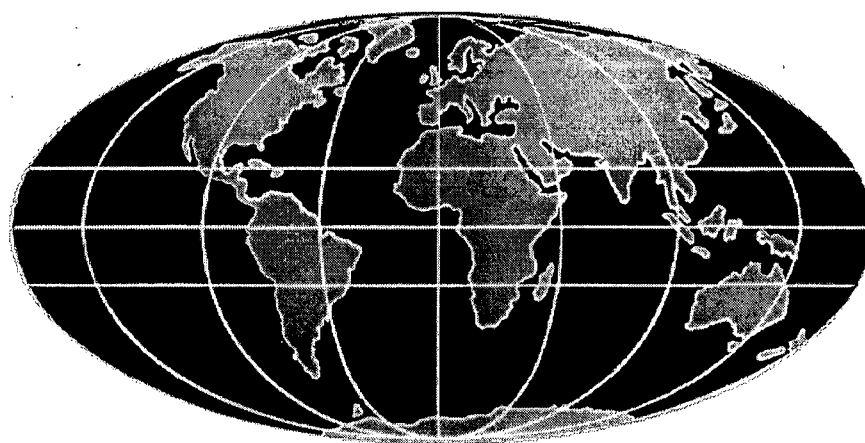


**TITLE: Bituminous surfacings for
heavily trafficked roads in
tropical climates**

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Bituminous surfacings for heavily trafficked roads in tropical climates

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- Increasing numbers of new roads in developing countries are being built with thick asphaltic concrete surfacings to accommodate increasing traffic volumes. However, in areas of high traffic stresses, such as climbing lanes and junctions, the use of asphaltic concrete designed by the Marshall method is often not appropriate, particularly at high pavement temperatures. In these situations the commonly-used 75-blow Marshall compaction method underestimates the effect of secondary compaction under traffic and many of these surfacings suffer structural instability leading to severe plastic deformation. This paper illustrates the importance of retaining sufficient voids in the mix after trafficking to prevent plastic deformation and discusses limitations associated with the Marshall design procedure.

Many developing countries have limited facilities for bituminous mix design and an improved method of design is proposed which requires only commonly available or inexpensive equipment. The procedure uses a combination of the Marshall test method and determination of a 'reference refusal density' using a vibrating hammer in accordance with the percentage refusal density test.

Keywords: bitumen & tar; research & development; roads & highways

Introduction

The standard of road networks in developing countries has continued to increase; gravel roads and earth tracks have been upgraded to all-weather standard by applying a sealed road surface, existing sealed roads have been strengthened, and new roads have been built with thick asphaltic concrete (AC) surfacings to accommodate increasing traffic volumes. However, in areas of high traffic stresses, such as climbing lanes and junctions, the use of AC designed by the Marshall method is often not appropriate, particularly at high pavement temperatures. A fundamental assumption in the Marshall procedure is that the density obtained during the test represents the ultimate density of the AC in the road pavement after years of secondary compaction under traffic. This is

very difficult to predict and, where loading conditions are severe, it is most likely that the commonly-used 75-blow Marshall compaction will underestimate the effect of secondary compaction.

2. When secondary compaction of the AC surfacing is underestimated there is a high risk that structural instability may develop and result in plastic deformation. Typical surfacing failures both on level roads and climbing lanes are illustrated in Figs 1 and 2. Such failures are an expensive waste of non-renewable resources because, in the majority of cases, the deformed asphalt must be removed and replaced with new material.

3. Plastic deformation of thick bituminous surfacings is by no means a new phenomenon. An OECD review in 1975¹ referred to widespread problems in Europe, North America and Japan and noted that, although the problems were more severe in countries with hot climates, hilly terrain and heavy traffic, there were also problems in temperate climates in more sensitive areas such as bends, junctions, etc. The report proposed bituminous mixes that were less susceptible to secondary compaction by traffic and suggested methods of designing these mixes that included: lowering the binder content, using a stiffer or a polymer modified binder, and improving aggregate angularity and grading.

