Hot Mix Asphalt Railway Trackbeds:
Trackbed Materials, Performance Evaluations, and Significant Implications

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Submitted for Presentation at the International Conference on Perpetual Pavements 2009; September 30 – October 2, 2009; Columbus, Ohio

Word Count:
7326 (including Figures and Table)

May 15, 2009

ABSTRACT

During the past 25 years several U.S. Railroad companies and the asphalt paving industry have developed recommended (optimum) designs and applications for using a layer of hot-mix asphalt (HMA) within the track structure in lieu of conventional all-granular subballast. The HMA mix is designed similarly to the bottom layer of perpetual highway pavement. Specifically, it is designed to be a medium modulus, flexible, low voids, fatigue resistant layer that will accommodate high tensile strains without cracking.

This paper presents the results of an investigation that evaluated the conditions and properties of trackbed materials after many years of service in various trackbed environments. The primary purpose for the initial testing program was to assess if any weathering or deterioration of the asphalt mixtures or binders or changes in the subgrade materials were occurring in the trackbed environments that could adversely affect long-term performance of the trackbeds. Seven HMA trackbeds, ranging in age from 12 to 25 years, on heavy traffic revenue lines in four states were core drilled. Test data on the HMA cores were compared with data normally expected when HMA is used in exposed layers on highway pavements. Tests on the HMA cores included thickness, density and voids analysis, asphalt binder content and resilient modulus. Additional tests for viscosity, penetration, and DSR were conducted on the recovered asphalt binders to determine the effects of weathering over extended periods in the trackbed environments. Also, tests on subgrade samples were performed. These tests included in-situ moisture content, soil classification, optimum moisture content/maximum density (Proctor) and California bearing ratio determinations.

The results of the testing program showed that the asphalt binders and HMA mixes do not exhibit any indication of excessive hardening (brittleness), weathering, deterioration or reduction in fatigue life after many years in the insulated trackbed environment. The primary indicators have remained essentially unchanged during the past nine years. The tests also showed that the in-situ moisture contents of the subgrades directly below the HMA layers were very close to laboratory determined optimum values for maximum density and load carrying capacity of the respective materials. Furthermore, in-situ moisture contents have remained essentially unchanged, at or near optimum, for the trackbeds. It is concluded that the benefits impact favorably on achieving long-term, cost-efficient operations for the rail transportation system in the United States.

INTRODUCTION

The concept of **Perpetual Asphalt Pavements**, or long-lasting asphalt pavements, has recently gained a measure of interest by highway design engineers. Actually, the term “perpetual” is somewhat misleading for highway pavements since it only applies to the base and intermediate layers. The thin **wearing surface layer** is considered to be “sacrificial” and thus must be renewed periodically. Renewing the thin wearing surface layer can be accomplished with minimal disruption to traffic operations and at only a fraction of the cost and traffic disruption of renewing the total pavement section.

In addition, recent mixture design innovations – primarily from the SHARP program and associated SUPERPAVE asphalt mixture design practices – have provided the technology to select optimum materials properties for the two underlying layers. Of particular importance for heavy traffic highways is selecting an **intermediate layer** to primarily carry the imposed loadings. This requires a high modulus, rut-resistant material of sufficient thickness, typically at least 4 to 7 in. (100 to 175 mm), to accommodate the high compressive loadings. In addition, it is desirable to select design parameters for the **base layer** to insure a flexible, fatigue resistant layer that is typically 3 to 4 in. (75 to 100 mm) thick. Selecting higher asphalt binder contents, than considered optimum for the wearing surface layer, can further ensure against fatigue cracking from the bottom layer. It is generally acknowledged that properly designed intermediate and base layers can be expected to have design lives of 50 years, and thus can be considered as a perpetual or long-lasting pavement.

The uses of Hot-Mix Asphalt as a subballast layer within railroad track structures for new trackbed construction and trackbed maintenance applications have grown steadily in the United States during the past 25 years. The asphalt layer (termed underlayment) is used in lieu of the conventional all-granular subballast layer as indicated in Figure 1. The underlayment is typically placed 5 to 8 in. (125 to 200 mm) thick and 12 ft (3.6 m) wide. A base mix having a 1.0 in (25 mm) maximum aggregate size, that is slightly “over asphalted”, with about 0.5 percent additional asphalt binder than normally specified for a highway pavement mix is considered the ideal mix for railway trackbed applications. The specified thickness of the overlying ballast is normally 8 to 12 in. (200 to 300 mm).

