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.

MOISTURE SENSITIVITY OF ASPHALT PAVEMENTS

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

Introduction

The presence of water (or moisture) often results in premature failure of asphalt pavements in the form of isolated distress caused by debonding of the asphalt film from the aggregate surface or early rutting/fatigue cracking due to reduced mix strength. Moisture sensitivity has long been recognized as an important mix design consideration. Francis Hveem (1), in 1940, realized the importance of water resistance and identified it along with consistency, durability, and curing rate or setting as the four critical engineering properties that need to be determined in the selection of quality asphalts for pavement construction. A recent survey (2) of 55 state and federal highway agencies showed that 87% of them test for moisture sensitivity and 82% require some type of treatment to resist moisture damage. As the concept of perpetual pavements and long life pavements become more popular, engineers must focus on how to minimize the detrimental effects of moisture damage.

What is Moisture Sensitivity?

Sources of moisture in an asphalt pavement can be either external or internal. Water can enter the pavement externally from the surface, laterally from poorly drained areas, and/or from underlying layers due to high ground water sources as shown in Figure 1. Moisture

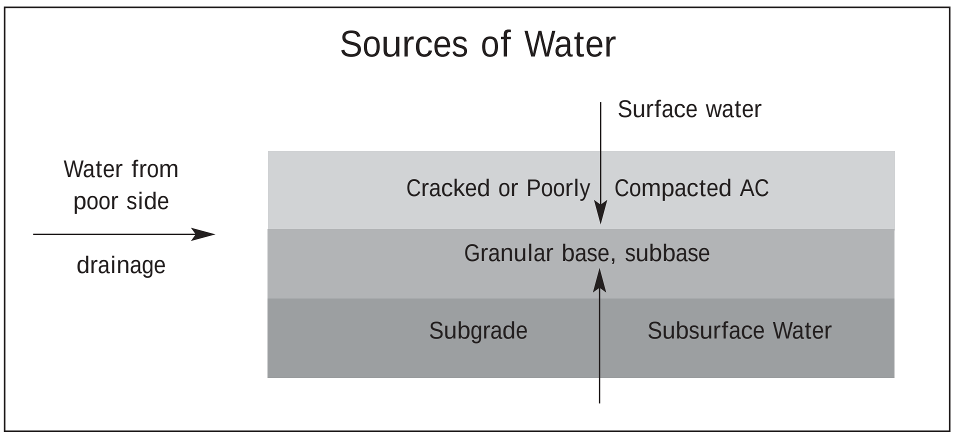

FIGURE 1:
Sources of Water (Moisture) in an Asphalt Pavement Structure.

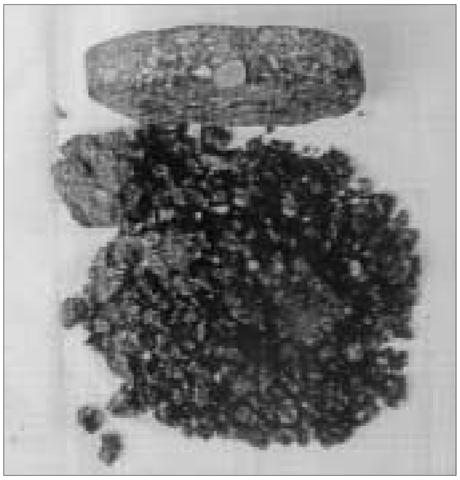

FIGURE 2:
Stripping in on Asphalt Pavement Due to Lack of Bond Between Asphalt and Aggregate.

can also be present internally in a newly constructed pavement as a result of inadequately dried aggregate. The presence of moisture, combined with the repeated action of traffic, accelerates damage to the asphalt pavement.

Moisture damage can come in many forms. Adhesive failure between the asphalt film and aggregate surface results in debonding which, in an advanced state, is identified as "stripping" similar to that shown in Figure 2. In essence, stripping converts a high strength asphalt treated pavement layer to a much weaker untreated aggregate section. When it occurs in isolated spots throughout the pavement, it can rapidly develop into potholes. Over more extensive areas, premature fatigue cracking or rutting may develop due to the reduced support strength of the overall pavement structure.

Debonding is not always necessary in a moisture sensitive situation. Water in the pavement may simply weaken the asphalt mix by softening or partially emulsifying the asphalt film without removing it from the aggregate surface. During this weakened state, the asphalt pavement layer is subjected to accelerated damage from applied traffic. An example of how asphalt mixture strength changes as a result of cycling from a dry to a water saturated condition is shown in Figure 3 (3).

Effects of Moisture Damage

Probably the most damaging and often hidden effect of moisture damage is associated with reduced pavement strength. Figure 4 compares the critical compressive stress and tensile strains at the bottom of an asphalt pavement layer in a moisture-free and moisture damaged pavement. The higher vertical compressive stress in the moisture damaged pavement can result in overstressing the underlying pavement layers and ultimately can create excessive permanent deformation or rutting in the wheel paths on the pavement surface. Higher tensile (bending) strains at the bottom of the treated pavement layer can translate into earlier than expected fatigue failure as shown in Figure 5. The higher bending strain, ε_2, associated with the moisture damaged pavement produces a much lower predicted fatigue life, N_2, than the bending strain, ε_1, associated with the dry asphalt pavement structure.

