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Evaluating the rutting resistance of asphalt mixtures using an advanced repeated load permanent deformation test under field conditions

Qiang Li [a,b], Fujian Ni [b,*], Lei Gao [b], Qingquan Yuan [c], Yuanjie Xiao [d]

[a] School of Civil Engineering, Nanjing Forestry University, Nanjing 210037, PR China
[b] School of Transportation, Southeast University, Nanjing 210096, PR China
[c] Jiangsu Jinghu Expressway Co., Ltd., Huai'an 223005, PR China
[d] Department of Civil & Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

HIGHLIGHTS

- An advanced repeated load permanent deformation (ARLPD) test was developed.
- The rutting resistance of asphalt mixtures was evaluated under field conditions.
- The combined rutting resistance were compared for various pavements.
- The test results were validated by the long term pavement performance data.

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ABSTRACT

Current widely used rutting tests are unable to accurately simulate the working conditions in actual pavements. To address this problem, an advanced repeated load permanent deformation (ARLPD) test was employed to evaluate the rutting resistance of asphalt pavements under field conditions. The stress state, lateral confinement, and temperature gradient in actual pavements could be simulated in this test. It was conducted on the multi-layer specimen for eighteen different structure combinations of asphalt layer in newly constructed pavement and rehabilitation projects at different temperatures. The rutting resistance and distribution were evaluated using various rutting indicators. Finally, findings from laboratory testing were validated using long term pavement performance data. It is found that the ARLPD test is repeatable. Distinct from other rutting indicators, the Flow Number (*FN*) Index can accurately screen the rutting resistance for different pavement structures. The SBS modified binder shows a positive effect on improving the rutting resistance. It is also observed that the cold in-place (CIR) mixture under a good curing condition could be used in the bottom asphalt layer for highway maintenance. Generally, the middle asphalt layer accumulates the greatest permanent deformation. The rutting distribution is relatively uniform in the CIR/overlay pavement or in the newly constructed pavement where SBS modified binder is used in the middle asphalt layer.

1. Introduction

Rutting caused by repeated loads at high temperatures is one of the major distresses in asphalt pavements. It is an accumulation of the permanent deformation mainly in the asphalt layers, especially in China where semi-rigid materials, such as cement stabilized macadam, are widely used in the pavement base [1]. Rutting not only affects the pavement ride quality but also leads to a serious safety issue for road users. Water pool in the ruts after rains and snows can cause vehicles hydroplaning or uncontrollable sliding with a high potential for traffic accidents [2]. Therefore, it is important to accurately evaluate the rutting resistance of asphalt mixtures in the design process of pavement structure and material.

Various laboratory tests have been developed to characterize the rutting resistance of asphalt mixtures. Generally, they fall into two categories: empirical and fundamental [3]. Although the empirical tests, such as Asphalt Pavement Analyzer (APA) and Hamburg Wheel Tracking Tester (HWTT), are readily applicable and can simulate the dynamic effect of field vehicle load, the fundamental engineering properties of the materials for pavement structural design and analysis could not be obtained from the test results [4]. The fundamental tests, such as triaxial repeated load permanent deformation (RLPD) test, can generate comprehensive

* Corresponding author. Tel.: +86 25 8379 3279; fax: +86 25 8379 4931.
E-mail address: nifujian@gmail.com (F. Ni).

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mechanical parameters. However, the complexity in equipment requirements and test procedures for lateral confinement may limit its application in the mix design process.

No single laboratory test has been universally accepted to have a good correlation with the field performance of asphalt pavements. The main reason may be that test conditions are greatly different between laboratory and field. Laboratory conditions are inconsistent with in situ pavement working conditions. In the laboratory, the fixed confining pressure, uniform temperature, and single layer specimen are generally selected. In contrast, the confinement of asphalt pavements in the field varies with the temperature, mix type, pavement depth, traffic loading, and the position of moving wheel loading [5]. Evident temperature gradient exists in asphalt layers, especially at high temperature seasons. The combined rutting resistance for different structure combinations of asphalt layer cannot be shown in laboratory either. All these differences limit the accuracy and reliability of laboratory tests. Therefore, an advanced laboratory test realistically simulating field conditions is urgently needed to evaluate the rutting behavior of asphalt pavements in a more reliable way.

Huang and Zhang [5] improved the conventional triaxial RLPD test using cylinder loading plates with a little smaller size centrally placed on the top and bottom surface of the specimen. The lateral asphalt mixtures can provide a varying confinement. Chen et al. [6] developed a uniaxial penetration test to simulate shear stress state and distribution in asphalt pavements. Xu and Solaimanian [7] analyzed the temperature gradient in pavements by constantly monitoring the change of temperature with conditioning time at different heights of the cylinder specimen. A temperature gradient controlling system for the wheel tracking test was proposed by Guan et al. [8] to simulate the pavement temperature field. Azari and Mohseni [9] conducted an incremental RLPD test to evaluate one specimen at several different temperature and stress levels. All these studies have taken a step forward in the modification of laboratory tests according to field conditions.

