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RUTTING OF ASPHALT CONCRETE PAVEMENTS

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ABSTRACT

A good network of roads is the backbone *for* the economic growth of the country. Pakistan has recently started the construction of the major motorways throughout the country. Due to high temperature and unregulated heavy truck traffic the pavements are subjected to very high stresses and strains. It is very important to use proper design, construction, and quality control procedures to built better quality roads and avoid premature failures.

More than 80% of the roadways in the world are flexible (asphalt concrete) pavements. Rutting, fatigue cracking, and low temperature cracking (shrinkage cracking) are the three most common distresses that contribute to the failure of flexible pavements. One of the major concerns for highway agencies and the asphalt paving industry is the excessive permanent deformation (rutting) of asphalt concrete pavements caused by heavy truck traffic on the highways.

One of the common methods to eradicate rutting on asphalt concrete pavements involves milling of the rutted areas and putting on asphalt concrete (AC) overlays. However this rehabilitation process, which is extremely expensive, provides no insurance that the overlaid pavement will not rut again.

Rutting on asphalt concrete pavement can develop due to improper pavement structural design, instability of asphalt mix used in the pavement and improper construction-®f the pavement structure. Currently available mechanistic flexible pavement design and analysis procedures can be used to design a flexible pavement with adequate structural capacity to minimize stresses and strains induced by the traffic loads. For the asphalt mixture used for the surface layer, the need for high rutting resistance is particularly critical, because it is subjected to much greater stresses under the heavy wheel loads.

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1- INTRODUCTION

Permanent deformation (rutting) is one of the major distresses causing failures of asphalt concrete pavements. Heavy truck traffic, increased wheel loads, and use of high-pressure radial tires have aggravated the problem of rutting of asphalt pavements all over the world. Extremely expensive rehabilitation process is required to eradicate the rutted pavements.

Rutting on asphalt concrete pavement can develop due to improper pavement structural design, instability of asphalt mix used in the pavement and improper construction of the pavement structure. Currently available mechanistic flexible pavement design and analysis procedures can be used to design a flexible pavement with adequate structural capacity to minimize stresses and strains induced by the traffic loads. This can reduce the permanent deformation in the materials comprising the pavement structure under traffic loading. Quality of the materials in an asphalt pavement structures including subgrade soils, aggregate subbase and base, and asphalt base and surface are important in affecting the rutting susceptibility of the pavements. If the materials used have high rutting susceptibility, there is no assurance that the pavement will be free of excessive rutting under repeated traffic loading, no matter how thick the pavement structure is designed and how well it is constructed. For the asphalt mixture used for the surface layer, the need for high rutting resistance is particularly critical, because it is subjected to much greater stresses under the heavy wheel loads. Adequate construction quality control during the construction is important to ensure that the placed materials will acquire specified quality.

Therefore, adequate design of the pavement structure, design and specification of the pavement materials, and the construction quality control are all equally important to ensure a better performance of an asphalt pavement.

Investigating permanent deformation of asphalt concrete mixtures and the rutting of asphalt pavements, a major distress in asphalt pavements, has been an active area of research for the last thirty years. Almost every subject related to rutting of asphalt concrete the researchers have studied pavements. Beginning with the First International Conference on the Structural Design of Asphalt Pavements (1962) to the Seventh International Conference (1992), many research papers have been presented on these subjects. These subjects have also been reported extensively in the proceedings of the Association of Asphalt Paving Technologists and the Transportation Research Records. This chapter reviews the theories associated with rutting, and the different models for estimating rutting of asphalt pavements.

2- MECHANISM OF RUTTING OF ASPHALT PAVEMENTS

Rutting in asphalt pavements develops because of the densification and shear flow in asphalt concrete layers and due to permanent deformations in the aggregate base, subbase and soil sub-grade. Rutting in asphalt concrete pavement usually appears as a longitudinal depression under the wheel paths of vehicles and a small bulging on the sides. The extent of rutting gradually accumulates with increasing numbers of wheel load applications on the pavement.

Two major phenomena contributing to rutting of asphalt concrete pavements are densification (decrease in volume and hence increase in density) and shear plastic deformation (Collop, Cebon and Hardy, 1995). These two phenomena contribute in varying degrees to the permanent deformations in all pavement layers including asphalt concrete surface course, asphalt base course, aggregate base and subbase and sub-grade.

