Principles of bituminous pavement design and the recent trends

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Introduction

Understanding pavement behaviour is a complex task. This complexity is due to the complex response of the individual pavement materials which is very difficult to predict. In a typical pavement a number of such materials are used together.

The concept of rational pavement design for design of bituminous pavement was conceived during the 1960s (Dorman 1962, Monismith et al. 1961). Its upgraded version is known as Mechanistic-Empirical (M-E) pavement design, and is at present popularly being used for design of bituminous pavements in various countries. A number of pavement design guidelines (Austroads 2004, French 1997, IRC:37 2001, MS-1 1999, NCHRP 2005, Theyse et al. 1996, Shell 1978) have adopted the M-E pavement design approach. However, experience based empirical pavement design approaches are also in vogue in various other guidelines (AASHTO 1993, Manual 1989, RN-29 1970, RstO 2000)

Basic principles of M-E pavement design

In M-E pavement design approach, the pavement is idealized as a layered structure (generally assumed as elastic for simplicity in analysis) consisting of three to four horizontal layers made up of bituminous surfacing, base, sub-base and the subgrade. Each layer is characterized by its elastic modulus, Poisson's ratio and the thickness. Fatigue, rutting and low temperature cracking are generally considered as the important modes of failure of a bituminous pavement structure. Attempts are also being made to include thermal fatigue and top down cracking into the design process (NCHRP 2005, RRD-307 2006).

The developed critical *initial* strain values for each of the failure modes are computed from suitable pavement analysis routine. The allowable strain values are obtained from the input parameters (related to pavement material, environment, traffic and design life). Finally, the process of pavement design involves adjusting and subsequently selecting the appropriate thickness values of various layers so that the critical strain parameters are within the allowable limits. The design thickness values, for a given set of input parameters can be estimated from ready-made pavement design charts available in various guidelines (Austroads 2004, IRC:37 2001, MS-1 1999, Shell 1978).

A typical pavement design chart developed considering fatigue and rutting are presented as Figure-1. It may be noted that the point ‘A’ is just safe from rutting but oversafe from

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fatigue considerations, point ‘B’ is just safe from rutting but unsafe from fatigue considerations, point ‘O’ is just safe from both fatigue and rutting considerations etc. Any thickness combination above the curve A-O-D is an oversafe design.

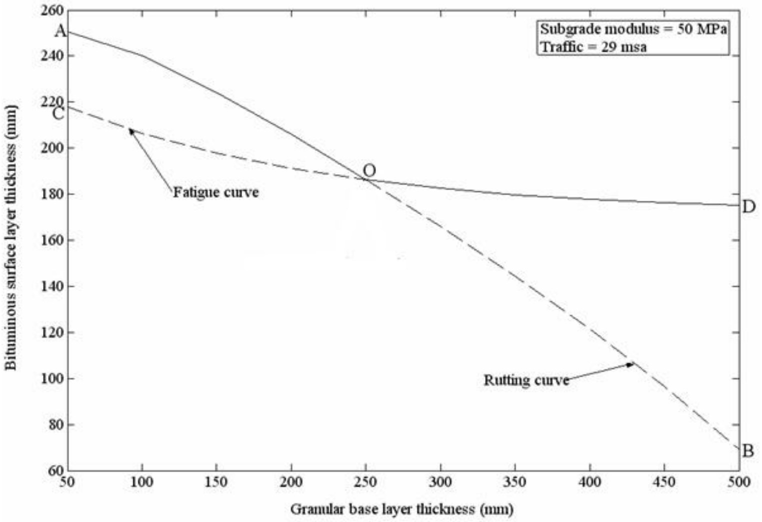

Figure-1 A typical bituminous pavement design chart considering fatigue and rutting

Thus, a typical pavement design process generates a number of possible alternative design solutions. It may be possible to identify certain specific thickness combinations which is optimal from material cost (Narasimham et al. 2001), structural serviceability or overall life cycle cost point of view (Abaza 2002, Abaza and Abu-Eisheh 2003, Mamlouk 2000).

Since the input parameters with which the pavement design system is based on, exhibit significant variability (Noureldin 1994, Timm et al. 1998, Kenis and Wang 2004), it would possibly be a better approach to consider these variabilities within the design process. This leads to considerations of reliability in the pavement design (AASHTO 1993, NCHRP 2005). Design of pavement, therefore, should consider both the aspects of economy and the design reliability.

Recent trends

Some of the recent issues related to (i) integrated mix design – structural design approach, (ii) damage considerations in pavement design, (iii) design of pavement with recycled/ marginal material are briefly discussed in the following paragraphs.

