Technology Transfer Program

TECHNICAL TOPICS

The Technology Transfer Program is the continuing education arm of UC Berkeley's Institute of Transportation Studies. Our mission is to transfer knowledge and skills from university research to applications in the planning, design, construction, operation and maintenance of efficient and effective state-of-the-art transportation systems.

The Pavement Research Center at UC Berkeley has been advancing pavement technical knowledge for nearly 50 years. The Center has led the way for many important discoveries in the field of pavement design including the development of elements of Superpave mix design technology through the Strategic Highway Research Program (SHRP). Currently the Center is conducting large scale accelerated vehicle testing of pavement structures in partnership with Caltrans, the South African Council of Scientific and Industrial Research, and Dynatest USA. A key role of the Center is the training of pavement engineering personnel. Through the Technology Transfer Program, the Center can provide a link between innovative developments in technology and practical engineering applications.

RUT RESISTANT ASPHALT PAVEMENTS

By Larry Santucci, LTAP Field Engineer, Tech Transfer Program
and Pavement Specialist, Pavement Research Center, UC Berkeley

Introduction

The three major distress conditions affecting the performance of asphalt pavements are permanent deformation or rutting, fatigue or load associated cracking, and low temperature or thermal cracking.

In an earlier technical topics article (Fall, 1998), we examined the causes of fatigue cracking and the importance of good compaction during construction to help minimize this type of distress.

In this article, we will examine the causes and potential cures of asphalt pavement rutting. Rutting on the asphalt pavement surface generally results from one of two conditions.

Types of Pavement Rutting

Rutting throughout the entire asphalt pavement structure is caused by overstressing the underlying base or subgrade layers. This overstressed condition can be the result of inadequate thickness design for the applied traffic or for the strength properties of the underlying materials. Moisture infiltration into the base or subgrade can also weaken these layers to the point that they deform permanently under repeated traffic. The rutted condition in the underlying layers is then reflected to the pavement surface, as shown in Figure 1.

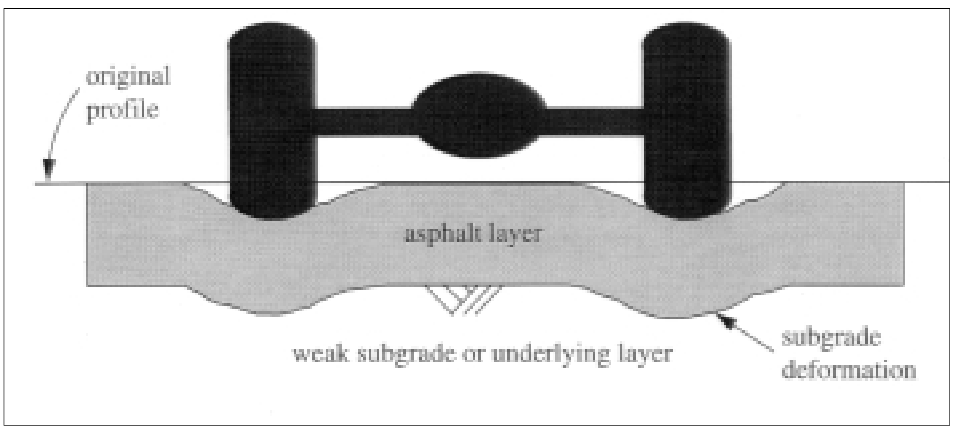

FIGURE 1:
Rutting in Subgrade or Base

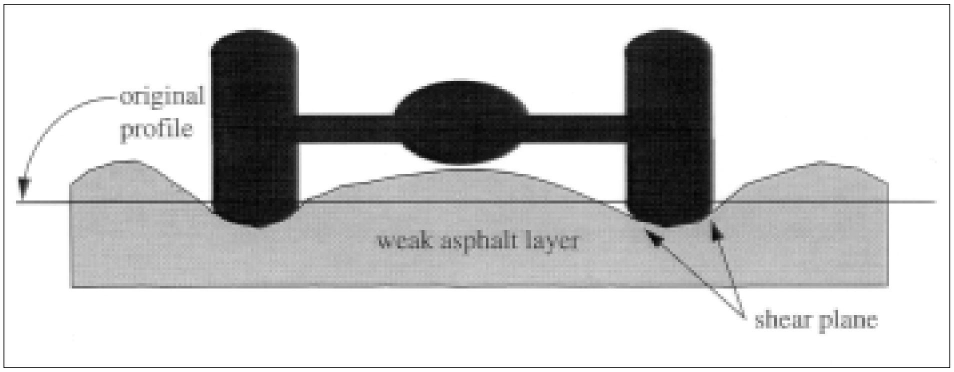

FIGURE 2:
Rutting in Asphalt Layer

A more common form of pavement rutting and the one we will focus on in this discussion occurs in the asphalt mix itself. Here the underlying layers perform fine and their boundary lines are unaffected by the distress occurring near the surface of the asphalt pavement, as shown in Figure 2. Rutting, in this instance, can be the result of an unstable asphalt mix, heavy vehicle traffic, and/or high pavement temperatures. Rutting of this type is often observed at intersections, bus stops, freeway off ramps, or under extreme loading situations on airport runways and dock loading facilities.