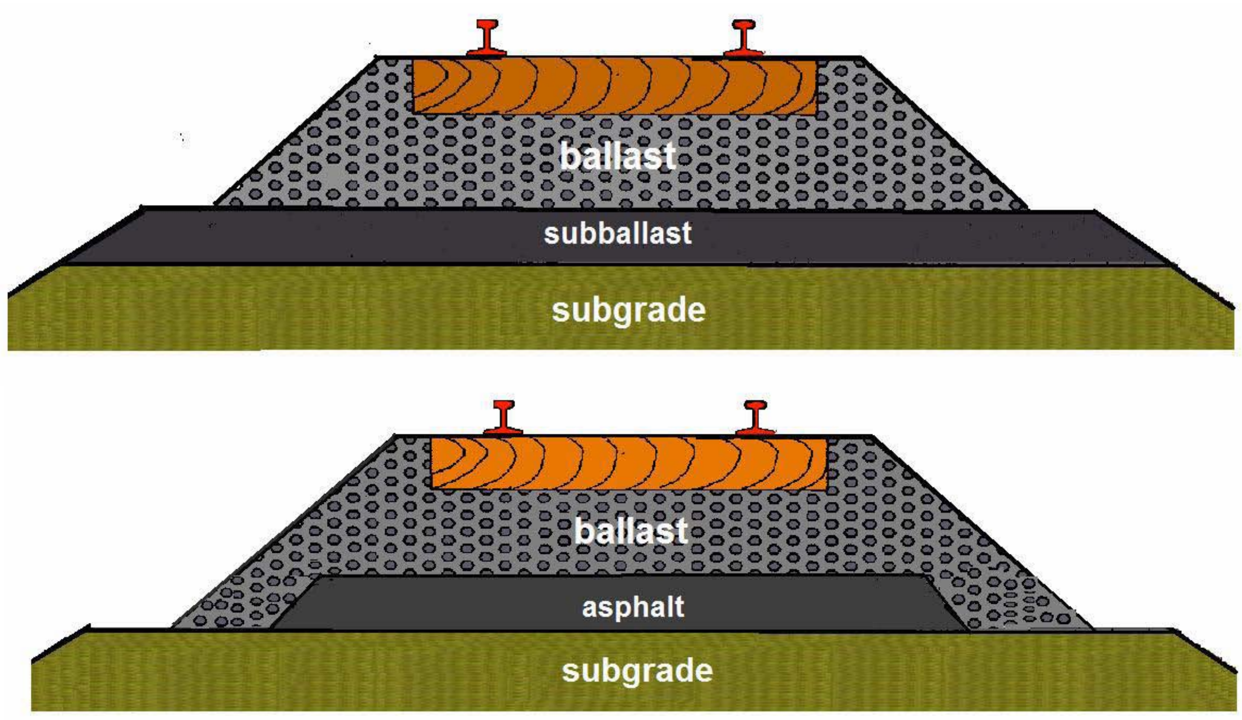


FIGURE 1 Cross-sectional views of typical all-granular and hot mix asphalt trackbeds.

It is of interest to note that the asphalt layer in the trackbed is somewhat synonymous with the base layer in the perpetual highway pavement design. It is protected from extreme environmental effects of sunlight, rainfall, and temperature due to the insulating effects of the overlying ballast and railway track. The wearing surface layer and intermediate layer of the perpetual highway pavement design provide similar insulation. In addition, the availability of oxygen is reduced which minimizes associated weathering and hardening of the asphalt binder.

The primary activity of the testing program described herein was a characterization and evaluation study to ascertain the effects of long-term exposure in various trackbed environments on the material properties of the trackbed materials – specifically the asphalt layer and underlying (roadbed) subgrade. The primary purpose of the testing program was to determine if any weathering degradation of physical/chemical deterioration of the materials were occurring that could adversely affect long-term performance of the trackbeds. Test data on the trackbed materials were compared to data obtained previously. The expected benefits and trackbed life projections are discussed relative to current basic design practices for perpetual highway pavements.

ASPHALT TRACKBED MATERIALS TESTS AND EVALUATIONS

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 reported in 2008 (*1*). Previous characterization studies, primarily conducted in 1998 (*2*,*3*), were available for selected projects and evaluated for comparison purposes. The test sites are listed in Table 1.

TABLE 1 Asphalt Test Trackbeds

Location	Year Asphalt Trackbed Installed	Age of Asphalt at Time of Testing (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

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 (Figure 2). The 6 in. (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 12 in. (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 (*1*). Summary information follows.

Geotechnical Tests and Evaluations

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.

FIGURE 2 Core drilling operation to obtain asphalt cores and underlying roadbed/subgrade samples.

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. Every effort was made to remove core drilling water, this protecting the integrity of the subgrade samples. No significant water penetrated the soil subgrades. No subgrade appeared to be wet of 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 3. There was an average net 0.1 percent decrease in moisture contents over the span of nine years.

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.

Standard Proctor moisture contents

These tests were conducted to determine the optimum moisture content for achieving maximum density. The minus 0.50 in. (12.5 mm) size material was removed. Figure 4 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 5 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 6. 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.

California bearing ratio

The 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 0.1 in. (2.5 mm) penetration.

The CBR values varied significantly reflective of the properties of the respective materials. A comparison of unsoaked and soaked CBR test values is presented graphically in Figure 7. 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. This relationship is shown graphically in Figure 6. 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.

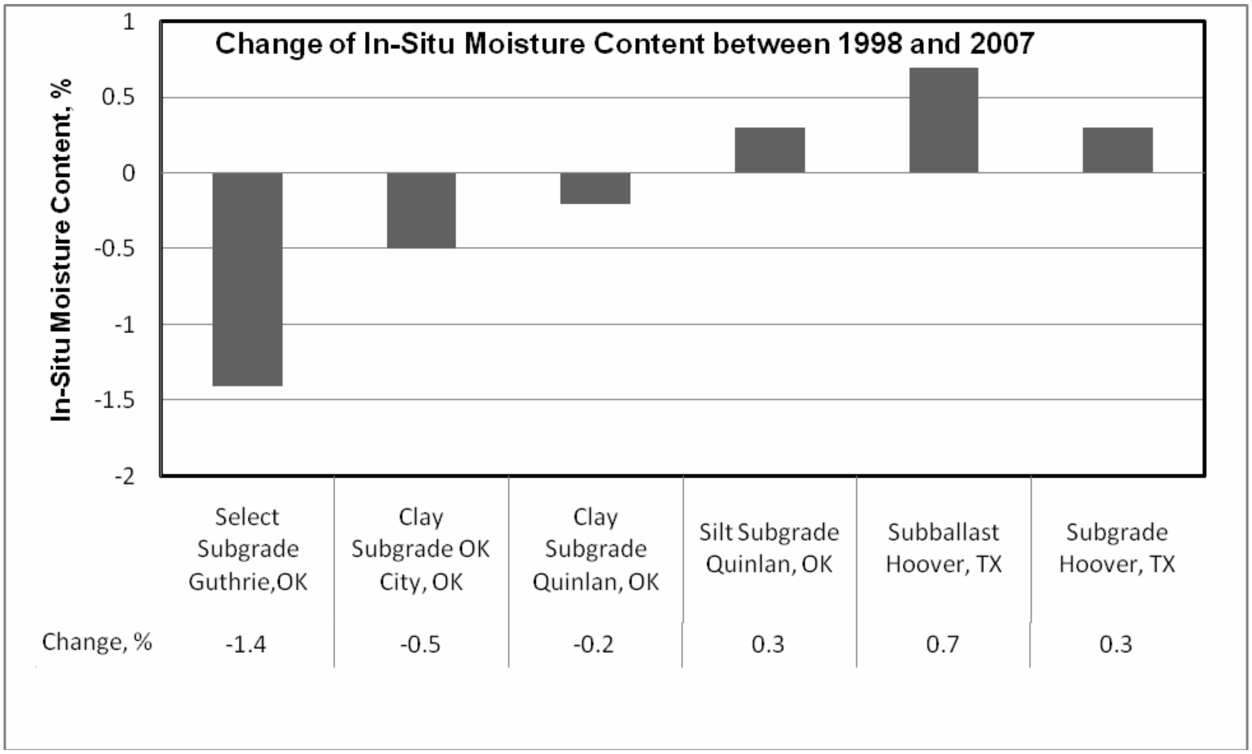


FIGURE 3 Changes in in-situ subgrade moisture contents between 1998 and 2007.