If the asphalt pavement structure is weak and large stresses and strains are induced in all the pavement layers under heavy wheel loads, initial densification and subsequent shear flow can be developed in various pavement layers. Under such a situation, all pavement layers contribute to total surface rutting of the asphalt pavement. The rut depth under the wheel paths will be the sum of the permanent deformations of all the pavement layers. Many of the previous asphalt pavement rutting evaluation studies considered the permanent deformations of sub-grade soil due to excessive vertical stress (or strain) on the top of the sub-grade due to heavy wheel loads as the primary cause contributing to the rutting of asphalt concrete pavements. The criterion of limiting sub-grade strain is used in the asphalt pavement design method developed by the Asphalt Institute (Shook et. al., 1982). Many other researchers have also used similar methodologies.

RUTTING OF ASPHALT CONCRETE MIXTURES

Using Current Pavement design methods, the stresses and strains in the sub-grade soils can be reduced to very small values, which can virtually eliminate permanent deformations in the sub-grade soils. Due to high wheel loads and high tire pressures of truck traffic, however, the asphalt concrete layers, particularly near the surface, are subjected to very high stresses which cannot be reduced through structural design. Consequently rutting of the asphalt pavement is more directly related to the permanent deformation characteristics of asphalt mixtures and is a much more difficult problem to deal with.

Studies on asphalt mixtures indicated that shear deformation rather than densification was the primary rutting mechanism (Highway Research Board, 1962) and (Hofstra and Klomp, 1972). Later research work of Eisenmann and Hilmer(1987) also concluded that if the pavement has been compacted to higher density during construction, thither densification during the application of wheel loads is unlikely, and rutting is induced predominantly due to shear flow of the asphalt mixture.

The results of the above study, presented in Figure 1, showed the development of rutting with increasing number of load repetitions on the pavement surface along the wheel paths and upheaval in the adjacent areas. It can be seen from the results that during the initial stage of wheel passes (500 to 1000 cycles), the increase in the permanent deformation beneath the wheel paths is much greater than the increase in the upheaval areas adjacent to wheel paths. This clearly indicates that most of the rutting at this stage is due to densification (decrease in volume). With the further increase in the number of wheel passes beyond the initial stage, the decrease in volume under the wheel paths is nearly equal to the increase in volume in the upheaval areas adjacent to the wheel paths. This shows that the densification under the wheel load has been completed and the most part of the rutting at this stage is caused by the displacement of the material with constant volume i.e. shear flow.

Thicker asphalt concrete layers exhibit more permanent deformation within the asphalt concrete layer, but the amount of permanent deformation does not increase directly with the increasing layer thickness beyond a certain threshold thickness of the asphalt layer. Any increase in the depth of the asphalt layer beyond this threshold will not influence the total rut depth within the asphalt layer.

Uge and Van de Loo (1974) demonstrated that the rut depth reaches a limiting value for an asphalt concrete layer thickness of 13 cm to 25 cm and any further increase in the depth has a negligible effect on the total amount of rutting in the asphalt layer. Similar findings were made during the AASHO road test, Highway Research Board (1962). This is due to the decrease in shear stresses at greater depth in the asphalt layers.

Hofstra and Kiomp (1972) observed during laboratory test track studies on asphalt pavements that the permanent deformation within the asphalt layer increases relative to the thickness of the asphalt layer. However, by increasing the thickness of the asphalt layer beyond 10 cm. further increases in permanent deformation of the asphalt layer was insignificant. Table 1 from Hofstra and Klomp (1972) shows that by increasing the thickness of the asphalt layer from 10 to 20 cm. the increase in permanent deformation is negligible. However, a significant increase in permanent deformation within the asphalt layer can be noticed when the layer thickness is increased from 5 to 10 cm. This also strengthens the belief that the larger portion of the total rut depth is contributed by the asphalt layer near the surface due to high shear stresses under the wheel load. These results reveal that if the supporting material under the asphalt concrete layer is reasonably stiff, most of the total pavement rutting develops within the asphalt concrete layer.