How can an engineer determine whether rutting in the asphalt pavement surface is due to distress throughout the entire pavement structure or due to failure in the asphalt layer only? A closer examination of Figures 1 and 2 shows that, in pavement structure rutting, the profile at the pavement surface is depressed fairly uniformly in the wheel paths of the pavement lane. Rutting in the asphalt mix, however, is generally accompanied by mix displacement next to the wheel loaded areas. Where this distinction is not obvious, the engineer should cut some trench sections across the pavement lane and examine the boundary lines of the various layers to determine the source of rutting.

Materials Selection

Aggregate properties and aggregate gradation play a major role in the potential for rutting of an asphalt pavement. The rutting resistance of an asphalt mix depends on the shear resistance of that mix. If the shear stress created by repeated wheel load applications exceeds the shear strength of the mix, as shown in Figure 3, then permanent deformation or rutting will occur. As one might suspect, cubical, rough-textured aggregates are more resistant to the shearing action of traffic than rounded, smooth-textured aggregates (Figure 4). Cubical aggregates also tend to interlock better, resulting in a more shear resistant mass of material. In addition, increased compaction during construction or the use of higher percentages of coarse aggregate fractions in the aggregate gradation provides more stone-to-stone contact in the asphalt mix which, in turn, helps reduce pavement rutting.

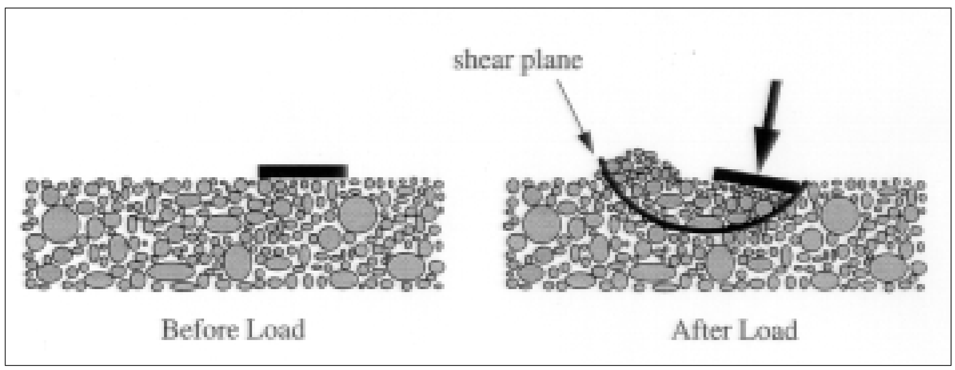

FIGURE 3:
Shear Loading Behavior of Aggregate

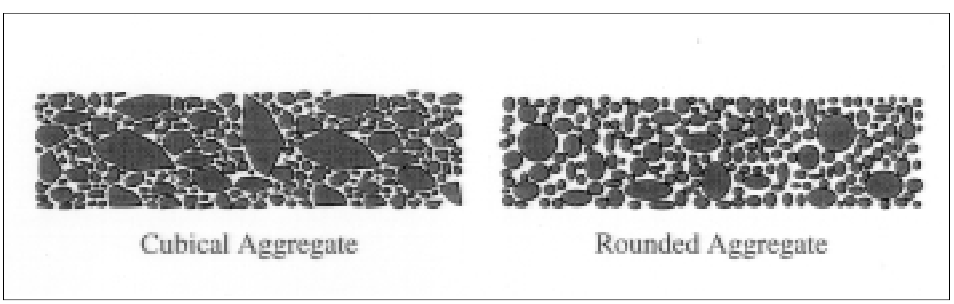

FIGURE 4:
Contrasting Stone Skeletons

The asphalt binder used in the mix also affects the rut resistance of an asphalt mix but to a lesser degree than the aggregate characteristics. A mix made with a soft grade of asphalt

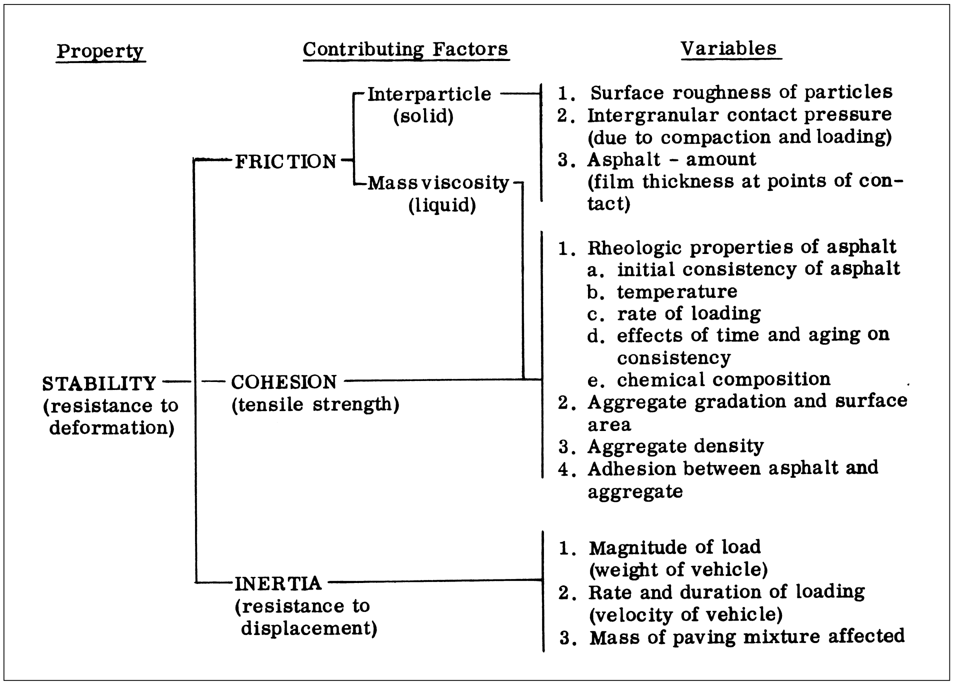

FIGURE 5:

