Mix Type Selection for Perpetual Pavements

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ABSTRACT

The notion of long-life asphalt pavements or Perpetual Pavements came about in the 1960s, although they were not recognized as such at that time. Using thick layers of HMA was seen as a way of reducing the total section thickness of the pavement. Since then, it has become apparent that this approach to design can lead to asphalt pavements that only need periodic resurfacing. Recently, strategies have been devised to ensure the proper structural design of these pavements. One of the keys to success in Perpetual Pavements is to design the different layers according to the functions they serve. This paper addresses the need to select the proper mixtures for different applications within the pavement structure. Dense graded, open graded, and stone matrix asphalt (SMA) mixtures are discussed and recommendations are made for their uses.

INTRODUCTION

Background

Perpetual pavements, also called extended life or long-lasting asphalt pavements, are not new to U.S. roads. The design and construction of full-depth and deep-strength asphalt pavement structures have been commonplace since the 1960s, when the analysis of the AASHO and other road tests in the U.S. and Britain showed that layers of asphalt mixtures could be successfully substituted for thicker layers of granular materials. (1) While the planning and placement of such asphalt pavements do not guarantee their ultimate performance, it is well known that when they are properly constructed these pavements can last for decades with only minimal traffic disruption to occasionally renew the surface material.

One of the chief advantages of these pavements is that the overall section of the pavement is thinner than those employing thick granular base courses. Because the total thickness of asphalt bound layers is greater, the potential for traditional bottom-up fatigue cracking and structural rutting are reduced, and pavement distress may be confined to the upper layer of the structure. Avoiding fatigue cracking that propagates from the bottom of the pavement and avoiding structural rutting is important because the long-term remedy for these distresses typically involves reconstruction of the pavement section. When surface distress reaches a critical level in a Perpetual Pavement, an economical solution is to remove the very top layer and replace it to the same level with a high-quality HMA surface.

The observations concerning long-life asphalt pavement performance in the U.S. have been confirmed by European experience (2, 3). In fact, the current European efforts in developing long-life asphalt pavement standards (4, 5) are being mirrored in the U.S. The Federal Highway Administration (6) and states such as Illinois (7) have embraced the idea of long-life asphalt pavements have begun initiatives to more thoroughly define the design, construction and maintenance standards.

A number of U.S. laboratory and field studies on Perpetual Pavements are continuing in an effort to refine the technology. Carpenter et al. (8) reported on a laboratory study to identify a fatigue endurance limit for hotmix asphalt, an effort that has been expanded by the Asphalt Institute (9) and through National Cooperative Highway Research Program (NCHRP) Project 1-38 (10).

The Perpetual Pavement concept has been used in the rehabilitation and reconstruction of a portion of Interstate Highway 710 in southern California. During the design and construction, innovative methods were employed to ensure long-life pavement and rapid placement of the roadway (11). This project incorporated the idea of using a “rich” bottom layer in the hopes of improving durability and possibly fatigue behavior. A rut resistant surface layer using a highly polymerized binder was also employed. HMA mixtures were subject to extensive mechanistic testing in the hopes of producing a long-lasting structure. It is now under traffic and performance monitoring is being done.

Beyond the realm of new construction, other efforts such as those by Rowe et al. (12) have examined means for evaluating and maintaining Perpetual Pavements on a portion of Interstate Highway 287 in New Jersey. They found that when the pavement is structurally sound, the placement of a thin overlay using a polymer modified binder in the HMA could keep the pavement in an excellent service condition.

Recent efforts in materials selection, mixture design, performance testing, and structural design offer the means to obtain long-lasting performance from asphalt pavement structures (greater than 50 years) while periodically replacing the pavement surface. The thrust is to combine a rut resistant, impermeable, and wear resistant top structural layer with a rut resistant and durable intermediate layer and a fatigue resistant and durable base layer as shown in Figure 1.