Contributors to Moisture Sensitivity

Aggregate makes up roughly 95% by weight of a dense graded asphalt mix with the asphalt binder being the remaining 5%. The type of aggregate used and its surface characteristics play a significant role in an asphalt pavement's resistance to water action. Physical properties of the aggregate, such as shape, surface texture and gradation, influence the asphalt content of the mix and hence the asphalt film thickness. Thick films of asphalt resist the action of water better than thin films. Rough surface textured aggre-

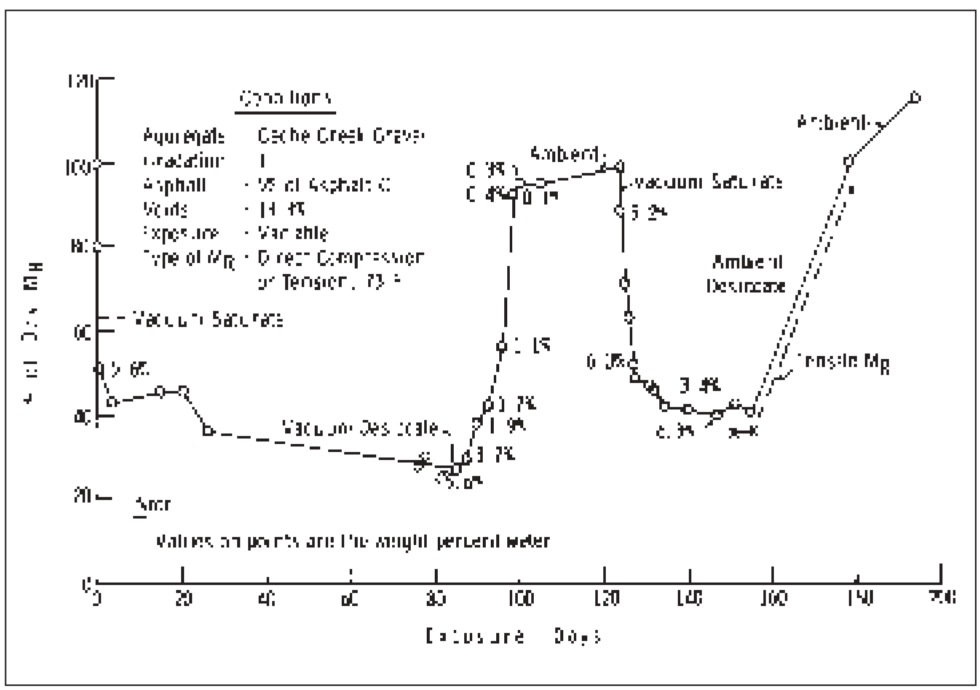

FIGURE 3:
Moisture Effects on Asphalt Mix Strength (3).

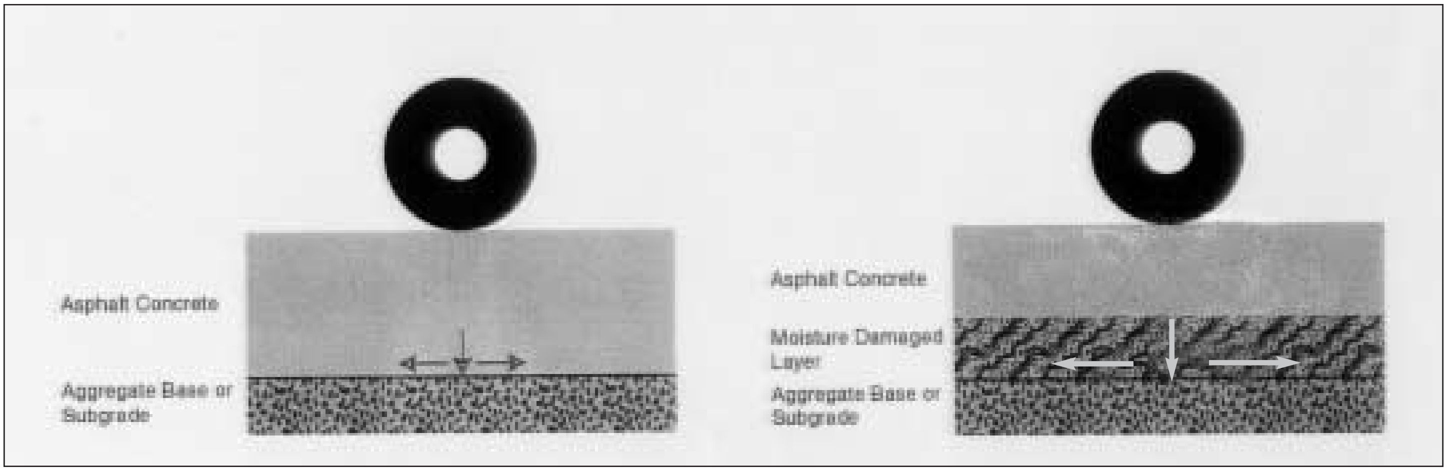

FIGURE 4:
Effect of Moisture Damage on Pavement Life.