Analysis of Stability of Asphalt Mixtures

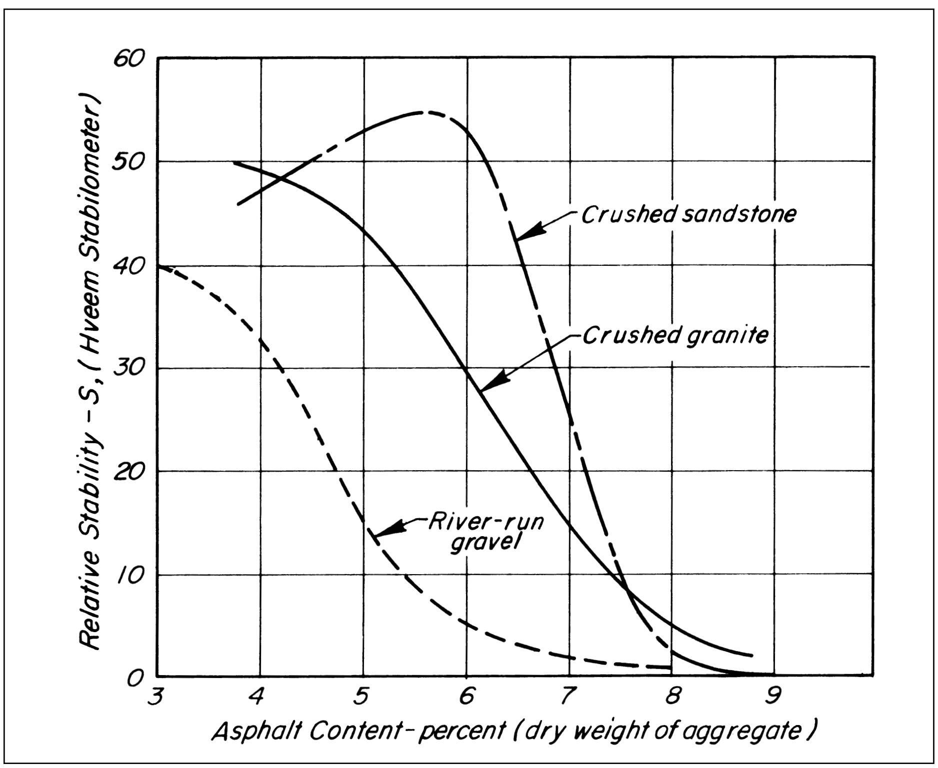

FIGURE 6:

Relationship Between Stability and Asphalt Content for Different Aggregates

cement will be less resistant to rutting at high temperatures than a comparable mix that contains a harder (more viscous) asphalt grade. Rutting in an asphalt mix normally occurs in the early years (<5 years) of a pavement's life when the asphalt binder is relatively low in viscosity. Rutting is less likely to occur in a pavement after the asphalt binder has aged or oxidized with exposure to the elements to a higher viscosity.

Existing mix design procedures measure the stability or strength of asphalt mixes as a way of predicting rut resistance. A mix that provides a high stability value in the laboratory will likely have good rut resistance in the field. The factors that affect stability are listed in the diagram in Figure 5. The importance of crushed versus rounded aggregate in terms of asphalt mix stability is depicted in Figure 6.

The shear resistance of an asphalt mix can be measured more directly in the laboratory using equipment developed from the Strategic Highway Research Program (SHRP). This equipment, called the Superpave Shear Tester (SST), is illustrated in Figure 7. Instrumentation of an asphalt mix specimen to measure displacement under repeated shear load applications is shown in Figure 8. The specimen is normally constrained to a constant height-constant volume condition during the test. The number of load applications to a selected level of permanent shear strain can be determined with the SST.