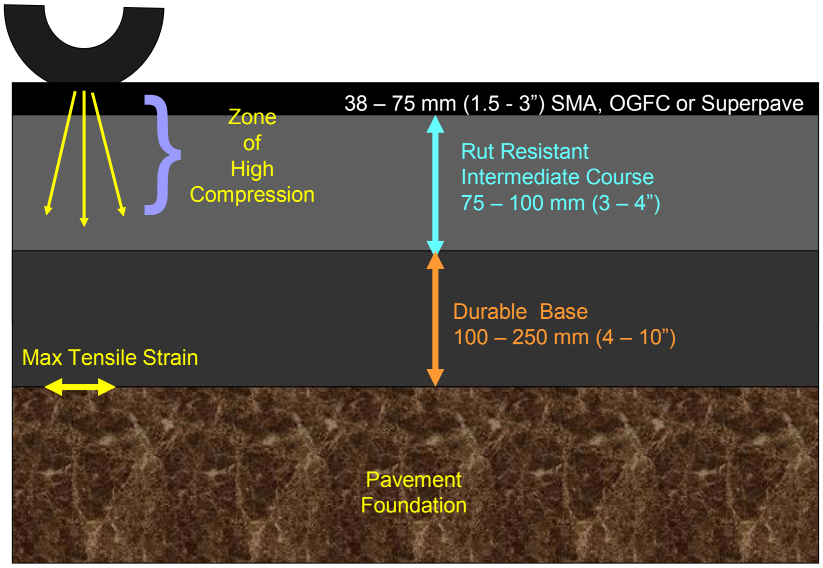

Figure 1. Perpetual Pavement Design Concept.

Scope

This paper will examine the role of hot mix asphalt (HMA) type selection relative to the desired performance of Perpetual Pavements. The characteristics of the base course, intermediate course, and wearing surface will be discussed in terms of the types of mixes satisfying these requirements.

PERPETUAL PAVEMENT DESIGN

Currently, the practice of pavement design is undergoing a transition from purely empirical methods to mechanistic-empirical design. Empirical approaches do not consider each pavement layer to explain its characteristics relating to fatigue, rutting, and temperature cracking. Instead, combinations of strength and layer thicknesses are used to predict a loss in ride quality or increase in distress levels over a given time period. Since each layer has its own part to play in performance, a new structural design method is needed to analyze the contribution of each pavement layer in the overall quality. The mechanistic-empirical approach meets this need.

Mechanistic techniques for asphalt pavement design have been around since the 1960s, although wider development and implementation started in the 1980s and 1990s. States such as Washington, Kentucky, and Minnesota are currently adopting mechanistic design procedures, and the American Association of State Highway and Transportation Officials is proceeding on the development and implementation of a new mechanistically-based pavement design guide.

Knowing the critical points in the pavement structure, one can design against certain types of failure or distress by choosing the right materials and layer thicknesses. In the case of the perpetual pavement, it would consist of providing enough stiffness in the upper pavement layers to preclude rutting and enough total pavement thickness and flexibility in the lowest layer to avoid fatigue cracking from the bottom of the pavement structure.

The approach adopted in California (13) is to consider the following pavement responses:

1. Shear strain in the surface layer underneath the edge of the loaded tire,
2. Horizontal strain at the bottom of the HMA underneath the wheels, and
3. Vertical strain at the top of the subgrade layer.

This method of design allows the pavement engineer to focus attention on selecting materials and asphalt mixtures that allow the pavement to achieve a very long performance life.

Timm and Newcomb (14) used this type of approach in the development of PerRoad, a design procedure which allows the user to input material properties, seasonal variations, material variability, and traffic to assess the pavement responses against limiting values. They used a probabilistic approach which allows the designer to evaluate the percent of time that critical design values are below the threshold values. Layer thicknesses can then be selected according to the relative risk of exceeding these levels.

DESIRED PAVEMENT LAYER CHARACTERISTICS

Crucial to the function and performance of long-life asphalt pavements is the proper selection of mixture types for the layers in the HMA. All layers should possess durability and constructability. Demands for fatigue resistance, rutting resistance, safety and noise reduction will depend upon the individual layer being designed.

