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아스팔트 콘크리트 혼합물의 소성변형시험 개발

Development of a Practical Rutting Characterization Method for Bituminous Mixtures

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A B S T R A C T

The main objective of materials testing is to simulate in-situ field conditions as closely as possible, including loading conditions, climatic conditions, etc. Also, the test method should be easy, inexpensive, simple, and efficient to conduct to become an acceptable standard laboratory testing method for many agencies. Based on these reasons, a new test method employing repetitive axial loading with confinement was developed to evaluate the rutting(permanent deformation) of asphalt concrete. The new laboratory test protocol was developed based on the study of the various structural analysis and field data. This protocol divides asphalt layer(s) into three categories depending upon the depth. Different temperatures and vertical stress levels were used in these areas.

KEYWORDS

rutting
characterization
bituminous mixtures
structural analysis
field data

재료시험의 주 목적은 작용되는 하중과 기후조건을 포함하여 현장조건과 가급적으로 유사한 조건하에서 모사하는 것이다. 또한 시험법은 쉽고 저렴하며 시험을 수행하기 간단하며 시험결과가 효율적 이어서 많은 기관에서 표준시험법으로 수용할 수 있어야한다. 본 연구에서는 이러한 내용에 근거하여 새로운 시험법인 구속응력을 가진 반복 축 하중 시험이 아스팔트 콘크리트 혼합물의 소성변형 시험으로 개발되었다. 본 연구에서 제시하는 소성변형 시험은 다양한 구조해석과 현장 데이터의 분석을 근거로 개발되었다. 본 아스팔트 콘크리트의 소성변형 시험법에서는 포장의 깊이에 따라 3가지 범주로 분류 하였다. 각 범주마다 다른 온도와 수직응력을 적용하여 시험을 수행하였다.

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1. Introduction

Characterization of paving materials based on mechanistic approaches is becoming more important as the paving society moves away from empirical to more rational pavement design methods. In flexible pavements, one of the most important component materials is asphaltic mixtures, not only because of its higher cost but also because of its primary contribution to pavement performance. Analysis results of the field rutting data suggest that an asphalt concrete layer should be divided into several layers for the laboratory characterization. This is because the major part of the permanent deformation was found to be originated from the top portion of the asphalt concrete layer rather than uniform distribution of permanent deformation along the depth of AC layer. The nonuniform contribution of permanent deformation along the depth was reasoned to be due to changes in temperature and stress level along the depth. Temperature measurements from the test sections have revealed that temperatures near the pavement surface are higher than temperatures at lower depths during the most of daytime.

The multi-layered structural analysis results from WES-5 showed significant variation of stress distribution within the asphalt concrete layer. The amount of vertical stress decreased with a hyperbolic trend as the depth increased. The higher stress level with higher temperatures near the pavement surface causes greater permanent deformation from the higher portions of asphalt layers. Therefore, based on their depths within the asphalt concrete layer, the asphalt concrete layers were divided into three groups for the permanent deformation characterization.

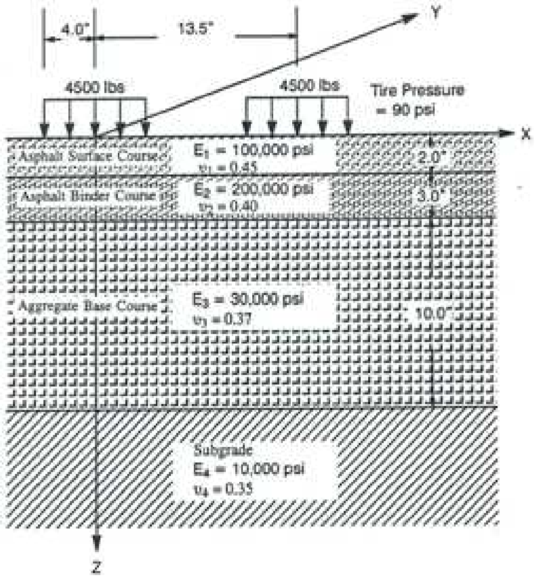
The general objective of materials testing is to simulate in-situ field conditions as closely as possible, including loading conditions, climatic conditions, etc. Also, the test method should be easy, inexpensive, simple, and efficient to conduct to become an acceptable standard laboratory testing method for many agencies. Based on these reasons, a new test method employing repetitive axial loading with confinement was developed in this research to evaluate the permanent deformation of asphalt concrete.