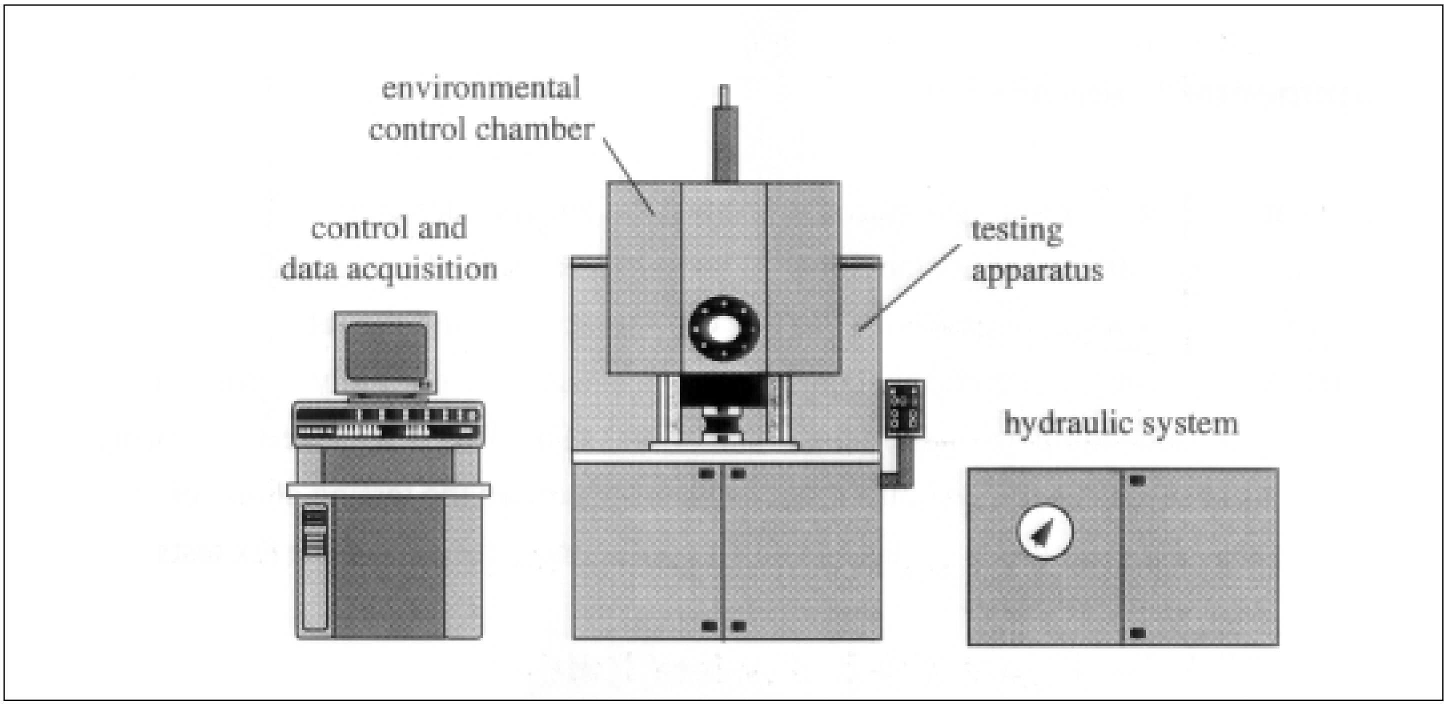

FIGURE 7:
Illustration of Superpave Shear Tester (SST) Made by Cox and Sons, Inc.

