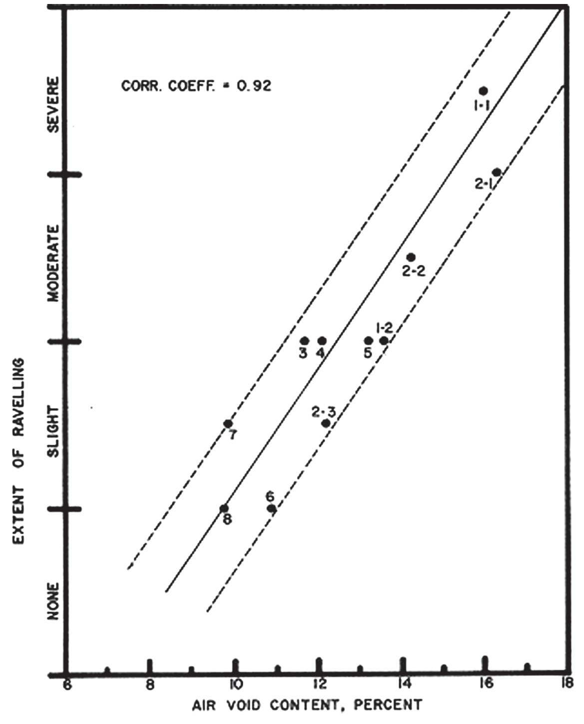

Fig. 1

Most states in the US and many countries have changed the compaction criteria from percentage of the lab density of the compacted specimen to percentage of theoretical maximum specific gravity (Gmm) of the loose bituminous mixture. The former criterion has caused all kinds of problems including a large day-to-day variation. The later criterion gives air voids in the paved mat directly. No less than 92 per cent of Gmm means no more than 8 per cent air voids in the compacted mat. No more than 97 per cent means no less than 3 per cent air voids in the compacted mat, which may induce bleeding and/or rutting. More and more agencies are moving towards Gmm, which is tested any way during the mix design and daily Marshall Test. So no new test is being introduced. Restricting per cent air voids in the mat also allows easy forensic analysis of compacted pavement later in its life without looking for old records on lab compacted density in files. Durability of bituminous pavement is directly related to air voids in the mat on the day of construction, and only vaguely and indirectly related to lab density obtained by a technician on the day of construction. This point has been debated extensively in the US for many years. Some states in the US are requiring 93 per cent minimum of the theoretical maximum specific gravity (that is no more than 7 per cent air voids in the mat when constructed), this is also recommended for India to increase the durability of bituminous roads.

There is no technical reason whatsoever not to allow coring for density measurements during the first 24 hours as stipulated in the MORTH Specifications. In fact many agencies in the US prefer taking cores on the day of paving before the mat is opened to traffic. 150 mm diameter cores should be taken after the entire thickness of the mat has cooled below 60ºC, which may take a few hours depending on the lift thickness and prevailing weather. No problems of core distortion whatsoever have been encountered. A large core diameter of 150 mm is preferred to obtain a good representative sample for density. However, cores with less than 100 mm should not be permitted. ASTM D 2726 should be used to measure the density of the extracted core.

4.3 Opening to Traffic

The current MORTH Specifications does not allow traffic for 24 hours after compaction. There is no technical reason not to allow traffic for 24 hours. It defeats the purpose of using hot bituminous mix, which lends itself to fast opening to traffic. Such unreasonable requirement of 24 hours does not exist anywhere in the world. If there is a fear that the traffic will rut the pavement, it means the mat has not been rolled enough. A requirement of 60ºC maximum mat temperature is insurance enough. In other words, it should be ensured that traffic is not allowed on the surface until the paved mat has cooled below a temperature of 60ºC in its entire depth. Under hot Indian climatic conditions during summer, it is estimated that a 50 mm thick bituminous layer should cool to 60ºC in about one hour and a 75 mm thick bituminous layer should cool to this temperature in about one and half hour. The time will be shorter if the weather is relatively cooler in spring and autumn and/or a strong breeze is present.

5 QUALITY CONTROL AND ACCEPTANCE

The present 2001 MORTH Specifications does not adequately address the quality control/quality assurance (QC/QA) aspect of the bituminous mixes, which is a very important element of a specification. Quality control is the responsibility of the contractor to keep a control on the process[32]. Quality assurance or acceptance is the responsibility of the specifying agency. For quality control, the agency specifies the types and minimum frequency of the tests to be conducted by the contractor during construction. Whereas the MORTH Specifications have addressed the quality control aspect, it needs to be specific about quality acceptance.