gates help promote better mechanical adhesion at the asphalt-aggregate interface. Surface chemistry of the aggregate is also important. Aggregates range from basic (limestone) to acidic (quartzite) as shown in Figure 6. Asphalt, on the other hand, has relatively few basic ingredients, but can have an acidic tendency depending on the asphalt source. Therefore, asphalt would be expected to adhere better to alkaline aggregates (opposite charges attract) such as limestone than to acidic siliceous aggregates.

Clay, either in the form of fine aggregate or as a thin coating over the larger aggregate particles, can create a major problem with moisture sensitivity. Clay expands in the presence of moisture and acts as an effective barrier to the adhesion of asphalt to the aggregate surface. Aggregates are normally tested to determine the amount of detrimental clay that might be present. The Sand Equivalent Test (4), developed in the early 1950s, has been used for this purpose in California and other states. Some researchers feel that a more sensitive test, such as the Methylene Blue Test (5), would be a better indicator of the presence of clay particles.

Asphalt properties also play a role in the moisture sensitivity of asphalt pavements. Complete coating of the aggregate surface during mixing is critical and is affected by the viscosity of the asphalt which, in turn, is controlled by the mixing temperature used in a hot mix plant. Asphalt film thickness, which was discussed earlier, is influenced by asphalt viscosity as well as the use of additives such as polymers or rubber. The source of the asphalt (or how it is produced in a refinery) can have some effect on its moisture sensitivity in a pavement. The use of blending components or processing techniques that increase the possibility of emulsification of the asphalt need to be avoided (6).

Sources of moisture during production of asphalt mixtures in a hot mix

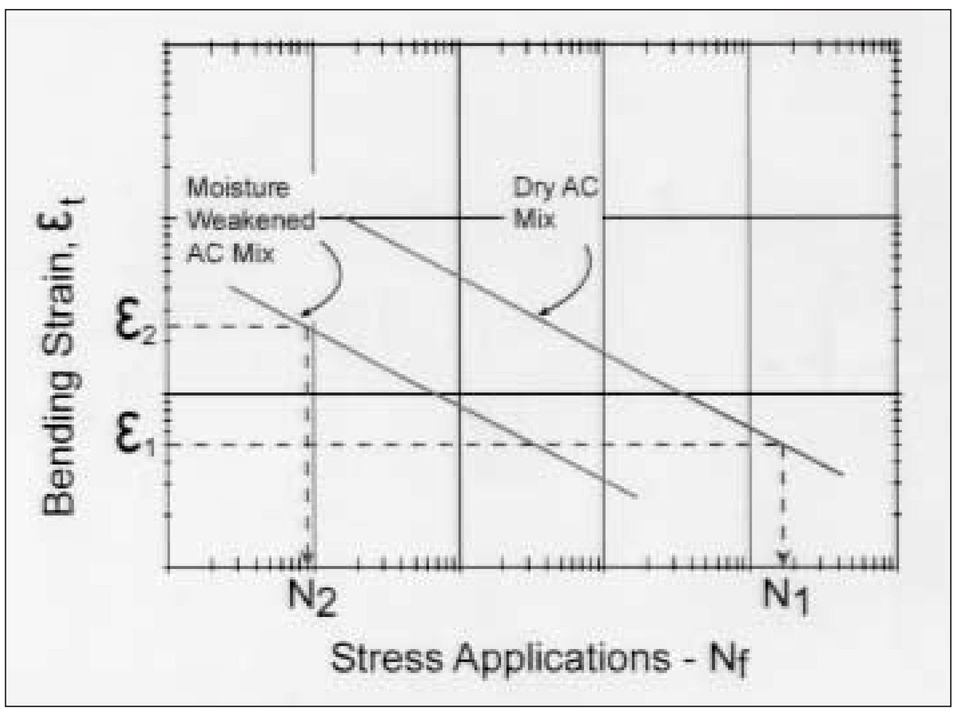

FIGURE 5:
Moisture Effect on Fatigue Response of Asphalt Pavements.

