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Determining temperature and time dependent Poisson's ratio of asphalt concrete using indirect tension test

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HIGHLIGHTS

- Studied temperature and time dependent Poisson's ratio of asphalt concrete.
- Relaxation and cyclic load tests are done at different temperatures.
- Poisson's ratio increases with time and temperature, however, not with frequency.
- Existing correlation between Poisson's ratio and dynamic modulus is satisfied.

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ABSTRACT

Poisson's ratio (v) of Asphalt Concrete (AC) is a fundamental input parameter to any numerical analysis based on elastic and viscoelastic constitutive properties. To this date, temperature- and time-dependent v-value has been determined by either a static or a relaxation test at a single temperature in diametrical mode. This study, for the first time, performs relaxation tests at different temperatures in diametrical mode. In addition, cyclic load testing is conducted at different temperatures and loading frequencies to determine the temperature- and frequency-dependent v-value of AC. Relaxation test results show that the v-value of AC increases with testing time and temperature. Dynamic load test results show that v-value of AC decreases with loading frequency; however, increases with temperature. To this end, measured v-value of AC is compared with the v-value predicted using model available in the new AASHTOWare Pavement Mechanistic-Empirical (ME) Design software. The measured v-value matches with the predicted v-value by the AASHTOWare Pavement ME Design software especially for AC that possesses high dynamic modulus.

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1. Introduction

Poisson's ratio (v) is a fundamental material property and an essential input parameter to many finite element and constitutive models of Asphalt Concrete (AC). The v-value of AC is usually considered not to be dependent on temperature, loading time and frequency of loading due to lack of sufficient test evidence [1,2]. This assumption may not be reasonable for AC; because AC is well known for its temperature, time and frequency dependency. The elastic v-value can be applied to a material when temperature, time or frequency dependency of its mechanical properties can be neglected. This may be the case for certain materials. However for AC, the inherent loading time or frequency dependency cannot be disregarded in many applications. Upon applying load, the deformational energy in AC is not only stored elastically, but part of it is invariably dissipated by viscous action. Therefore, the v-value of AC must be determined considering temperature, time and frequency of loading.

Accurate measurement of the v-value is essential for pavement design. Because, change in v-value can result in different predictions of structural responses and distresses. To prove this, a preliminary analysis has been performed in the present study using the AASHTOWare Pavement Mechanistic-Empirical (ME) Design software (previously known as Mechanistic-Empirical Pavement Design Guide (MEPDG)). The geometry, material properties and all other design inputs were kept the same except the v-value in different simulation runs by the AASHTOWare Pavement ME design software. The input parameters are considered based on typical highway pavement in New Mexico. The parameters are listed as follows: AC thickness = 200 mm, base aggregate (crushed stone) = 200 mm, subgrade = AASHTO A-4 soil [3], initial two-way

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annual average daily traffic = 1500, number of lanes in design direction = 2, percentage of trucks in design direction = 50, percentage of trucks in design lane = 95, operational speed = 60 mph (97 kmph), climate: New Mexico (Albuquerque International Airport), ν-value = varied from 0.1 to 0.45 including the AASHTOWare Pavement ME Design default value [4].

The analysis was run for 20 years of design life and the two major distresses, rutting and top–down cracking (longitudinal cracking) are recorded and shown in Fig. 1. These two distresses were considered arbitrary. The other distresses such as alligator cracking may be affected. However, discussing the effect of ν-value on all distresses may be too much discussion for showing the importance of ν-value. It can be seen from Fig. 1 that both the rutting and top–down cracking increase with a decrease in ν-value, which is much expected. Vertical stress increases with the decrease in ν-value. Consequently, rutting and top–down cracking increase with a decrease in ν-value. The total rutting is 27 mm for ν-value = 0.1 and 14 mm for ν-value = 0.45. Similarly, the top-down cracking is 354 m per km for ν-value = 0.1 and 36 m per km for ν-value = 0.45. There is almost 10-fold difference in top down cracking due change in ν-value from 0.1 to 0.45. At any rate, on the point being made by this example calculation is that the ν-value is very important for accurate prediction of the distresses in asphalt pavement.

Past studies intensively explored ν-value using relaxation tests in uniaxial mode [5,6]. In addition, frequency and temperature dependency of ν-value has been investigated by applying cyclic load on uniaxial sample [7–10]. However, not a significant amount works were conducted on ν-value using Indirect Tensile (IDT) mode. Note that IDT test is very popular in asphalt society for its simplicity in AC's performance evaluation. Therefore, research on ν-value using IDT samples may be praiseworthy for permanent literature.