Constructability is usually translated to mean the ability to compact the material. For this, guidance is given in NCHRP Report No. 531 (15). The recommendation from this study is for the individual lift of material being placed to be four times the nominal maximum aggregate size of the mix for coarse graded mixtures or three times the nominal maximum aggregate size for fine graded mixture. Much of the guidance here and further useful information can be found in Garcia and Hansen (16).

Durability is the material's resistance to aging and weathering and it is a requirement for all pavement layers. Except where water is intended to drain through the mix, the HMA should be as impermeable as possible so that water cannot find its way into the structure and cause stripping or other moisture susceptibility problems. The aggregate should not be susceptible to freeze-thaw damage, and this can be assessed through sodium or magnesium sulfate testing. It is advisable to perform some sort of test on the mixture's ability to resist moisture damage such as the AASHTO T283 test or the Hamburg Rut Test.

HMA Base Course

This layer comprises the greatest portion of the HMA in a pavement structure. Although it is not subject to the same demands as the surface course, it may still be in the zone of high compressive stresses, and it is exposed to perhaps the wettest continuous conditions from the surrounding soil in the HMA. Since it is located at the bottom of the HMA, it is here that the fatigue resistance of the pavement is truly important.

Fatigue resistance is mostly provided by the total thickness of all HMA layers. The tensile stress, and therefore the tensile strain, at the bottom of the HMA decreases as a function of the cube of the thickness. This strain reduction due to increasing thickness provides more protection against fatigue cracking than relying solely on increasing modulus which provides a linear decrease in tensile strain. However, the French (17) have used a high modulus base mix to justify a thinner section in their long-life asphalt pavements.

Durability in this bottom layer of HMA can be increased by decreasing the permeability of the mix. This can be accomplished in two ways. One is to use a fine graded mix which leads to smaller and more encapsulated air voids. Another method is to use a coarser, large stone mix with a lower design air void content, say 3.5 percent as opposed to 4.0 percent. The larger sized aggregate may be more economical in some regions since not as much crushing is required. It can also form the basis for a rut-resistant stone skeleton, and the added asphalt will decrease the permeability sometimes associated with these mixtures.

The impermeability of the base will be directly affected by the ability to compact the material. As mentioned before, selecting the appropriate lift thickness for the nominal maximum aggregate size is key to improving the compaction and reducing the permeability. Also important to this objective is the condition of the pavement foundation which provides the reaction to compaction forces. A stiffer, uniform foundation will result in better HMA density than one which is relatively soft or non-uniform (18).

In consideration of economy and performance, dense graded HMA is recommended for use in base layers. Either fine graded or coarse graded mixtures can be used, however precautions should be taken with coarse graded mixtures to avoid problems with segregation and permeability. Generally speaking, unmodified asphalt binder should be used in the mix with typical aggregates. If traffic is allowed on the base mix for an extended period of time, a polymer modifier or a crushed gravel or stone might be considered to avoid premature rutting (16).

In some cases, an asphalt-treated permeable base (ATPB) may be used as a drainage layer. This is an open-graded mixture, usually made with a large NMAS, placed to remove moisture from underneath the pavement. In order to prevent moisture from being trapped under pavement, edge drains are highly recommended with ATPBs, and along with edge drains comes the need to clean and maintain the outlets.

Intermediate or Binder Course

The intermediate or binder course is placed between the base and wearing surface. This portion of the pavement is subject to higher stresses than the base, however it is not exposed to the traffic and elements that the wearing course experiences. Typically it is placed in a thinner layer than the base, and the nominal maximum aggregate size is smaller than in the base. Using a smaller sized aggregate will also facilitate the smoothness of the final wearing course.

It is not generally recommended to use mix types other than dense graded mixtures in the intermediate layer, because it is often not warranted. If heavy loading is expected or the facility is subjected to high traffic, then polymer modified asphalt could be used in conjunction with crushed aggregate to provide rutting resistance. Even on medium traffic roads, if the intermediate course is subjected to traffic for an extended period, then the use of crushed aggregate might be justified to prevent rutting before the surface is placed.