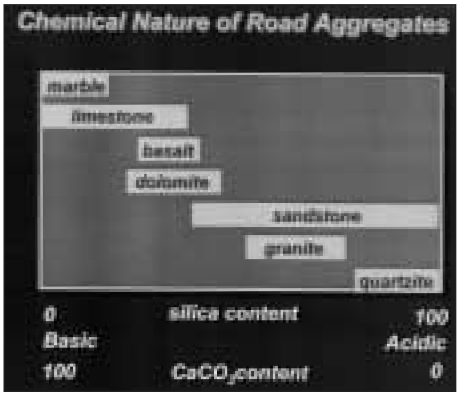

FIGURE 6:
Chemical Nature of Road Aggregates.
(Courtesy of Akzo Nobel Surface, Chemistry LLC)

plant should be identified and minimized. The most likely source results from inadequate drying of the aggregate used in the mixes. Although moisture limits are normally imposed on the mix, small amounts of moisture left in the deep interstices of the aggregate can escape in the form of steam and ultimately strip the asphalt film from the aggregate. Other areas where moisture may appear are at the base of hot mix storage silos or near the edge of windrows during placement of fresh asphalt mix on the highway.

The primary construction issue that needs to be addressed in making asphalt pavements more moisture resistant is adequate compaction during construction. Better compaction of dense graded asphalt mixes leads to lower air void content and lower permeability of the completed pavement. Both factors reduce the ability of external moisture from entering the pavement. However, designers and contractors have to be cautious that increased compaction does not produce a mix with too few voids that, in turn, can result in an unstable mix susceptible to pavement rutting.

Other construction concerns include the building of composite pavements that can trap moisture between pavement layers. Placing an open graded mix over a dense graded asphalt mix can result in ponding of water on the surface of the dense graded mix unless proper drainage is provided. The surface of the dense graded mix may need to be milled to remove depressions and restore appropriate slopes for drainage of water that permeates the open graded overlay. Impermeable fabric and chip seal interlayers between a dense graded asphalt pavement and a dense graded asphalt overlay can result in an increased moisture content on the top as well as the bottom of the interlayer. The sources of moisture are rainfall and moisture vapor from underlying soil layers. Moisture damage can also occur under surface chip seals placed over asphalt mixes that are moisture sensitive.

Mechanisms of Moisture Damage

Several theories have been proposed to describe the mechanisms of moisture damage. In reality, many of these mechanisms may occur during varying stages of moisture damage to the pavement structure. Some of the mechanisms suggested include *detachment, displacement, emulsification, pore pressure build-up.*

Detachment of the asphalt film from the aggregate surface takes place when water rather than asphalt becomes the preferred coating of the aggregate. The surface tension of water and asphalt are important factors in this battle to determine which liquid wets the aggregate surface. Figure 7 illustrates a moisture wetted versus an asphalt wetted aggregate surface.

Displacement or debonding occurs when water actually displaces the asphalt that was originally bonded to the aggregate. The chemistry of the aggregate surface in the form of surface charges and the nature of the asphalt binder play major roles in the displacement process. A displaced or debonded asphalt layer is illustrated in Figure 8.

Emulsification of the asphalt film can occur in a pavement due to the presence of emulsifying agents in the aggregate such as clay particles or agents in the asphalt binder itself. Traffic provides the action needed to promote emulsification. The resulting emulsion may migrate to the pavement surface and produce localized fat spots. The process of emulsification is normal-

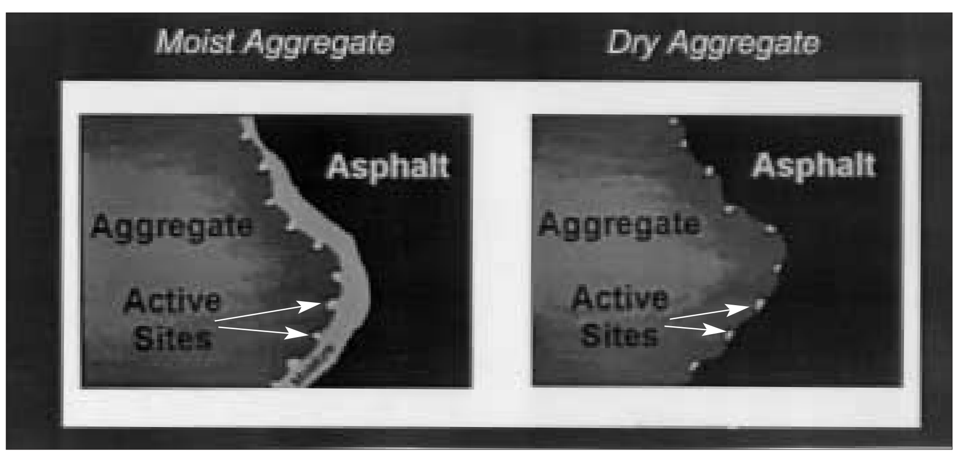

FIGURE 7:
Coating without Chemical Bond in a Moist and Dry Environment.
(Courtesy of Akzo Nobel Surface Chemistry LLC)

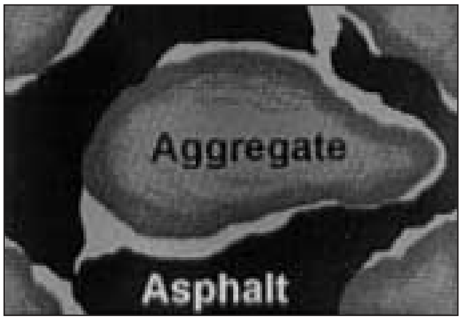

FIGURE 8:
Stripping of Asphalt Film from the Aggregate Surface.
(Courtesy of Akzo Nobel Surface Chemistry LLC)

ly reversible once the water is removed. The strength cycling illustrated in Figure 3 is similar to what occurs in an emulsification/drying process.

