Hot-Mix Asphalt (Bituminous) Railway Trackbeds: In-Track Tests, Evaluations, and Performances -- A Global Perspective

Part III -- U.S. Asphalt Trackbed Materials Evaluations and Tests

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ABSTRACT: The railway industry throughout the world continues to emphasize the importance of developing innovative trackbed design technologies for both heavy tonnage freight lines and high-speed passenger lines. The purposes are to achieve high levels of track geometric standards for safe and efficient train operations while minimizing long-term track maintenance costs and extending track component service lives. During the past several decades designs incorporating a layer of asphalt (or bituminous) paving material, similar to a highway pavement asphalt base layer, as a portion of the railway track support structure have steadily increased until it is becoming a common or standard practice. In this, the third part of a three part paper, performance-based tests and analyses are provided indicating superior performance of asphalt track structures.

1 EVALUATIONS AND TESTS

Numerous in-service trackbeds have been subjected to a variety of materials sampling and core-drilling activities to ascertain the properties of the subgrade and asphalt materials, and in-situ tests to obtain trackbed pressure and deflection test measurements as performance indicators. Primary activities described herein are 1) track materials characterization and evaluation studies to ascertain the effects of long-term exposure in various environments - specifically the asphalt layer and underlying (roadbed) subgrade and 2) in-situ pressure and deflection measurements under train operations to determine structural enhancement characteristics of asphalt underlayment trackbeds (Rose, 2013).

2 EVALUATION STUDIES

Seven asphalt trackbeds, located in four different states, ranging from 12 to 25 years old and having various asphalt thicknesses and trackbed support materials, were selected for materials characterization studies. Samples were obtained during summer 2007 and the detailed results were previously reported in 2008 (Rose and Lees, 2008). Previous characterization studies, primarily conducted in 1998 (Rose, Brown and Osborne, 2000) (Rose, 1998), were available for selected projects and evaluated for comparison purposes. The test sites are listed in Table 1.

Core samples were taken at three randomly selected locations for each trackbed evaluated. After removing the ballast, the asphalt layer was core drilled from the field side crib area next to the rail.

Location	**Year Trackbed Installed**	**Age of Asphalt (years)**
Conway, KY	1983	15 and 24
Cynthiana, KY	1984	14 and 23
Deepwater, WV	1984	14 and 23
Guthrie, OK	1989	9 and 18
Oklahoma City, OK	1982	16 and 25
Quinlan, OK	1995	3 and 12
Hoover, TX	1994	4 and 13

Table 1. Asphalt Test Trackbeds.

The 150 mm diameter asphalt cores were extracted and the core drilling water was immediately removed so that it would not contaminate the underlying subgrade. The conditions of the cores were observed, measurements were taken, and the cores were sealed in plastic bags for transportation to the testing laboratory. The subgrade underlying the asphalt was removed with an auger for a 300 mm depth below the asphalt. The soil was sealed in plastic bags for immediate transportation to the testing laboratory. Detailed information and descriptions of the tests and evaluations are contained in the 2008 AREMA Conference Proceedings (Rose and Lees, 2008). Summary information follows.

2.1 *Geotechnical Tests and Evaluation*

The in-situ moisture contents of the subgrade samples were determined for comparisons with subsequent analyses. In addition, typical grain size analyses and Atterberg limits tests were conducted in order to classify the subgrade materials. Standard Proctor moisture-density relationships were established and California Bearing Ratio (CBR) tests were conducted on the materials prepared at their respective optimum moisture contents and tested in the unsoaked condition immediately and in the soaked conditions after 96 hours.

2.1.1 *In-Situ Moisture Contents*

There was significant interest in determining the prevailing moisture contents for the subgrade materials directly under the asphalt layer and comparing these with the previous 1998 in-situ measurements and with the optimum moisture contents for the respective materials. No subgrade appeared to be wetter than optimum based on initial observations.

In-situ moisture contents varied relative to the type of subgrade soil, but were very site specific and comparable with values obtained during the 1998 sampling. These data are shown in Figure 1. There was an average net 0.1 percent decrease in moisture contents over the span of nine years.

2.1.2 *Unified Soil Classifications*

The test projects were selected to include a wide variety of subgrade materials, ranging from reasonable high plastic clays to more silty/sandy materials having little or no plasticity. The soil classifications ranged from SM, CL, ML, and SC

2.1.3 *Standard Proctor Moisture Contents*

These tests were conducted to determine the optimum moisture content for achieving maximum density. The minus 12.5 mm size material was removed. Figure 2 shows the change in optimum moisture contents for the six samples between 1998 and 2007 sampling. The changes were typically less than 1 percent, indicating similar materials. Figure 3 is a graphical comparison of the measured in-situ moisture contents and the Proctor optimum moisture values. The linearity of the relationship is shown in Figure 4. Note that the R value is in excess of 0.9 indicating very good correlation. The in-situ moisture contents were very close to optimum values. These findings indicate that the subgrade materials under the asphalt layer can be considered, for design purposes, to have prevailing moisture contents very near optimum for maximum densification and strength.

In addition, strength or bearing capacity values used in design calculations for asphalt trackbeds should be reflective of optimum moisture content values. It is common practice, when designing conventional all-granular trackbeds, to assume the subgrade is in a soaked condition, which for most soils is a weaker condition than when the soil is at optimum moisture.