2. Selection of Rutting Test Conditions

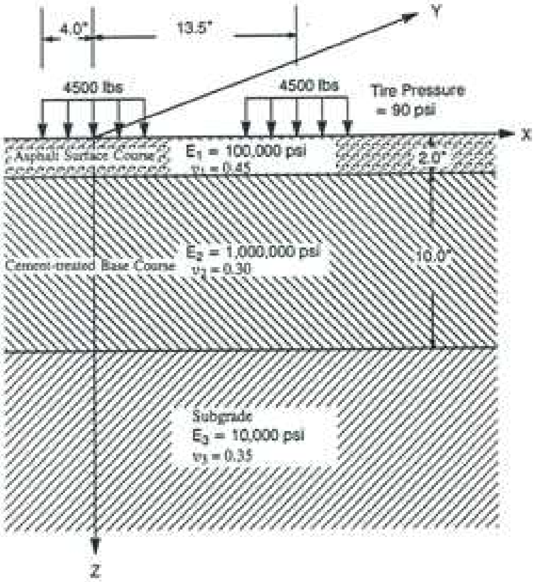
A haversine load with a 0.05-second load duration and 0.25-second rest period was repeated until the number of load applications reached 100,000 cycles. The 0.05 second of loading time results from the measured response under the speed limit of 55 miles (88.50 km) per hour at the three-inch depth within the asphalt concrete layer. The main reason for the use of the repeated loading instead of creep loading is that the loading history of the cyclic loading is much closer to the actual traffic loading than the constant creep loading. Also, it has been reported (Barksdale et al, 1977; Monismith et al, 1988) that the repeated loading tests appear to be more sensitive to mixture variables than the creep tests.

Barksdale et al. (1977) reported that, on the basis of the Shell creep tests, an increase in the asphalt content of a particular mixture from 4.5 to 5.5 percent should not have a significant effect on the rut depth. Results of repeated load triaxial tests on the same mixture, however, indicated that such an increase in asphalt content could increase the rut depth by 16 percent. On the basis of extensive testing, it was concluded that the repeated load triaxial tests appear to better measure rutting characteristics than the creep test does. Monismith et al. (1988) reported similar conclusions. They compared the response of three mixtures under both creep and repeated loading. They could not find any noticeable differences among the mixtures for creep loading while they noticed differences in the repeated load data. These findings suggest that the repeated loading test may be a more appropriate laboratory testing method to characterize the permanent deformation of asphalt mixtures than the simple creep test.

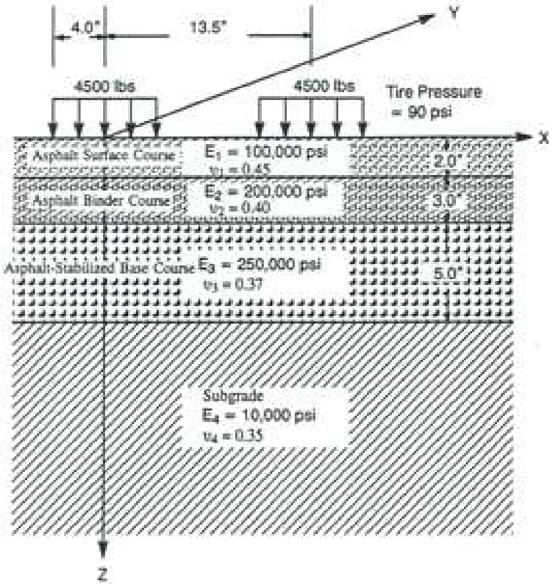
To simulate the field stress conditions better, structural analysis was performed using WES5 on three typical asphalt concrete pavement design types with aggregate base, cement-treated base, and full depth. Fig. 1 (a) through (c) show the three typical asphalt concrete pavement design types. The field stress conditions corresponding to the three typical asphalt concrete pavement design types are presented in Fig. 2 to 4. It is noted that the negative sign was used for compressive stresses. These figures show how the stresses are changing at different locations within the asphalt concrete layer. For the structural analysis, tire pressure of 90 psi was assumed with an axle loads of 18 kip (80.06 KN). Based on this analysis, vertical stresses of 90, 80, and 50 psi (620.73, 551.76, and 344.85 KPa) were determined to characterize the permanent deformation of AC layer for the top surface layer (less than 2 inches (5.08 cm)), the intermediate layer (between 2 and 5 inches (5.08 and 12.70 cm)), and the deep layer (deeper than 5 inches (12.70 cm)), respectively.



