Concepts of Perpetual Pavements

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The construction of long-lasting hot mix asphalt pavements has been practiced for a number of decades in the United States. Full-depth (asphalt courses used for all layers above subgrade) and deep-strength (asphalt surface and asphalt base over a minimal aggregate base above subgrade) pavements were originally designed for 20-year life expectancies. One of the primary advantages to these designs was that the total pavement sections were thinner when compared to conventional designs of asphalt over thick aggregate bases. As these full-depth and deep-strength pavements performed beyond their design lives, the vast majority only required surface restoration such as a thin overlays or mill and overlay. This practice of replacing only the surface offers a number of rehabilitation advantages in terms of speed of construction (user delay costs) and construction costs. The challenge for today is to obtain a longer surface life on a long-lasting asphalt support structure. Recent efforts in materials selection, mixture design, performance testing, and pavement design offer a methodology which may be employed to obtain very long-term performance from asphalt pavement structures (greater than 50 years) while periodically (approximately every 20 years) replacing the surface (top 25 to 100 mm) of the pavement. This concept has been proposed for use in Europe and it is rapidly gaining acceptance in the United States. The common theme in these approaches 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.

The concept of long-lasting asphalt pavements is not new. Full-depth and deep-strength asphalt pavement structures have been constructed since the 1960s. Full-depth pavements are constructed directly on subgrade soils and deep-strength sections are placed on relatively thin (4 to 6 in.) granular base courses. 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. Such pavements have the added advantage of significantly reducing the potential for fatigue cracking by minimizing the tensile strains at the bottom of the asphalt layer. Furthermore, a study by the National Center for Asphalt Technology suggests that when rutting occurs in thick pavements, it is likely to be confined to the top 2 in. of the structure (*1*). When this occurs, an economical solution is to remove the top layer of material and replace it to the same level (mill and fill).

Thick asphalt pavements must be designed and constructed to ensure performance for the traffic, climate, and soils in given areas. For example, unless proper attention is given to frost protection, ride quality may degenerate from good to poor in a matter of months because of differential frost heave in the subgrade. Other performance problems in thick asphalt pavements could include a lack of durability (stripping) in intermediate layers and thermal cracking allowed

to progress to very severe levels causing a loss of ride quality and secondary fatigue cracking. While these distresses are not unique to thick asphalt pavements, their effects become magnified by the amount of material that must be dealt with when correcting them.

In a case study representative of good performing pavements, a recent review of thick (200 mm or greater) asphalt pavements on Interstate 90 through the state of Washington revealed that none of these sections had ever been rebuilt for structural reasons (*2*). The pavement ages ranged from 23 to 35 years, and thick asphalt concrete (AC) pavements on this route comprise 40 percent of the length (about 225 out of 580 km). West of the Cascade Mountains, near Seattle, the average age at resurfacing was 18.5 years. On the eastern side of the state, the average time until first resurfacing was 12.4 years and the time until second resurfacing was 12.2 years. This type of performance, while good, can be significantly improved with new technology.

Recent efforts in materials selection, mixture design, performance testing, and pavement design offer a methodology which may be employed to obtain long-lasting performance from asphalt pavement structures (greater than 50 years) while periodically (approximately every 20 years) replacing the surface of the pavement. This concept has been proposed by Nunn et al. of the Transport Research Laboratory in the United Kingdom (*3*). The California Department of Transportation, with the assistance of a research team at the University of California, Berkeley, is planning the rehabilitation of a concrete freeway near Long Beach using the concept of a perpetual asphalt pavement as an overlay to the broken and seated concrete (*4*). Finally, Von Quintas proposed this approach in the rehabilitation of the southeast corridor in Denver (*5*). The common theme in these approaches 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 (Figure 1). For areas where the use of an open-graded friction course is desired, this feature can be incorporated and viewed as a renewable wearing course.

