INTRODUCTION

1.1. Background

India has 3.3 million kilometers of road network, which is the second largest in the world. The government of India initiated the National Highway Development Project (NHDP) to upgrade about 13,000 km of the existing national highways to four/six-lane facility at an estimated cost of Rs. 54,000 crores. Port Connectivity is another major project in road sector which aims to provide connectivity to the 11 major ports of India to the nearest national highway to facilitate smoother cargo evacuation. This project covers about 1,100 km length and is estimated to cost Rs 4,000 crores.

Rutting, fatigue cracking and low temperature cracking are the three most common distresses that contribute to failure of flexible pavements. Most of the NHDP sections, currently being built, have bituminous surfaces with dense bituminous mix (DBM) and bituminous concrete (BC) as binder and wearing courses respectively. These layers are constructed as per the specifications laid down by the Ministry of Road Transport and Highways (MORTH, 2001) and under a very rigid quality control regime. In spite of this, many of the bituminous surfaces have started showing premature signs of distress in the form of rutting and cracking. This obviously indicates that the current specifications have proved inadequate in addressing the requirements of the Indian Highways. There is of course the possibility of some or many of these failures having caused by poor construction practices.

Some of the factors causing distresses in bituminous pavements in India are high pavement temperatures, heavy axle loads, high tyre pressures and possibly inadequate binder and mix specifications. For a major portion of Indian highways, low temperature cracking is not an issue while it is one of the main modes of failure of bituminous materials considered in some countries.

Efforts are being made in India in the recent past (Panda, 1996; Palit, 2001; Punith, 2005; Kumar et al., 2006; Chowdary, 2008; and Rajan, 2010) to examine the characteristics of binders produced in India and those of the mixes prepared using these binders. These research

efforts, which are very limited in number, involve experimentally and/or numerically evaluating relevant characteristics of these materials. Agencies concerned in most of the advanced countries have realized the need for performance based specifications for bituminous mixes and have worked towards developing the specifications applicable for the climatic and traffic conditions prevalent in their countries besides considering the material availability and construction practices adopted.

In the absence of any major programme for systematically collecting the long-term performance of bituminous pavements, it is necessary to undertake steps for improving, to the extent possible, the understanding of the behaviour of the bituminous binders available in India and about the performance of the bituminous mixes prepared using these binders. As mentioned earlier, rutting and cracking (bottom-up and top-down) of bituminous layers are the main distress modes of concern in India. The present investigation has been taken up with this background. Broad objectives and scope of the investigation are presented in the following section.

As mentioned earlier, many of the bituminous surfaces constructed in the recent past have shown cracking and rutting distresses. Most of the highway sections on which the bituminous layers were constructed were two-lane two-way highways which were strengthened and widened to four-lane sections. These pavements are subjected to high traffic volumes with about 5 million standard axle load repetitions expected on the design lane within one year. Overloading of commercial vehicles and high pavement temperatures in summer have also been major contributors for distresses.

Though bottom-up fatigue cracking caused by repeated flexure of bituminous layers is generally expected, there have been many instances in India of failures caused by cracking initiated from surface of the pavement. It is proposed to carryout fatigue evaluation of bituminous concrete mix at a temperature of 25^0C using the repeated indirect tensile test facility available with the transportation engineering laboratory of IIT Kharagpur. It is also proposed to do an analytical evaluation of typical bituminous pavements for top-down cracking susceptibility taking into consideration heavy load, high surface temperatures and

surface tractive forces applied due to braking and rolling. It is also proposed to calibrate the laboratory fatigue equations using available performance data of in-service pavements.

Heavy loads (due to overloading), heavy traffic volumes and high pavement temperatures in summer, have been major contributing factors for rutting in India. The adequacy of the current specifications adopted in India for design of bituminous mixes is also being questioned in the context of rutting of bituminous layers. The contribution of the binders to rutting failures is also being examined by different agencies. It is proposed, in this research, to evaluate the rutting performance of bituminous concrete mix prepared with different types of binders. Static indentation test, a simple test for evaluation of permanent deformation of bituminous mixes, has been selected for this purpose. It is also proposed to monitor the rutting performance of similar in-service mixes to calibrate the laboratory rutting models.

The Indian Roads Congress (IRC: 37, 2001) guidelines for design of flexible pavements identify bottom-up cracking and permanent deformation caused in subgrade as well as bituminous layer. However, performance criteria are available in IRC: 37 (2001) for only bottom-up cracking in bituminous layer and subgrade related rutting. Even these criteria were developed based on limited performance data collected in the 80's and 90's. The material specifications and construction practices adopted for pavements considered in the earlier performance studies are different from those used in the recent past. It is, thus, necessary to conduct investigations to generate information regarding the characteristics of bituminous mixes and their cracking and rutting characteristics for the advancement of pavement design and maintenance methodology in India.