(a) with aggregate base course



(b) with cement-treated base course



(c) with full depth AC course

Fig. 1. Typical asphalt concrete pavement design type

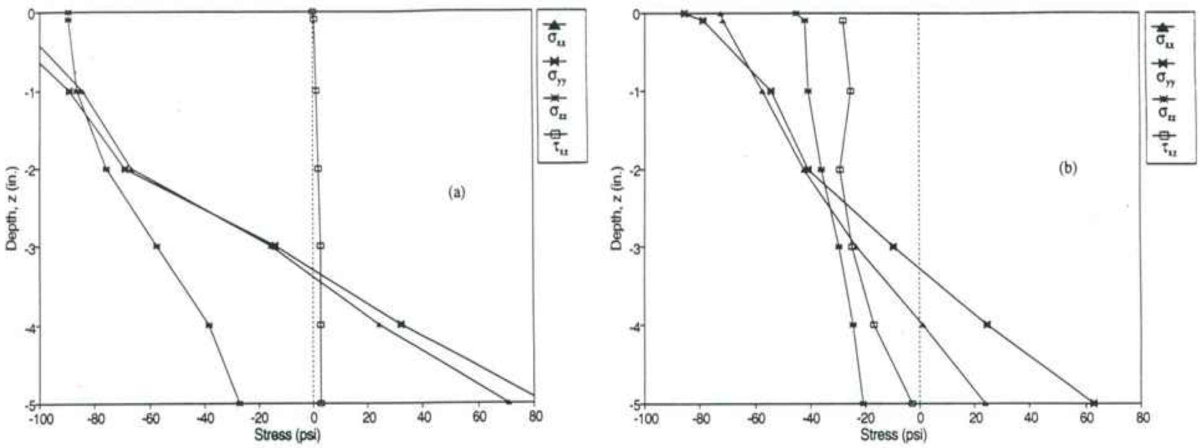


Fig. 2. Stress distributions in pavement section shown in Fig. 1(a)
(a) at X=0, Y=0 and (b) at X=4 in., Y=0.

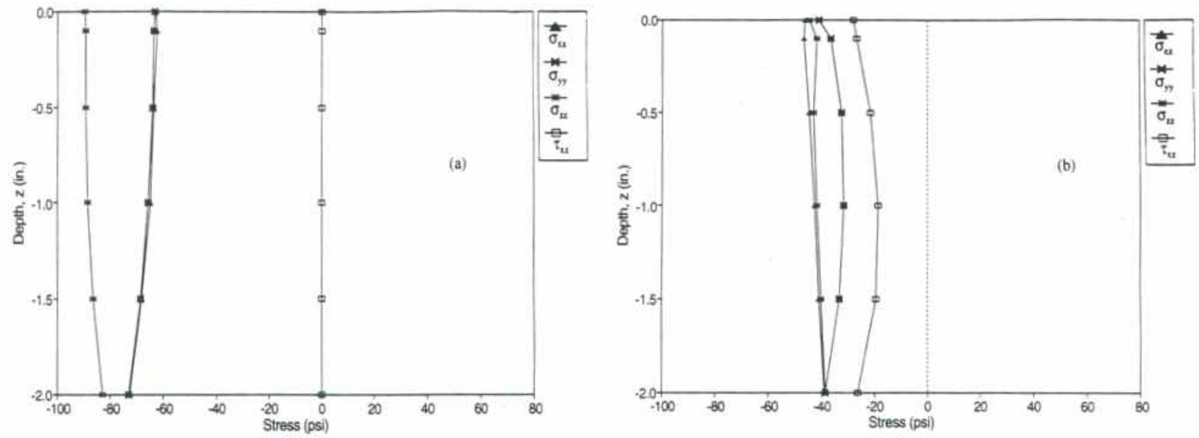


Fig. 3. Stress distributions in pavement section shown in Fig. 1(b)
(a) at X=0, Y=0 and (b) at X=4 in., Y=0.