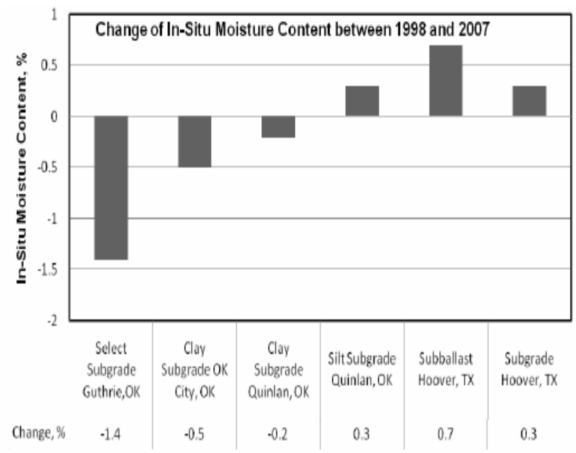


Figure 1. Changes in in-situ subgrade moisture.

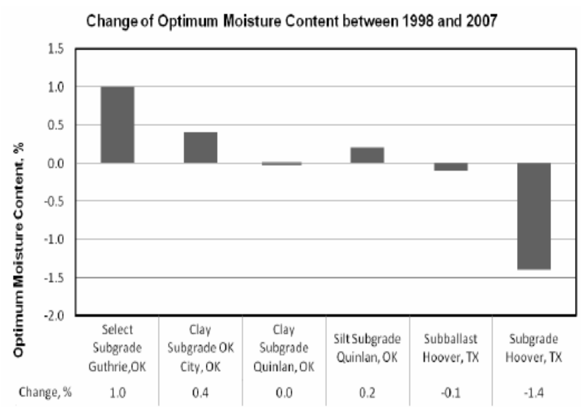


Figure 2. Changes in optimum subgrade moisture.

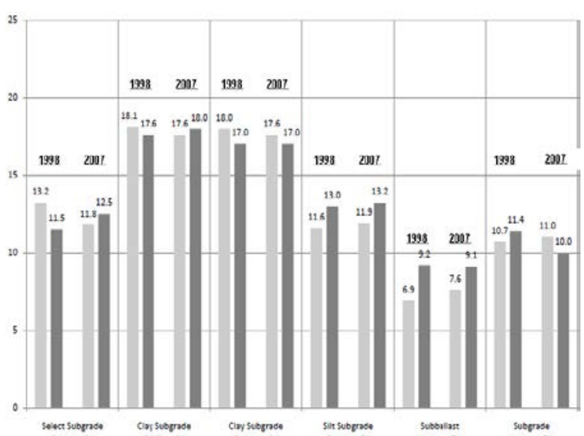


Figure 3. Comparison of 1998 and 2007 measured in-situ moisture contents and optimum moisture contents.

2.1.4 *California Bearing Ratio*

CBR specimens were prepared at moisture contents determined from the Proctor tests to be optimum for maximum density. Specimens were tested immediately in the unsoaked condition. Companion specimens were soaked in water for 96 hours prior to testing. Tests were conducted at 2.5 mm penetration

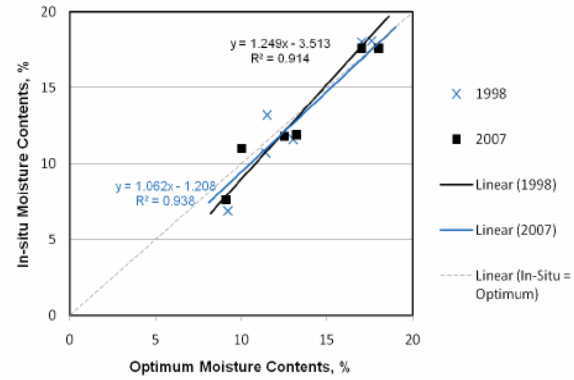


Figure 4. Relationships for roadbed/subgrade in-situ and optimum moisture contents.

The CBR values varied significantly reflecting the properties of the respective materials. A comparison of unsoaked and soaked CBR test values is presented graphically in Figure 5. CBR values were significantly lower for the soaked samples, particularly those containing clay size material, which had values in the low single digits. Test results for the 1998 and 2007 sampling were reasonably close considering that materials sufficient for only one unsoaked and one soaked specimen per site were available for tests. Likely the 1998 and 2007 test comparisons would have been less variable had additional tests been conducted to obtain averages based on several replicable tests.

As noted previously, the in-situ moisture contents for individual samples were very close to those determined from the Proctor test to be near optimum. Since the unsoaked CBR values are derived from tests on samples at optimum moisture contents, and the test results from samples under asphalt trackbeds were determined to be at or very near optimum moisture contents, it is obvious that the unsoaked CBR bearing capacity values are appropriate to use for structural design calculations. The soaked (lower) CBR values result in a conservative overdesign. The preceding statements are not necessarily applicable to the open all-granular trackbeds, which are prone to variable moisture contents depending on the amount of rainfall and surface drainage conditions, and corresponding variations in support strength. The subgrade/roadbed materials underlying the asphalt layers were at moisture contents near optimum, and based on long-term monitoring at two sites; maintain optimum moisture conditions for indefinite periods.