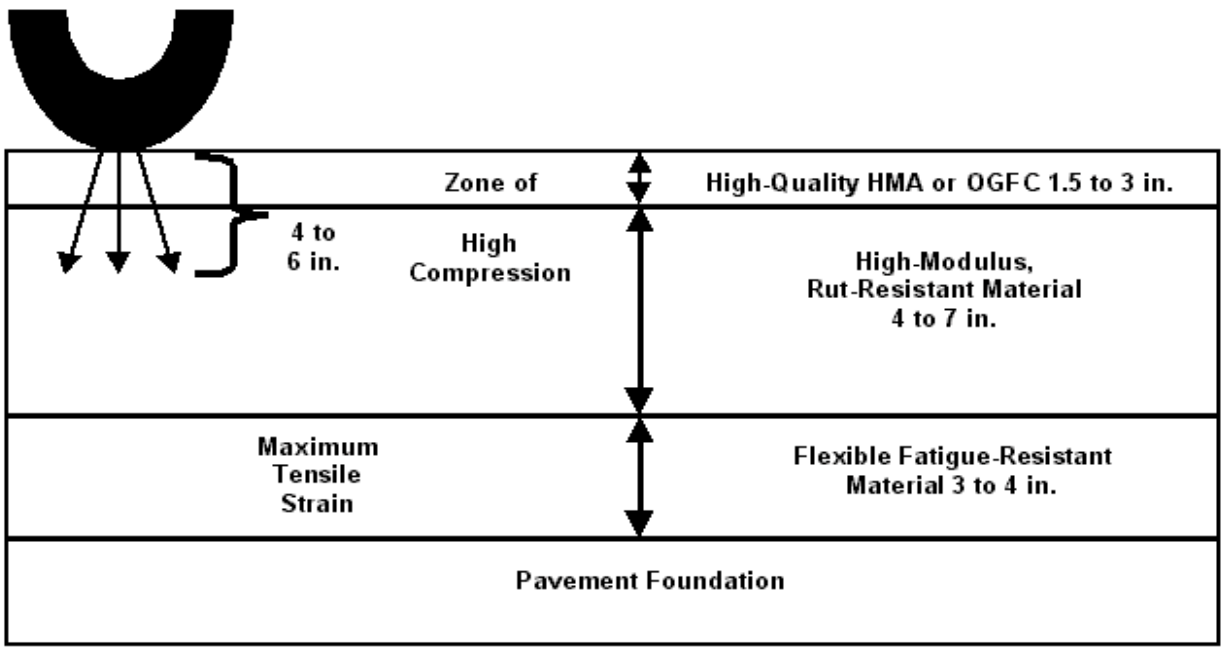


FIGURE 1 Perpetual pavement design concept (HMA = hot-mix asphalt).

MECHANISTICALLY BASED DESIGN

Given the innovative approach to performance-specific design in each layer, it will be necessary to use a structural design method that allows for an analysis of each pavement layer. Most current pavement design procedures do not consider each layer of the asphalt pavement structure. Instead, all of the asphalt layers are considered in combination using a factor such as a layer coefficient in the 1993 *AASHTO Pavement Design Guide*. This layer coefficient represents the behavior of the material relative to overall pavement performance, in terms of serviceability, at the AASHTO Road Test. It cannot be used to explain the load carrying characteristics of the pavement with respect to fatigue, rutting, and temperature cracking. Thus, a newer approach to pavement design is needed—the mechanistic–empirical approach.

The concept of using a mechanistic approach to pavement design is not new. Techniques for calculating stresses in asphalt pavements have been around for over 60 years. Using these tools for design dates back to the 1960s, although wider development and implementation started in the 1980s and 1990s. States such as Washington, Kentucky, Illinois, and Minnesota are in the process of adopting mechanistic design procedures, and under the auspices of the NCHRP, work is proceeding on the development of a new mechanistically-based *AASHTO Pavement Design Guide*.

In mechanistic design, the principles of physics are used to determine a pavement's reaction to loading. 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.