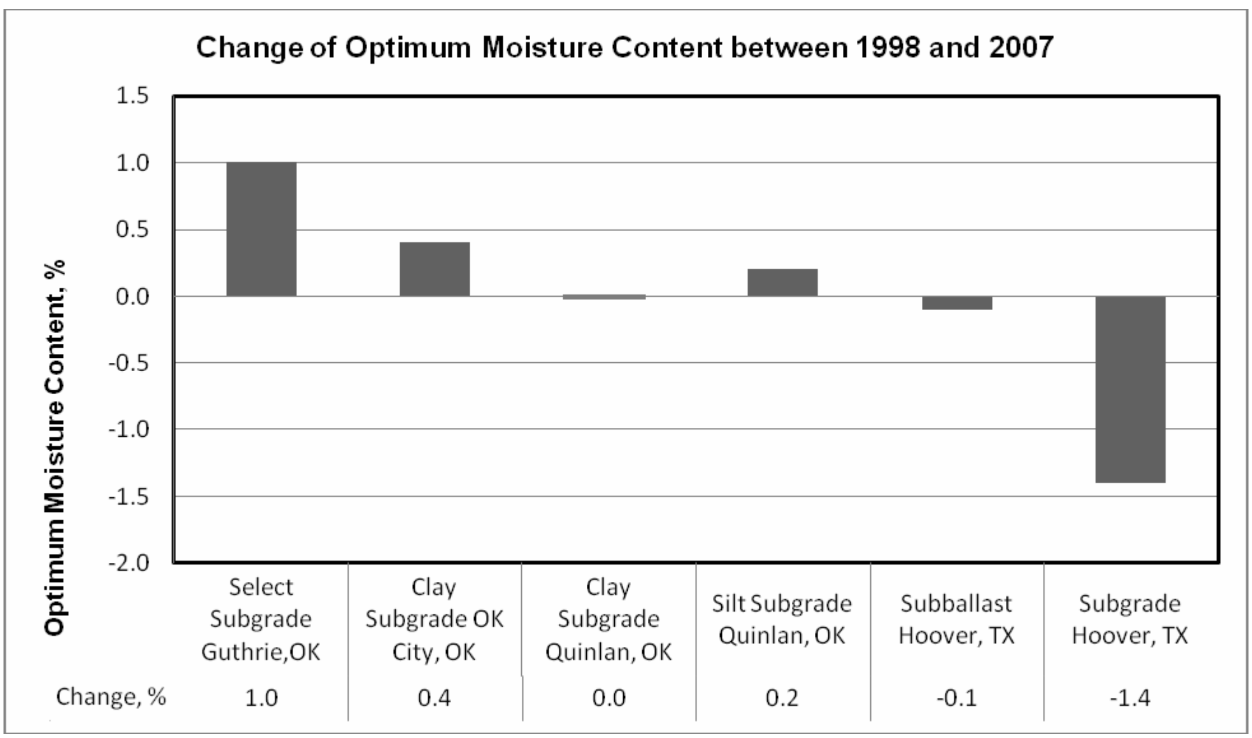


FIGURE 4 Changes in optimum subgrade moisture contents between 1998 and 2007.