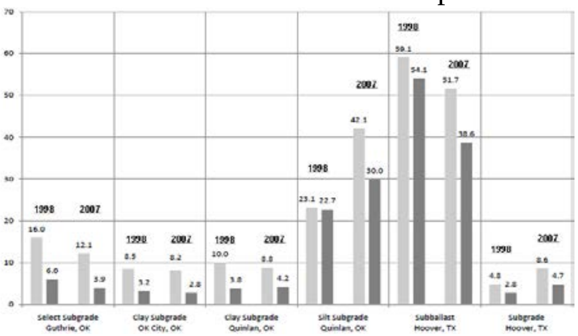


Figure 5. Comparison of 1998 and 2007 unsoaked and soaked CBR test values for the roadbed/subgrade samples.

2.2 *Asphalt Mixture Test and Evaluations*

The asphalt cores were subjected to density, voids analysis and resilient modulus tests. Subsequently the asphalt binder was extracted, using trichloroethylene, in order to determine the asphalt binder contents and extracted aggregate gradations. The extracted binder was subsequently recovered from the solvent for penetration, viscosity, and dynamic shear rheometer tests.

2.2.1 *Mix Extraction Tests and Core Analyses*

The extraction test results were indicative of dense-graded base mixes with 25 mm maximum size aggregate and about 6 percent of the aggregate passing the No. 200 sieve. These are basically in conformance with guidelines previously described (Rose, 1998) (Rose, 2006). Asphalt binder contents varied somewhat, ranging from 4.5 to 7.0 percent. No particular changes were evident in aggregate gradations or asphalt binder contents over the period of years.

Tests on the asphalt cores included density and voids analyses and resilient modulus tests. The air voids were typically higher than desirable for five of the sites ranging from 5 to 9 percent. The air voids were purposefully maintained at 2 to 3 percent range at three of the sites. This low range is considered to be optimum to resist premature oxidation of the binder. Average air voids for each site were less than the 8 percent maximum normally believed to represent the upper limit to provide an impermeable layer.

The industry standard resilient modulus test was used to measure the modulus of elasticity of the asphalt cores. Repeated loads were applied to a cylindrical specimen and the displacements were measured. The values were measured under indirect tensile loading for the resilient modulus. Tests were conducted at two standard temperatures which represent the nominal lowest, 5°C and highest, 25°C, temperature asphalt experiences in the insulated trackbed environment.

Values were typically several orders of magnitude higher at the lower temperature, which is normal for a viscoelastic, thermoplastic material – and is characteristic of the asphalt binder in the mix. At lower temperatures, the asphalt becomes stiffer, as reflected in higher modulus (or stiffness) values. At higher temperatures, the asphalt becomes less stiff. Obviously, for asphalt highway environments, where the asphalt is exposed to greater temperature extremes, the stiffness differences from winter to summer are significantly greater than those existing in the insulated trackbed environment.

Figure 6 is a plot of Resilient Modulus versus Age for the asphalt mixes. The "circled" symbols represent data for cores (obtained from the trackbed in 1998) that cured the final nine years in the laboratory environment. They are plotted directly above the railroad cured data for similar ages. Note that the lab core modulus values were higher than the in situ cores.

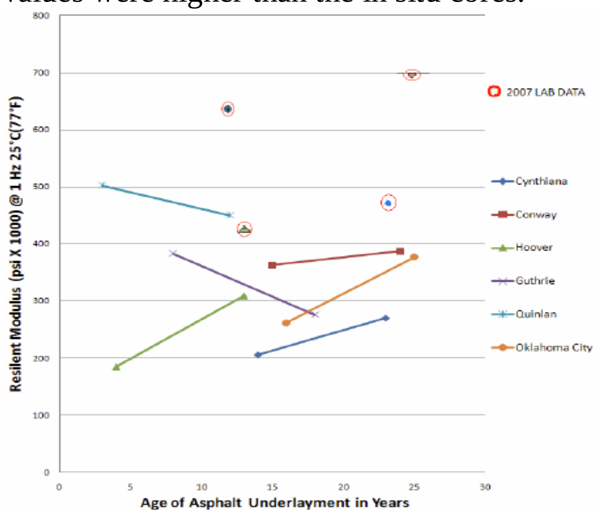


Figure 6. Resilient modulus versus age of asphalt.

The measured modulus values are reasonably consistent for the various sites. There is no particular trend or changes in modulus as a function of time. The mixes vary in asphalt contents, densities, aggregate gradations, and binder properties from site-to-site, which can be expected to produce variations in modulus values. However, these variations are minimal and have little effect on behavioral properties. The significant factor is that the values are reasonably typical for new, unweathered mixes not exemplifying fatigue and cracking – thus low values, or exemplifying hardening/weathering of the binder – thus high values. The values are basically intermediate in magnitude, even after many years of loading and weathering in the trackbed. The asphalt appears to be undergoing little, if any, weathering or deterioration in the trackbed environment.

2.2.2 *Recovered Asphalt Binder Tests*

Tests for Penetration, Absolute and Kinematic Viscosities, and Dynamic Shear Rheometer were conducted on the recovered asphalt binders. A plot of Absolute Viscosity versus Age of the Asphalt Underlayments is presented in Figure 7. The data points circled at the ends of the trend lines represent the 2007 values. The preceding data points are for test values nine years prior, or 1998 values.