4. The importance of maintaining sufficient voids in the mix (VIM) after trafficking was emphasized in the *Desert Roads Manual*² which required that heavy duty dense bitumen macadam for use in hot arid areas should retain a VIM of not less than 3% at refusal density. Further work³ showed that the resistance to deformation of continuously graded mixes increased as the voids in the mineral aggregate (VMA) decreased until refusal density was approached at very low values of VMA, when resistance to deformation began to decrease rapidly. The initial increase in resistance to deformation was thought to be caused by the increase in aggregate contact as the coarser particles were forced together. However, as compaction was increased further, the fines/filler mortar gradually filled more of the void space between the coarse particles, eventually reducing aggregate contact and making the mix less resistant to deformation. These results again infer that a minimum level of

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VIM at refusal density would prevent the majority of failures through plastic deformation.

5. Despite these and other published design modifications for continuously graded mixes in hot climates, there are still far too many occasions in the developing world when limited maintenance resources are being used to resurface roads that have failed through premature plastic deformation.

Full-scale trials and failure investigations

6. The Transport Research Laboratory (TRL), in cooperation with both the Public Works Institute in Malaysia (IKRAM) and the Institute of Road Engineering (IRE) in Indonesia, has undertaken research to investigate the nature of premature plastic deformation and also developed low-cost mix design procedures that will prevent its occurrence.

7. The research in Malaysia centred around two sets of experimental surfacing trials on a particularly severe climbing lane on the Kuala Lumpur-Karak highway, which carried more than 1000 commercial vehicles per day.^{4,5} The climbing lane had a grade of 6% and the average speed of the commercial vehicles was 15 km/h. The studies have shown that the AC wearing course materials designed by the Marshall procedure were compacted by the slow-moving and heavy vehicles. Fig. 3 illustrates this effect and shows that a rapid decrease in void content in the surfacings, of typically 2%, occurred over the first few months. After this, the rate of secondary compaction decreased as the materials approached their refusal densities. In this case the refusal density is the maximum density to which each particular material will be compacted by the traffic using the climbing lane.

8. Further monitoring of these trials has shown that if the level of air voids in the surfacings can be maintained above 3% at its refusal density, then there is a high probability that plastic deformation of the material will not occur.

9. In addition to the research in Malaysia, the results of further investigations on heavily trafficked roads and climbing lanes in the Middle East and East Africa have confirmed these findings. In these studies the material properties of deformed AC surfacings were compared to the properties of materials which had performed satisfactorily. The results, shown in Fig. 1, confirm those found in Malaysia - namely, that if mixes can be designed in such a way that there is a residual void content of 3% after compaction by traffic, the surfacing is unlikely to fail through premature plastic deformation.

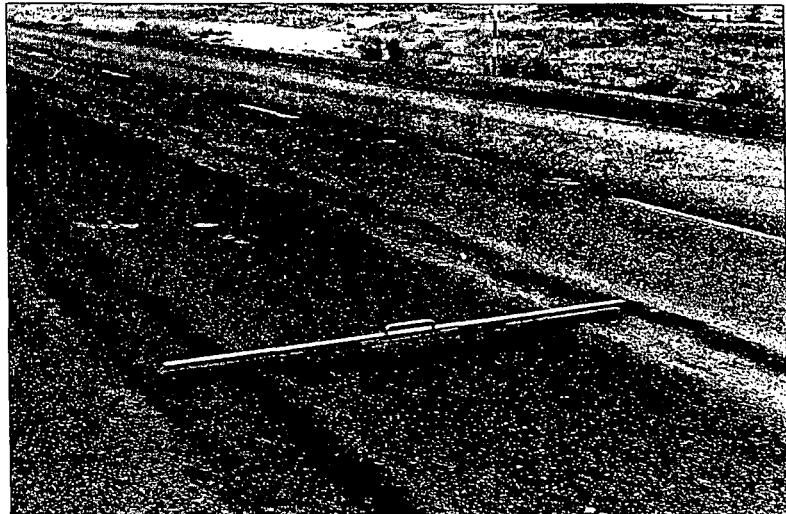


Fig. 1. Deformation on level road

Recent design developments

10. The occurrence of plastic deformation as a result of increased heavy traffic has led to corresponding changes in existing design procedures and also to the development of other design techniques. Most notable of these is the recent change in the Marshall design procedure⁶ and the development of the SUPERPAVE method of design as part of the Strategic Highway and Research Programme.⁷ Both these methods emphasize the importance of maintaining a minimum level of voids after secondary compaction by traffic.