Lee and Kim [11] determined the complex ν-value with respect to angular frequency and time by a creep test up to 100 s using IDT mode. The researchers used only a single temperature (10 °C). However, temperature varies a lot in real pavement. ν-value at other temperature is also an interesting research topic. Therefore, temperature dependency of ν-value using IDT test is still an unsolved issue. Frequency and temperature dependency of ν-value using IDT test has been conducted by Kim et al. [12]. The researchers evaluated the dynamic ν-values at different temperatures and frequencies of loading using IDT test. The ν-value is reported to be about 0.15 and 0.25 at −10 °C and 10 °C, respectively. This means the effect of temperature on dynamic ν-value is quite large. However, the effect of loading frequency was not very clear from their study. In addition, ν-value was observed by them so high, around 0.8 at 35 °C. Therefore, further investigations are needed to examine the effects of temperature and loading frequency on ν-value using IDT test.

From the above discussion, it is evident that ν-value of AC has been determined for single temperature, so far, by relaxation test using IDT samples. The effects of various temperatures on ν-values have not been studied. In addition, the effects of loading frequency and temperature on the dynamic ν-values using IDT test are still unsolved issues. Moreover, the correlation between ν-value and $|E^*|$ can be beneficial for designing pavement using the Pavement ME Design software. All these effects and correlation are studied herein.

2. Objectives

The specific objectives of this study are to:

(a) Determine the temperature- and time-dependent ν-values of AC material by relaxation tests using IDT samples.
(b) Determining ν-values at different temperatures and frequencies of loading by cyclic loading tests on IDT samples.
(c) Examine the correlation between the measured ν-value with the $|E^*|$ of AC.

3. Backgrounds

The horizontal stress along the horizontal direction, σ_x and the vertical compressive stress along the vertical direction, σ_y in IDT sample, as shown in Fig. 2, can be written as follows [13]:

$$\sigma_x = \frac{2P}{\pi a d}\left\{\frac{\left(1-\frac{x^2}{R^2}\right)\sin 2\alpha}{1+\frac{2x^2}{R^2}\cos 2\alpha+\frac{x^4}{R^4}} - \tan^{-1}\left[\frac{1-\frac{x^2}{R^2}}{1+\frac{x^2}{R^2}}\tan\alpha\right]\right\}$$

$$\sigma_x = \frac{2P}{\pi a d}[f(x)-g(x)] \tag{1}$$

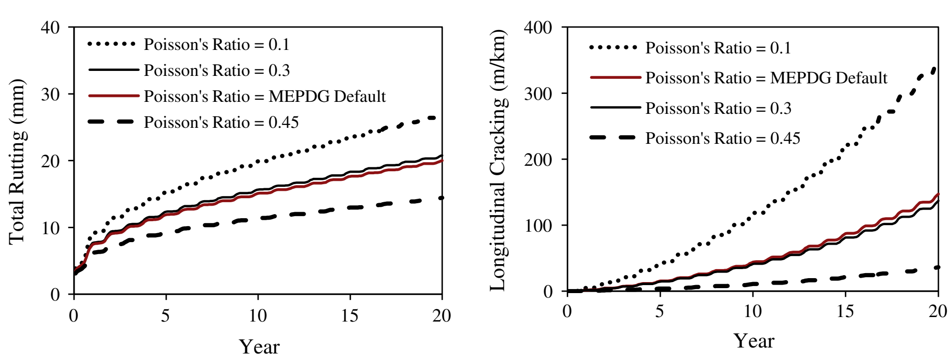
$$\sigma_y = -\frac{2P}{\pi a d}\left\{\frac{\left(1-\frac{y^2}{R^2}\right)\sin 2\alpha}{1-\frac{2y^2}{R^2}\cos 2\alpha+\frac{y^4}{R^4}} + \tan^{-1}\left[\frac{1+\frac{y^2}{R^2}}{1-\frac{y^2}{R^2}}\tan\alpha\right]\right\}$$

$$\sigma_y = -\frac{2P}{\pi a d}[m(y)+n(y)] \tag{2}$$

where

$$f(x) = \left\{\frac{\left(1-\frac{x^2}{R^2}\right)\sin 2\alpha}{1+\frac{2x^2}{R^2}\cos 2\alpha+\frac{x^4}{R^4}}\right\};$$

$$g(x) = \tan^{-1}\left[\frac{1-\frac{x^2}{R^2}}{1+\frac{x^2}{R^2}}\tan\alpha\right];$$



(a) Effect of ν-value on rutting (b) Effect of ν-value on top-down cracking

Fig. 1. Effects of ν-value on the distresses of AC pavement.

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