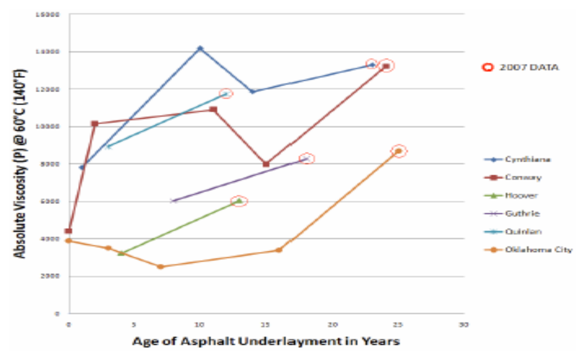
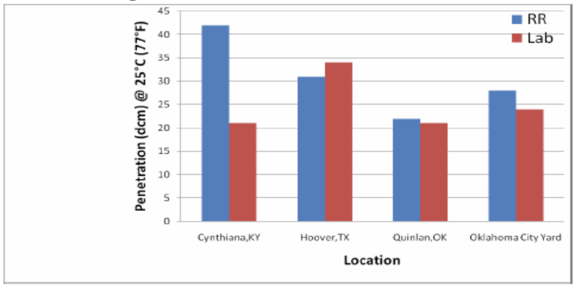


Figure 7. Absolute viscosity versus age of asphalt.

Penetration values will tend to decrease and viscosity values will tend to increase with time due to expected oxidizing and hardening of the asphalt binders. There is indication of this phenomenon when comparing the 1998 and 2007 test values. However, the Abson method (ASTM D1856) was used for the 1998 and prior asphalt recoveries; whereas, the Rotary Evaporator method (ASTM D5404) was used for the 2007 recoveries. The Rotovapor method is considered more effective at removing the solvent. Therefore, the 2007 penetration values would be expected to be lower and the 2007 absolute viscosity values would be expected to be higher than their respective 1998 values. These trends are evident from Figure 8.

It is likely that the original asphalt binders were PAC 60-70 penetration or AC-20 viscosity graded. The effects of short-term aging (elevated temperatures) during the pavement construction process and long-term aging for several years will reduce the binder penetration to the 25 to 40 range and the absolute viscosity at 60°C will be maintained to less than 15,000 poises (ASTM, 2007). These samples meet these criteria, indicating minimal oxidation and weathering.



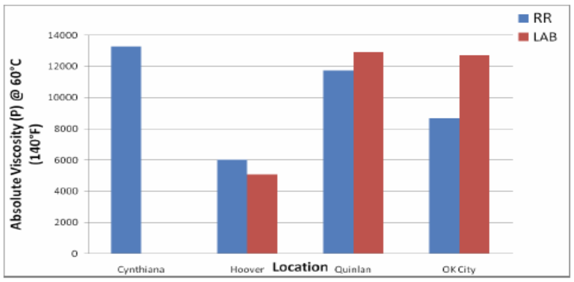


Figure 8. Penetration and absolute viscosity for railroad and laboratory-cured asphalt cores.

The Dynamic Shear Rheometer (DSR) procedure for evaluating asphalt binders was developed in the mid-1990s. Fortunately this test was conducted in 1998 on samples from 5 of the 6 sites and this data is compared to the 2007 data in Figure 9. The standard for performance grade asphalt binders, after short- and long-term aging, is that the DSR at 25°C should be less than 5,000 kPa. Note that all of the samples are well below 5,000 kPa, another indication that the asphalt binders in the trackbed cores are not oxidizing and hardening excessively (ASTM, 2007).

It is not surprising that the asphalt binders in the trackbed cores are not oxidizing and hardening to the extent normally observed for asphalt highway pavements. This is largely due to two factors. The surface of the asphalt is typically submerged 500 mm from the surface (atmosphere) by the ballast/tie cribs and the depth of ballast below the ties. The lack of sunlight and reduced oxygen largely negates normal weathering which occurs in highway pavements exposed to sunlight.
Secondly, the range of temperature extremes which the HMA mat undergoes from summer to winter is significantly less in the insulated trackbed environment than for exposed highway pavements. This information was developed initially during 1982 and 1995 tests in Kentucky from buried thermistors, and reported previously (Rose, Brown and Osborne, 2000). Additional tests during 2000 at the AAR Pueblo test site confirmed the previous tests (Li, Rose and LoPresti, 2001).

3 IN-SITU TRACKBED TESTS

Two test sites (revenue and non-revenue) were utilized to obtain trackbed pressure and deflection measurements. The Revenue line is the CSXT 36 MGt heavy tonnage Mainline between Cincinnati, OH and Atlanta, GA at Conway, KY. Two 305m long asphalt underlayment sections, consisting of 125 mm and 200 mm thick layers of asphalt, were placed during 1983. This section of track has remained virtually maintenance free for nearly 25 years and has been subjected to numerous tests and evaluations.

The Non-Revenue line is on the High Tonnage Loop at the Transportation Technology Test Center (TTCI) near Pueblo, CO. Two 107 m long asphalt underlayment sections, consisting of 100 mm and 200 mm thick layers of asphalt, were placed during 1999 over the soft clayey subgrade portion of the test track. Test trains with 36 metric ton axle load continuously circle the loop to provide accelerated loading (Li, LoPresti and Davis, 2002).