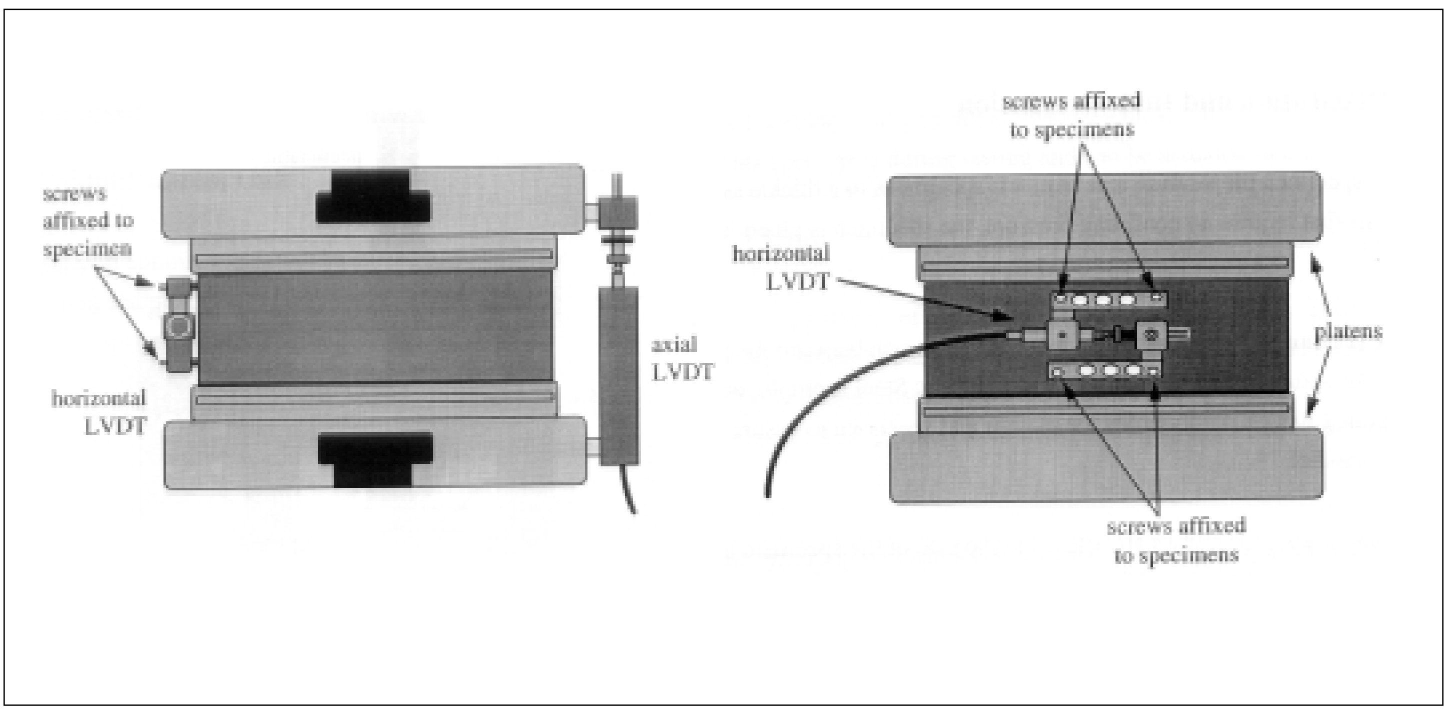

FIGURE 8:
Specimen Instrumentation for Unconfined Cox SST Tests

Modified asphalts can provide greater resistance to rutting at elevated temperatures than conventional asphalts. In the example shown in Figure 9, a PBA 6A polymer modified asphalt mix withstood more repetitions to 5% permanent strain in the SST than an identical mix which contained unmodified AR 8000 asphalt. Repeated load shear tests were run at 50 C for three different asphalt binder contents. The target repetitions indicated on the chart represent design traffic for two different time periods in the life of the pavement structure. The PBA 6A asphalt mix at 4.7% asphalt content exceeds the 660,000 repetition target predicted for the first 5 years of traffic when rut resistance is most critical while the AR 8000 at 4.7% asphalt content satisfies the lower 146,000 repetition level (estimated design traffic during stage construction of the project). As a result, the AR 8000 mix was selected for the main portion (lower layers) of the asphalt pavement structure and the more rut resistant PBA 6A mix was the preferred choice for the upper portion of the pavement.