4- DESIGN AND ANALYSIS OF ASPHALT PAVEMENTS AGAINST RUTTING

Over the past three decades, extensive research has been undertaken to combat the problem of rutting in asphalt concrete roads. Several methods have been proposed for the design and analysis of asphalt concrete pavements. Most of these methods are analytically based, mechanistic, or mechanistic-empirical procedures.

Most of the earlier methods of designing flexible pavements and even the 1986 AASHTO flexible pavement design method, made use of the empirical relationships (pavement thickness versus traffic) developed largely on the basis of observed performance from the AASHO Road Test (1962), These methods include the AASHTO method of flexible pavement design and the methods proposed by F inn et al., (1962) and Shook, (1964). The temperature moisture and other environmental conditions significantly affect behavior of asphalt concrete while no consideration was given to different environmental conditions in the development of the empirical methods mentioned above. Shook et al. (1982) and many other researchers have raised these concerns about empirical design methods.

Mechanistic-empirical approaches for designing asphalt pavements, however, are currently the most popular. Such approaches consist of a theoretical procedure combined with the observed pavement performance data. Strict mechanistic pavement design methods have the potential to provide improved design capabilities with regard to traffic, materials and environment. However, due to the complexity of the behavior of the pavement systems and the materials under different service conditions, strict mechanistic approaches have been unable to predict pavement responses and distresses accurately. As a result, the use of a mechanistic-empirical approach becomes the only practical way of designing asphalt pavements.

5- MECHANISTIC-EMPIRICAL DESIGN AND ANALYSIS APPROACH

The general methodology of a mechanistic-empirical procedure for flexible pavement design is shown in Figure 2. The general approach for this procedure can be described as follows:

1. A trial pavement section is selected including number of layers, the thickness of each layer, and the type of material in each layer.

2. A primary response model is selected and the basic material properties for use in the primary response model are determined.

3. Traffic input data, wheel load configuration and number of cycles for design of each type of distress are determined.

4. The proposed pavement system is analyzed (for the known traffic and environmental conditions) by the primary response model to calculate stresses strains and deflections at critical locations (usually at the top of the subgrade layer and at the bottom of asphalt concrete layer) to obtain the primary response parameters *(Q,E,S*). Primary response systems usually make use of linear elastic theory, finite element, or viscoelastic approaches.

5. Allowable permanent rut depth in the wheel path and the allowable percentage of pavement cracking is established. Then the permanent distresses in terms of rutting and cracking within the pavement life are computed using the distress subsystems (fatigue cracking, rutting, and low temperature cracking)., The stresses, strains and deflections calculated from the primary response models and material characteristics are used in the distress subsystems.

6. The calculated distresses within the design life are then compared with the already established allowable distresses.

If the calculated pavement performance is not within the desired range of performance, then the design is modified in the step 1 and the procedure is repeated until the calculated performance is within the range of desired performance criteria.

There are several mechanistic design schemes which are similar to this approach, including Kenis (1977) Claessen et al. (1977), Southgate et al. (1977), Ce'lard (1977).

6- SHARP-SUPER?AVE ASPHALT CONCRETE MIX DESIGN SYSTEM

Superpave (Superior Performing Asphalt Pavements) is the final product of the Strategic Highway Research Program (SHRP) Asphalt Research Program. This is a comprehensive performance based system of asphalt mix design. The mix design system was developed to consider and minimize permanent deformation, fatigue cracking and low temperature cracking (Kennedy et. al., SI-IRP-A-410, 1994). Superpave represents an improved system for specifying component materials (Asphalt binder and Aggregate), asphalt mixture design. Federal Highway Administration (FHWA) started implementing this new design system in 1994 and now most of the states are designing their mixtures using Superpave design system. The results of pavement performance show that Superpave mixtures are more resistant to rutting and cracking.

7- CONCLUSIONS AND RECOMMENDATIONS

1. Rutting in Asphalt pavements develops gradually with increasing repetitions of wheel loads and appears as a longitudinal depression in the wheel path with small heave on the sides.

2. Rutting is caused by a combination of densification and shear deformation: however, shear deformation is considered to be the primary cause of rutting.

3. To minimize rutting on an asphalt pavement for a given traffic condition, a strong pavement structure must be designed. A proper pavement structure design, selection of the suitable materials and strict quality construction control should tend to lower the stresses and strains induced by the wheel loads in different pavement layers and minimize the permanent deformation within each pavement layer. This has been the common practice of the highway industry.