The ability to achieve proper density in the HMA binder layer will depend upon the support from the base layer. If the base does not provide a firm reaction surface to the compactors then the intermediate layer will bend excessively and most likely crack. This will provide an avenue for moisture to penetrate the material and adversely affect its durability.

The intermediate layer is often subjected to the highest shear stresses in the HMA layers as shown in Figure 2. This makes the tack coat between the surface and binder course very important. If the shear stress overcomes the interface friction, the surface layer could slip over the binder layer resulting in surface cracking. The high shear stress in this layer also makes it imperative that the mix be as resistant to permanent deformation as possible. Thus, rut testing or permanent deformation testing may be warranted, especially on high volume roads.

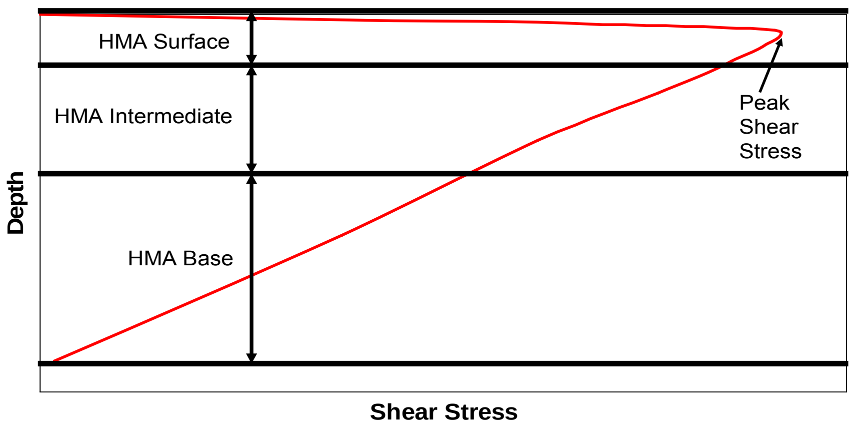

Figure 2. Shear Stress Variation with Depth at the Edge of Load in HMA.

Surface or Wearing Course

This is the top of the pavement, and it is subjected to the harshest traffic and climatic conditions. It is also the location of the tire/pavement interface where safety and noise reduction considerations must be taken into account.

Because of high vertical compressive stresses from truck tires (Figure 3), it is advisable to use crushed aggregate for both medium and high traffic conditions, while a limited amount of gravel might be used in the mix for low volume roads. For the same reason, a polymer modified asphalt should be used as the binder for high-volume roads.

This portion of the pavement will also be subjected to the highest temperature changes as illustrated in Figure 4, so the thermal stresses, both on a daily and an annual basis, will be higher than for the lower layers of the pavement. In some parts of the country, such as the northern tier and the high desert, a polymer modified asphalt that will allow the material to be subjected to low temperatures without cracking will be justified.

Safety encompasses two issues: skid resistance and visibility. Skid resistance is normally accommodated through the use of low-polish value aggregates or, in some instances, by specifying particular mineralogy. In dense and gap graded aggregate mixtures, it is important that the surface have the proper microtexture to provide friction. Visibility may be enhanced through the reduction in splash and spray by the use of an open graded friction course (OGFC). These mixtures are designed to drain water off the surface of the road, reducing hydroplaning and improving the visibility of drivers. OGFC mixtures have gained more acceptance in the southern U.S. than in the north, but there are states, particularly in the northeast that have used them with good success.