Recently, an advanced repeated load permanent deformation (ARLPD) test protocol was developed by Yuan [10]. In this test, stress state and lateral confinement in actual pavements were simulated by designing appropriate dimensions of specimen and loading plate. The pavement temperature field was achieved using heat insulation measures, temperature monitoring, and conditioning test in the laboratory. It shows promising applicability as it makes a beneficial attempt to keep laboratory testing conditions consistent with the working conditions in actual pavements. Also, both laboratory-made and field-cored samples are applicable to this test.

2. Objectives

The main objective of this study is to evaluate the rutting resistance of different types of asphalt pavement in China under actual field conditions. To accomplish this objective, the ARLPD test was conducted on eighteen different structure combinations of asphalt layer for newly constructed hot-mix-asphalt (HMA) pavements and rehabilitation projects. For each structure combination, the multi-layer specimen was either made in the laboratory or cored from the in-service pavements. The rutting resistance of various structures was compared using several rutting indicators and the 3-stage model. The effects of the structure, material, and environment were analyzed. The rutting distribution in pavements was also evaluated. The laboratory findings were finally validated in the field.

3. ARLPD test method

To simulate in situ pavement working conditions as much as possible the laboratory test should simultaneously satisfy the following requirements:

(1) The multi-layer specimen including all asphalt layers is used to reflect the combined rutting resistance of asphalt pavements and rutting contribution of each layer.
(2) The lateral confining pressure varying with the loading, temperature, and mixture properties is supplied by specimen itself during the testing process.
(3) The stress level and distribution in specimens are in accordance with those in actual pavements.
(4) The temperature gradient along the specimen height is accurately simulated under a given air temperature.

In the conventional triaxial RLPD test, only the fixed confining pressure is provided due to the limits of the equipment. However, the confinement distribution is not uniform in actual pavements. Therefore, the relatively smaller loading plate was selected and the vertical loading was applied on the central part of the specimen surface in the ARLPD test. The rest part could supply the confining pressure which varies with the loading, temperature, and mixture type. The cylindrical specimen of 150 mm in diameter was used. Its height depended on the specific pavement structure of interest. The optimum diameter of the loading plate (80.6 mm) was determined using the finite element method (FEM) simulation to supply enough confining pressure for the specimen. The shapes of horizontal normal stress S_{11} curves obtained from this test were close to those from actual pavements, as shown in Fig. 1. The S_{11} values in the laboratory specimens were about 80% of those in actual pavements since the specimen is lack of constraint caused by the lower layers, such as base, subbase, and subgrade. Although there are some differences between the ARLPD test and actual pavement, a smaller size of the loading plate cannot be accepted. Because the diameter in 80.6 mm was larger than three times of nominal maximum aggregate size (NMAS) for most asphalt mixtures typical used in China. It can eliminate the size effect which will introduce much greater errors.

A transient pavement temperature field FEM model based on heat transfer theory was employed to predict the hourly temperature at each pavement depth. The pavement temperature T_{pave} values at different depths under the maximum air temperature T_{air} in the area were selected as target testing temperatures for different heights of the specimen in the ARLPD test. To obtain the calculated temperature gradient, the heat-insulated paint and rock wool pile were used on the bottom and side of the cylinderal specimen. Only the top can transfer external heat. A conditioning and temperature monitoring test was performed to measure the temperature variation with time. Three thermocouples were sealed in the specimen at the mid-depth of the top, middle, and bottom asphalt layers all along the center line, respectively. The T_{pave} at pavement surface corresponding to a given T_{air} obtained from FEM calculation was chosen as the conditioning temperature in the environmental chamber. Actually, the target testing temperatures at different heights of the specimen cannot be simultaneously reached. As a result, the minimum public time interval to approximately obtain target testing temperatures (±1 °C) for different asphalt layers was used for testing. The process of determining testing conditions for temperature gradient simulation is shown in Fig. 2. More details about the test method could be found elsewhere [10].

4. Experimental program

4.1. Materials

Eighteen structure combinations of the asphalt layer widely used for highway construction and rehabilitation projects in Jiangsu, China were tested in this study, as shown in Table 1. The first eight ones (A1–D2) were used for newly constructed HMA pavements. Other ten ones (E1–G1) including the techniques of cold in-place recycling (CIR), milling, overlay, and performance evaluation were used for pavement rehabilitations.