Pore pressures can build up in an asphalt pavement due to the action of traffic in the presence of moisture. These pressures alternating between compression and tension can result in a debonding of the asphalt from the aggregate or a raveling of the pavement surface.

Test Methods to Predict Moisture Sensitivity

Numerous laboratory tests have been developed over the years in an effort to predict the moisture sensitivity of asphalt mixtures. The Moisture Vapor Susceptibility (MVS) Test was incorporated into the Hveem Mix Design procedure in 1946 to evaluate the adverse effects of water vapor entering the asphalt pavement from underlying layers (7). In essence, the MVS Test is a Stabilometer Test run on a test briquette subjected to water vapor exposure. Although not routinely used today by Caltrans, the test is still included in Section 39 of Caltrans Standard Specifications.

Other tests used to evaluate the stripping potential of asphalt mixes include:

- Boiling Tests (ASTM D3625)
- Freeze-Thaw Pedestal Test
- Lottman Indirect Tension and/or Modulus Test
- Indirect Tension Test with moisture saturation only (ASTM D4867)
- Indirect Tension Test with moisture saturation and one freeze-thaw cycle (AASHTO T283)
- Immersion Compression Tests (ASTM D1075)
- Hamburg Wheel Tracking Test

Summaries of each test procedure are included in Tables 6-11 of reference 8 and reference 9.

The *Boiling Test* subjects a loose sample of coated mix to boiling water for a period of from 1 up to 10 minutes depending on the agency involved. Many feel that this test provides a good initial screening of materials for differentiating stripping or non-stripping potential.

The *Freeze-Thaw Pedestal Test* subjects small briquettes to repeated freeze-thaw cycles until cracks are detected. The briquettes are made up of asphalt and a uniform sand size fraction of aggregate. Some researchers (10) have found this test predicts stripping potential well while others (11) have found little correlation between laboratory and field results.

The *Indirect Tension Tests* used to evaluate the moisture sensitivity of asphalt mixtures are generally variations of the test originally developed by Lottman (12). The basic differences are the conditioning procedure used or the level of air voids selected. Samples are compacted to 7± 1 percent voids in the ASTM D4867 and AASHTO T283 procedures while samples in the Lottman procedure are compacted to the air void content expected in the field (normally 6 to 8 percent). All of the indirect tension procedures condition the samples using vacuum saturation levels of between 55 and 80 percent. Some procedures include a freeze-thaw cycle. Some believe that the Lottman procedure is too severe because of internal

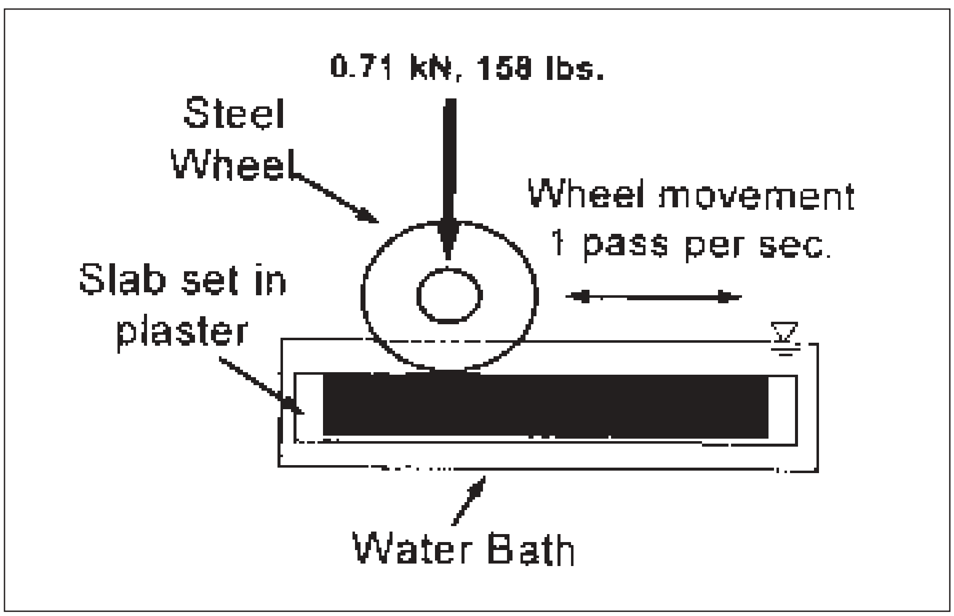

FIGURE 9:
Schematic of Hamburg Wheel Tracking Device Used to Evaluate Water Sensitivity of Asphalt Mixtures (14).