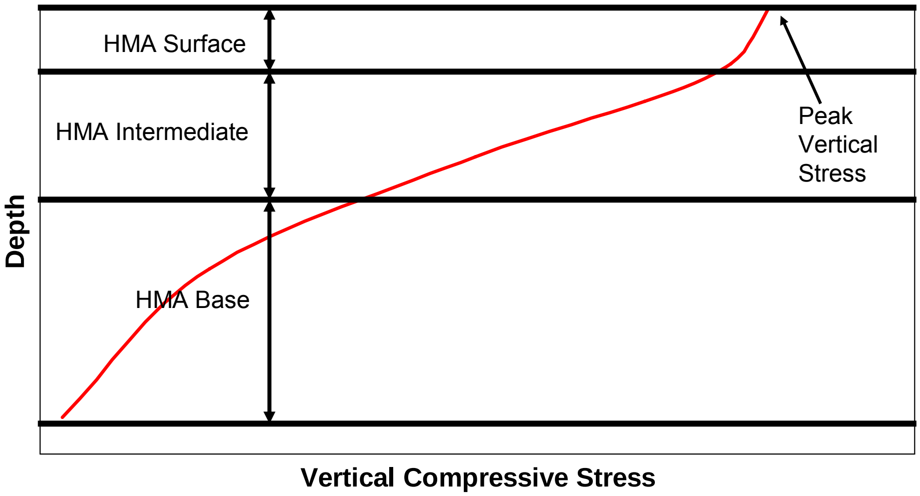

Figure 3. Vertical Compressive Stress Variation with Depth at the Center of Load in HMA.

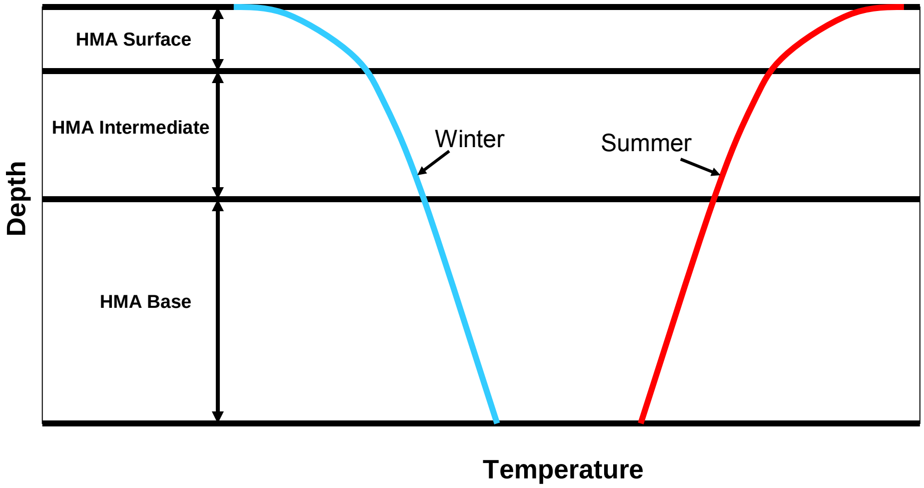

Figure 4. Temperature Variation with Depth for Summer and Winter.

Noise reduction (19) is important in metropolitan areas and environmentally sensitive areas. Road noise is caused primarily by the interaction between tire treads and pavement surfaces at speeds greater than 80 km/hr (50 mph). The road surface can be specifically designed to reduce road noise by using a smaller microtexture. Generally, the approach should be to use a smaller surface aggregate to reduce noise or provide a porous pavement surface that can absorb the sound. In the former case, a small NMAS dense graded or gap graded mixture can be used, and in the latter, an OGFC with a smaller sized aggregate such as 9.5 or 12.5 mm can work very well.

MIX TYPE SELECTION FOR FUNCTION

As discussed in the previous section, the layers of a Perpetual Pavement are designed for specific purposes according to desired characteristics and the distresses that may originate at specific locations within the pavement structure. In this section, the desired features are discussed along with the types of mixtures providing those characteristics.

Dense Graded Mixtures

Dense graded asphalt mixtures have been the traditional standard for HMA pavements. Of the different types of mixtures discussed in this paper, they are the most economical and the easiest to produce. Ranging from a 37.5-mm to a 4.75-mm NMAS, these mixtures provide a great deal of flexibility in their application from large-stone mixes used in heavy loading applications to thin overlays. Since the advent of Superpave, studies have shown that surface rutting has decreased dramatically (20). The survey of contractors and state highway agencies included in that work showed that the overall performance of asphalt roads has improved with Superpave. Since these mixtures may be used in all layers of a Perpetual Pavement, they must possess some aspects of all the characteristics mentioned above.