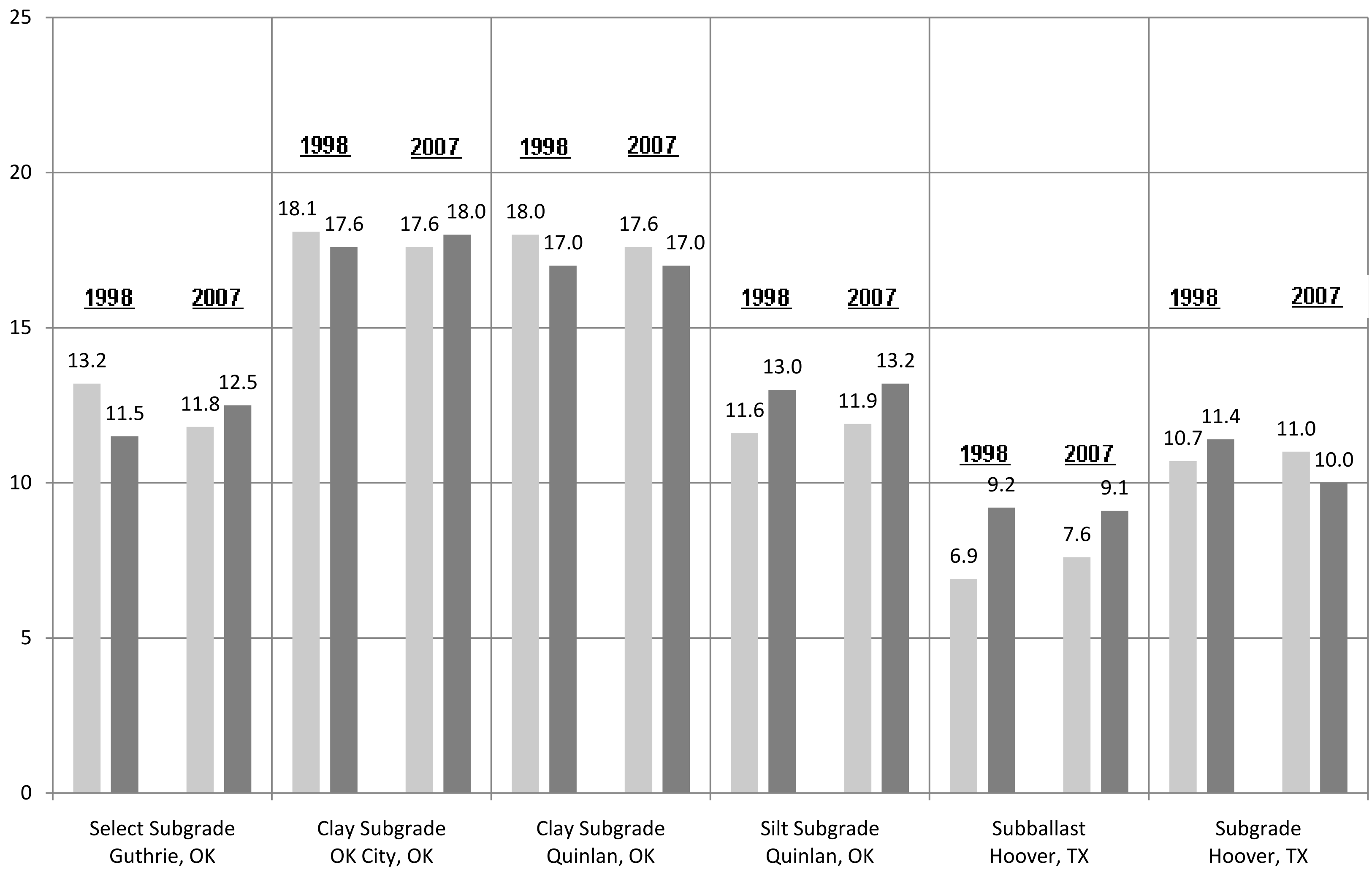


FIGURE 5 Comparison of 1998 and 2007 measured in-situ moisture contents and optimum moisture contents for the roadbed/subgrade samples.

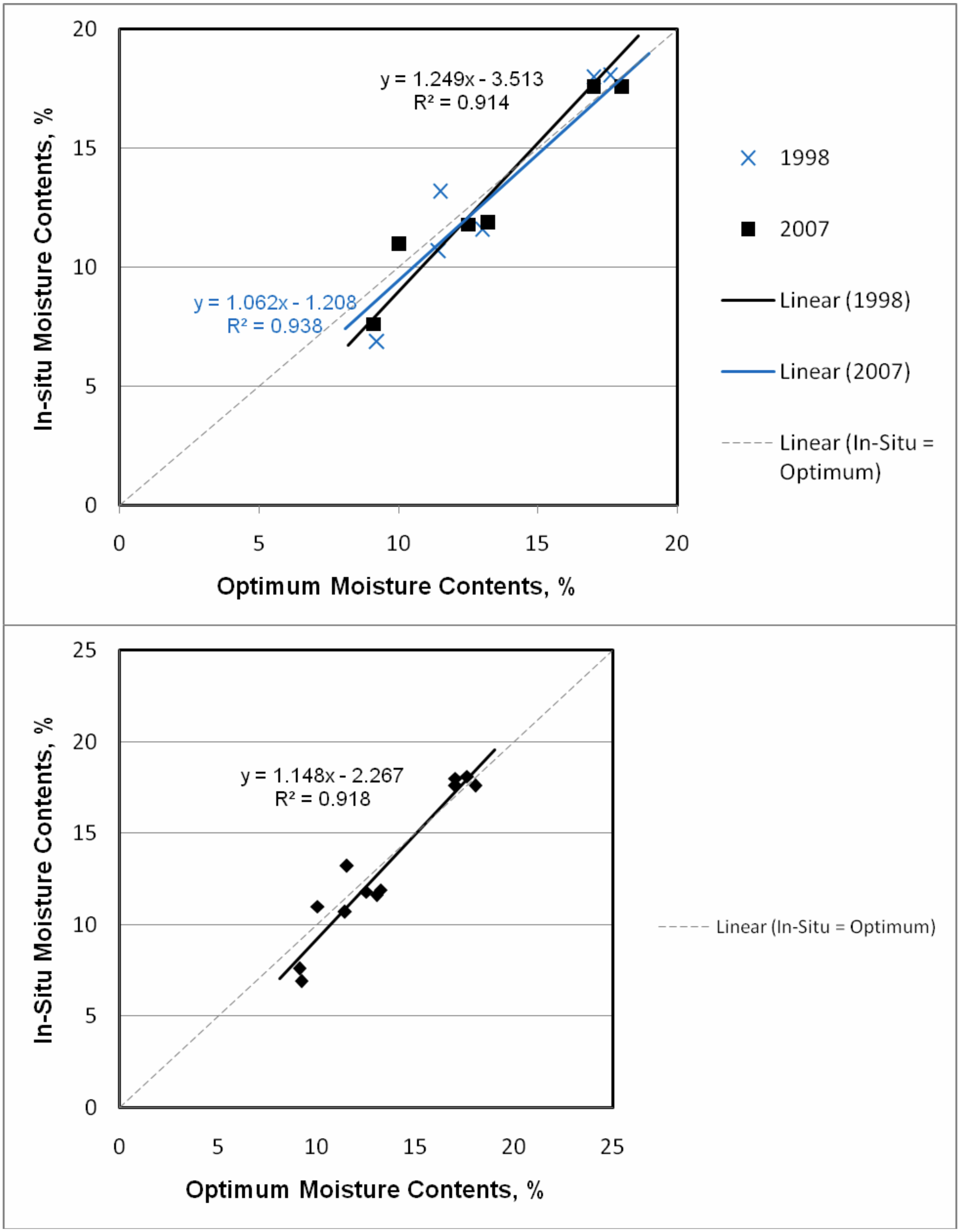


FIGURE 6 Relationships for roadbed/subgrade in-situ and optimum moisture contents.