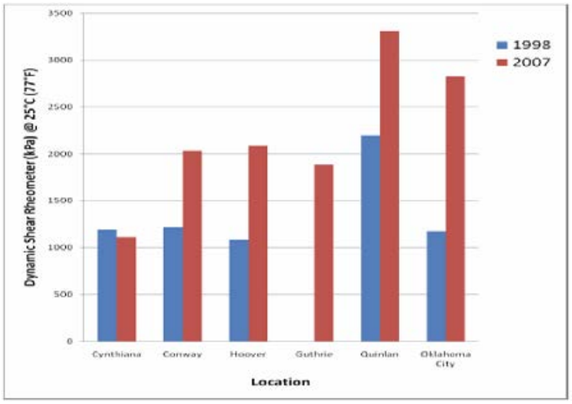


Figure 9. Dynamic shear rheometer values for 1998 and 2007 tests.

3.1 *Pressure and Deflection Measurement Techniques*

Pressures exerted by the wheel loads on the trackbed support materials were obtained with Geokon Model 3500 Earth Pressure Cells using Snap-Master as the data acquisition system. These were imbedded in the track structure above and below the HMA mat. Figure 10 shows a schematic view of the pressure cell configuration for in-track tests.

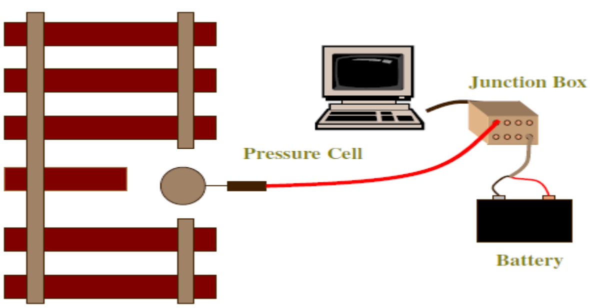


Figure 10. Pressure cell measurement configuration.

Pressures exerted by the wheel loads on the ties and plates were obtained with the Tekscan pressure distribution system. The measurements were made with a thin (0.1 mm thick) matrix-based sensor consisting of two flexible polyester sheets with silver conductive electrodes printed on them. The illustration in Figure 11a shows a basic sensor and its components. Figure 11b shows a view of an in-track test (Rose & Stith, 2004).

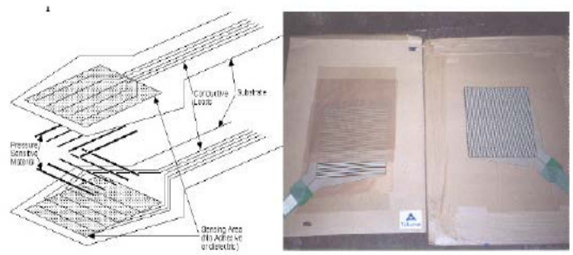


Figure 11a. Basik Tekscan senson schematic (www.tekscan.com/technology).

Figure 11b. In-track view of Tekscan pressure distribution system.

Deflections under the dynamic loadings of the railcars were recorded in conjunction with the pressure measurements using Linear Variable Displacement Transducers (LVDT). An obstacle to using LVDTs to measure track deflections is establishing a fixed point of reference (datum). The fixed datum is achieved by driving a 25 mm diameter steel rod through the track structure and into solid sub-strata. Therefore, the rod is unaffected by the passing of the trains and remains at a fixed elevation. Figure 12a is a schematic view of the LVDT configuration for in-track tests. Figure 12b is a view of an in-track test arrangement. The LVDT consists of a nonmagnetic shell and a magnetic core. The relationship between input and output voltage is related to displacement.

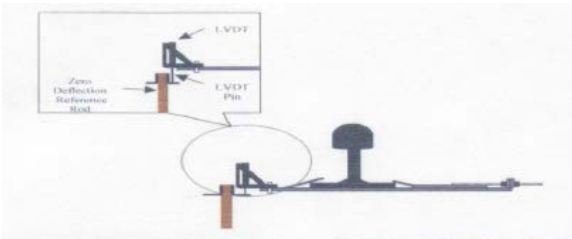


Figure 12a. LVDT measurement configuration.


Figure 12b. In-track view of LVDT deflection testing.

The LVDT is attached to a removable clamp that can be secured to the base of the rail. Snap-Master is used as the data acquisition system for obtaining the deflection measurements in the real-time domain. Track deflection is considered to be a primary indicator for predicting track strength, life, and quality. Excessive deflection causes accelerated movement and wear of ballast and ties through inter-partical powdering and abrasion. The ideal track structure provides a balance of stiffness and flexibility – not too stiff, not too resilient.

3.1.1 *Conway, KY (CSXT) Test Results*

A variety of trains were measured including a loaded coal train, mixed freight train, and five locomotives in several Tekscan pressure distribution tests. The tests mainly focused on 1) obtaining in-track pressure measurements at the rail base/tie plate interface 2) evaluating the ability of Tekscan to record higher speed trains in a section of open track, and 3) evaluating the effects of different types of plates – machined steel, polyurethane, and rubber. The output from the Tekscan sensors that were placed at the rail base/tie plate interface showed that the force was concentrated over a few small areas of the hot-punched steel plates, producing a few very high pressure peaks.