There is no question that quality acceptance should be based on statistical principles[29]. A bituminous paving project should be divided into lots and payment factors should be applied on a lot by lot basis. For example, a lot can be defined as one day's bituminous mix production or a maximum tonnage of bituminous mix such as 400 or 500 tonnes. A lot is further divided into 3 to 5 sublots, which are sampled and tested at random. A test value such as bitumen content is obtained for each sublot. The test values of the sublots are analyzed statistically to assess the quality of the lot and its pay factor. The standard test method for determining the bitumen content to be used should be specified such as ASTM D 2171, "Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures". Different test methods give different test results.

Pay factors are determined using three main systems: Percent Within Limits (PWL) of the Specification; difference between average sample test value and target Job - Mix Formula (JMF); and probability based. Sample mean values are used in all three methods, but only the PWL and probability based Specifications use the sample standard deviation or variance, which takes into account material variability.

The US Federal Highway Administration is encouraging the states to implement a form of PWL Specification. PWL is defined as the percentage of lot falling between the lower Specification limit and the upper Specification limit. For example, if the JMF bitumen content is 6.0 +/- 0.4 per cent, the percentage of bituminous mix having bitumen content between 5.6 and 6.4 per cent. The concept of PWL is based on a normal distribution curve; the percentage of the population within certain limits can be calculated by knowing the area under the curve. After the test values of the sublots are determined, their average and standard deviation is calculated to define the normal distribution for the lot. Using the lower and upper tolerance values, the PWL is calculated using a set of formulae. The pay factor is then based on the PWL value. Normally, a pay factor of 1.0 (100 per cent pay) is applied if the PWL is at least 90 per cent. That is, 10 per cent material of slightly lesser quality is acceptable.

Although the PWL system of quality acceptance is preferred, it may be too complex and hard to comprehend by the contractors and agency engineers in India at this point in time. Because of this complexity some states like Alabama in the US are using simpler systems. Alabama uses the arithmetic average of the absolute values (negative or positive) of the deviations of sublot values from target. For example, the target JMF bitumen is 6.0 per cent and the test values of 4 sublots are 5.7, 6.1, 5.6, and 6.2. Then, the actual deviations are - 0.3, +0.1, - 0.4 and +0.2. The absolute deviations are 0.3, 0.1, 0.4, and 0.2, averaging at 0.25. The Alabama Department of Transportation Specifications[1] give tables for determining pay factors corresponding to the number of tests (sublots) and the arithmetic average of the absolute values of the deviations. Table 8 is such a table for bitumen content. Pay factor of 1.02 means 100 per cent plus 2 per cent added bonus, 1.00 means 100 per cnet payment, and so forth. Similar tables are available for voids in the lab compacted Marshall specimens and in-place mat density. Whichever test parameter such as bitumen content, voids in lab compacted specimens, and in-place density gives the lowest pay factor, that pay factor is applied to the bid price of the whole lot. The test parameters generally used for price adjustments in order of preference are: in-place mat density, voids in lab compacted specimens, bitumen content, and gradation (usually one or two sieves such as 2.36 mm or 0.075 mm are adequate, too many sieve sizes would dilute the Specifications unnecessarily).

Table 8 Pay Factors for Bitumen Content (After Alabama, Ref. 1)

Arithmetic Average of the Absolute Values of the Deviations of the LOT

Acceptance Tests from the Job-Mix Formula

Lot Pay Factor →	1.02	1.00	0.98	0.95	0.90	0.80*
1 Test	-	0.00-0.62	0.63-0.68	0.69-0.75	0.76-0.88	Over 0.88
2 Tests	-	0.00-0.44	0.45-0.48	0.49-0.53	0.54-0.62	Over 0.62
3 Tests	-	0.00-0.36	0.37-0.39	0.40-0.43	0.44-0.51	Over 0.51
4 Tests	0.00-0.19	0.00-0.31	0.32-0.34	0.35-0.38	0.39-0.44	Over 0.44

* The Department may require removal and replacement of the LOT.

Many states in the US have developed their own statistically based quality acceptance criteria using test data from some pilot projects. Similar data needs to be developed in India. However, Specifications such as that of Alabama can be introduced as a starting point subject to revision later based on test data collected and analyzed in India.