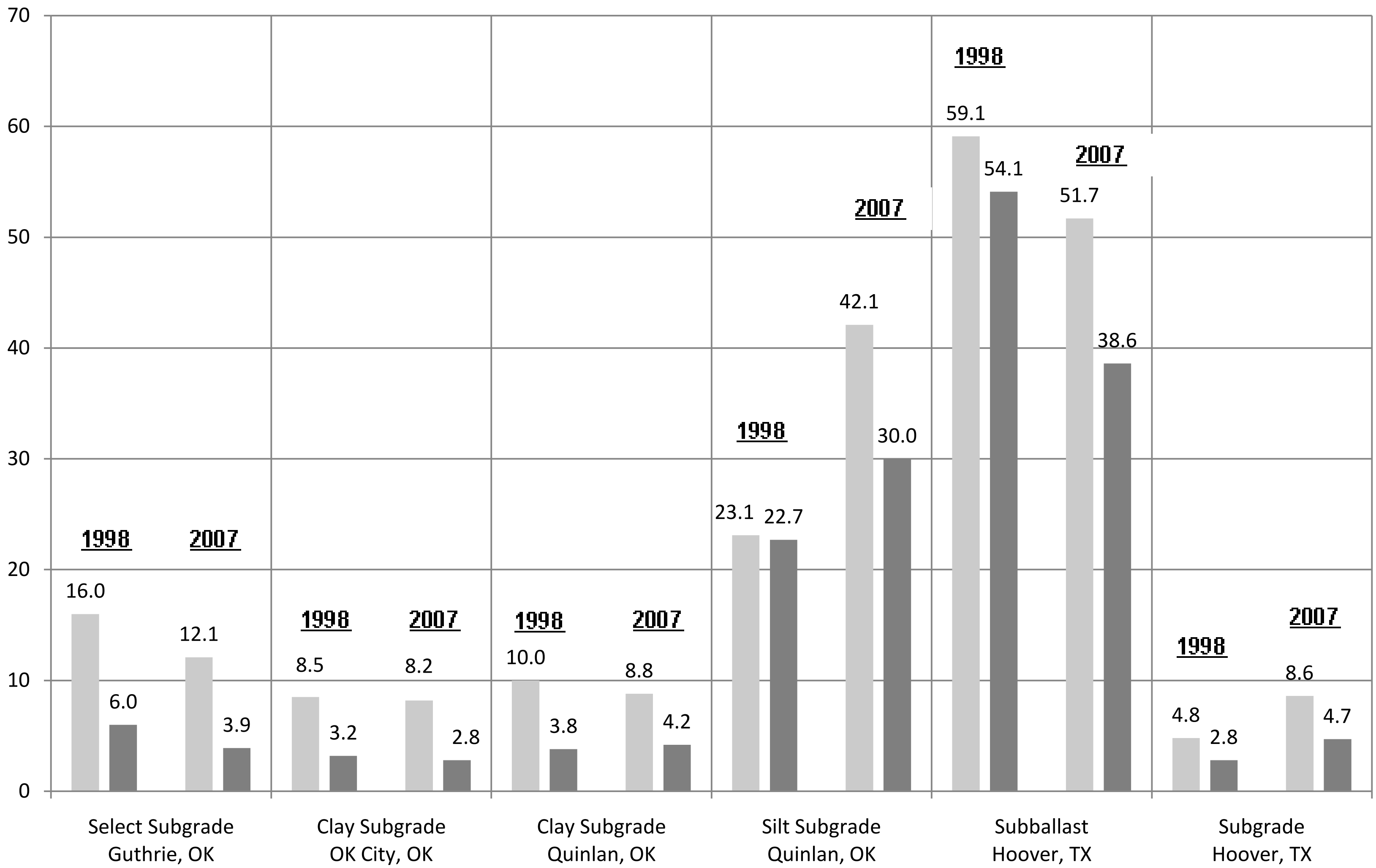


FIGURE 7 Comparison of 1998 and 2007 unsoaked and soaked CBR test values for the roadbed/subgrade samples.

Asphalt Mixture Tests 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.

Mix extraction tests and core analyses

The extraction test results were indicative of dense-graded base mixes with 1.0 in. (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 (*3*,*4*). 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 (41°F) and highest, 25°C (77°F), 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 8 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 modulus values for the cores cured the last nine years in the laboratory were higher than the cores in the railroad environment.

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. 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.

Recovered asphalt binder tests

Tests for Penetration, Absolute and Kinematic Viscosities, and Dynamic Shear Rheometer were conducted on the recovered asphalt binders. Plots of Penetration and Absolute Viscosity versus Age of the Asphalt Underlayments are contained in Figure 9. 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.

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 10.

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 (140°F) will be maintained to less than 15,000 poises (*5*). These samples meet these criteria, indicating minimal oxidation and weathering.

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 11. The standard for performance grade asphalt binders, after short- and long-term aging, is that the DSR at 25°C (77°F) should be less than 5,000 kPa. Note in Figure 11 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 (*5*).

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 20 in. (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 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 (*2*). Additional tests during 2000 at the AAR Pueblo test site confirmed the previous tests (*6*).

SUMMARY AND CONCLUSIONS

The primary purpose of this investigation was to determine, based on test results, current materials 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.