Monismith and Long have suggested that the limiting tensile strain at the bottom of the asphalt layers should be no greater than 60 $\mu\varepsilon$, and that at the top of the subgrade the vertical strain should be limited to 200 $\mu\varepsilon$ (*4*). Asphalt thickness proposed in other procedures shows these strain levels to be reasonable (*3*, *5*).

In order to initially implement this design procedure, assumptions will have to be made regarding the expected performance of the pavement system. This can be accomplished using existing performance relationships for fatigue failures as done by Von Quintus (*5*), although they would be somewhat conservative. More precise estimates of rutting in the surface and top-down fatigue cracking will have to be developed over time to improve the design concept and avoid overly conservative pavement designs.

MATERIAL CONSIDERATIONS

Since the hot-mix asphalt (HMA) pavement will be tailored to resist specific distresses in each layer, the materials selection, mix design, and performance testing will need to be specialized for each layer material. The mixtures' stiffnesses will need to be optimized to resist rutting or fatigue cracking, depending upon which layer is being considered, and durability will be a primary concern for all layers.

Base Layer

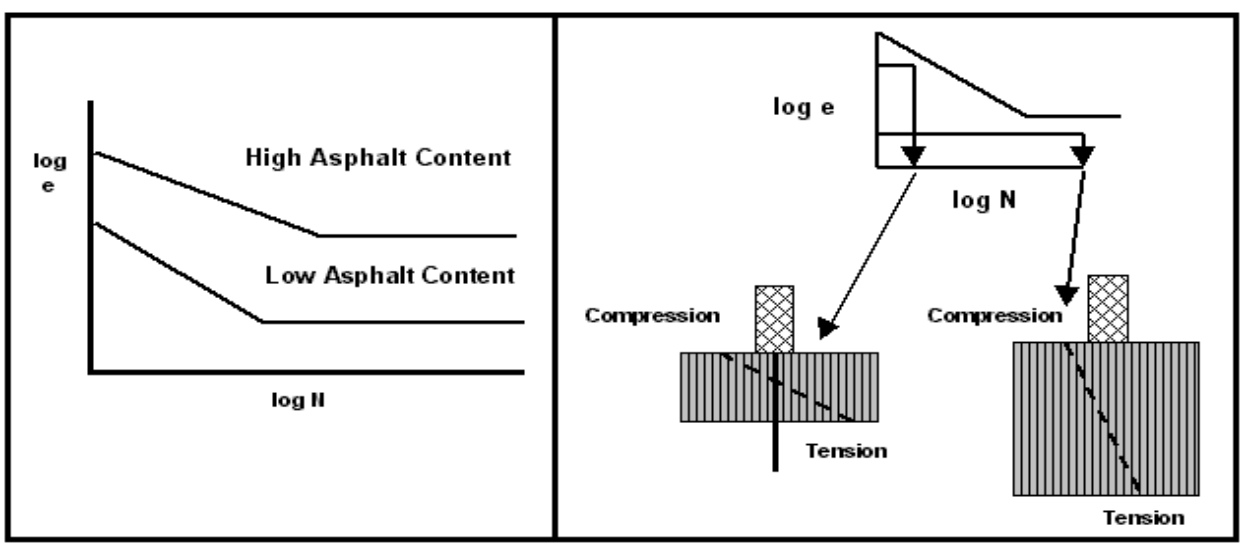
The base layer of HMA must resist the tendency to fatigue crack from bending under traffic loads. The main mixture characteristic which can help guard against fatigue cracking is a higher asphalt content (Figure 2a). The use of a finer aggregate gradation can also make a mixture more fatigue resistant. These characteristics, in combination with an appropriate total asphalt thickness, will provide insurance against fatigue cracking from the bottom layer (Figure 2b). Durability of this layer will be provided primarily by the higher asphalt content.