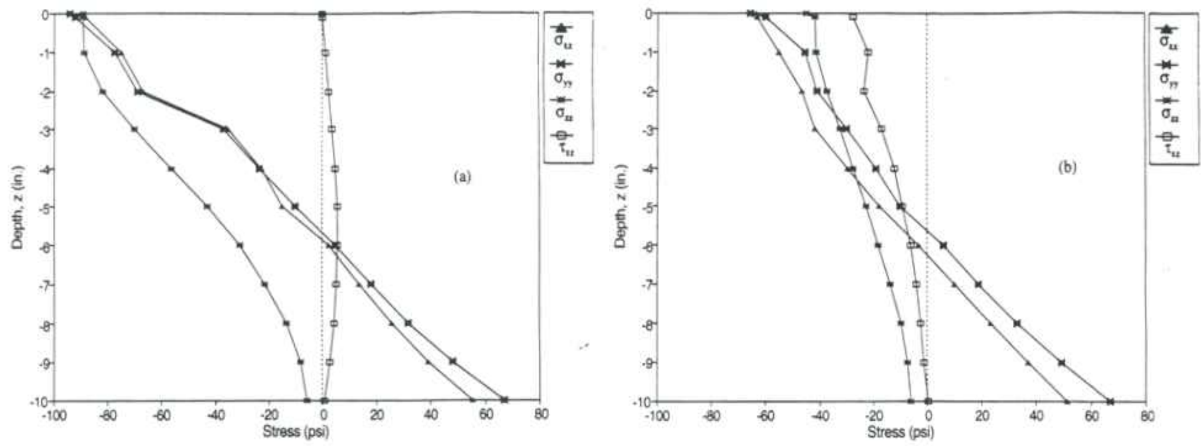


Fig. 4. Stress distributions in pavement section shown in Fig. 1(c)
(a) at X=0, Y=0 and (b) at X=4 in., Y=0.

The history of the use of vertical stress levels can be found from the following literature review (Kim, N., 1994; Little et al, 1993; Von Quintus et al, 1991). Von Quintus et al. used linear elastic theory to calculate the distribution of vertical compressive stresses within the asphalt concrete layer. They suggested using 65 psi (448.31 KPa) in the uniaxial static creep test at 140°F (60°C). Little et al. (1993) reported that for the majority of designs a uniaxial stress of between 50 and 60 psi (344.85 and 413.82 KPa) would be appropriate.

The temperatures used in the tests of this research were 104°F (40°C) for the surface materials (less than 2 inches (5.08 cm)) and 95°F (35°C) for the other materials (deeper than 2 inches (5.08 cm)). The temperature of 104°F (40°C) for the surface materials was selected based on the range of measured pavement temperatures and because of the history of the use of this temperature for creep testing and the selection of this temperature by AAMAS. The selected testing conditions on loadings and testing temperatures are summarized in Table 1.

Table 1. Selected rutting test conditions.

Position in AC Layer	Vertical Stress (psi)	Temperature (°F)
Top 2 inches	90	104
Between 2 and 5 inches	80	95
Below 5 inches	50	95

The selection of the test temperatures in this study can be supported by the following previous researches (Bonnot, 1986; Mahboub et al, 1988). Bonnot (1986) selected a test temperature of 140°F (60°C) for wearing-course asphalt concrete and 122°F (50°C) for base courses. These temperatures were chosen to be relatively high to represent the most unfavorable conditions expected in France. Mahboub et al. (1988) reported that the permanent deformation was ignorable at temperatures below 50°F (10°C). A testing temperature of 104°F (40°C) was selected by Little et al. (1993) for creep testing because of the history of the use of this temperature for creep testing.

3. Structural Analysis of Rutting Test Configuration

To estimate the stress distribution in the specimen under the new testing configuration (repetitive axial loading test with confinement), the structural analysis was conducted using finite element method (FEM). The loading condition and the specimen geometry of the testing configuration were axisymmetric and the corresponding axisymmetric structural analysis was performed.

To check the validity and compatibility of the stress conditions, the stress conditions from the laboratory testing configuration using FEM were compared with those from the field using WES 5. The comparison results between the field stress conditions and the laboratory stress conditions for the three typical asphalt concrete pavement design types are presented in Fig. 5 through 7. Generally, the vertical stresses from the laboratory testing method showed a good agreement with those from the field throughout the different design types. However, the stresses at the loading edge from the laboratory testing configuration were lower than the those from the field throughout the different design types. In particular, the vertical stress and the shear stress at the loading edge may affect the laboratory rutting performance significantly due to the selected laboratory rutting test configuration. Also, it should be noted that the lateral confining pressures from the laboratory testing configuration were lower than those from the field.