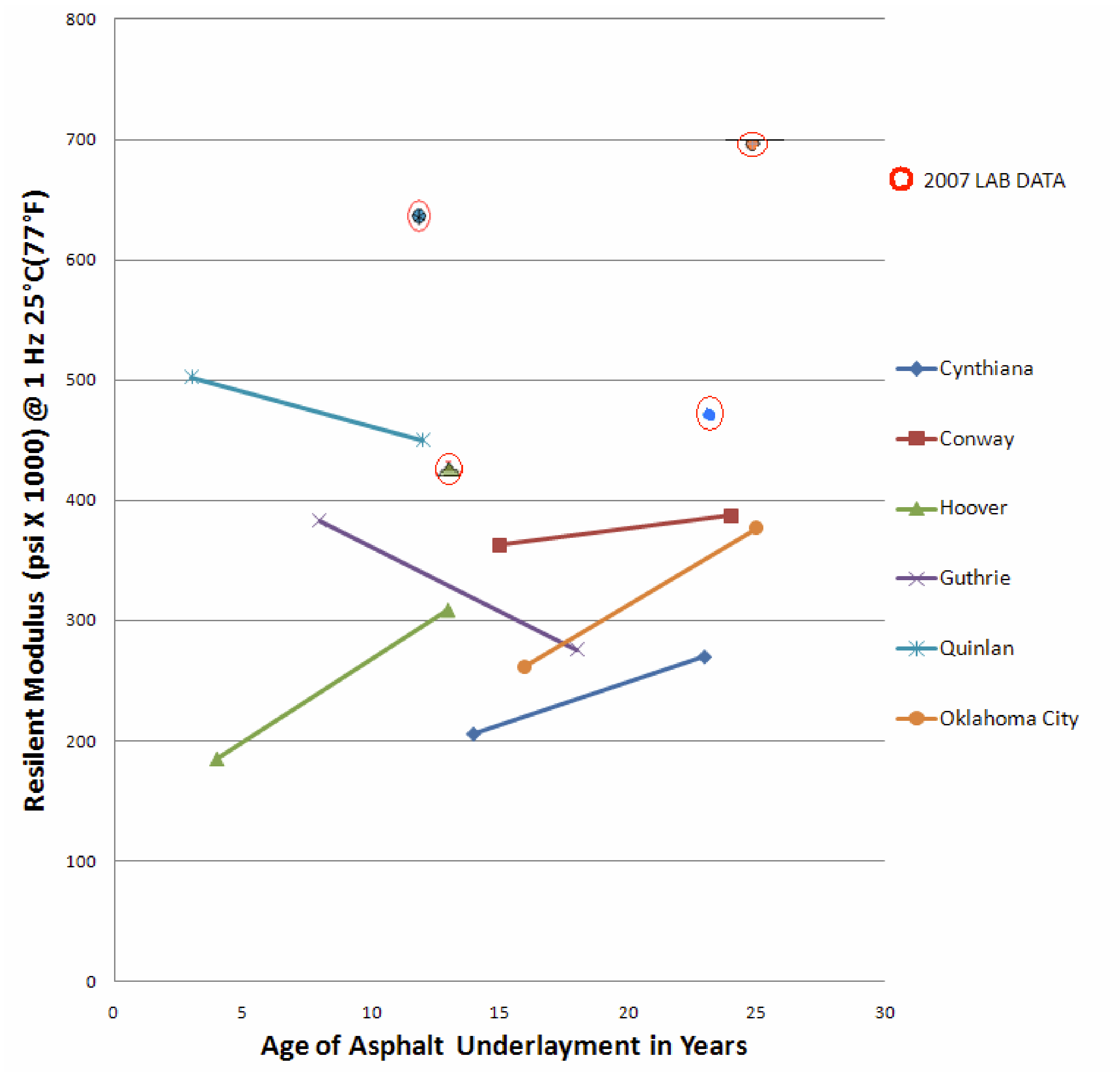
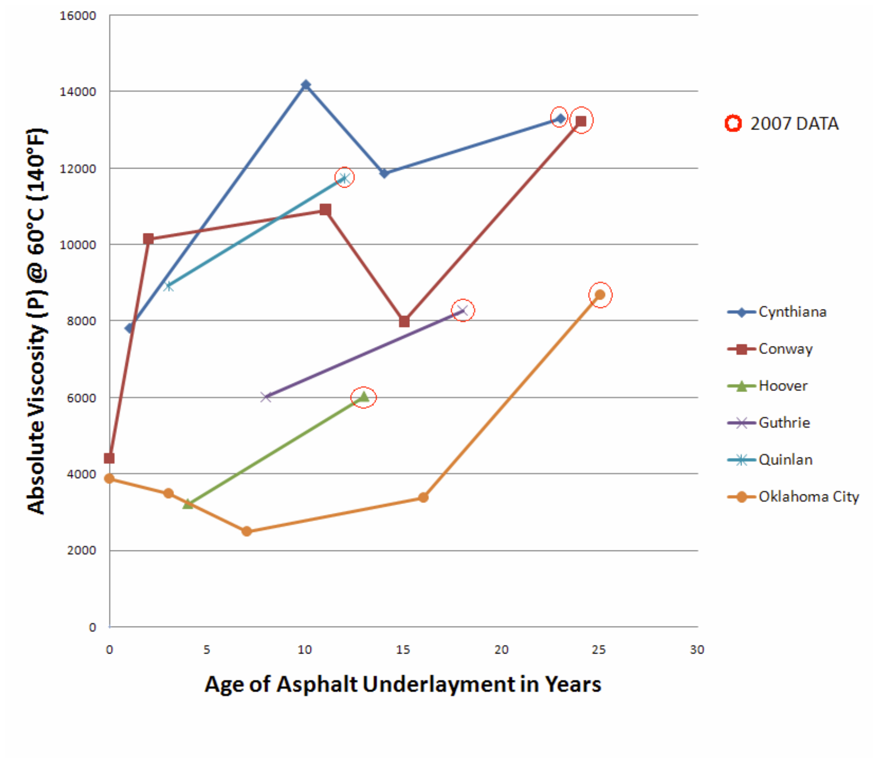


FIGURE 8 Resilient modulus versus age of asphalt.