Integrated mix design – structural design

The mix specification in India has rather evolved through experience on construction and performance. The fatigue life of a bituminous layer can be increased by increasing the bitumen content (Harvey and Tsai 1996, Sousa et al. 1998). But, voids in mineral aggregates (VMA) being fixed for a given aggregate gradation, increase in bitumen content will result in less air voids, which is undesirable for a mix. Thus, there is a need to deviate from the specified gradation in order to come up with *non-standard* gradations, which possibly can give rise to better fatigue lives, yet without compromising with volumetric and strength requirements (Das 2004).

Softer grades of bitumen exhibit relatively higher fatigue life compared to harder grades of bitumen. Similarly, for a given grade of bitumen, the fatigue life increases with the increase in the bitumen content. Higher bitumen content or softer grade of bitumen enhances the fatigue life but the stiffness modulus may fall. A designer's objective is to achieve both high stiffness and high fatigue life for an economical design. This mutually contradictory situation can be handled by using bituminous layer(s) which is made richer in bitumen content (or softer grade of bitumen) towards the bottom portion (Das 2004, Das and Pandey 2000). These considerations, taken together, are expected to result in economical design of bituminous pavements.

Damage considerations in pavement design

The pavement is not designed from the ultimate stress conditions, rather designed from the considerations of number of repetitions it can handle. Most of the time field calibrated transfer functions (for fatigue, rutting, top down cracking etc.) are used for finalizing the design thicknesses of pavement. These transfer functions primarily relate the *initial* strain conditions of the pavement with the life of the pavement (for a given type of distress). This approach does not, in general, consider the propagation of damage and therefore, can not predict the structural state of the pavement at any other interim time. Understanding the damage process will enable the pavement designers to design a pavement with enhanced confidence and will subsequently to avoid the use of *shift factor*s in the design process.

Understanding damage in a pavement is a very complex process due to inherent complexities associated in modeling the material response. As well, there are different types of damages that may occur to the pavement. The failure mechanisms of individual types of damages are different than each other.

For bituminous mixes, for instance, the classical approach for composite material modeling, such as Voigt, Ruess and Hasin-Shtrikman (Hasin and Shtrikman 1963, Lakes 1998) does not hold good. This is because bitumen does not behave as an elastic material, and also the aggregates, as particulate intrusions, posses high volume fraction. Through a successful modeling of bituminous layer, one should be able to predict the location of crack initiation, rate of crack propagation, and the path it follows in an in-service pavement. Figure-2 shows an effort towards predicting crack location for laboratory samples tested with controlled loading and temperature conditions (Bandyopadhyaya 2005).

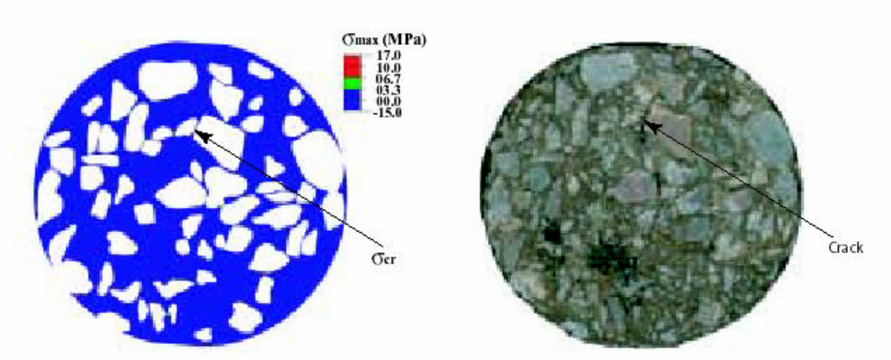

Figure-2 Comparison of initial crack location between numerical and experimental results (Bandyopadhyaya 2005)

Pavement design with unconventional/ recycled materials

Locally available marginal aggregates (and even the industrial wastes), which can not otherwise be used directly for road construction, can possibly be acceptable in cemented form (by using lime/ cement/ bitumen etc). The cemented material used as base / sub-base layer can impart extra fatigue life to a pavement (Das and Pandey 1998).

The depleting natural resources, and disposal problem of deteriorated pavement material necessitate adoption of pavement recycling technology. In recycling process, the reclaimed pavement material, fresh aggregates, virgin bitumen, and rejuvenator are added in such a proportion that the resultant mix performs *as good as* the fresh mix. The performance of such recycled mix needs to be studied in the laboratory (or in the field) so as to estimate the design thickness of the recycled pavement. The constituent proportion of the recycled mix and the design thickness together determine the overall economy in the material cost (Aravind and Das 2007). In a similar way performance based/ related pavement design needs to be developed for various unconventional material including the waste materials seeking potential application in pavement construction.

Closing remarks

Researchers are striving to reduce the empiricism in the pavement design process, and trying to make it more mechanistic in its approach. This would enhance the confidence in pavement design and its performance prediction, even when a new material is used in pavement construction.

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