11. The Marshall method of determining the desired bitumen content is by far the most common procedure used to design continuously graded mixes in developing countries. It has proved to be robust and inexpensive and is enshrined in most of the general specifications found in the developing world. The method requires test specimens having increasing bitumen contents to be moulded at a specified

Fig. 2. Deformation of climbing lane



compactive effort under standard conditions. The compactive effort varies according to the traffic level, with a maximum of 75 blows of the Marshall hammer on both sides of the specimen usually being assumed as appropriate for traffic levels of more than one million equivalent standard axles. In the past⁸ the optimum bitumen content of the mix was then determined by taking an average of the bitumen contents which gave

- (a) maximum unit weight
- (b) maximum stability
- (c) air voids of 4%.

To be acceptable the mix also had to comply with a number of empirically-derived criteria, namely, minimum values of stability and flow and VIM and VMA within defined ranges.

12. One disadvantage of this method was that the optimum bitumen content was often higher than that bitumen content which corresponded to 4% air voids and therefore the design mix could possess air voids somewhat less than 4% and often close to 3%. When this occurs the mix becomes more susceptible to plastic deformation, particularly if the compaction under traffic is greater than the equivalent of 75 blows of the Marshall hammer. This is often the case on most climbing lanes.

13. In the latest versions of the design manual^{16,9} there are two major changes. First, the introduction of a criterion to limit the voids filled with bitumen, particularly at high traffic levels; and second, a recommendation to select the design bitumen content as that which will result in 4% void content. Both these changes tend to increase the air voids in the design mix and therefore reduce the possibility of the surfacing reaching an unacceptably low level of air voids after secondary compaction by traffic.

14. The 1994 version of the manual also states 'mixtures that ultimately consolidate to less than 3% air voids can be expected to rut and shove' and emphasizes that the design range of air voids (3-5%) is the level desired after several years of compaction by traffic. However, it is not explicit on how this level of compaction can be simulated in the test procedure, stating that 'the design range (3-5% air voids) will normally be achieved if the mix is designed at the correct compactive effort and the air voids after construction is about 8%'. The results from the study in Malaysia tends to confirm this fact with the voids in the wheelpath decreasing by ~3-4% over a period of two years (see Fig. 3). However, the surfacing material outside the wheelpaths is unlikely to receive appreciable secondary compaction and the binder may be prone to ageing and subsequent cracking.^{10,11}

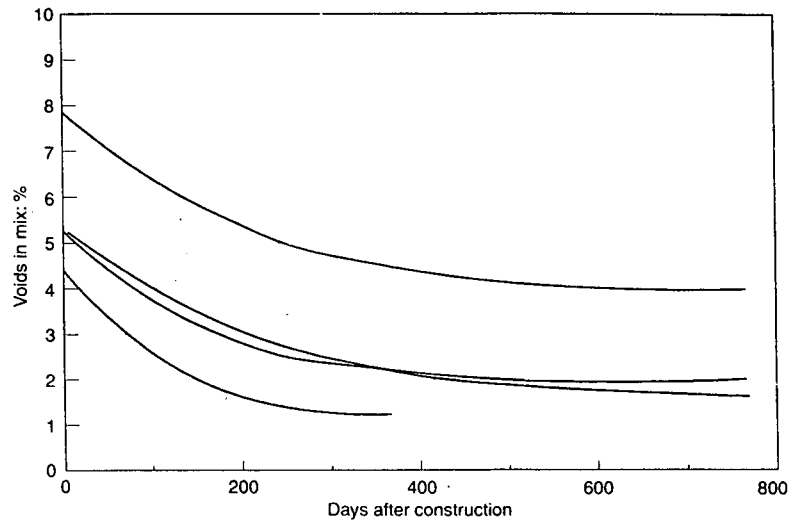


Fig. 3. Reduction in VIM in the wheelpath; wearing course mix designed by Marshall Procedure (75 blows)

