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Damage Behavior of Cement-Treated Base Material

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Abstract
Cement treated base (CTB) is a cement stabilized material which becomes more important to a modern road pavement under a better performance perspective. However, CTB has the inherent characteristic of fatigue deterioration corresponding to damage evaluations under repeated loading; but relatively rare fatigue and damage studies of CTB have been performed. Therefore, damage developments of CTB specimens tested under different loading conditions were characterized in this study. This because stress/strain state and fatigue life of materials are all related to their damage evolutions. Results from unconfined compressive tests revealed that damage evolutions of CTB specimens depended on the monotonic-compressive loading rates. Moreover, the cyclic flexural beam tests were also performed to determine the fatigue damage evolutions of CTB specimens. The test results showed that damage evolutions of CTB specimens subjected to cyclic bending forces were influenced by the levels of applied strain. However, the damage evolutions were independent from the loading waveforms. In addition, the prediction models for damage evolutions of CTB were also developed in this study. The natural logarithmic model was found to provide the most reliable values of predicted damage variable compared to the other mathematical models used in this study. It was also discovered that regression parameters of the developed model can be estimated by the function of an applied strain level. Furthermore, this study reveals that the fatigue behavior of CTB specimens can be predicted based on the damage variables.

Keywords: Bound cement-treated base course, damage variable, fatigue damage, continuum damage mechanics

1 Introduction

Cement-treated base (CTB) is the product of soil-cement stabilization technique by mixing a conventional road base material with a prescribed amount of cement, and water. In general, cement content in a CTB mixture is considerably less than that used in concrete. Appropriate quantities of cement and water for a CTB mixture are determined based on the mix design process of CTB. In such mix design process, unconfined compressive strength (UCS) of CTB is generally specified to meet requirements of pavement structure [1,2]; subsequently, the trial-and-error process is performed with

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varying cement contents in a series of CTB mixtures until achieving a required UCS value at a specific cement content. Furthermore, the optimum moisture content (OMC) derived from the compaction test protocol is generally specified as a proper amount of water for a CTB mixture. CTB with a relatively high cement content and a significant UCS value can be classified as a bound (fully stabilized) material of which tension resistance reveals. At present, the bound CTB is considerably required to serve better performance road pavement with longer lifetime and less maintenance. Nevertheless, the bound CTB is a relatively stiff material which may undergo fatigue failure under traffic. Accordingly, the design lifetime of pavement structure with a bound CTB layer strongly relies on fatigue deterioration of CTB under traffic [3,4]. However, current fatigue prediction models of CTB, following any pavement design guideline, used for an estimation of a whole pavement life are empirical [5]. Therefore, it is necessary to develop a more mechanistic-based fatigue prediction model of CTB to overcome shortcomings of using those empirical-based prediction models. Continuum damage mechanics (CDM) has been successfully applied to develop mechanistic fatigue deterioration models of asphalt concrete [6] and conventional concrete material [7,8]. These models were established based on the assumption that fatigue failure is principally caused by damage evolutions within the mass of materials. Consequently, prior to establish a fatigue deterioration model of CTB, it is important to examine the characteristics of damage growths induced by various loading conditions. Therefore, this study aims to characterize damage evolutions of the bound CTB material under two loading regimes of monotonic and cyclic loading. Bound CTB specimens were performed under the testing conditions of different loading rates of monotonic-compressive loading and cyclic flexural loadings.

1.1 Current Fatigue Model of Cement-Treated Materials

Austroads [9] has recommended the equation to estimate the in-service fatigue life of a CTB layer in pavement as following:

$$N = RF\left(\frac{278FS+\frac{1070000}{E_f}-311}{\mu\varepsilon}\right)^{12} \tag{1}$$

where N is the in-service fatigue life (cycles), RF is the project reliability factor, FS is the design flexural strength (MPa), E_f is the design modulus of cemented material (MPa), and $\mu\varepsilon$ is the load-induced tensile strain at the base of the cemented material (micro-strain). The design modulus in Eq. (1) can be either obtained from the flexural beam test or the empirical equation recommended by the guideline [9]. Moreover, Eq. (1) was developed based on a series of test results of the test specimens prepared using 12 parent materials collected nationwide across Australia (accept from Northern Territory and Tasmania).

1.2 CDM for Fatigue Modelling

CDM is the discipline that quantifies the microscopic damage of a material on the macroscopic scale, using internal damage variables [10]. Consequently, damage variable (D) has generally been employed as the indicator of representing damage levels. The minimum value of D ($D = 0$) indicates that the status of a material is at the original stage without any damage; vice versa, the fully damage status of a material is specified if D attains to the maximum value of $D = 1$. Therefore, the stress-strain constitutive law with consideration of material damage [8] can be draw as follows:

$$\boldsymbol{\sigma} = (1-D)\boldsymbol{C}:\boldsymbol{\varepsilon} \tag{2}$$

where $\boldsymbol{C}$ is the fourth-order undamaged Hooke's elasticity tensor, $\boldsymbol{\sigma}$ is the second-order stress tensor, $\boldsymbol{\varepsilon}$ is the second-order strain tensor, D is the damage variable, and the symbol of ":" represents the double tensor contraction. In the one-dimensional problem, $\boldsymbol{C}$ is equivalent to Young's modulus (E) of a