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Design of semi-rigid type of flexible pavements

Pranshoo Solanki [a,*], Musharraf Zaman [b]

[a] College of Applied Science and Technology, Illinois State University, Campus Box 5100, Normal, IL 61790, USA
[b] School of Civil Engineering and Environmental Science, The University of Oklahoma, 202 W. Boyd Street, Room 334, Norman, OK 73019, USA

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Abstract

The primary objective of the study presented in this paper is to develop design curves for performance prediction of stabilized layers and to compare semi-rigid flexible pavement designs between the empirical AASHTO 1993 and the mechanistic-empirical pavement design methodologies. Specifically, comparisons were made for a range of different sections consisting of cementitious layers stabilized with different types and percentages of additives. It is found that the design thickness is influenced by the type of soil, additive, selection of material property and design method. Cost comparisons of sections stabilized with different percentage and type of additives showed that CKD-stabilization provides economically low cost sections as compared to lime- and CFA-stabilized sections. Knowledge gained from the parametric analysis of different sections using AASHTO 1993 and MEPDG is expected to be useful to pavement designers and others in implementation of the new MEPDG for future pavement design.

Keywords: Semi-rigid; Mechanistic; Resilient modulus; Fatigue life; Reliability; Traffic

1. Introduction

The basis of the AASHTO 1993 flexible pavement design method was a landmark pavement performance test (AASHO Road Tests) conducted in the late 1950s near Ottawa, Illinois, at a cost of $27 million (1960 dollars) [7,18]. This experiment consisting of 288 flexible pavements generated substantial database of pavement performance observations, which formed the basis for the pavement design methodology adopted by AASHTO. However, the new Mechanistic-Empirical Pavement Design Guide (MEPDG) adopted a mechanistic-empirical approach to the damage analysis of flexible pavements. The design process involves computing the pavement structural response to the load (i.e., stresses and strains), translating them into damage, and accumulating the damage into distresses, which reduce pavement performance over time [18].

Due to the effort toward implementation of the MEPDG, several state agencies and researchers have evaluated flexible and rigid pavement sections using both empirical and mechanistic-empirical design methods (see e.g., [9,16,6,11]. However, no studies to the author's knowledge compared design of semi-rigid type flexible pavements using both AASHTO 1993 and MEPDG. Also, only a limited level of attention has been devoted to the MEPDG performance prediction capabilities of pavement systems involving stabilized layers [23]. Since the MEPDG is intended to replace the previous AASHTO 1993 pavement design guide, which based primarily on empirical methods, it is important to evaluate and compare semi-rigid pavement designs using both the AASHTO 1993 and the MEPDG guides.

Consequently, the primary objective of the study presented herein is to develop design curves for performance

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[*] Corresponding author.
E-mail addresses: psolanki@ilstu.edu (P. Solanki), zaman@ou.edu (M. Zaman).
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prediction of stabilized layers and to compare semi-rigid flexible pavement designs between the empirical AASHTO 1993 and the mechanistic-empirical pavement design methodologies. These comparisons span a range of different sections consisting of cementitious layers stabilized with different types and percentages of additives. Also, specific emphasis is devoted to the influence of stabilized subgrade layer properties and reliability levels on the comparisons. Further, cost comparisons of different sections stabilized with different additive types and contents were also pursued.

2. Semi-rigid type flexible pavement

Several classical books and references (e.g., [1,7,2,18,15] are available that present the terms rigid or flexible to separate different possibilities of pavement structures. The term rigid refers to pavements with the top layer made of cement concrete material; the term flexible is associated with pavements with asphalt concrete (AC) layer on the top. The conventional flexible and rigid pavements differ in the way each structure distributes the vertical pressure over the subgrade. A rigid pavement tends to cause a dispersed spread of pressure over the lower layers. On the other hand, the response to loads on a flexible structure is more concentrated near the loaded area. Thus, considering the presence of a cementitiously stabilized layer on the subgrade of a flexible pavement, the pressure spread over the subgrade tends to become more diffused compared to a conventional flexible pavement case. This behavior of flexible pavement having a cementitiously stabilized layer puts it into a new category called semi-rigid type flexible pavement [4]. According to the MEPDG, a pavement section having some type of chemically stabilized (pozzolanic) layer below the asphalt concrete layer is defined as a semi-rigid pavement [2].