The mix design for this layer can be accomplished using Superpave guidelines for lower pavement layers. The AC should be defined as that which results in a high in-place density. The asphalt grade used in this layer should be high enough to provide protection against rutting at this layer in the pavement. The low-temperature characteristics should be the same as those of the intermediate layer. If this layer is to be opened to traffic during construction, provisions should be made for rut testing the material. Performance testing for the material in this layer should include a fatigue or stiffness test as well as a moisture susceptibility test.

Another approach to ensuring the fatigue life is to design a thickness for a stiff structure such that the tensile strain at the bottom of the asphalt layers is insignificant. This would allow for the use of a single-mix design in the base and intermediate layers, precluding the need to switch mix types in the lower pavement structure.

Intermediate Layer

The intermediate or binder layer must combine the qualities of stability and durability. Stability in this layer can be obtained by achieving stone-on-stone contact in the coarse aggregate along with using a binder with an appropriate high-temperature grading. The internal friction provided by the aggregate can be obtained by using crushed stone or gravel and ensuring an aggregate skeleton by testing for the voids in coarse aggregate (*6*). One option would be the use of a large



(a) **(b)**

FIGURE 2 Fatigue resistant asphalt base: (a) improve fatigue resistance with high asphalt content mixes, and (b) minimize tensile strain with pavement thickness (log e = log of strain; log N = log of number of cycles to failure).

nominal maximum size aggregate (37.5 mm), but the same effect could be achieved with smaller aggregate sizes so long as stone-on-stone contact is maintained. The high-temperature grade of the asphalt should be the same as the surface to resist rutting. However, the low-temperature grade could probably be relaxed one grade, since the temperature gradient in the pavement is relatively steep and the low temperature in this layer would not be as severe as the surface layer (Figure 3). The mix design should be a standard Superpave approach, and the design asphalt content should be the optimum. Performance testing should include rut testing and moisture susceptibility. Although a test for fundamental permanent deformation properties is currently being developed in a NCHRP project, it is recommended that a rut testing device be used in the interim to evaluate mixtures in order to protect against early rutting.

Wearing Surface Layer

The wearing surface requirements depend on local experience and economics. In some cases the need for rutting resistance, durability, impermeability, and wear resistance dictate the use of a stone matrix asphalt (SMA). This might be especially true in urban areas with high truck traffic volumes. Properly designed and constructed, a SMA will provide a stone skeleton for the primary load carrying capacity, and the matrix (combination of binder and filler) gives the mix additional stiffness and impermeability. The matrix can be obtained by using a polymer-modified asphalt, relatively stiff unmodified binder with fibers, or an asphalt binder in conjunction with specific mineral fillers. Maryland, Georgia, and Wisconsin have had great success in applying SMAs on high-volume roadways. Durability can be achieved by minimizing the voids in the in-place mixture.

In instances where the overall traffic is not as high or in cases where the truck traffic is lower, the use of a well-designed, dense-graded Superpave mixture might be more appropriate.