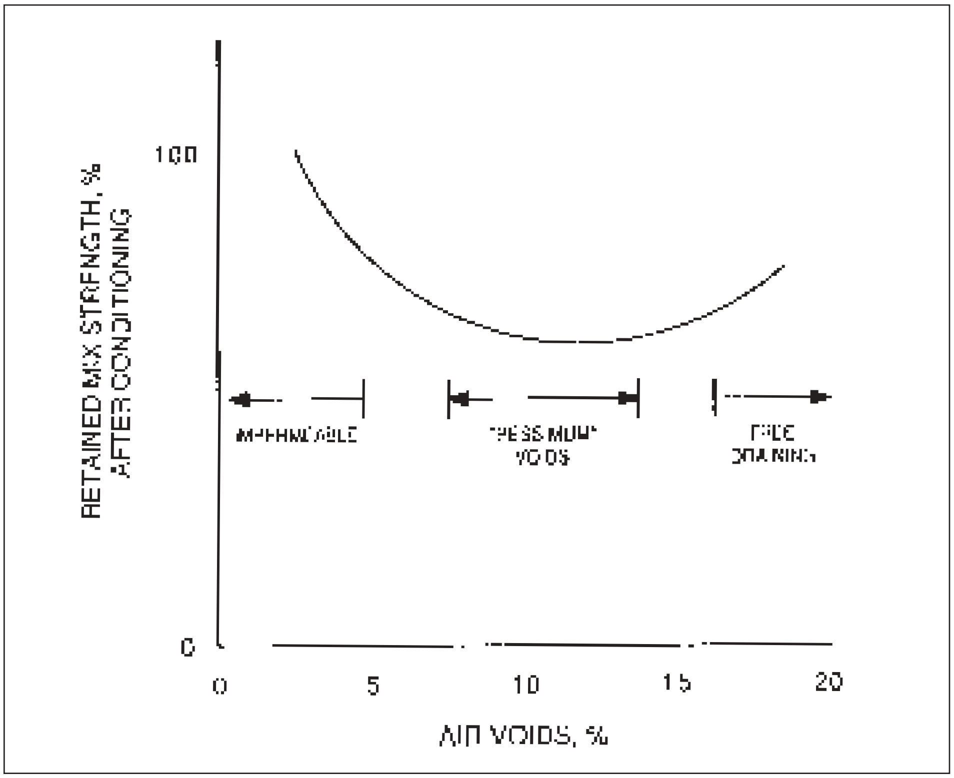

FIGURE 10:

Relationship Between Air Voids and Retained Mix Strength After Moisture Conditioning According to Pessimum Voids Theory (8, 16).

water pressures created during the vacuum freeze to warm water soak cycle. A tensile strength ratio (TSR) is normally used to evaluate the test results. The TSR is obtained by dividing the value for tensile strength from the conditioned sample by the result from the unconditioned sample. Normally, a retained strength ratio of 70 percent is recommended. However, some agencies call for a ratio as high as 80 percent. Caltrans is considering a range of TSR values in its selection of treatment methods to minimize moisture damage.

The *Immersion Compression Test* uses samples (4-in. diameter by 4-in. high) that are compacted by the double plunger method with a pressure of 3,000 psi. Specimens are conditioned by water soaking only at 120 F or 140 F and then tested for compressive strength. A retained ratio of 70 percent or higher is generally required. This test has met with mixed success. Some researchers have criticized the test for producing results near 100 percent even when stripping was evident (13).

More recently, the *Hamburg Wheel Tracking Test,* shown schematically in Figure 9, has been used as a “go-no go test” by some agencies to evaluate the water sensitivity of compacted asphalt specimens (14). The test samples are either slabs or side-by-side cores subjected to repeated application of a steel wheel. Testing of the specimens is done under water. The condition of the samples is observed (rutting, stripping, etc.) after a given number of wheel passes. Some researchers consider this to be a very severe test, but it does seem to eliminate mixtures prone to moisture damage (15). It may also exclude mixtures that perform well in the field.

Treatment Techniques

The primary methods of treating moisture sensitive mixtures involve the use of lime or liquid additives. The intent of both techniques is to modify the surface chemistry at the aggregate-asphalt interface in order to promote better adhesion. Lime treatment is widely used throughout the southern and western parts of the United States. Lime treatment is generally of two types: dry lime addition to moist aggregate or lime marination of aggregate stockpiles. Lime marination is essentially a lime slurry soaking of the aggregate over a period of time. Both approaches seem to produce the desired results although many feel that lime marination is slightly more effective. However, lime marination can be significantly more expensive due to processing requirements and/or space limitations at the contractor’s plant site.