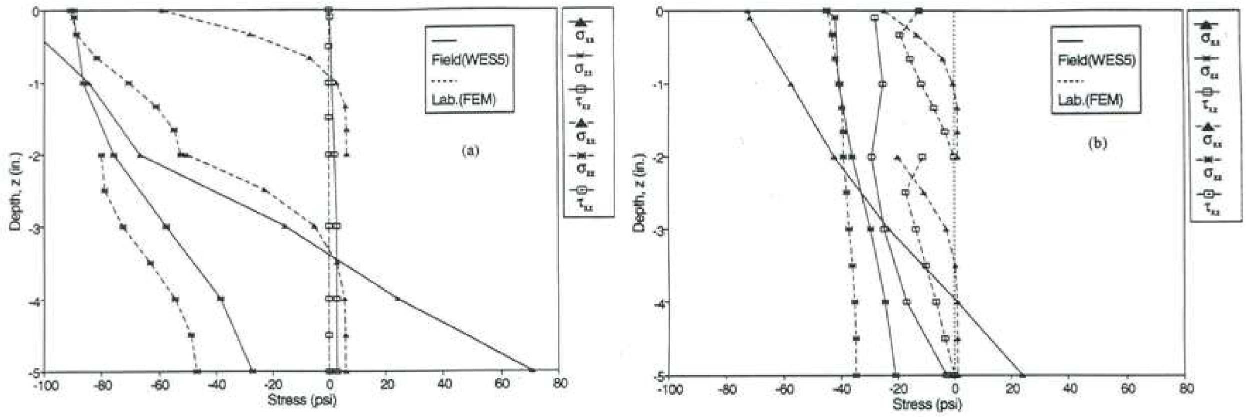


Fig. 5. Comparison of stress distributions in pavement section shown in Fig. 1(a) (a) at X=0, Y=0 and (b) at X=4 in., Y=0.

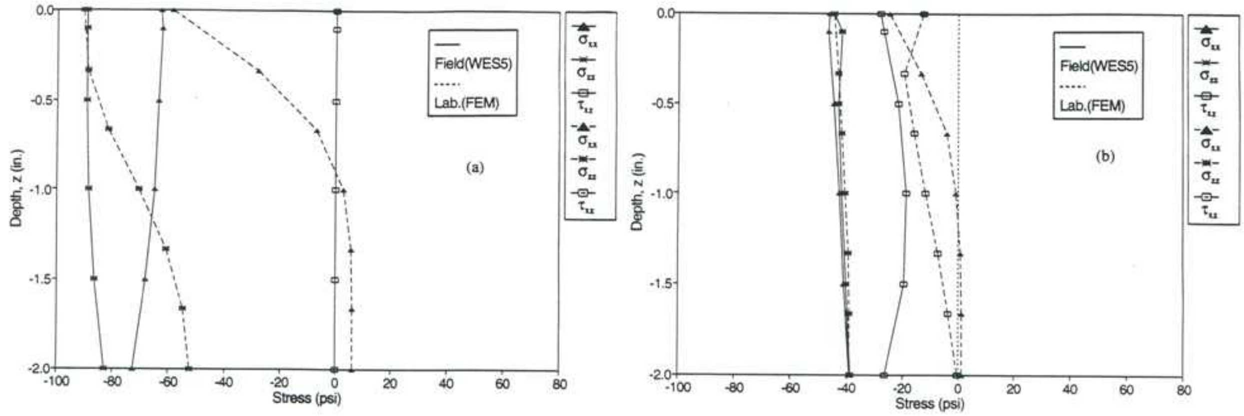


Fig. 6. Comparison of stress distributions in pavement section shown in Fig. 1(b) (a) at X=0, Y=0 and (b) at X=4 in., Y=0.

