An integrated approach to mix design and structural design for bituminous pavements

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Abstract: For bituminous pavements, generally, the mix design and the structural design are handled as two different processes. That is, after finalizing the mix design, material properties of the mix are used as input to the structural design to decide the pavement layer thicknesses. For alternative mix types or mix designs, the material properties would be different, resulting in multiple structural design solutions. The present article briefly discusses the possibility of integrating the process of mix design and structural design so as to achieve a better economy.

Introduction

The structural design of a bituminous pavement is based on various input parameters related to material, traffic and environment. As an outcome of structural design, the thicknesses of various layers are decided.

To economize the pavement design, a designer may select different combinations of materials for different layers. For example, a designer may choose from Bituminous Concrete (BC), Dense Bituminous Macadam (DBM) or Semi-Dense Bituminous Macadam (SDBC) as bituminous surfacing (MORT&H 2001). The mix designs of various alternative mixes are different and may even be different within the same type of mix.

During structural design of pavement, the material properties of these individual bituminous mixes are generally assumed as given and are supplied by the mix designer. However, there is scope to integrate the mix design and the structural design, rather than considering these two as two separate processes. This has been elaborated further in the following.

Background

Through bituminous mix design, a suitable quantity of bitumen is recommended (for the best performance of the mix), for a given aggregate gradation. Even though there are various methods of mix design, in general, these methods consider volumetric and strength parameters to decide the bitumen content (AI 1997, 2001, Roberts et al. 2002). Additionally, performance based or performance related studies may also be conducted (AI 2001, Harrrigan et al. 1994).

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Mechanistic-empirical approach is a contemporary method of bituminous pavement design (AI 1999, Austroads 2004, IRC 2001; NCHRP 2004, Shell 1978). In this method, the critical stress/ strain parameters are estimated through pavement analysis of trial sections. Subsequently, the longevity of the pavement (being designed) is obtained through transfer functions which are calibrated based on field performance data of pavements built earlier.

Integration of mix design and structural design

As the mix design is finalized, the stiffness modulus and the laboratory performance equations (for example, fatigue and rutting equations) of the mix are generally used as an input to the pavement design. It is possible to achieve different values of stiffness moduli and coefficients of performance equations for the same type of mix by varying the gradation, bitumen type or quantity of bitumen etc. These parameters (i.e. stiffness modulus and performance equations) affect the value of the pavement design thicknesses.

In a mix design process, sometimes a balance needs to be drawn between conflicting properties. For example, bituminous mixes having higher stiffness modulus may show an inferior fatigue performance compared to mixes with low stiffness modulus. A pavement designer would be keen to have a mix, which would have both high stiffness modulus as well as satisfactory fatigue performance.

For example, if the field calibrated fatigue equation is taken as, $N_{ff} = 0.1 \times (\varepsilon_t)^{-3.565} \times (E)^{-1.4747}$, where, N_{ff} = fatigue life, ε_t = tensile strain at the bottom of bituminous layer and E= stiffness modulus of the bituminous mix (Das and Pandey 1999), the variation of fatigue life with the variation of stiffness modulus of bituminous mix can be obtained as shown in Figure 1. In this example, standard dual wheel load of 20.5 kN each with tyre contact pressure of 0.7 MPa have been considered. The thicknesses of the bituminous and the granular layers have been taken as 150 mm and 300 mm respectively and the stiffness moduli of granular layer and the subgrade are taken as 300 MPa and 50 MPa respectively.

As apparent from the above equation, the stiffness modulus of bituminous mix affects the fatigue life in two different ways. Increase of stiffness modulus reduces the tensile strain at the bottom of the bituminous layer which is beneficial (towards the improvement of fatigue life); but increase of stiffness modulus may also cause the mix to become harder indicating reduced fatigue life. Due to the combined effect of these two factors, the calculated fatigue life is observed (refer Figure 1) to decrease and then increase with the increase of stiffness modulus of bituminous mix for the present case.

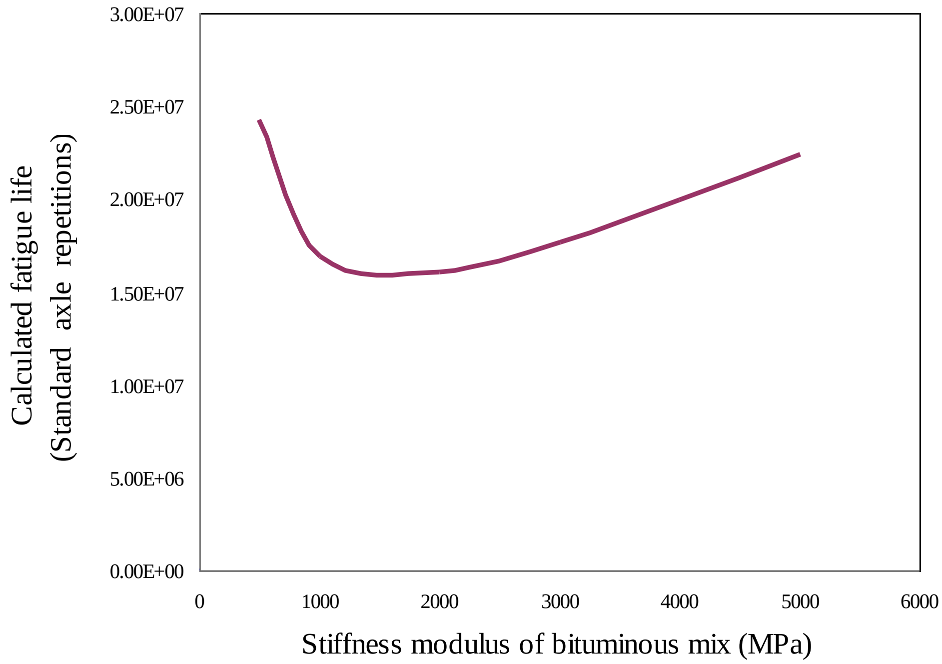

Figure 1 Variation of calculated fatigue life with stiffness modulus of bituminous mix.

Since, increase of stiffness modulus of bituminous mix has a varied effect on the calculated fatigue life, a mix designer needs to suitably develop a mix so that the mix parameters of the designed mix fall within the desirable range of properties. Thus, a mix designer may require an input from the pavement designer prior to the finalization of the mix design.

The benefit as well as the disadvantage of use of higher stiffness modulus of bituminous mix can be handled by using rich bottom bituminous pavement (Harvey et al. 1997, Monismith et al. 2001) or bituminous mixes with different bitumen viscosities as two bituminous layers (Das and Pandey 2000) etc. Through appropriate pavement design it may be possible to keep the material cost unaffected or even better (compared to conventional pavement design), yet increasing the longevity of the pavement.

The same logic can further be extended while using recycled mix in bituminous pavement. The recycled mix may have a different stiffness modulus and fatigue performance (Aravind and Das 2007, Huang et al. 2004) than the corresponding virgin mix. The combined effect of these properties would determine the structural thickness of the pavement (Aravind and Das 2007, Haji et al. 2010). Thus, the percentage usage of reclaimed bituminous pavement (RBP) in the recycled mix and the design thickness of the recycled bituminous layer, together, would determine the overall economy in the material cost.

Closure

The present article has briefly discussed the interplay between mix design and the structural design of pavement. Since material parameters of the finalized bituminous mix affect the pavement design (and thereby its economy), it may be helpful to have a prior information on desirable values of the mix parameters for the specific pavement design problem. A mix designer can then subsequently design the constituent proportions of the mix to achieve the target values of the relevant mix parameters.

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