Liquid additives are also used widely throughout the country. Liquid antistrips can be of several different types but most are amine-based compounds that are usually added to the asphalt binder at the refinery or through in-line blending at the contractor’s hot mix plant. The liquid antistrips are designed to give the asphalt binder an electrical charge opposite that of the aggregate and hence promote better adhesion at the asphalt/aggregate interface. It is important to pre-test any liquid antistrip with the job aggregate and job asphalt to determine its effectiveness. Any change in asphalt source, aggregate source, or additive should generate additional tests to see how the changes may have affected the moisture resistant properties of the mix.

Impact of Compaction

Adequate compaction plays a major role in the moisture sensitivity of asphalt pavements. The “pessimum voids" theory, shown in Figure 10, suggests that moisture damage should be less for impermeable or free-draining mixtures. The worst condition would be dense graded asphalt pavements containing 8 - 12 percent air voids where moisture can readily enter the pavement but not easily escape. The presence of water plus the action of traffic accelerates damage to the pavement. This theory was confirmed to some extent by data shown in Figure 11 on the retained strength of laboratory prepared cores in a SHRP research study on moisture sensitivity (16). It appears that improved compaction to reduce the void content of the finished pavement to the 6 - 8 percent range will go a long way toward improving moisture resistance. Reducing the void content of dense graded asphalt mixtures will also reduce the permeability (amount of interconnected voids) in the pavement.

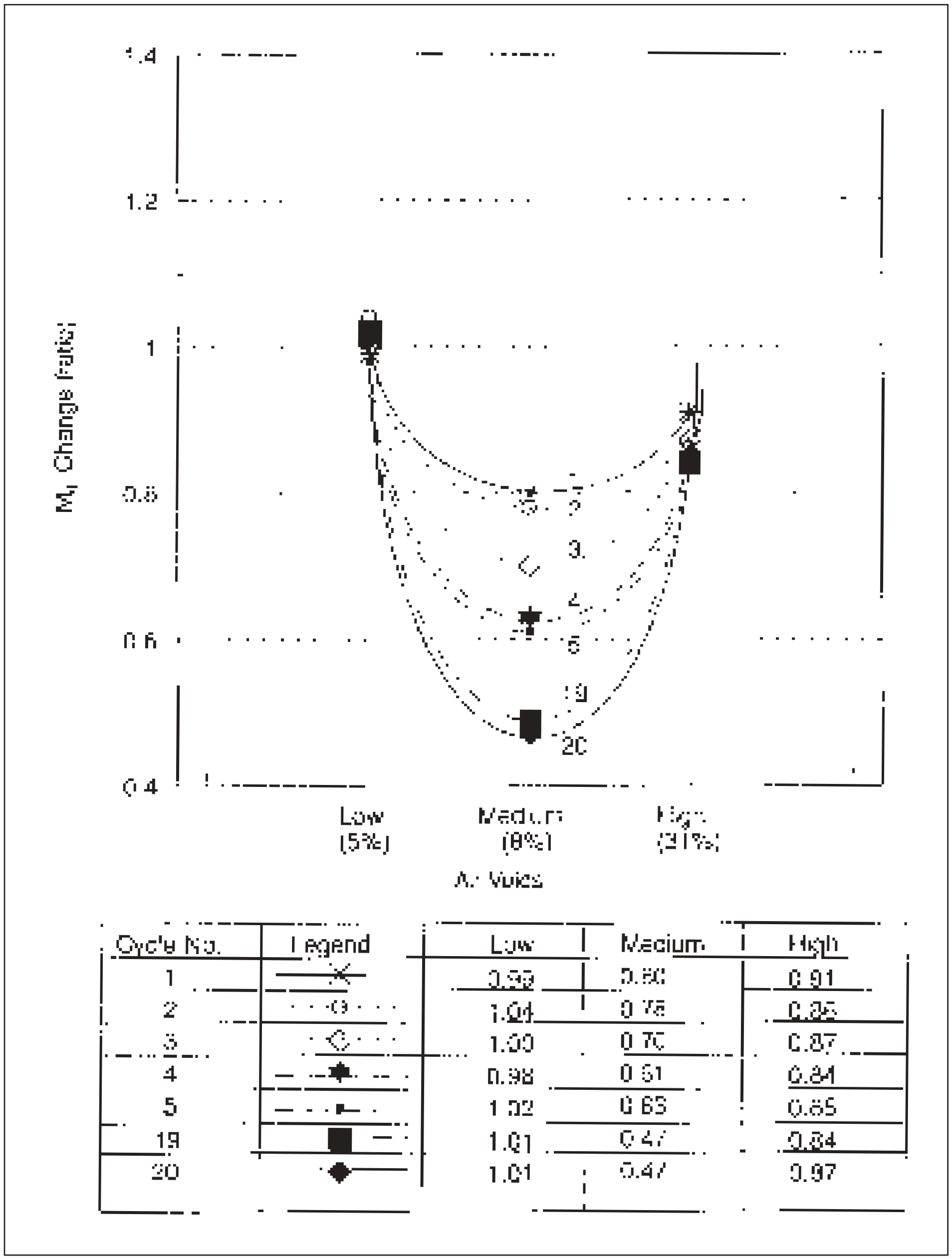

FIGURE 11:

Laboratory Results Showing Air Voids Effect on Retained Mix Strength (16).