4. Mechanistic-Empirical Design procedures should be used to design the pavements structure.

5. Axle load limits for the trucks should be strictly implemented. Even a very small percentage of extra heavy wheel loads can severely damage the road system.

Due to viscoelastic nature asphalt mixtures are more susceptible to rutting in high temperature environments. Use of asphalt modifiers can significantly improve the performance of asphalt pavements in high temperature areas.

SHRP Superpave mixture design system should be adopted. This is a comprehensive performance based system of mixture design and takes into account the traffic as well as environmental conditions.

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Table 1. Permanent Deformation Results for Pavement of Different Thickness. From Hofstra and Klomp (1972)

Type of Mix.	Layer Thickness (cm)	Rut Depth (cm)	Subgrade Deformation (cm)	Change in 1 thickness of Asphalt Layer	
				(cm)	(%)
Asphaltic Concr. (1)	20	1.6	-	1.6	8
Asphaltic Concr. (1)	10	1.7	0.2	1.5	15
Asphaltic Concr. (1)	5	2.3	1.8	0.6	12
Sand Asphalt 1 (round sand, 7% bit.)	10	1.25	0.2	1.0	10
Sand Asphalt II (round sand, 9% bit.)	10	2.6	0.05	2.5	25
Sand Asphalt III (crusher sand, 7% bit.)	10	0.8	0.4	0.4	4

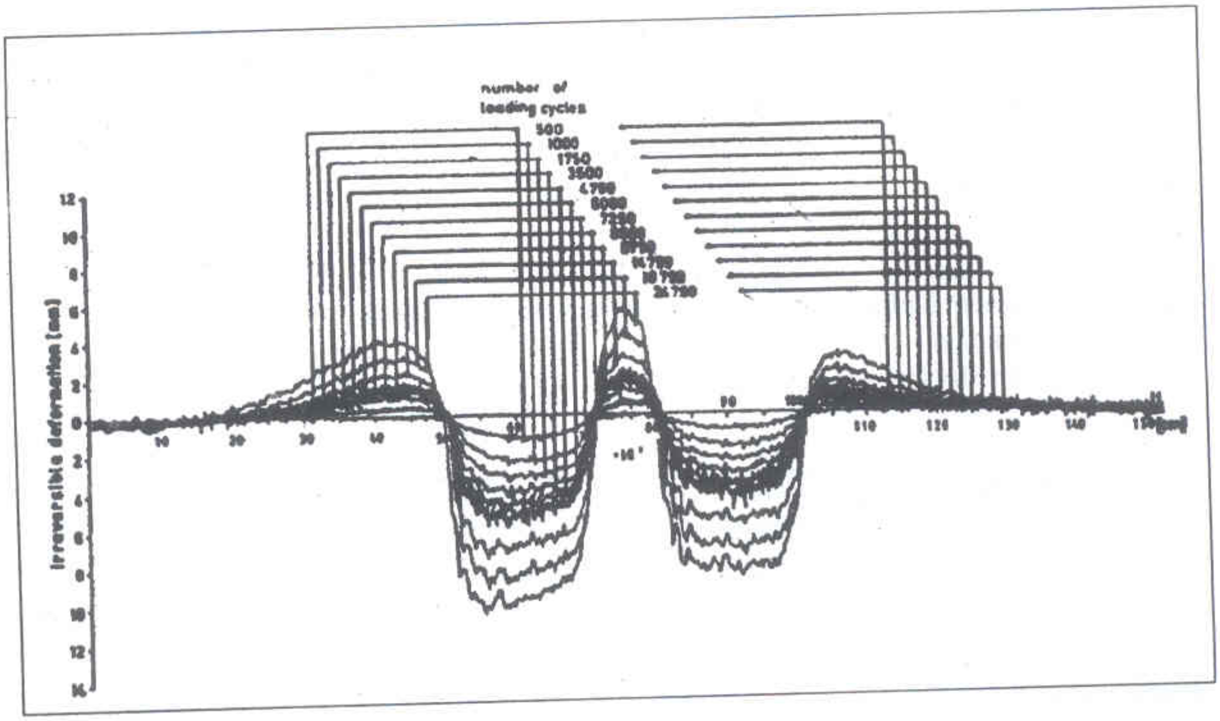

Figure1. Example of Superimposed Transverse Surface Profiles of rutted pavement. (From Eisenmann & Hilmer, 1987)

