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Criteria for controlling rutting of asphalt concrete materials in sloped pavement

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HIGHLIGHTS

- Specimen in rutting test and actual pavement are modeled.
- Long-term rutting depth of actual pavement is predicted.
- Material criteria are put forward with traffic volume and gradient of slope.
- A method is provided for controlling long-term rutting depth.

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ABSTRACT

The development of rutting is one of the most common distresses in asphalt pavement. Especially at road sections with longitudinal slope, the problem is more serious than sections with no slope. This is because the slope decreases the average speed of vehicles running upward, so the total loading time increases dramatically. In China, dynamic stability (DS) in rutting test is used as the main experimental criteria to control the asphalt concrete (AC) materials before construction. It is supposed that the larger the DS index is means the material has better capability of retarding the ruts' development after constructed. Fixed DS criteria are set for diverse road situations. These differences in situations exhibit in structure and materials, traffic volume, climate condition and the gradient of sloped pavement. This paper aims at establishing a new control approach of AC material for dealing with rutting problem. Finite element method (FEM) is used to simulate two objects: specimen in rutting test and typical actual pavement with slope. In these simulations, the constitutive model of AC is the common basis. Through the model, specimen in rutting test and actual pavement are connected. It provides a possible way to control pavement rutting by computing and providing detailed criteria for specific project with special situations. These criteria change with actual service circumstances of pavement. Compared with fixed criteria, they are more flexible, accurate and feasible for using in rutting control practice.

1. Introduction

1.1. Rutting computation method

The rutting of asphalt pavement derives from the non-linear, viscous and plastic properties of asphalt concrete (AC). It includes the viscoelastic and viscoplastic characteristics of asphalt and the plastic properties of gravel and soil. Rutting can be described as the unrecoverable vertical deformation. Establishing suitable constitutive model for AC is very important to analyze pavement structure and predict its response during usage. It is true for rutting prediction too. The former researchers [1–3] have drawn the conclusion that model should represent the deformation rule of AC pavement under high temperature and heavy load.

Archilla and Medanat [4] considered finite element method (FEM) provides a convenient approach to attain valid analyzing results from actual engineering structures. Especially in terms of considering viscoelastic property of AC, FEM can provide a practical and precise approach. This method can be used widely. It has become one of the most promising methods to investigate rutting problem of AC pavement [5].

Since 1990s, with the development of computer technology, FEM has become more and more popular. Now, the rutting prediction researches evolve from linear viscoelastic theory to non-linear viscoelastoplasticity theory. Corresponding studies in China are a little tardier. In 1990s, rutting researches were mainly based on high temperature performance experiments. Some prediction models were developed. It can be conclude that, the trend of rutting research is changing from elastic theory to viscoelastic and plastic theory, from linear theory to non-linear theory.

FEM can deal with more than one kind of constitutive relations in one computed body. It can be used to simulate complex structures.

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Using FEM to analyze rutting problem is a numeric, simple and realistic way to attain reasonable results.

At present, many researchers use FE software to solve rutting problems. This paper uses ABAQUS to analyze and decide the requirements for AC material in order to control pavement rutting, especially pavement at longitudinal slope sections.

1.2. Material control for reducing rutting

Under actual service circumstances of pavement, for retarding the development of rutting, the only way is to modulate the structure and material properties of pavement. It includes adding rutting-resistance layer and choosing AC materials with better high-temperature performance. Rutting is very sensitive to heavy load and its loading time. At road sections with longitudinal slope, average vehicles' speed decreases when running upward. It results in more serious rutting distress at these sections. Special attention should be focused on this problem. This research tries to develop a series of material controlling criteria for road sections, which have different vehicle volumes and longitudinal slopes.

In the mid 1980's the Georgia loaded-wheel tester (GLWT) was developed. In 1996, Pavement Technology Inc. manufactured the first asphalt pavement analyzer (APA). This device is a modification of the GLWT and also can be used for rutting susceptibility of HMA pavements. The mix verification tester (MVT) is a device developed for testing rut susceptibility of field mixes. It uses the same standards as the APA, but is only capable of testing two gyratory or one beam compacted specimen at the same time. The MVT was developed to be used in a field laboratory because of its smaller size and weight [6]. But until recently, there is no criterion to directly measure rut susceptibility of HMA mix being placed on the roadway during production, not to mention the criteria of AC materials used at longitudinal slopes.