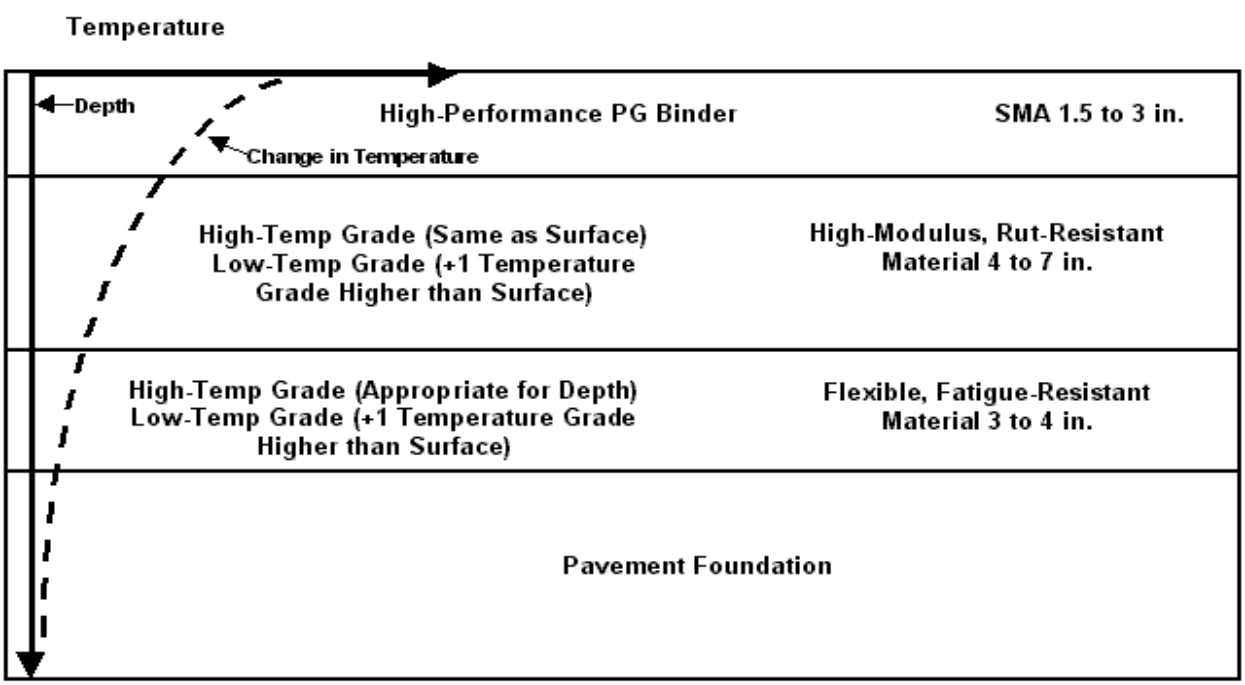


FIGURE 3 Impact of temperature gradient on asphalt grade (PG = performance grade).

As with the SMA, it will be necessary to design against rutting, permeability, weathering, and wear. It is recommended that some type of performance test be done during mixture design; at a minimum, this should consist of rut testing.

Depending upon climate, to avoid rutting the performance grade should be bumped to at least one high temperature grade greater than normally used in an area. The low temperature grade should be that normally used in the area for perhaps a 95 or 99 percent reliability in resisting thermal cracking.

Likewise, by minimizing the total voids in the mixture, the impermeability of the mix is ensured. Wear resistance may be provided by using a high-quality aggregate with a low-polish value. The stiffness of this layer is critical in obtaining a 20-year surface without rutting. The aggregate structure should be evaluated using the approach described for the intermediate layer, and performance testing should consist of rut testing at least.

CONSTRUCTION

Construction of this type of pavement will require great attention to detail and a commitment to build with quality from the bottom up. In the process of building the roadway, modern methods of testing should be employed to give continuous feedback on the quality of materials and construction.

The foundation must be able to support paving and compaction operations. Materials for this layer may include sand or sandy-gravel subgrades, stabilized fine-grained subgrade, unstabilized or stabilized granular base materials, or rubblized concrete. Thus, this layer must be well compacted, smooth, and stiff enough to support construction traffic and provide resistance to rollers. Although no specific guidance exists on what the construction stiffness of the underlying layer should be, this should be relatively simple to determine with tools such as the dynamic cone penetrometer.

In service, one objective would be to minimize volume changes in the foundation layer due to swelling soils or frost heave. Local experience would best dictate how to handle these situations by, for instance, the use of stabilizers, overburden, or soil mixing. Weakening of soils during certain seasons of the year would also need to be addressed, and it might be necessary to provide drainage or a granular interlayer to ensure a consistent foundation during the service life. Nunn suggests a minimum design modulus value of about 50 kPa for the foundation layer (*3*).