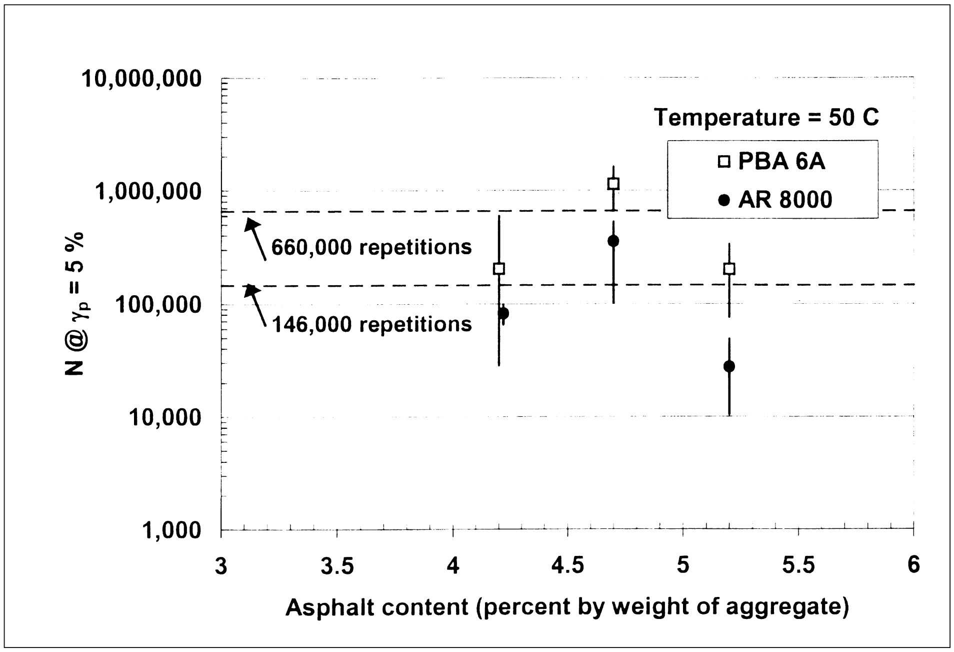

FIGURE 9:
Repetitions to 5 Percent Permanent Shear Strain
Versus Binder Content

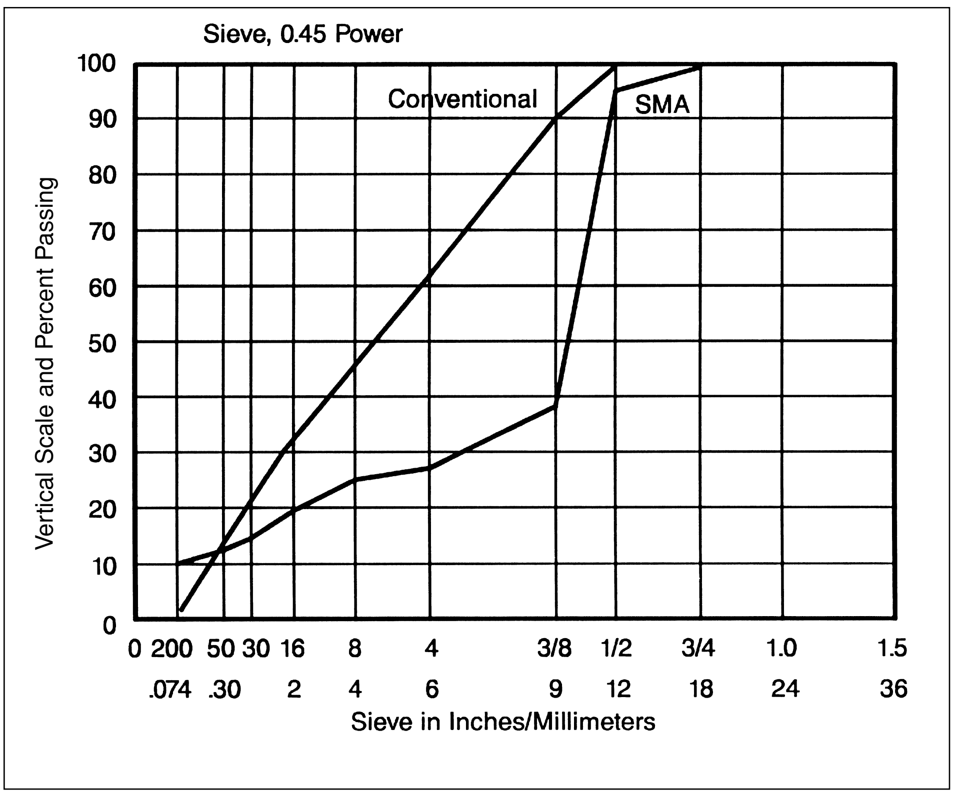

FIGURE 10:
Mix Comparisons

Asphalt Mix Types

The primary asphalt mixes used in California are dense graded mixes with an aggregate gradation similar to that shown for the conventional mix in Figure 10. Other mix types that use higher percentages of coarse aggregates, such as certain Superpave mixes and Stone Matrix Asphalt (SMA) mixes are finding increased use in states such as Maryland and Georgia. SMA mixes have been used successfully in Europe for several years. A typical aggregate gradation for an SMA mix is compared with a dense graded mix in Figure 10. These mixes are designed to provide more direct stone-to-stone contact to help resist rutting. The schematic in

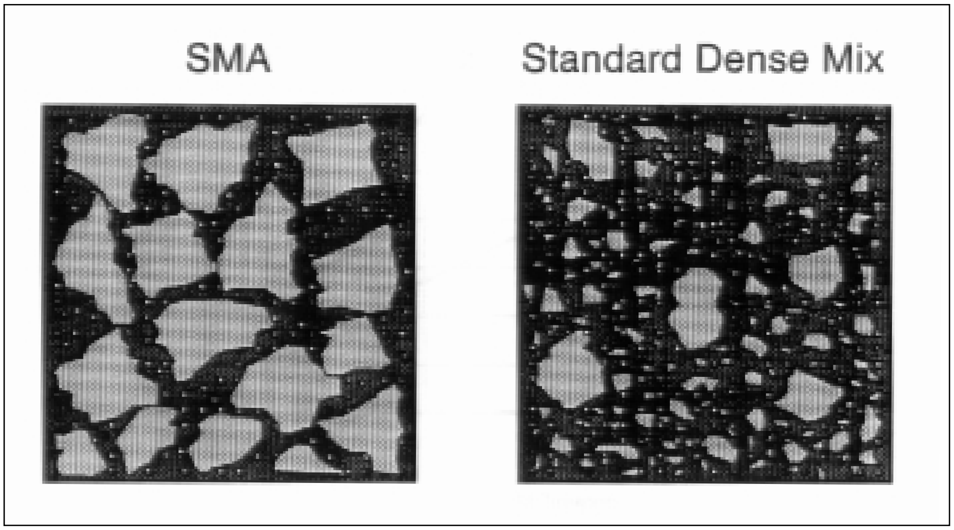

FIGURE 11:
Comparison of SMA to Dense Graded Mix

Figure 11 illustrates the difference in structure between an SMA mix and a dense graded asphalt mix.

In an SMA mix, the stone skeleton is intended to carry the load and the fine aggregate particles are used to fill up the void space in the skeleton. In a dense graded mix, the fine aggregate is locked between larger aggregate particles and load is transferred through the entire uniformly graded structure.

This does not mean that dense graded mixes cannot be rut resistant. Good compaction of a dense graded asphalt mix that forces interlock of high quality rough textured aggregate (both coarse and fine) will produce a mix capable of withstanding the shearing action of repeated vehicle loads.

Compaction Effects

We saw, in our discussion on the fatigue behavior of dense graded asphalt mixes, how good compaction practices during construction could significantly improve pavement fatigue resistance. We noted that about a 3-fold increase in pavement fatigue life can be realized by increasing relative compaction from 95% to 98% or, in essence, reducing air void content in a dense graded asphalt mix from approximately 8-10% to a range of 5-7%.

Similarly, improvements in the rutting resistance of asphalt pavements can be expected with an increased compactive effort. The primary benefit of increased compaction is to pack and orient the aggregate particles in the asphalt mix, as shown in Figure 12, into an interlocking mass of material that resists shear deformations.

An analysis of results from a full scale pavement test track in Nevada, referred to as WesTrack, showed that a reduction in air void content improved the rut resistance of most asphalt pavement sections. Figure 13 illustrates the influence of air void content for a fixed asphalt content, passing 200 percentage, and fine aggregate content on the predicted number of equivalent single axle loads (ESALs) to a 15 mm (0.6 in.) rut depth. Under these conditions, a 1.7-fold increase in rut resistance can be expected from a drop in air void content from 8% to 5%.