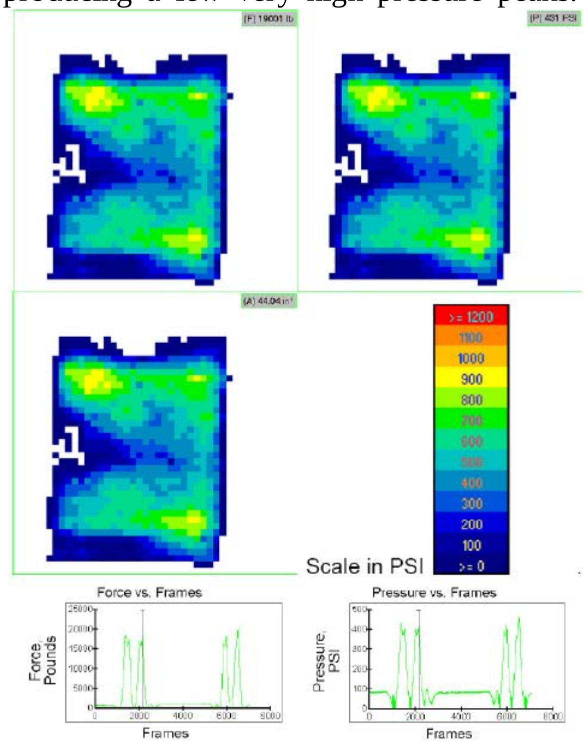


Figure 13. Typical distribution between a machined steel plate and the rail base (Rose and Stith, 2004).

Typical results for pressure distributions at the rail/tie plate interface for a steel tie plate are presented in Figure 13 (Rose & Stith, 2004). The peak rail base/tie plate interface pressures typically range from 800 to 4,200 kPa provided the pressures were distributed fairly uniformly. It is obvious that rigid objects such as commercially produced plates and rail bases will inevitably have a few high contact points on their supposedly "flat" surfaces. Assuming the plate does not deform, these three or possibly four high points would assume the entire applied load resulting in very poor pressure distribution. This was precisely what results from initial tests yielded.

Figure 14 is a typical plot of the pressures exerted on top of the HMA mat for an empty coal train in the time domain (Rose, Li and Walker, 2002). Vertical pressures imposed by typical 130 metric ton locomotives and loaded coal cars range from 90 to 120 kPa on top of the HMA mat. The average locomotive wheel load is 16 metric tons. Pressures are reduced to 15 to 30 kPa under the 29 metric ton empty cars, which have an average wheel load of 3.5 metric tons.

The beam action of the track, which distributes the concentrated wheel loadings over several ties and the confined, high modulus ballast layer, serve to effectively reduce the heavy wheel loadings. By comparison, an 82 kg person will exert about 40 kPa pressure while standing on a level surface. Furthermore, typical tire pressures imposed on highway asphalt surfaces under loaded trucks range from 700 kPa to over 1,050 kPa depending on the magnitude of loading and tire configurations.

Trackbed vertical stress levels on top of the HMA mat under heavy tonnage railroad loadings are very low and only a fraction of those imposed by high-pressure truck tires on highway pavements. The HMA mat should have an extremely long fatigue life at the load-induced pressure levels existing in the trackbed environment.

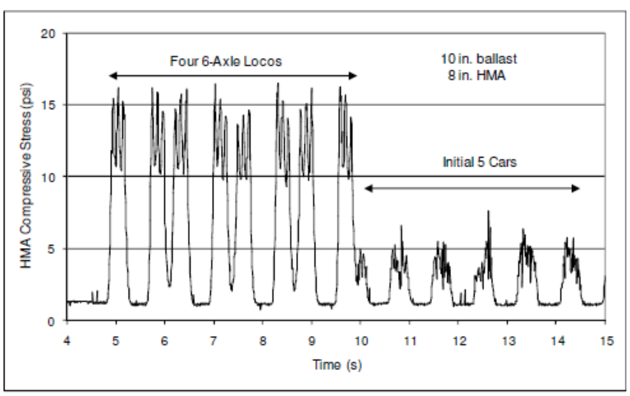


Figure14. Representative dynamic compressive stress on HMA layer measured for empty coal train.

Dynamic track deflections were recorded in conjunction with the pressure measurements using LVDTs referenced to a fixed datum. Figure 15 is a typical plot of rail deflections under 130-metric ton locomotives and loaded cars. The deflections average 6.4 mm for wood tie track and around 1.3 mm for concrete tie track. These are considered optimum for both track types.

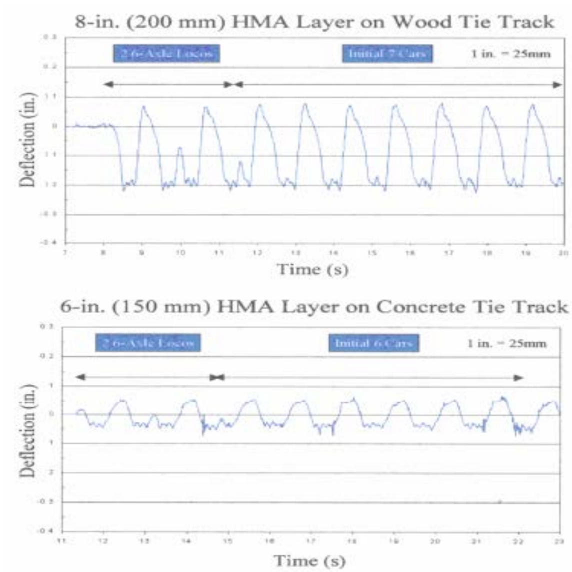


Figure 15. Deflections under loaded coal train.