6 CONCLUSIONS AND RECOMMENDATIONS

The following general guidelines have been provided in the Paper to obtain long lasting bituminous pavements:

a) Specification for Paving Bitumen IS 73:2006, which specifies Viscosity Grades (VG) only should be used to ensure optimum rut resistance in bituminous pavements. The use of substandard bitumen based on the older, now defunct IS 73 (which specified penetration graded bitumen) should be discontinued immediately. For example, VG-30 bitumen should be used in lieu of 60/70 penetration bitumen and VG-10 should be used in lieu of 80/100 penetration bitumen. The Paper gives guidelines for selection of VG grades in India based on climatic conditions.

b) There is a need to restrict the amount of natural sand (which tends to have rounded particles) to 10 per cent in wearing and binder course (within top 100 mm of pavement) and to 50 per cent in base course (more than 100 mm from the pavement surface). This would reduce the potential for rutting in bituminous courses. Right now, there is no restriction on the amount of natural sand in the fine aggregate for all bituminous mixes.

c) Asphalt Institute MS-2 (latest edition) should be followed completely in designing dense graded bituminous mixes using the Marshall method. This includes selecting design bitumen content corresponding to 4.0 per cent air voids. Maximum specific gravity of mix should not be calculated with a formula but measured by using ASTM D 2041. The calculated maximum specific gravity usually gives erroneous values of air voids and VMA because the actual amount of bitumen absorbed by the aggregate is not considered. Bulk specific gravity of coarse aggregate and fine aggregate should be measured in accordance with ASTM C 127 and C 128, respectively. The current BIS standards should not be used for measuring aggregate specific gravity, since they are outdated and will give erroneous results.

d) MORTH Specifications should be able to be used on all types of roads: NH, SH, MDR, and ODR. Therefore, 50-blow Marshall Design should be used for low to medium traffic roads and 75-blow Marshall Design should be used for high traffic roads (carrying more than 1500 commercial vehicles per day). Revised mix design requirements have been presented in the Paper for both levels of compaction.

e) A revised table of mixing, laying, and rolling temperatures has been presented corresponding to new bitumen viscosity grades.

f) Right now, the MORTH Specifications do not have adequate mat compaction requirements. It has been recommended that the density of the finished compacted layer should not be less than 92 per cent nor more than 97 per cent of the theoretical maximum specific gravity of loose mix determined by ASTM D 2041. 150 mm diameter cores should be obtained to measure the pavement density.

7 ACKNOWLEDGEMENT

The opinions expressed in this Paper are those of the authors only.

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Annex A
(Clause 2.2)

OUTLINE OF AASHTO T 283, "RESISTANCE OF COMPACTED ASPHALT MIXTURES TO MOISTURE-INDUCED DAMAGE"

A-1 SCOPE AND SUMMARY OF TEST METHOD

This method covers preparation of compacted bituminous mixtures and the measurement of the change of diametral tensile strength resulting from the effects of water saturation and laboratory accelerated stripping phenomenon with a freeze-thaw cycle. The result may be used to predict long-term stripping susceptibility of bituminous mixtures and evaluate liquid anti-stripping additives that are added to bitumen or pulverized mineral materials such as hydrated lime, which are added to the mineral aggregate.

Each set of 6 compacted specimens is divided into two equal subsets. One subset is tested in dry condition for indirect tensile strength. The other subset is subjected to vacuum saturation and a freeze-thaw cycle (thawing in a hot water bath) before testing for indirect tensile strength. Numerical indices of retained indirect tensile strength properties are calculated from the test data obtained by testing the two subsets: dry and conditioned.

A-2 TESTING EQUIPMENT

a) Vacuum container, vacuum pump, manometer, and other accessories as specified in ASTM D 2041, "Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures".

b) Balance or scale accurate to 0.1 per cent of the test load.

c) Two water baths capable of maintaining temperatures of 60ºC +/- 1ºC and 25ºC +/- 0.5ºC.

d) Freezer maintained at -18ºC +/- 3ºC.

e) 10 ml graduate cylinder.

f) Loading jack and ring dynamometer (Marshall stability testing machine can be used) to provide a vertical rate of deformation of 50 mm (2 inches) per minute and capable of reading the maximum failure load.

g) Steel loading strips with a concave surface having a radius equal to the normal radius of the test specimen. The loading strips shall be 12.7 mm (0.5 inch) wide for specimens 100 mm (4 inches) in diameter. The loading strips for 150 mm (6 inches) diameter specimens shall be 19.05 mm (0.75 inch) wide. The length of the loading strips shall exceed the thickness of the specimens. Steel strip are provided at the top and bottom of specimens during indirect tensile testing.