Laboratory trials

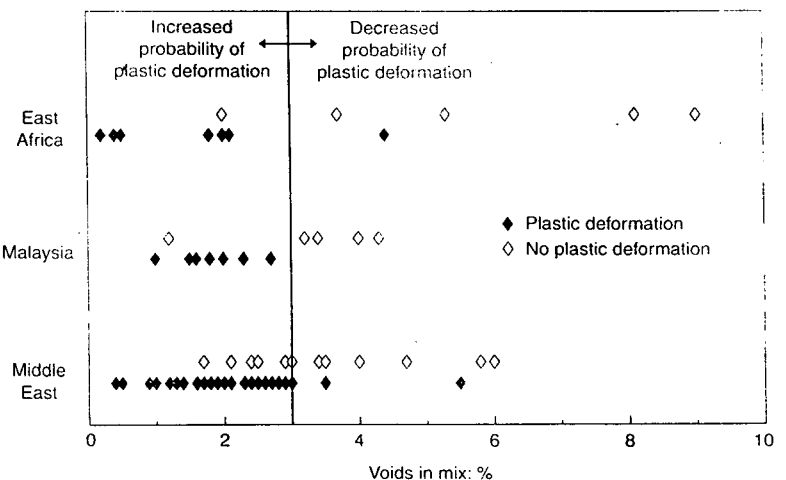
The effect of compaction level chosen for mix design

15. It is clear that the level of compaction used for designing a mix, which is to be subjected to severe loading conditions, is fundamental to the long-term performance of the material. Laboratory tests have shown that the selection of a fixed number of blows in the Marshall test is an arbitrary one if there is no prior knowledge of the degree of secondary compaction that will occur under traffic.

16. In the laboratory, samples of an AC wearing course were subjected to 75-, 120-, 300- and 600-blow Marshall compaction and also to refusal compaction using an electric vibrating hammer. The vibrating hammer test is based on an extended form of the compaction procedure used in the percentage refusal density (PRD) test¹² and is discussed more fully later in this paper.

17. Figure 5 shows the relationship between VIM and bitumen content for the

Fig. 4. Occurrence of plastic deformation in the wheelpath



selected levels of compaction. The results demonstrate that the use of 75-blow compaction for design, when secondary compaction in the road is better represented by 300-blow compaction, will probably result in plastic deformation. This is because at 75-blow compaction, 3% air voids is obtained at a bitumen content of approximately 4.7%. If secondary compaction is indeed equivalent to 300 blows in the Marshall test then the resulting air voids at a bitumen content of 4.7% will be reduced to approximately 1.8%, that is, considerably less than the 3% criterion.

18. The refusal density obtained in the vibrating hammer test could be adopted as a 'reference density'. This is because a mix which is capable of retaining 3% air voids at this reference density can not undergo a further reduction of air voids to below 3% under secondary compaction, since it is unlikely that the vibrating hammer produces a density which is significantly less than the absolute maximum that can be achieved.

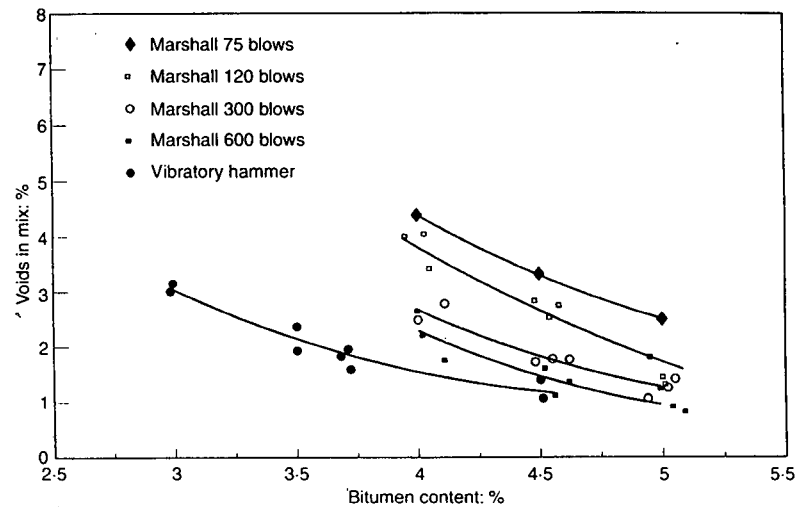
Bituminous surfacings for severely loaded sites

19. The capacity of a given graded aggregate to carry bitumen is controlled by the VMA after compaction. The effect of VMA on the relationship between VIM and bitumen content when subjected to compaction to refusal is shown in Fig. 6 for six mixes with different aggregate gradings.