Closing Thoughts

This article has focused on the moisture sensitivity of asphalt pavements. Moisture can have equally damaging results on concrete pavements with distresses such as slab rocking, corner cracking, edge cracking, etc. The primary message should be that water (moisture) is a serious enemy to the long life performance of all pavements. Designers and construction engineers need to take into account proper drainage techniques and construction practices to minimize this form of pavement damage.

Caltrans has devoted significant resources in an effort to better understand and address the problem of moisture sensitivity. As part of this effort, Caltrans is hosting a national seminar on the moisture sensitivity of asphalt pavements in San Diego, California on February 4-6, 2003. Invited researchers and practioners from around the country will present papers in their areas of expertise on this subject. The seminar will include break out sessions to discuss and prepare a "best practices" approach and action plan to mitigate the problem. The seminar will be followed by several 1-day training sessions throughout the state for Caltrans and industry personnel.

The ITS Technology Transfer Program is offering a 3-day course on Moisture Sensitivity of Asphalt Pavements on March 25-27, 2003 which covers in more detail many of the topics discussed in this article. For more information on instructors, topics covered, and registration procedures, log onto www.its.berkeley.edu/techtransfer or contact Larry Santucci at 510-231-9428.

REFERENCES

1. Hveem, F. N., "Quality Tests for Asphalts—A Progress Report", *Proceedings*, Association of Asphalt Paving Technologists, Vol. 15 (1943).

2. Survey by Tim Aschenbrener, Colorado DOT, for National Seminar on Moisture Sensitivity of Asphalt Pavements scheduled for February 4-6, 2003, San Diego, California, August, 2002.

3. Schmidt, R. J. and P. E. Graf, "The Effect of Water on the Resilient Modulus of Asphalt Treated Mixes', *Proceedings*, Association of Asphalt Paving Technologists, Vol. 41 (1972).

4. Hveem, F. N. "Sand Equivalent Test for Control of Materials During Construction", *Proceedings*, Highway Research Board, Vol. 32 (1953).

5. International Slurry Seal Association, "Test Method for Determination of Methylene Blue Absorption Value (MBV) of Mineral Aggregate Fillers and Fines", ISSA Bulletin 145 (1989).

6. King, G. N., S. W. Bishara and G. A. Fager, "Acid/Base Chemistry for Asphalt Modification", *Proceedings*, Association of Asphalt Paving Technologists, Vol. 71 (2002).

7. Skog, J. and E. Zube, "New Test Methods for Studying the Effect of Water Action on Bituminous Mixtures", *Proceedings*, Association of Asphalt Paving Technologists, Vol. 32 (1963).

8. Hicks, R. G. "Moisture Damage in Asphalt Concrete", *NCHRP Synthesis of Highway Practice 175*, Transportation Research Board, National Research Council, Washington, D.C. (1991).

9. Kast, O. and W. von der Weppen, "Beurteilung der Standfestigkeit von Asphaltbeton-Deckschichten mit Hilfe des Spzirbildungsteste", *Bitume 6* (1978).

10. Kennedy, T. W., F. L. Roberts, and K. W. Lee, " Evaluation of Moisture Susceptibility of Asphalt Mixtures Using the Texas Freeze-Thaw Pedestal Test", *Proceedings*, Association of Asphalt Paving Technologists, Vol. 51 (1982).

11. Parker, F. and M. S. Wilson, "Evaluation of Boiling and Stress Pedestal Tests for Assessing Stripping Potential of Alabama Asphalt Concrete Mixtures", *Transportation Research Record 1096,* Transportation Research Board, National Research Council, Washington, D.C. (1986).

12. Lottman, R. P., "Predicting Moisture-Induced Damage to Asphaltic Concrete", *NCHRP Report 192,* Transportation Research Board, National Research Council, Washington, D.C. (1978).

13. Stuart, K. D., "Evaluation of Procedures Used to Predict Moisture Damage in Asphalt Mixtures", *Report No. FHWA/RD-86/091,* Federal Highway Administration, Washington, D.C. (1986).

14. Blankenship, P. B., A. H. Myers, A. S. Clifford, T. W. Thomas, H. W. King, and G. N. King, "Are All PG 70-22s the Same? Lab Tests on KY I-64 Field Samples", *Proceedings*, Association of Asphalt Paving Technologists, Vol. 67 (1998).

15. Rand, D. A., Paper presented in Session 3, "Field Observations and Validation, Designed Tests and Forensic Analysis", *Moisture Damage Symposium,* Petersen Asphalt Research Conference, 39th Annual Meeting, Laramie, Wyoming, July 15-17, 2002.

16. Terrel, R. L. and J. W. Shute, "Summary Report on Water Sensitivity", *SHRP-A/IR-89-003,* Strategic Highway Research Program, National Research Council, Washington, D.C. (1989).