A-3 TEST PROCEDURE

a) Make at least 6 compacted specimens for each mixture, 3 to be tested dry and 3 to be tested after partial saturation and moisture conditioning with a freeze-thaw cycle. Some extra specimens will need to be made to establish compaction procedures in order to obtain specified air void contents in the test specimens by trial and error.

b) Compact the 6 specimens with a Marshall compactor so that the compacted specimens have air voids of 7.0 +/- 0.5 per cent. This level of high air voids can be obtained by adjusting the number of Marshall blows applied on each side of the specimen by trial and error (start at about 10 blows as a starting point). Air void content must be calculated from the bulk specific gravity of the compacted specimen (determined by saturated surface dry method as per procedure given in the Asphalt Institute MS-2) and the maximum theoretical specific gravity of the loose bituminous mixture obtained by ASTM D 2041.

c) Separate the 6 specimens into 2 subsets so that the average air voids of the two subsets are approximately equal. One set will be tested dry. Keep it at room temperature and then place in a 25ºC +/- 0.5ºC water bath for 2 hours prior to determining their indirect tensile strength. The other subset will be conditioned as follows:

1) Place and submerge the 3 specimens in the vacuum container filled with water at room temperature. Apply a vacuum of 13-67 kPa absolute pressure (10-26 inches Hg partial pressure) for 30 minutes. Remove the vacuum and leave the specimens submerged in water for 5 to 10 minutes.

   [**Note:** The water saturation procedure noted above deviates from AASHTO T 283, which obtains a specified degree of saturation. The above procedure keeps the time of saturation constant.]

2) Wrap a plastic film around each saturated specimen and place the wrapped specimen in a plastic bag containing 10 ml of water and seal the plastic bag. Place the plastic bag in a freezer at temperature of -18ºC +/- 3ºC for a minimum of 16 hours. Remove the specimens from the freezer.

3) Place the specimens in a water bath maintained at 60ºC +/- 1ºC for 24 hours. Remove the plastic bag and the plastic film from each specimen after placing the specimens under water.

4) Remove the specimens from hot water bath and place in a water bath maintained at 25ºC +/- 0.5ºC for 2 hours.

5) Remove the conditioned specimens and test for indirect tensile strength.

d) Determine the indirect tensile strength of the 3 dry and 3 conditioned specimens at 25ºC +/- 0.5ºC after removing from water bath. First, measure their mean thicknesses (t). Then place the two steel loading strips on the bottom and top of the specimens across diameter and place in the Marshall testing machine or a compression-testing machine. Apply load to the specimens diametrally at a vertical rate of 50 mm (2 inches) per minute.

e) Record the maximum compressive strength noted on the testing machine and continue loading until a vertical crack appears in the specimen. Remove the cracked specimen from the machine and visually estimate the approximate degree of moisture damage (extent of stripped or bare aggregate) on the fractured faces of the specimen on a scale of 0 to 5 (5 being the most stripping).

f) Calculate the tensile strength of each specimen as follows in SI units:

$$St = 2000\ P/\pi t\ d$$

where, St = tensile strength, kPa; P = maximum loads, N; t = specimen thickness, mm; d = specimen diameter, mm;

g) Express the numerical index of resistance of bituminous mixture to the detrimental effects of water as the ratio of the original strength that is retained after accelerated moisture and freeze-thaw conditioning.

h) Calculate the Tensile Strength Ratio (TSR) as follows:

Tensile strength ratio (TSR) = S_2 / S_1

where, S_1 = average tensile strength of the dry subset, kPa; S_2 = average tensile strength of the conditioned subset, kPa

Annex B
(Clause 3)

OUTLINE OF ASTM D 2041, "THEORETICAL MAXIMUM SPECIFIC GRAVITY AND DENSITY OF BITUMINOUS PAVING MIXTURES"

B-1 SCOPE AND SUMMARY OF THE TEST METHOD

This test method covers the determination of the theoretical maximum specific gravity and density of uncompacted bituminous paving mixtures at 25ºC. The theoretical maximum specific gravity (Gmm) is used: (a) to calculate air voids in compacted bituminous mixtures, (b) to calculate the amount of bitumen absorbed by the aggregate, and (c) to provide target value for the compaction of paving mixtures in the field.

A sample of loose paving mixture is placed in a tared vacuum vessel. Water at 25ºC is added to completely submerge the sample. A specified amount of vacuum is gradually applied to remove the air bubbles entrapped between bituminous mix particles. After the vacuum is released, the volume of the sample of the voidless paving mixture is obtained by either immersing the vacuum container with the sample in a water bath and weighing or by filling the calibrated vacuum container level full of water and weighing in air.

B-2 TESTING EQUIPMENT

a) **Container (either a or b below)**

1) Vacuum bowls - Either a metal or plastic bowl with a diameter ranging from 180 to 260 mm and a bowl height of at least 160 mm. The bowl shall be equipped with a stiff, transparent cover fitted with a rubber gasket and a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.