20. The mix which had VMA of only 9.9% can only carry 3% bitumen if it is to retain 3% air voids at refusal density. This mix was typical of a wearing course material and would be too stiff to be workable during construction. As the VMA at refusal density increases, so the bitumen content, which can be carried without reducing VIM to less than 3%, also increases. With information such as that shown in Fig. 6 it is possible to choose an aggregate grading which simultaneously meets the requirements of sufficient bitumen for good workability during construction and sufficient voids to maintain a value of VIM of 3% at refusal density.

21. For severe sites, the basecourse specifications given in TRL's Overseas Road Note 31¹³ are likely to produce the most appropriate mix. The aggregate grading of these materials is summarized in Table 1.

22. Ensuring that the composition of a mix is correct and that the VIM value will not fall below 3% is a vital part of the design process. However, the degree of aggregate interlock and friction between particles also has an important bearing on the resistance to shear failure of a bituminous mix. Uncrushed rounded gravel could meet the minimum VIM requirement when compacted to refusal in a mould, but aggregate interlock is unlikely to be sufficient to prevent shear failure under heavy



traffic. Additional tests are therefore required to determine the likely performance of asphaltic surfacings under heavy traffic. Such tests can include

Fig. 5. Effect of compactive effort on wearing course mix

- (a) determinations of mix stiffness moduli
- (b) wheel tracking rates at temperatures of 45°C and 60°C.

23. Many developing countries do not have the facilities for such performance testing but do have considerable experience of the performance of materials designed by the Marshall method. It is therefore recommended that in these cases the normal Marshall design procedure,⁶ using 75 blows on each face, should be completed first to ensure the normal Marshall design parameters can be met. This, together with past experience, is likely to ensure that

Table 1. Basecourse grading

BS test sieve: mm	% by mass passing sieve	
	Asphaltic concrete	Dense bitumen macadam
28	100	100
20	80-100	95-100
14	60-80	65-85
10	—	52-72
6.3	—	39-55
5	36-56	—
3.35	—	32-46
2.36	28-44	—
1.18	20-34	—
0.6	15-27	—
0.3	10-20	7-21
0.15	5-13	—
0.075	2-6	2-8
Bitumen grade: pen	80/100 or 60/70*	80/100 or 60/70*
Bitumen content: %	4.8-6.1†	5.0 ± 0.5†

*60/70 is preferred.

†Determined by Marshall design method.

the aggregate being used will be satisfactory in terms of having good particle interlock.

Refusal density design for severely loaded sites

24. Some authorities have adopted a procedure using increased numbers of blows of the Marshall hammer to design surfacings which will retain a required minimum level of VIM after compaction by traffic. An alternative is to use the vibrating hammer as described earlier. Neither of these methods exactly reproduces the mode of compaction which occurs under heavy traffic; however, the latter procedure is preferred because it allows a degree of kneading of the mix which is more representative of field compaction and it is a much quicker method.

25. After the Marshall design binder content, for 75-blow compaction, has been determined, samples are made with bitumen contents decreasing in 0.5% increments from the design value. These samples are then subjected to vibratory compaction to establish the bitumen content at which 3% VIM is retained at refusal density.

Vibrating hammer compaction

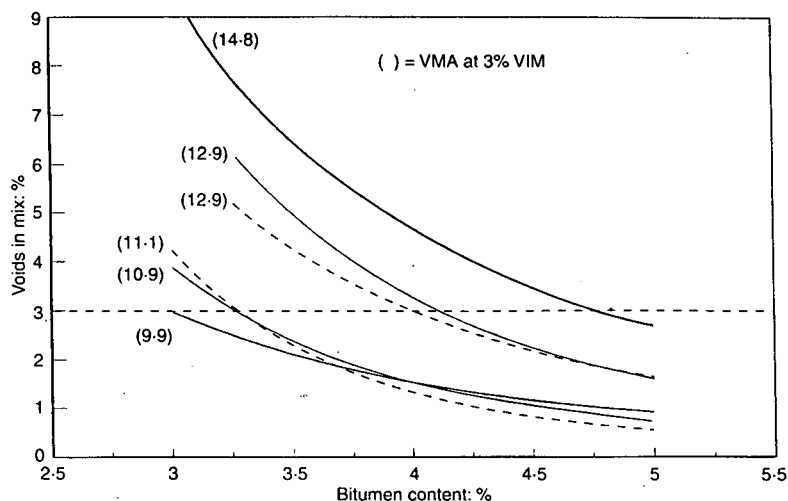
26. The equipment and the method of compaction used in the vibrating hammer test procedure are in accordance with the PRD test.¹² The sample is compacted in a 152–153 mm diameter mould to approximately the same thickness as will be laid on the road. Two tamping feet are used, having diameters of 102 mm and 146 mm.