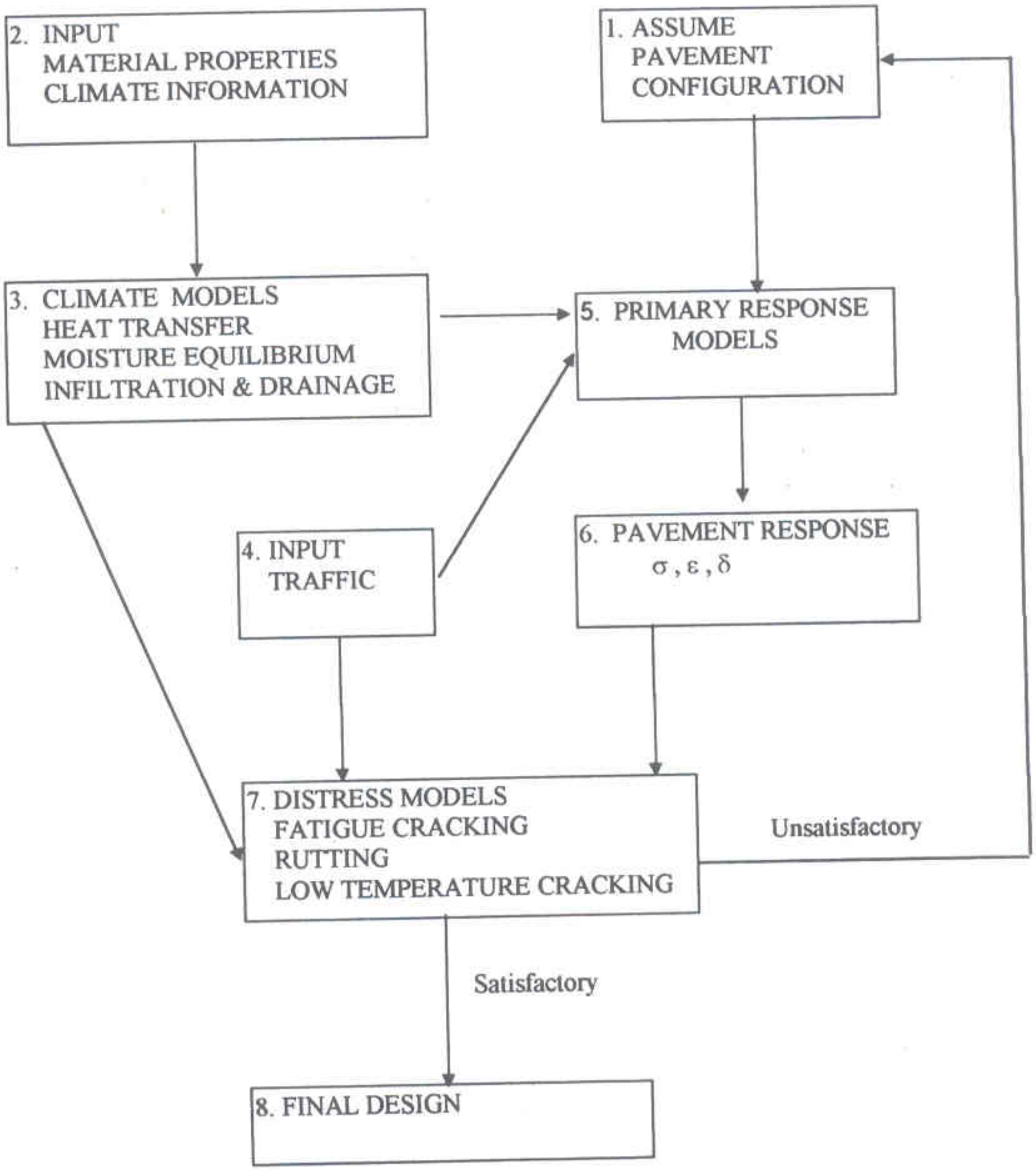

Figure 2. Schematic of the Mechanistic-empirical procedure.