3. Design curves for fatigue life of stabilized subgrade layer

3.1. Structural model

The computer program KENLAYER [7], which is based on multi-layer elastic theory, was employed to calculate the structural response in terms of stresses, strains, and deflections in various layers of 25 hypothetical pavement sections (described in the next section).

3.2. Sample Preparation and resilient modulus

In this study, Vernon series (V-soil) soil which is classified as lean clay (CL) in accordance with Unified Soil Classification System was used. Specifically, liquid limit and plasticity index of V-soil were 37 and 11, respectively. A total of three different additives, namely, hydrated lime, class C fly ash (CFA) and cement kiln dust (CKD) were used in this study. A total of 16 specimens were prepared in this study. The procedure consists of adding a specific amount of additive to the raw soil. The amount of additive (6% for lime and 10% for CFA and CKD) was added based on the dry weight of the soil. The additive and soil were mixed manually for uniformity. After the blending process, a desired amount of water was added based on the optimum moisture content (OMC) determined using standard Proctor test in accordance with ASTM D 698 test method. The mixture was then compacted in a mold which had a diameter of 101.6 mm and a height of 203.2 mm to reach a dry density of between 95% and 100% of the maximum dry unit weight (MUW) determined using standard Proctor test. After compaction, specimens were cured at a temperature of 23.0 ± 1.7 °C and a relative humidity of approximately 96% for 28 days. A total of four replicates were prepared for each additive content and tested for resilient modulus in compression (M_r). The M_r tests were performed in accordance with the AASHTO T 307 test method. An outlier approach was used by employing t-statistic to discard the test results if a sample result deviates significantly from the average of M_r results obtained from four replicates. The critical value (t-critical) for student's t-test is taken at a significance level (α) of 0.05.

The test procedure for resilient modulus in tension (M_{rt}) consisted of applying six stress sequences. Each test sequence consisted of a haversine-shaped load pulse having a duration of 0.1 second and a rest period of 0.9 second. A Material Testing System (MTS) electro-hydraulic test system was used to load the specimen. The load-deformation response was recorded for the last 5 cycles of each stress sequence using a computer controlled FlexTest SE Test Controller. A 22.2 kN (5,000 lbs) load cell was used for applying load on the specimens. The vertical and horizontal deformations were measured by two LVDTs having a stroke length of 2.54 mm (0.1 in), attached in the diametrically perpendicular direction of one face of the specimen (see [27] for detailed test procedure). A set of four specimens were prepared for each soil-additive mixture. The specimens were tested for M_{rt} by applying different stress levels. The applied stress level for M_{rt} test was chosen according to the indirect tensile strength of the specimen of each set. The M_{rt} for each sequence was calculated from the average recoverable deformation and average load from last five cycles using the following equation [29,17]:

$$M_{rt} = \frac{2P}{\pi D t \Delta H_T \left(D^2 + D_g^2\right)} \left\{ (3+\nu) D^2 D_g + (1-\nu) \times \left[D_g^3 - 2D\left(D^2 + D_g^2\right) \tan^{-1}\left(\frac{D_g}{D}\right) \right] \right\} \quad (1)$$

where, t = thickness of the specimen, P = repeated load, ΔH_T = total recoverable horizontal deformation, D = diameter of specimen, υ = Poisson's ratio, and D_g = distance between LVDTs measuring horizontal deformations. The value of Poisson's ratio was used as 0.2 consistent with the range of 0.1–0.3 reported by the MEPDG [2].