27. The smaller tamping foot is used for most of the compaction sequence, which involves moving the foot from position to position to cover the whole of the surface of the sample. At each position compaction should continue for between 2 and 10 s, the limiting factor being that the material should not be allowed to 'push up' around the compaction foot. The compaction sequence is continued for a total of 2 min \pm 5 s. The larger tamping foot is then used to smooth the surface of the sample.

28. Irrespective of layer thickness, a spare base-plate should be used so that the mould can be inverted. The sample is forced to the new base-plate with the larger tamping foot and the compaction sequence repeated to ensure that refusal density is achieved.

29. To ensure that the reference refusal density is obtained in thick layers, it may be necessary to repeat this procedure a second time. It is suggested that trial mixes with a bitumen content which corresponds to approximately 6% VIM in the Marshall test are used to

(a) determine the mass of material required to



- give a compacted thickness of approximately the same thickness as for the layer on the road
- (b) determine the number of compaction cycles which will ensure that the reference refusal density is achieved.

Fig. 6. Relationships between mix properties at refusal density

Transfer of laboratory design to compaction trials

30. After the standard PRD cycle, samples of basecourse which have been compacted from the loose state can be expected to have densities between 1.5% and 3% lower than for the same material compacted in the road and then cored out and subjected to the PRD test. This is an indication of the effect of the different compaction regime and is caused by a different resultant orientation of the particles. The differences between the densities for laboratory compaction and field samples after refusal compaction should be measured to confirm whether this difference occurs.

31. A minimum of three trial lengths should be constructed with bitumen contents at the laboratory optimum for refusal density (3% VIM) and at 0.5% above and below the optimum. The trials should be used to

- (a) determine the rolling pattern required to obtain a satisfactory density
- (b) establish that the mix has satisfactory workability to allow a minimum of 93% of PRD (standard compaction¹²) to be achieved after rolling
- (c) obtain cores so that the maximum binder content which allows 3% VIM to be retained at refusal density can be confirmed.

32. For a given level of compaction in the Marshall test, VMA reduces to a minimum and then increases as bitumen content is increased. However, samples compacted to refusal density will have sensibly constant values of VMA over a range of bitumen contents before the

aggregate structure begins to become 'over-filled' and VMA increases. This means that during the trials it will be a relatively simple matter to determine the sensitivity of the mix to variations in bitumen content and to confirm the bitumen content required to give a minimum of 3% VIM at refusal density. If necessary the aggregate grading can be adjusted to increase VMA which will reduce the sensitivity of the mix to changes in bitumen content.

33. A minimum of 93% and a mean value of 95% of the standard PRD density is recommended as the specification for field compaction of the layer. From these trials and the results of the laboratory tests, it is then possible to establish a job mix formula. After this initial work, subsequent compliance testing based on analysis of mix composition and refusal density should prove to be speedy, especially if field compaction is monitored with a nuclear density gauge. This initial procedure is time-consuming, but is justified by the long-term savings that can be made by extending pavement service life and minimizing eventual rehabilitation costs.

34. It is essential to seal mixes designed by this method with a surface dressing. This greatly reduces the risk of premature 'top down' cracking associated with bitumen age hardening.^{10,11} This is important not only during the period when secondary compaction occurs in the wheelpaths but also for long-term protection of those areas which will not be trafficked and which are likely to retain air voids above 5%.

Summary

35. Research has shown that the risk of plastic deformation in asphaltic concrete surfacings on severely loaded sites can be minimized if VIM of at least 3% can be retained after secondary compaction by traffic.

36. A methodology which combines two standard test procedures has been proposed for the design of bituminous surfacings for such sites in developing countries with tropical environments and where, as is commonly the case, equipment for mix design is limited. While the procedure described will bring immediate benefit to many road projects, improvements in the methodology can be expected with the further introduction of suitable laboratory mix performance tests.

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