Rutting test is used broadly in China. Dynamic stability (DS) index is used commonly to evaluate rutting susceptibility of AC. This test is carried out at 60 °C as required in Chinese specification [7]. Three AC layer systems are the most frequently used pavement structure. There are two kinds of criteria for different types of asphalt. As to AC using modified asphalt, depending on the average high temperature in July, the criterion is from 800 to 3000 (1/mm). As for AC using regular asphalt, it is from 400 to 800. These criteria are used for the two upper layers of the three AC layers pavement. For bottom layer, it is lower, as listed in Table 1 [8].

The simple performance test (SPT) criteria are used to help select the most appropriate mix and structure combination during both the HMA mix and flexible pavement design process. In NCHRP report 580 [9], a simple example of how these SPT criteria would be implemented is presented in Table 2. This table shows that for a given mix and structure combination, at a given set of environmental and traffic level conditions, a minimum (allowable) SPT value would be required to limit a given pavement distress to a user-defined maximum desired value. This would be identical to selecting the maximum rut depth desired in the HMA pavement. When a laboratory or in situ measured mix SPT value is compared to this "allowable SPT," an assessment can be performed on the mix to determine whether it is acceptable or not, as shown in Table 2.

These typical tests and indicators shown above are realistic methods used for AC material control. However, they have not being closely connected to the performance of AC placed on road yet.

1.3. Problems at present

Although rutting researches have lasted for years, and many achievements have been made, there are still some core problems left unresolved. Especially for road sections with longitudinal slopes:

(1) The special driving condition of vehicles on slope is usually not considered, but it definitely influences the rutting situation of AC layers.
(2) The gradients of slopes are usually not considered.
(3) The relationship between laboratory experiment and actual performance of pavement has not been investigated thoroughly, so there is no detailed and corresponding standard that can be used for the rutting control of AC materials at sloped road sections.

As generally known, rutting of AC pavement results from the properties of AC materials. It is critical to establish a method, which can provide effective, flexible and feasible material control criteria for specific road sections, especially at sloped sections. This is the focus of this research.

2. Objectives and method

2.1. Objectives

As mentioned above, for controlling the rutting of AC pavement, there are some AC material control tests and criteria. However, these criteria are fixed or have nothing to do with the actual circumstances of pavement in service period. They do not change with different traffic volumes, temperature conditions and pavement structures. In other words, there are no practical criteria established at all. It results in poor pavement performance, distress or potential waste of material capability.

This paper intends to establish a series of rutting control criteria. Numerical simulation is used to investigate the developing rule of rutting in laboratory and field. They are connected by the properties of AC materials. These properties are represented by parameters of AC used in constitutive model of FEM. Based on this connection between specimen and actual pavement, experimental control criteria of AC materials can be established to meet specific rutting control requirement of pavement.

This is especially useful to control the material properties used at sloped sections. When the gradient and length of the slope grow, vehicles pass this section with a lower speed in upward direction. It results in the increasing in loading time. As a result, rutting is much more severe than horizontal sections.

DS is used as a regular experimental indicator for detailed material control. Based on the vehicles, temperature and structure conditions, different DS requirements are put forward as criteria to limit the long-term rutting depth below a reasonable value.

2.2. Method

Rutting influences the smoothness and safety of driving. It becomes worse mostly in the hottest days in a year, typically July or August. Increments of several millimeters can be observed in a few days.

Table 1
DS criteria in rutting test for AC material selection (1/mm).

Asphalt type	Layer position	Average daily highest temperature in July (°C)		
		Higher than 30	20–30	Lower than 20
AC (using regular asphalt)	Upper and middle layers	800	600	400
	Bottom layer	500	400	300
AC (using modified asphalt)	Upper and middle layers	1500–3000	1000–2000	800

Notes: 1. AC using modified asphalt seldom used for bottom layer; 2. For AC using modified asphalt, except the average daily highest temperature in July, the lowest temperature in winter is used for sub-zone zone too, and different criteria are used for different sub-zones, the given range is the lowest and highest criteria for all sub-zones.