Based on the wheel loadings and measured track deflections, the calculated dynamic track modulus (stiffness) values are in the 17 MPa range for wood tie track and around 52 MPa for concrete tie track. These are also considered optimum. The concrete tie track deflects much less than the wood tie track and is thus much stiffer. This increases pressure within the ballast. The ballast must be properly supported from below so it can develop high shear strength to reduce the higher than normal imposed loading pressures. The high modulus HMA mat provides increased support and confinement for the ballast in concrete tie track.

3.1.2 *TTC (Pueblo) Test Track Results*

HMA underlayment sections were placed over a soft subgrade (low track modulus) and subjected to 36-metric ton axle loads. The use of HMA underlayment was intended to reduce load-induced stresses to the subgrade and to provide a waterproof layer over the underlying soil. Since its installation, the performance of this test track has been evaluated in terms of track geometry degradation with traffic as well as the amounts of track modulus increase and subgrade stress reduction compared to conventional granular layer construction (Li, Lopresti and Davis, 2002).

Track modulus test results were obtained at 83 MGt. Subgrade stress was measured under a static wheel load of 18 metric tons. The average modulus values for the two HMA segments were 20 MPa and 23 MPa for the fully consolidated ballast (increased from 18 and 19 MPa), respectively, at 0 MGt. The track modulus for the 450-mm granular track averaged 14 MPa. As a result, the measured subgrade stresses were lower for the asphalt trackbeds than for the 450-mm granular track. Under an 18-metric ton static wheel load, only 50 to 55 kPa of subgrade stress was generated under the HMA underlayments, compared to 83 kPa under the 450 mm granular track structure.

To indicate how stresses induced by wheel loads are reduced from the HMA to the subgrade, Figure 16 shows the dynamic stress results under an actual train operation at 64 km/hr measured on the 200 mm HMA surface as well as on the subgrade surface. As illustrated, use of a 200 mm HMA underlayment reduced the subgrade stress by approximately one-half.

In addition, the data in Figure 16 indicates that the dynamic pressures measured on the top of the HMA surface for the 15 to 18 metric ton wheel loads range from 75 to 130 kPa. These values compare favorably with the 90 to 120 kPa dynamic pressures measured on top of the HMA mat at the CSXT Conway test site for the 16 metric ton wheel loads, as was indicated in Figure 14.

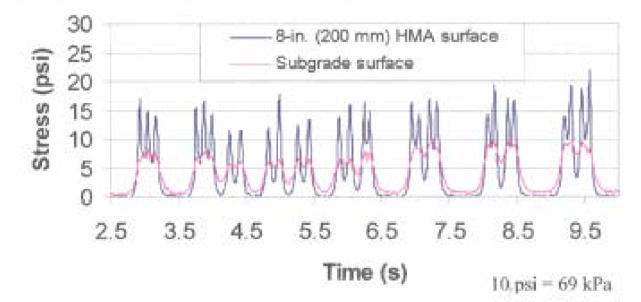


Figure 16. Reduction of dynamic stresses from HMA surface to subgrade surface under 35 MT axle cars.

4 ANALYSIS

Material characteristic evaluations were conducted on asphalt cores and subgrade/roadbed samples from seven asphalt trackbeds. The trackbeds were from 12 to 25 years old when tested and were distributed over four states. The inherent conditions varied significantly from site-to-site. These include asphalt thickness and composition, ballast thickness, trackbed support, and traffic. Previous characteristic evaluations were available for the projects and the results were included for comparisons with recent evaluations.

The significant finding relative to the materials (old roadbed/subgrade) directly under the asphalt layer is that the in-situ moisture contents are very close to laboratory determined optimum values for maximum density of the respective materials. The asphalt layer is not performing as a membrane to collect and trap moisture, thus weakening support. Actually, since the in-situ moisture contents are at or near optimum for maximum density, the strengths and load carrying capacities of the underlying materials are also at or near optimum. Furthermore, average moisture contents remain essentially unchanged, at or near optimum, for the two projects from which previous data was available. For design purposes, it is reasonable to base strength or bearing capacity values at optimum conditions (moisture content and density) for the material under the asphalt layer.

Therefore, using strength or bearing capacity values determined for the soaked condition, common for highway designs, is inappropriate for asphalt trackbed designs. The unsoaked, optimum moisture content condition is consistent with in-service trackbed conditions.

An equally significant finding, relative to the asphalt cores characterizations, is that the asphalt binders and asphalt mixes do not exhibit any indication of excessive hardening (brittleness), weathering, or deterioration even after many years in the trackbed environment. This is considered to be primarily due to the insulative effects of the overlying ballast which protects the asphalt from excessive temperature extremes and oxidation and hardening of the asphalt binder. These factors will contribute to a long fatigue life for the asphalt layer. There is no indication that the asphalt layers are experiencing any loss of fatigue life based on resilient modulus test on the extracted cores.