Durability can be achieved in dense graded mixes by ensuring good compaction and choosing the proper mix for a specific location in the pavement. The use of coarse graded aggregate with a large NMAS can result in permeability that is undesirable, especially on the surface. Reducing the permeability of large stone mixes can be achieved by using thicker lifts for compaction, reducing target air voids, and using as dense a gradation as possible while maintaining the proper voids in mineral aggregate (VMA).

Resistance to permanent deformation is important in surface and intermediate HMA layers. Proper material selection for dense graded mixes is important in maintaining this characteristic. The two aspects mixtures must have to resisting rutting are the internal friction provided by the aggregate interlock and the cohesiveness or stiffness of the binder. It is not so important that the mix contains large or coarse graded aggregate as it is that an interlocking between crushed aggregate is achieved. A study conducted at the National Center for Asphalt Technology has shown that fine graded mixtures may provide as much resistance to rutting as coarse graded (21). As mentioned above, high temperatures in the surface may dictate the use of a polymer modified asphalt binder in the wearing course.

Cracking resistance in dense graded mixtures must come primarily from the binder, although there is some indication that crack growth in mixtures with finer aggregate gradations may be slower than in mixtures with coarser aggregate. A recent survey showed that thermal cracking has decreased since the introduction of the Superpave PG grading system for asphalt binders (20) which points to the need for proper asphalt selection for the surface and binder courses. As previously mentioned, fatigue cracking resistance should primarily come from the thickness design of the Perpetual Pavement rather than relying only upon the characteristics of the HMA base layer. Carpenter (8) has shown that asphalt mixtures have an endurance limit or a limiting strain value of about 70 $\mu\varepsilon$ below which fatigue damage will not occur.

Gap Graded or Stone Matrix Asphalt (SMA)

This asphalt mixture technology was brought to the U.S. from Europe in the early 1990s where it has served as the premier surface mixture (22). Since that time, SMA has become a standard high-volume surface mix in a number of states, including Maryland, Georgia, Wisconsin, Indiana, Michigan, and others. It is a rut-resistant and crack-resistant asphalt surface mixture. Gap grading of the crushed aggregate provides for mechanical interlocking that resists rutting. The high VMA is largely occupied by the mastic which is comprised of asphalt, mineral filler, and fiber. The mastic keeps the mix from being permeable and helps it to resist cracking.

A polymer modified binder is typically used in SMA. This provides additional protection from rutting as well as providing a stiffer binder that will not flow out of the mix (drain-down) during construction. The mineral filler used in SMA is usually a high quality material generated from aggregate crushing operations. High quality filler helps to stiffen the asphalt more. The fiber may be either cellulose or mineral fiber, and it helps to keep the mastic in place during construction as well as providing some tensile capability within the mix.

Production of SMA requires close attention to detail, because control of aggregate, asphalt and additive proportions is crucial to both the construction and performance of the material. Because SMA is a binder-rich mixture, its placement and compaction is frequently cited as being easier than conventional dense graded mixes. More details on the design and construction of SMA mixtures may be found in Hughes and Kandhal (22).

Open Graded

The use of open-graded mixes is increasing in the U.S. Several technological advances have made this type of mixture more popular, especially as an asphalt surface. Open-graded mixtures contain a one-size aggregate, and unlike SMA the VMA is primarily air voids so that water can drain through the mix. This prevents water from accumulating on the pavement surface which eliminates hydroplaning as well as the splash and spray that can occur on more impermeable surfaces.

Since they are used primarily on the surface of high-volume roads, it is important that the aggregate in OGFCs be 100 percent crushed material to resist rutting. The asphalt binder should be polymer modified to add more strength to the mix, and fiber should be added to reduce drain-down and promote a thicker film of asphalt to coat the aggregate. The OGFC should be designed so that it has an air void content in the range of 18 to 22 percent (23).