1.2. Objective and Scope of the Investigation

The broad objective of the investigation has been selected as evaluation of rutting and cracking characteristics of bituminous concrete mixes with different binders. As bituminous concrete (BC) is the most commonly used surface layer for national highways and other heavily trafficked roads, it is proposed to investigate the performance of bituminous concrete mix. Since, the mix behaviour is significantly influenced by the characteristics of the binder used,

BC mixes with six different binders are proposed to be evaluated. Three unmodified binders and three modified binders have been considered.

The scope of the work includes the following:

- To determine the physical and rheological properties of modified and unmodified binders under different temperature and frequency conditions and to assess the relative performance of the binders in terms of rutting and cracking parameters and temperature susceptibility. It is proposed to use VG-40, VG-30, and VG-10 viscosity grade unmodified binders and PMB-40, PMB-70 (polymer modified binders) and CRMB-60 (crumb rubber modified) modified binders. VG-30 grade bitumen is commonly used in bituminous layers in India. VG-10 (softer) and VG-40 (harder) grades of bitumen were considered for the sake of comparison. Three types of modified binders, generally used in India, have also been selected.
- To evaluate the resilient moduli of mixes prepared using different binders with different binder contents at varying temperature and loading conditions.
- To identify typical values of resilient moduli that can be selected for bituminous concrete layer for analysing pavements.
- To develop correlation between resilient modulus of mix and binder parameters.
- To compare laboratory and field moduli of different mixes and propose shift factors.
- To evaluate the fatigue characteristics of different mixes prepared using different binders. It is proposed to carryout fatigue tests at 25^{0}C under repeated indirect tensile test mode.
- To develop a relationship for estimation of fatigue life of the BC mix as a function of binder parameters.
- To examine, numerically, the top-down cracking (TDC) susceptibility of different mixes. As it is very difficult to experimentally simulate top down cracking produced by horizontal surface forces and high mix temperature, it has been decided to resort to numerical evaluation of TDC susceptibility.
- To evaluate the permanent deformation characteristics of different BC mixes at high service temperatures of 50^{0}C and 60^{0}C and to compare them with rutting characteristics of in-service pavement layers.

- To propose a relationship between rutting of mix and binder characteristics.

1.3. Thesis Layout

The thesis has been organised into eight chapters:- introduction, literature review, binder characterization, preliminary evaluation of bituminous mixes, resilient modulus, cracking characteristics, rutting characteristics and conclusions.

Chapter 1 is the introduction to the thesis and it presents the need for the present study and details of the scope of work selected. **Chapter 2** presents the present knowledge on the effect of binder on the performance of bituminous mixes. It covers different models available for estimation of resilient modulus, fatigue and rutting behaviour. Details of different investigations carried out on the six selected binders are given in **Chapter 3.** In **Chapter 4** some preliminary investigations conducted on bituminous concrete (BC) mix prepared using different binders have been discussed. Indirect tensile test results are presented in this chapter.

The experimental programme adopted for evaluation of the resilient moduli of different mixes under different temperature and loading (frequency and time) conditions has been presented in **Chapter 5**. The influence of temperature, binder type, binder content and loading condition has been discussed in this chapter. Details of Falling Weight Deflectometer (FWD) evaluation of three different stretches of an in-service pavement and comparison of the backcalculated moduli of the mixes with laboratory determined moduli of field cores and moduli of laboratory mixes are given in this chapter.

The experimental investigation conducted for evaluation of the fatigue behaviour of different BC mixes (with different types of binders and with different binder contents) have been presented in **Chapter 6.** Correlation between fatigue life and mix parameters has been examined in this chapter. Top-down cracking (TDC) susceptibility of different mixes has been examined numerically. The details are given in **Chapter 6.** The detailed experimental programme considered for evaluating the relative rutting characteristics of

BC mixes is discussed in **Chapter 7**. Comparison of the field rutting performance of some similar mixes has also been discussed in this chapter.

The conclusions drawn from the present investigation have been presented in **Chapter 8**. Scope for future work has also been given in this chapter. This chapter is followed by a list of references. **Appendix A** of the thesis contains the procedure adopted for calibration of the FWD sensors, deflection data collected in two different seasons and the normalized backcalculated moduli of bituminous layer.