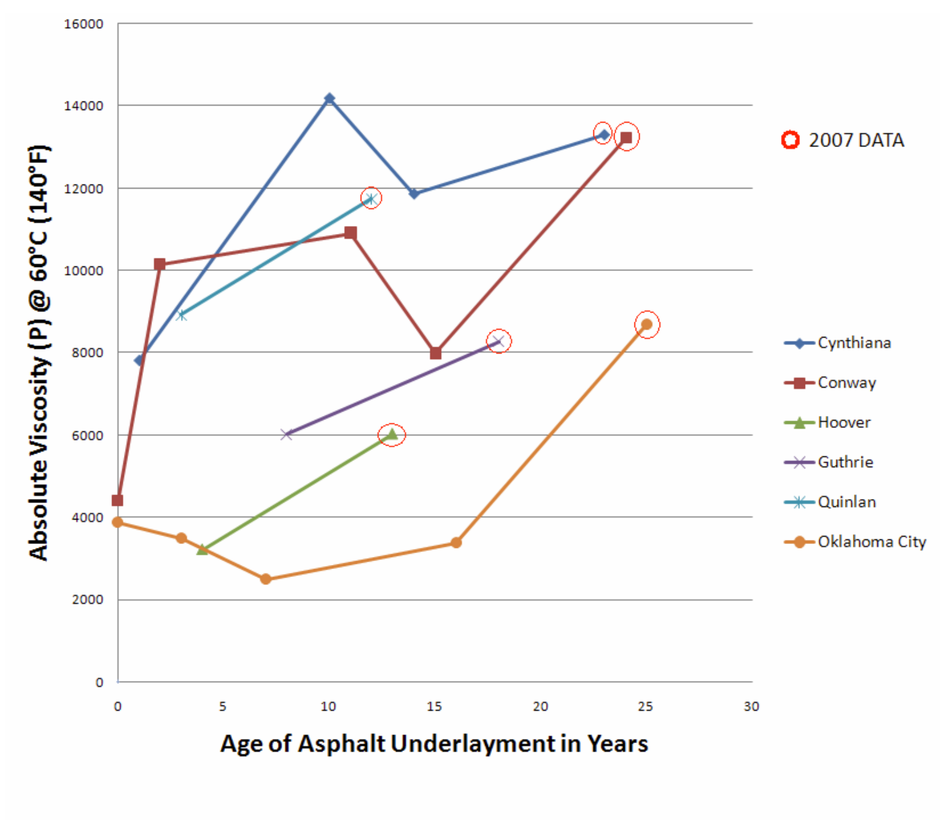
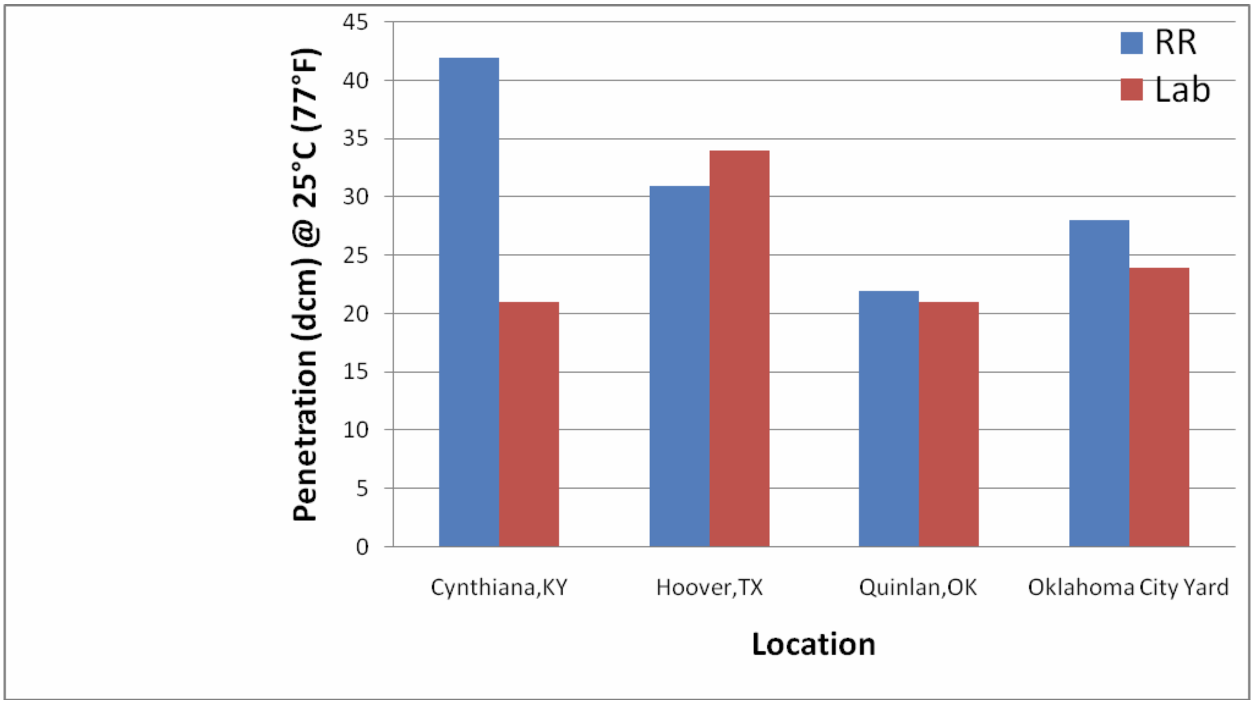


FIGURE 9 Penetration and absolute viscosity versus age of asphalt.



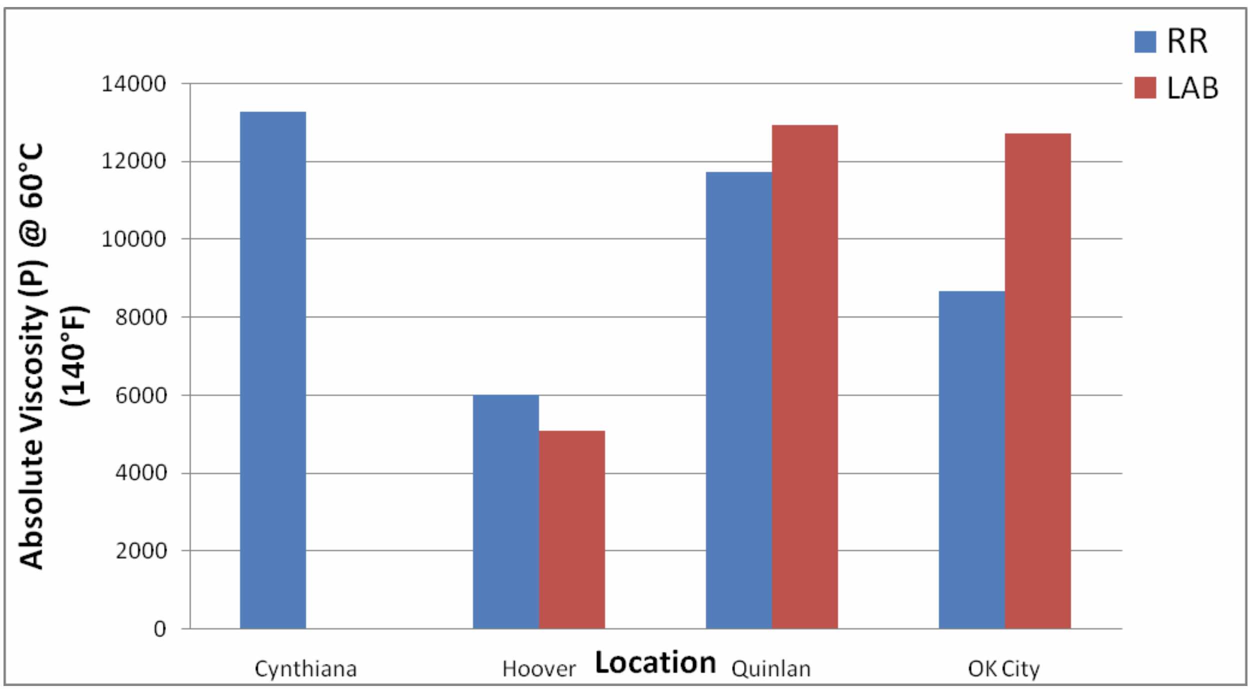


FIGURE 10 Penetration and absolute viscosity values for railroad and laboratory-cured asphalt cores.