Asphalt treated permeable bases are generally used at the bottom of pavements in areas where it is desirable to remove water from underneath pavement structures. They are generally large-stone open graded mixtures of 25 or 37.5 mm (1 or 1.5 in.) aggregate. The asphalt content is usually low, being on the order of two percent or so. The binder in ATPB is unmodified, and would be typical of that found in other HMA base layers. Because of its placement at the bottom of the HMA structure, it is important that the aggregate selected for this type of mixture have a history of resistance to stripping.

SUMMARY OF RECOMMENDATIONS

Where it is practical and meaningful, performance testing of HMA mixtures, especially during the mix design is very desirable. At this point in time, performance predictions based on the physical testing of asphalt mixtures is crude at best, but performance testing does allow for comparison between different mixtures and might indicate any potential for early failure. An excellent reference on performance testing is Zhang et al (24). While bottom-up fatigue cracking and deep structural rutting may be adequately addressed through proper design, other distresses such as surface rutting and durability require proper material selection, and, in some cases, testing.

Table 1 shows recommended mixture types for different pavement layers and traffic levels. The thickness of lifts is defined in terms of the nominal maximum size of the aggregate for proper constructability and compaction. It needs to be stated that a given layer of the HMA (base, intermediate, surface) may be comprised of more than one lift of material. While the recommendations for the different types of mixtures are taken from Garcia and Hansen (16), the lift thicknesses have been modified according to NCHRP Report 531 (15).

Table 1. Summary of Mix Type Recommendations for Perpetual Pavements (After 16 and modified according to 15).

Pavement Layer	**Mix Type**	**NMAS, mm (in.)**	**Lift Thickness Range, mm (in.)**[1]	**Traffic Level, MESAL**[2,3]		
				<0.3	**0.3-10**	**>10**
Base	Dense, Fine	37.5 (1-1/2)	110-150 (4.5-6)	√√	√√	√√
		25 (1)	75-100 (3-4)	√√	√√	√√
		19 (3/4)	60-75 (2.5-3)	√√	√√	√√
	Dense, Coarse	37.5 (1-1/2)	150-190 (6-7.5)	√√	√√	√√
		25 (1)	100-125 (4-5)	√√	√√	√√
		19 (3/4)	75-100 (3-4)	√√	√√	√√
	ATPB	37.5 (1-1/2)	75-100 (3-4)			√√
		25 (1)	50-100 (2-4)			√√
		19 (3/4)	40-75 (1.5-3)			√√
Intermediate	Dense, Fine	25 (1)	75-100 (3-4)	√√	√√	√√
		19 (3/4)	60-75 (2.5-3)	√√	√√	√√
	Dense, Coarse	25 (1)	100-125 (4-5)	√√	√√	√√
		19 (3/4)	75-100 (3-4)	√√	√√	√√
Surface	Dense, Fine	19 (3/4)	60-75 (2.5-3)	√√	√√	√
		12.5 (1/2)	40-60 (1.5-2.5)	√√	√√	√
		9.5 (3/8)	25-40 (1-1.5)	√√	√√	√
		4.75 (1/4)	15-20 (0.5-0.75)	√√	√√	√
	Dense, Coarse	19 (3/4)	75-100 (3-4)			√√
		12.5 (1/2)	50-60 (2-2.5)			√√
		9.5 (3/8)	40-50 (1.5-2)			√√
	SMA	19 (3/4)	50-60 (2-2.5)		√	√√
		12.5 (1/2)	40-50 (1.5-2)		√	√√
		9.5 (3/8)	25-40 (1-1.5)		√	√√
	OGFC	12.5 (1/2)	25-40 (1-1.5)			√√
		9.5 (3/8)	20-25(0.75-1)			√√

Notes:

1. Lift thickness conversion is approximate for practical design.
2. MESAL – Millions of Equivalent Single Axle Loads
3. (√) indicates “Recommended”, (√√) indicates “Strongly Recommended”.

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