The asphalt pavement engineer must be cautious, however, and not overcompact the mix to an unstable condition. Laboratory test results, shown in Figure 14, suggest this condition is reached for a dense graded asphalt mix at about 3% air void content. For example, the stress level at 2 percent strain that an asphalt mix with 5% or more asphalt content can with-

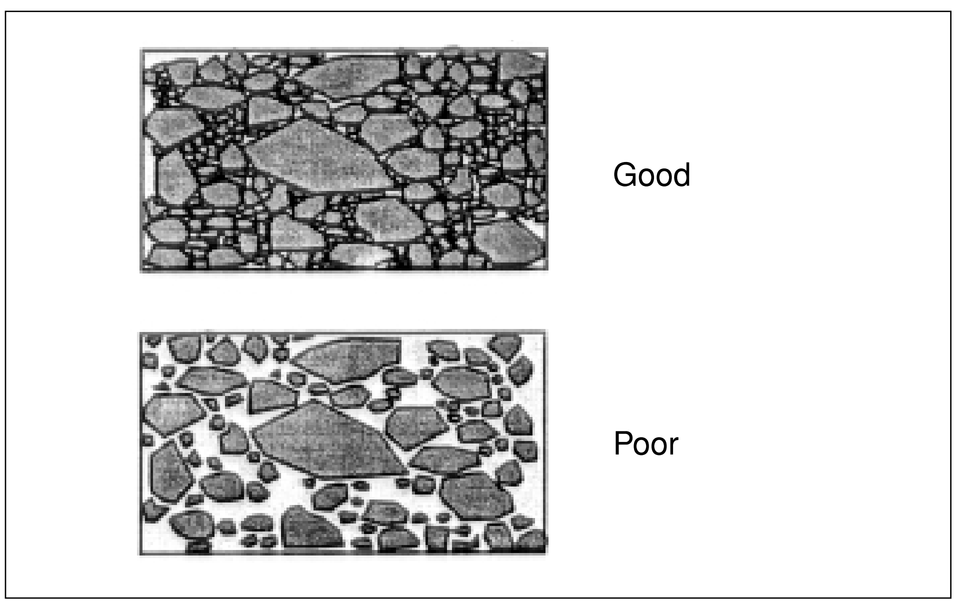

FIGURE 12:
Impact of Compaction on the Orientation and Interlock of Aggregate Particles in an Asphalt Mix

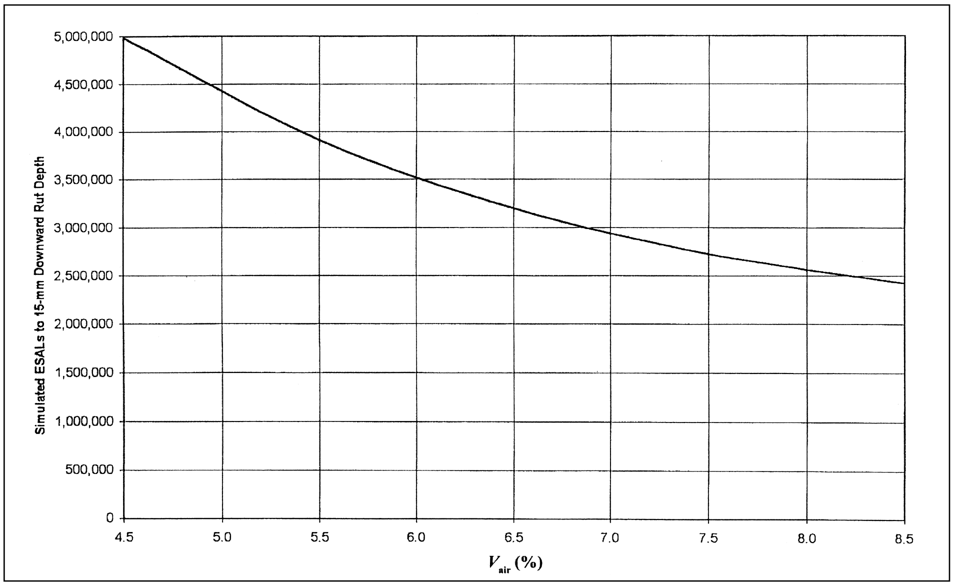

FIGURE 13:

Effect of Mix Variables on Estimated ESALs to 15 mm (0.6 in.) Rut Depth for a Range in Air-Void Contents; P_{Wasp}=5.5%; P_{200}=6.0%; fine aggregate=28%

stand in Figure 14 drops off dramatically for air void contents of 3% or less. An air void content of 5-6% (about 98-99% relative compaction) in the field for a dense graded asphalt mix seems like a reasonable target to realize good rutting and fatigue resistance but still provide a margin of safety against the instability associated with lower void content mixes.

Mix Design Considerations

The Superpave Shear Tester discussed earlier is a very valuable tool for evaluating the rut resistance of an asphalt mix. Superpave Regional Centers and some state transportation laboratories across the country have this equipment. However, it is not broadly used as yet in most asphalt mix design procedures. Therefore, we need to rely on existing procedures, such as the Hveem and Marshall design procedures, until the newer technology developed under SHRP is more widely adopted.

The Hveem mix design procedure, currently used in California, has served the industry well for over 50 years. Unfortunately, limitations to the procedure are beginning to appear as we experience heavier loadings and traffic on our highways and airport runways. One way to account for these increased levels of traffic is to apply additional compactive effort to the asphalt mix specimens we test in the Hveem design procedure.