The typical failure modes experienced by asphalt highway pavements are 1) rutting at high temperatures, 2) cracking and fatigue at low temperatures, 3) stripping/raveling under the suction of high tire pressures on wet pavements, and 4) progressive fatigue cracking due to inadequate subgrade support, generally augmented by high moisture and improper drainage. These conditions do not exist in asphalt railroad trackbeds. For example, the temperatures are not sufficiently high to promote rutting. Conversely, the temperatures are not sufficiently low enough to promote low temperature cracking and decreased fatigue life, nor do the asphalt binder weather or harden excessively in the insulated trackbed environment which would have further negative influence on cracking and fatigue life. Obviously the tendency to strip/ravel is essentially eliminated in the trackbed environment since there is no rubber suction action. Also, the moisture contents of the underlying subgrade/roadbed support materials are maintained at or near optimum for maximum density and support strength.

In addition, peak dynamic vertical pressures on top of the asphalt layer are typically less than the 138 kPa under 130 metric ton locomotives and heavily loaded cars (Rose, 2008) (Anderson and Rose, 2008). This is only two to three times larger than the pressure exerted by an average-size person standing on an asphalt pavement, and much less than pressures exerted by heavily loaded highway trucks, which can be in excess of 690 kPa. These peak dynamic pressures are further reduced to less than 69 kPa under the asphalt layer at the subgrade interface (Li, Rose and LoPresti, 2001).

5 CLOSURE

This paper presented test results for material properties of the asphalt and underlying materials in order to assess if any weathering or deterioration of the materials was occurring in the trackbed environment which could adversely affect long-term performance of asphalt underlayment trackbeds. Based on the findings and analyses of the research reported herein, asphalt underlayments installed in conformance with basic design and construction practices should have an extremely long service life as a premium subballast to properly support railroad tracks. There is no indication of any deterioration or cracks of the asphalt after many years of heavy traffic under widely varying conditions.

Ancillary benefits of a long-lasting premium subballast support material for railroad tracks include the following:

increased strength, decreased abrasion, and increased life of the ballast; decreased wear and improved fatigue life of the ties, rail, and premium-cost track components such as special trackworks; a consistent level of track stiffness (modulus) designed for optimum levels; reduced maintenance activities and associated track closures; and improved adherence to track geometric parameters. All of these benefits impact favorably on achieving efficient operation of the rail transportation system.

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7 REFERENCES

Anderson, J.S. and J.G. Rose (2008) "In-Situ Test Measurement Techniques within Railway Track Structures," *Proceedings of the Joint Rail Conference* 2008, Wilmington, DE, 21 pages.

ASTM (2007) American Society for Testing and Materials. *Standard Specification for Performance Graded Asphalt Binder*, ASTM D6373, Book of Standards Volume: 0403, 2007, 5 pages.

Li, D., J. Rose, and J. LoPresti. (2001) *Test of Hot-Mix Asphalt Trackbed over Soft Subgrade Under Heavy Axle Loads,* Technology Digest-01-009, Assoc. of American Railroads, April, 2001, 4 pages.

Li, D., Lopresti, J., and Davis, D. (2002) *Application and Performance of Hot-Mix Asphalt Trackbed over Soft Subgrade*. Railway Track & Structures, January, pp. 13-15.

Rose, J. and H. Lees. (2008) Long-Term Assessment of Asphalt Trackbed Component Materials' Properties and Performance, Proceedings of the American Railway Engineering and Maintenance-of-Way Association 2008 Annual Conference, Salt Lake City, UT, September, 2008, 28 pages.

Rose, J. (2006) *Hot-Mix Asphalt in Railway Trackbeds*, ASPHALT, Asphalt Institute Magazine, Vol. 21, No. 3, 2006, pp. 22-25.

Rose, J. (1998) *Long-Term Performances, Tests, and Evaluations of Asphalt Trackbeds*. Proceedings of the American Railway Engineering and Maintenance-of-Way Association 1998 Conference, September, 1998, 27 pages.

Rose, J., E. Brown, and M. Osborne. (2000) *Asphalt Trackbed Technology Development; The First 20 Years*. Transportation Research Record 1713, Transportation Research Board, 2000, pp. 1-9.

Rose, J., Li, D., and Walker, L. (2002) Tests and Evaluations of In-Service Asphalt Trackbeds. *Proceedings of the American Railway Engineering and Maintenance-of-Way Association* 2002 Annual Conference & Exposition, September, 30 pages.

Rose, J., Stith, J. (2004) *Pressure Measurements in Railroad Trackbeds at the Rail/Tie Interface Using Tekscan Sensors*. American Railway Engineering and Maintenance-of-Way Association, 2004 Annual Conference & Exposition, September, 21 pages.

Rose, J.G (2013) "Selected In-Track Applications and Performances of Hot-Mix Asphalt Trackbeds," *Proceedings of the Joint Rail Conference* 2013, Knoxville, TN, April, 10 pages.

Rose, J.G. (2008) "Test Measurements and Performance Evaluations of In-Service Railway Asphalt Trackbeds," *Proceedings of the Transportation Systems 2008 Workshop*, Phoenix, AZ, 17 pages.