2) Vacuum flask for weighing in air only - A thick-walled volumetric glass flask with a capacity of approx. 4000 ml, fitted with a rubber stopper with a connection for the vacuum line. The hose connection shall be covered with a small piece of fine wire mesh to minimize loss of any fine material from the mix.

b) Balance capable of being read to the nearest 0.1 gram. If weighing is to be done under water, a suitable suspension arrangement shall be provided for weighing the sample while suspended from the center of the balance

c) Vacuum pump, capable of evacuating air from the vacuum container to a residual pressure of 4.0 kPa (30 mm of Hg) or less. Provide a suitable trap between the pump and container to minimize water vapour entering the vacuum pump.

d) Residual pressure manometer or calibrated absolute pressure gauge with a bleed valve to adjust the vacuum level.

e) Water bath capable of maintaining a constant temperature of 25º +/- 1ºC and suitable for immersion of the suspended container.

B-3 CALIBRATION OF CONTAINERS

a) Bowls - Determine the mass (B) of the container immersed in water at 25º +/- 1ºC. If the bowl is used for weighing in air, place the volumetric lid on the bowl while under water. Remove the water-filled bowl with the lid in place and dry prior to determining the combined mass of the bowl, lid and water. Repeat 3 times and average the 3 masses. Designate the average mass as D.

b) Flasks - Calibrate the volumetric flask by accurately determining the mass of the flask filled with water at 25º +/- 1ºC. Use a glass cover plate to ensure the flask is completely full.

B-3 TEST PROCEDURE

a) Separate the particles of the loose paving mixture (while it is warm) by hand so that the particles are not larger than about 6 mm. Don't fracture the aggregate. Place the mix sample directly into the tared bowl or flask. Weigh the container with the sample and designate the net mass of the sample only as A. Note- The minimum sample size shall be 1500 g for mixes with nominal maximum aggregate sizes of 12.5 mm or smaller; and shall be 2500 g for mixes with nominal maximum aggregate sizes from 19 to 25 mm.

b) Add sufficient water at 25ºC to cover the sample completely. Place the cover (bowels) or stopper (flasks) on the containers.

c) Place the container with the sample and water on a mechanical agitation device or agitate manually at frequent intervals (2 to 3 minutes). Begin removing entrapped air by gradually applying vacuum and increasing the vacuum pressure until the residual manometer reads 3.7 kPa +/- 0.3 kPa (27.5 mm +/- 2.5 mm of Hg). After achieving this level within 2 minutes, continue the vacuum and agitation for 15 +/- 2 minutes. Gradually release the vacuum with the bleed valve.

d) Weighing in water - Suspend the bowl (without lid) and contents in water for 10 +/- 1 minutes and then determine mass. Designate the mass under water of the bowl and sample as *C*.

e) Weighing in air

Bowl - Submerge the bowl and sample slowly in the 25º +/- 1ºC water bath. Keep it there for 10 +/- 1 minutes. Immerse the lid in water and slide it onto the bowl without removing water from the bowl so that no air is trapped inside the bowl. Remove the bowl with the lid in place from the water bath. Dry the bowl and lid with a dry cloth. Determine the mass of the bowl, sample, and lid and designate it as *E*.

Flask - Fill the flask slowly with water ensuring not to introduce any air into the sample. Place the flask in water bath for 10 +/- 1 minutes to stabilize the temperature at 25ºC without submerging the top of the flask. Completely fill the flask with water using a cover plate without entrapping air beneath the cover plate. Wipe the exterior of the flask and cover plate. Determine the mass of the flask, plate and its contents completely filled with water. Designate this mass as *E*.

f) Calculations

Calculate the maximum specific gravity of the sample of loose paving mixture as follows:

1) Bowls Used Under Water Determination:

$$Gmm = A / [A-(C-B)]$$

Where, *Gmm* = maximum specific gravity of the mixture; *A* = mass of the dry sample in air, g;
B = mass of bowl under water, g; *C* = mass of bowl and sample under water, g;

2) Bowls in Air Determination:

$$Gmm = A / (A+D-E)$$

Where, *Gmm* = maximum specific gravity of the mixture; *A* = mass of dry sample in air, g;
D = mass of lid and bowl with water at 25ºC, g; *E* = mass of lid, bowl, sample and water at 25ºC, g

3) Flask Determination.

$$Gmm = A / (A+D-E)$$

Where, *Gmm* = maximum specific gravity of the mixture; *A* = mass of dry sample in air, g;
D = mass of cover plate and flask filled with water at 25ºC, g;
E = mass of flask, cover plate, sample, and water at 25ºC, g