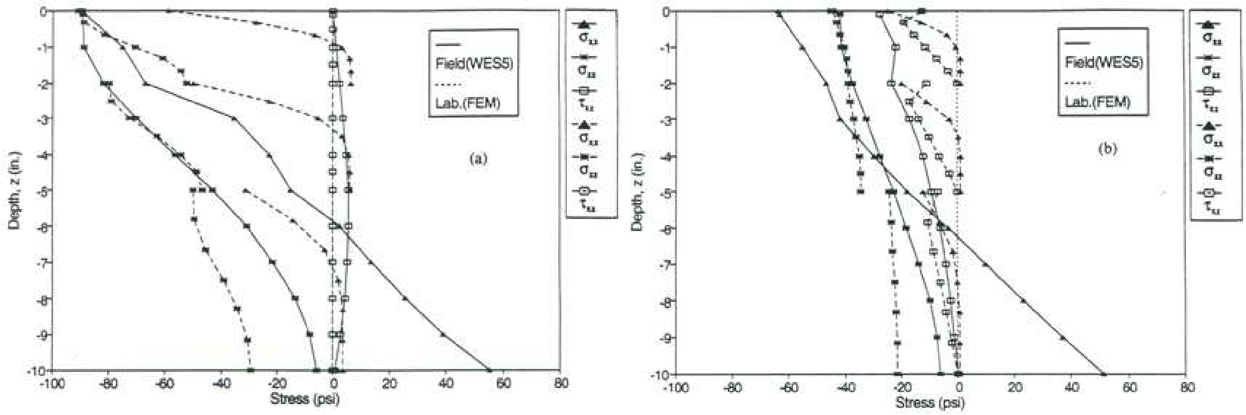


Fig. 7. Comparison of stress distributions in pavement section shown in Fig. 1(c) (a) at X=0, Y=0 and (b) at X=4 in., Y=0.

4. Proposed Rutting Test Method

To more accurately represent the field stress conditions, a lateral confining pressure was applied. This was achieved by applying the axial load through a 4-inch (10.16-cm) diameter loading plate on a 6-inch (15.24-cm) diameter specimen. The material that is not underneath the loading plate creates a lateral confining pressure on the material that is underneath the loading plate. In addition, the testing mode can avoid the discontinuity problem between the loading and unloading parts of the specimen due to the existence of the ring-shaped ligament outside of 4-inch (10.16-cm) diameter of the cylindrical specimen. This is one of the advantages of this test method compared to the conventional triaxial test in which the lateral confining pressure is supplied by pneumatics or hydraulics. The schematic drawing of the repetitive axial loading test with confinement is presented in Fig. 8. This testing method can be conducted using conventional uniaxial testing equipment and therefore, easily adoptable to many agencies.

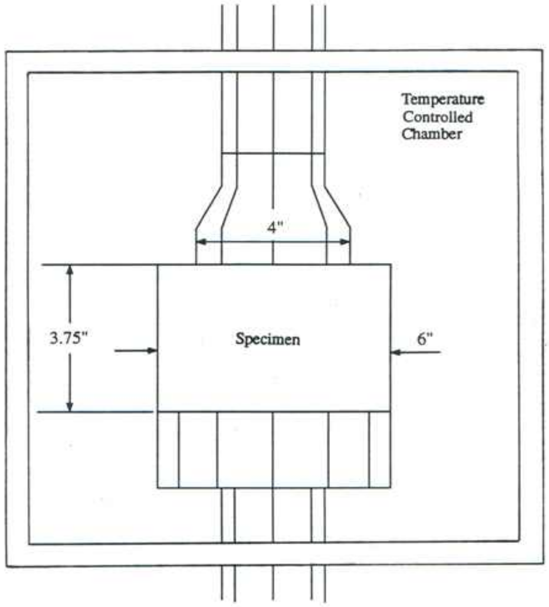


Fig. 8. Schematic drawing of the repetitive axial loading test with confinement

The repetitive axial load was applied on top of a 6-inch (15.24-cm)diameter specimen through the 4-inch (10.16-cm) diameter upper loading plate, causing the confining lateral pressure from the ring-shape ligament outside of 4-inch (10.16-cm) diameter of the specimen. The diameter of the bottom plate was kept six inches (15.24-cm) so as not to introduce any extraneous deformation due to the weight of the unsupported portion of the specimen. Test data of each channel were collected at the speed of 400 readings per second (0.0025 second per reading). Vertical load and corresponding cumulative permanent vertical deformation were measured.

5. Conclusions

Various structural analysis and temperature measurement for the flexible pavements with different designs were performed in this research. Within the limits of the study, the following primary conclusions can be drawn:

(1) The repetitive axial loading test with confinement was developed as a means of characterizing the rutting

performance of asphalt concrete. The proposed rutting test method must be easy, inexpensive, simple, and efficient to conduct to become an acceptable standard laboratory testing method for many agencies.

(2) The testing mode can avoid the discontinuity problem between the loading and unloading parts of the specimen due to the existence of the ring-shaped ligament out side of 4-inch(10.16-cm) diameter of the cylindrical specimen. This is one of the advantageous of this test method compared to the conventional triaxial test in which the lateral confining pressure is supplied by pneumatics or hydraulics.

(3) A new laboratory test protocol was developed based on the study of the structural analysis and field data. This protocol divides asphalt layer(s) into three categories depending upon the depth. Different temperatures and vertical stress levels were used in these areas.

Acknowledgement

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