Based on some research done to evaluate premature rutting failures on the San Francisco airport taxiways, it has been suggested that additional tamps be applied to asphalt mix samples in the Hveem kneading compactor beyond those used in the original procedure. The additional tamps, in the order of 500 to 1,000 depending on traffic loading conditions, are applied at 140 F (60 C) to the mix sample. Hveem Stability Values are then determined on the mix compacted with the standard procedure as well as one subjected to the additional tamps at 60 C. A sharp drop off in stability would indicate a mix that might be susceptible to rutting under heavy traffic. Figure 15 shows the effect of additional tamps on the characteristics of an asphalt mix

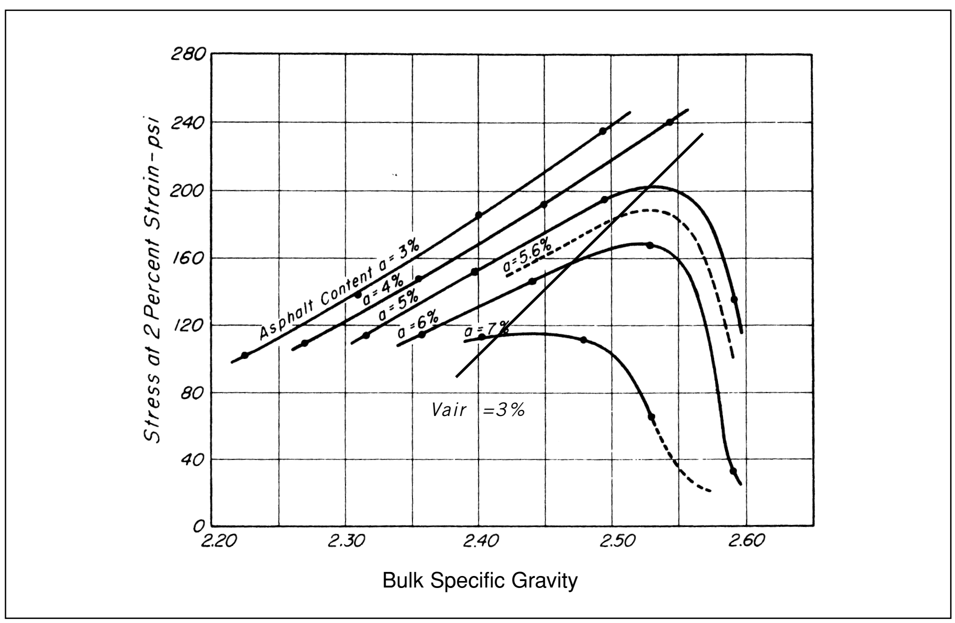

FIGURE 14:

Relationship Between Bulk Specific Gravity (density) and Stress at 2 Percent Strain for Constant Asphalt Contents.

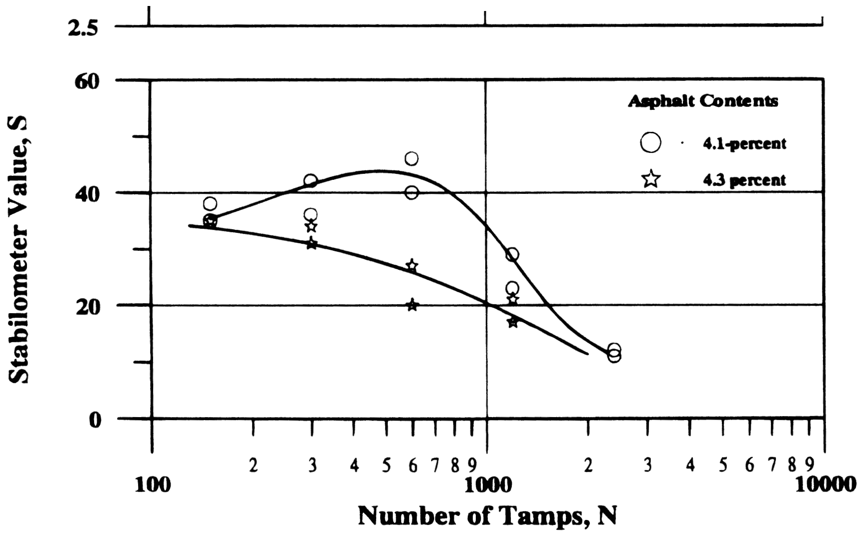

FIGURE 15:

Influence of the Number of Tamps on Hveem Stability Values

designed for heavy loads in a hot desert environment. In this example, an asphalt mix with 4.1 percent asphalt by weight of mix increased in Hveem Stability using up to 600 tamps in the kneading compactor while the same mix with 4.3 percent asphalt showed a sharp drop in stability with additional tamps. This concept is also being used by designers to select appropriate asphalt mixes for intersections, bus stops, etc. where rut resistance is a concern.

Summary

Asphalt mixes can be designed to resist rutting with the proper selection of materials, good construction practices, and the use of appropriate mix design methods. Good quality crushed aggregates and a higher percentage of coarse aggregates in the aggregate gradation play major roles in improving the shear resistance of an asphalt mix. The asphalt binder selected is also important but to a lessor degree than aggregate characteristics.

Good compaction practices during construction will improve the rut resistance of asphalt pavements by increasing the interlock of aggregate particles in the mix. Reducing the air void content (within limits) of dense graded asphalt mixes has been shown in the laboratory and in full scale test pavements to improve the rut resistance as well as the fatigue resistance of the pavement.

Developments from SHRP have provided new testing tools to evaluate the rut resistance of asphalt mixes. Modification of existing mix design procedures to account for heavy traffic situations can be employed now to help designers select higher strength asphalt mixes.

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