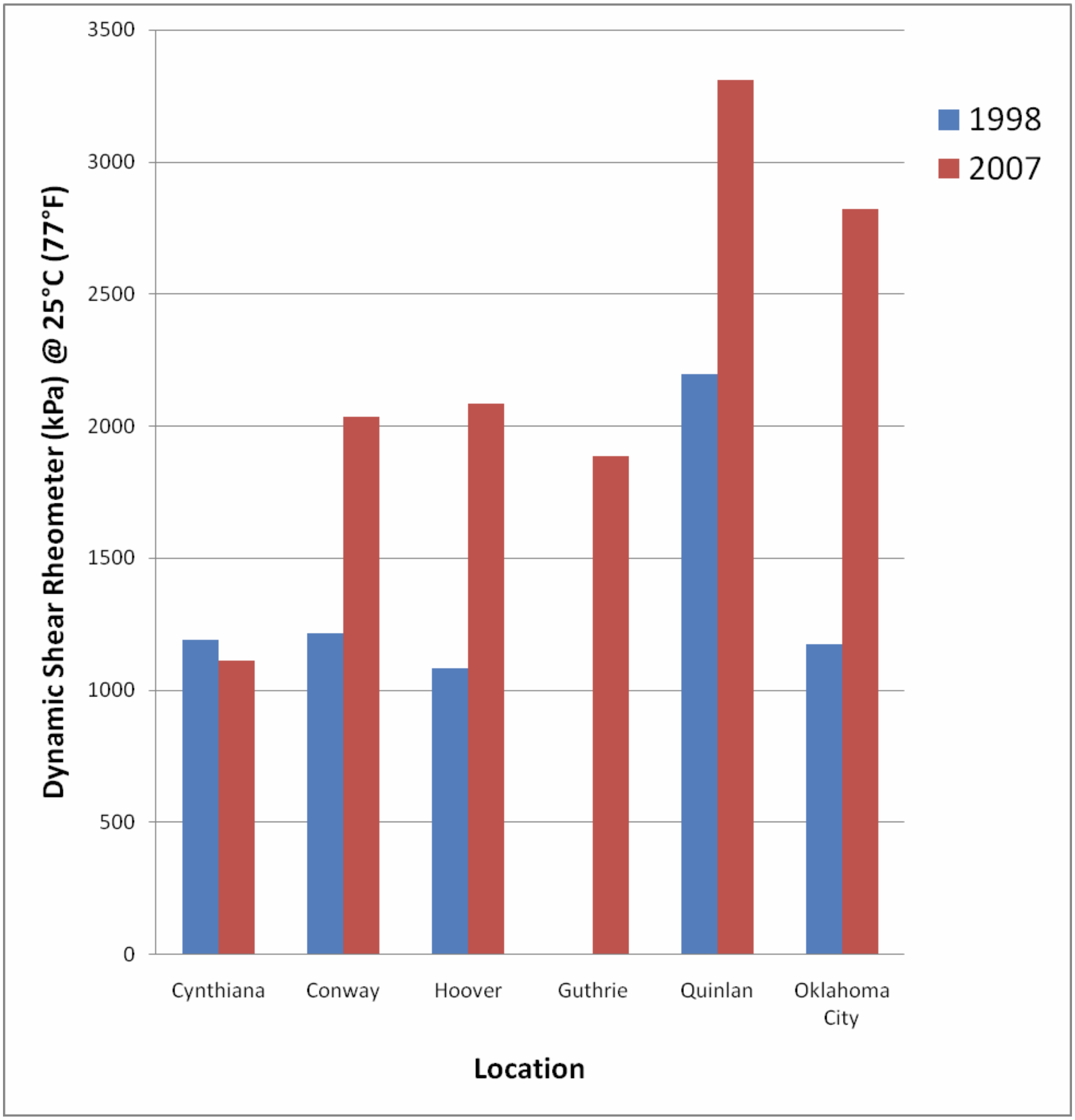


FIGURE 11 Dynamic shear rheometer values for 1998 and 2007 tests.

Material characterization 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 characterization 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. 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 20 psi (138 kPa) under 286,000 lb (130 metric ton) locomotives and heavily loaded cars (*7,8*). 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 100 psi (690 kPa). These peak dynamic pressures are further reduced to less than 10 psi (69 kPa) under the asphalt layer at the subgrade interface (6).

Based on the findings and analyses of the research reported herein, asphalt underlayments installed in conformance with the basic design and construction practices also reported herein 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.

ACKNOWLEDGEMENTS

The research was primarily supported by CSX Transportation and the BNSF Railway Company. The geotechnical laboratory testing was performed by the Geotechnical Branch of the Kentucky Department of Transportation. The asphalt laboratory testing was performed by the National Center for Asphalt Technology at Auburn University. William (Zack) Dombrow, BNSF Summer Intern from the University of Illinois, assisted with the 2007 sample collections and tests.

REFERENCES

1. Rose, J. and H. Lees. 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.

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

3. Rose, J. *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.

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

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

6. Li, D., J. Rose, and J. LoPresti. *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.

7. Rose, J. *Test Measurements and Performance Evaluations of In-Service Railway Asphalt Trackbeds*, Proceedings of the Transportation Systems 2008 Workshop, Phoenix, April, 2008, 24 pages.

8. Anderson, J. S. and J. G. Rose."In-Situ Test Measurement Techniques Within Railway Track Structures," 2008 ASME/IEEE/ASCE Joint Rail Conference Proceedings, Wilmington, DE, April, 2008, 21 pages.