With modern HMA pavements, good construction practices ensure good performance. With the possible use of polymer-modified asphalts, it will be critical to avoid overheating the binder in the construction process. New industry guidelines are being developed to ensure the proper handling and application of polymer-modified asphalt binders. Segregation in coarse aggregate mixtures is another area of concern, but again, proper handling of the material during manufacture, transport, and laydown can prevent the problem. Segregation may be measured with infrared temperature techniques and laser texture methods such as the Rosan procedure (*7*). Achieving density in the various layers of HMA can be done by following the lessons learned during the implementation of Superpave and the successful applications of SMA (*8, 9, 10*).

Volumetric control of the mixtures by the contractor will be the key to consistency and quality in the final product. The contractor should have access to a fully equipped and staffed quality control laboratory. Periodic testing and data analysis with good quality control and inspection techniques will ensure that the desired characteristics will be imparted to the pavement. Nuclear methods of testing may be used for the assessment of in-place density, thickness can be continuously monitored with ground penetrating radar, and smoothness can be evaluated with new lightweight profilometers.

PERFORMANCE MONITORING AND RESURFACING

To maintain the pavement in its optimal state, it will be necessary to periodically monitor its performance. The chief idea is to keep all forms of distress in the top few inches of the HMA. Thus, distresses such as top-down fatigue cracking, thermal cracking, rutting, and surface wear may be confined to no deeper than the original thickness of the wearing course. Once the distresses have reached a predetermined level, the surfacing would be programmed and an evaluation of the pavement structure would be undertaken.

It will be important to identify the distress types and levels that should trigger the resurfacing activity. Annual surveys of pavement distress and ride quality will need to be conducted to monitor surface conditions and to track deterioration with time. The structural evaluation would be accomplished by thickness verification using either cores or ground-penetrating radar and by deflection testing. The cores and radar could also be used to indicate problems with moisture susceptibility. The design assumptions inherent in the original design can be verified through deflection testing and interpretation by backcalculation of layer moduli. In the event of changes such as a weakening of the underlying soil through increased moisture content, a slight additional thickness may be planned for the resurfacing to ensure the perpetual nature of the structure.

The first step in the resurfacing process will be the removal of the existing surface to the depth of the distress. This could vary between 1 and 4 in. of milled depth. The milled material would be replaced, and, if needed, a slight additional thickness could be placed. This layer would need to have the same characteristics as the original surface, i.e., rut resistance, durability, thermal cracking resistance, and wear resistance. If new and more promising asphalt surfacing materials are available in the future, they could be employed in the resurfacing. Essential to the performance of the resurfaced pavement is the assurance of bonding between the new wearing course and the existing pavement. A tack coat will be needed to ensure this bond. Pavement monitoring and the programming of future resurfacing would proceed as before.

SUMMARY

The perpetual pavement offers engineers the ability to design for specific modes of distress. Resistance to bottom-up fatigue cracking is provided by the lowest asphalt layer having a higher binder content or by the total thickness of pavement reducing the tensile strains in this layer to an insignificant level. The higher binder content in this layer will also provide durability. The intermediate layer will provide rutting resistance through stone-on-stone contact and durability through proper selection of materials and a greater film thickness on the aggregates. The uppermost structural layer will have the qualities of resistance to rutting, weathering, thermal cracking, and wear, and these may be provided by SMAs or dense-graded Superpave mixtures. An open-graded friction course may be employed in some areas to promote surface drainage and act as a renewable surface.

The knowledge and engineering capability to design and build such a structure exists. However, this information and the design procedure must be synthesized into a useful system for engineers. Also, refinements need to be made to ensure that the concept may be employed at a variety of local levels. It has been suggested that an international team of experts be assembled to accomplish this task. They would be responsible for producing broad guidelines for materials selection, mixture design, pavement design, construction, performance monitoring and

resurfacing. It is expected that individual countries and regions would then tailor the process according to their needs.

The long lasting pavement is a valid concept, and it is gaining national and international momentum. The development of guidelines for pavement design, materials selection and construction could be relatively rapid. Validation of the pavement design procedure and refinement of the materials selection process would need to occur over a longer time period.

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