SYNOPSIS

To sustain a road network in a healthy and efficient operational condition, proper maintenance is necessary. This requires pavement evaluation both from structural and functional considerations. It is desirable that such an evaluation is quick, reliable and accurate. Some of the parameters considered in the structural evaluation are the thickness of individual layers, their strength properties, interlayer bond conditions, presence of local anomaly, progression of internal crack, etc. Various non-destructive test methods have been developed for structural evaluation of asphalt pavements. Often, different combinations of such methods are required for a comprehensive evaluation. Spectral analysis of surface waves (SASW) is one of such methods that has been primarily used for estimation of thickness and elastic modulus of asphalt pavement layers. The current research explores the possibility of using this method for evaluation of various other structural parameters as well, so that it can be subsequently used as a tool for comprehensive structural evaluation of asphalt pavements.

The objectives of this thesis are to study (i) estimation of thermal profile of asphalt layer and its applications, (ii) evaluation of asphalt layer interface bond condition and (iii) detection of anomaly and crack within the asphalt layer using SASW method.

First, the development of the SASW test system and the SASW testing process is undertaken. The results derived from SASW testing can be expressed in the form of an experimental dispersion curve (EDC). After obtaining the EDC, the first question being considered, is whether the EDC contains the thermal profile information for the asphalt layer; and if so, is it possible to estimate it? This would enable one to obtain the thermal profile quickly and non-destructively, without the use of sensors installed within pavement structure for temperature measurement. This can subsequently be used for various pavement engineering applications such as estimation of elastic modulus profile, overlay design, thermal stress calculations, etc. The next question being considered, is whether the EDC contains information on the condition of the bond present at the

interface between the two asphalt layers; and if so, is it possible to estimate it? It may be noted that EDC, in such a case, may also contain the thermal profile information of the asphalt layers. Therefore, in order to study the bond condition, one has to first estimate and remove the thermal profile influence from the EDC. Subsequently, effort has been made to quantify the asphalt layer interface bond condition. In a similar manner, the EDC curve has been studied to detect the presence of anomaly and crack within the asphalt layer.

Development of the SASW test system consists of development of the test apparatus, testing procedure and the data analysis procedures. The advantages of this indigenously developed test apparatus are its low cost, low power requirement and ease of use. The use of a USB DAQ card makes this apparatus portable and reduces heating. Further, the use of high frequency, high sensitivity accelerometers helps in testing for shallower depths and recording of week signals respectively.

Development of testing procedure comprises of (i) test geometry selection (for appropriate generation and detection of Rayleigh waves), (ii) experimental parametric study (to decide on impact source and receiver spacing), and (iii) study on the effect of accelerometer-pavement coupling. Development of data analysis procedure comprises of (i) generation of representative EDC, and (ii) development of numerical model (based on Finite Difference formulation) for theoretical dispersion curve (TDC) generation.

The development of in-situ pavement testing facility comprises of construction of the asphalt pavement test section incorporating various bonding and anomaly conditions (denoted by A, P, E, B, C, and W, SA, LA, SPL, SP) along with the installation of thermocouple array. The bonding conditions include continuous asphalt (A), partial binder (P), excess binder (E), bentonite slurry (B), and chalk powder (C); and anomaly conditions include wood piece (W), small aggregates (SA), large aggregates (LA), steel plate (SPL), and steel pipe (SP) buried within the asphalt layer.

Preliminary tests are performed to check for the operational condition of the developed test system and the in-situ pavement testing facility. The recorded temperature readings from the thermocouples are checked for accuracy. The test section is checked for its thermal homogeneity. The thermal profile is studied for its trends in terms of hourly variation and these are verified with those reported in the literature.

For SASW tests, an equal source-receiver and receiver-receiver spacing and a hand-held instrumented hammer, as impact source and trigger device, are used. In some cases, a metal ball is also used to generate higher frequencies and for shallower target depths (in which case, the accelerometer signal is used as the trigger device).

Existence of thermal profile along the depth of asphalt layer causes variation in elastic modulus. This study suggests an approach to estimate the thermal profile of asphalt layer using SASW method. To establish the influence of thermal profile on EDC, SASW testing is conducted on the test section of the in-situ pavement testing facility at various times of the day and EDCs are generated. Simultaneously, thermal profile information of the asphalt layer is also collected from the installed thermocouples. The EDC is compared with a TDC which is generated for a given set of elastic modulus values as input. These elastic modulus values are related to the measured thermal profile as well as the field compaction level and type of mix of the asphalt layer of in-situ pavement testing facility. Suitable laboratory tests are conducted to establish this correspondence.

For TDC generation, apart from the developed Finite Difference based numerical model (p2), a simplified average model (p1) is also proposed. The generated TDCs using model p1 and p2 for the measured thermal profile are then compared with the representative EDC. Once the EDC and the generated TDC matches, it is established that the EDC contains the complete information of the thermal profile of the asphalt layer.

Having established that the EDC contains the thermal profile information, the next task is to develop a methodology to estimate the thermal profile when only EDC is available. For this purpose, backcalculation is utilized using model p1 to get the estimated thermal profile.

Subsequently, this approach can be used for various application purposes, for example, to generate elastic modulus profile of the asphalt layer, calculation of thermal stress, overlay design, etc.

To explore the use of SASW method for evaluation of asphalt interlayer bond condition, a study is undertaken for developing the methods for detection of different bond types/conditions as well as for estimation of asphalt layer interface bond shear strength (BSS) from the EDC obtained by SASW testing.

SASW testing is performed on blocks of pavement test section, having different bond conditions between asphalt layers. The EDCs thus generated will also have an influence of thermal profile which is removed before using them for further analysis. For verification of the developed experimental method of bond detection, the Finite Difference based numerical model p2 is modified to incorporate the bonding condition at the mutual interface of two asphalt layers. The dispersion curves generated from the modified model p2 and SASW testing are compared.

For developing a method to estimate the layer interface BSS from EDC, a laboratory test apparatus is developed to find such estimates for field core samples. Core samples are taken from various test locations having different asphalt layer interface bond conditions, in IIT Kanpur campus and BSS estimates are found. SASW field testing is also performed at the same locations and EDCs are generated. A method is proposed to quantify the asphalt layer interface bond shear strength using EDC. Both the BSS estimates are compared which gives verification of the proposed method.

Detailed SASW testing is conducted on blocks of pavement test section having different types of anomalies (W, SA, LA, SPL, SP) and EDCs are generated. Testing is performed on two different test lines, one directly above the anomaly and the other away from it. The generated EDCs (after removing the influence of thermal profile) are compared with that of the continuous asphalt block (A). Separate SASW testing is performed on asphalt slabs for detection of vertical crack.

It is evident from these studies that such a varied application potential in a single portable NDT equipment can prove to be enormously beneficial for pavement network maintenance and rehabilitation. The specific contributions from this thesis are summarized as follows.

In this thesis, a simplified method is proposed to estimate the thermal profile of an asphalt layer from EDC obtained by SASW testing. It provides a simple and quick procedure to estimate the actual elastic modulus profile of a thick asphalt layer. The Finite Difference based numerical model is modified to incorporate the interlayer bond condition. A method is proposed to quantify the interlayer bond condition using the EDC, which gives reasonably good estimates of the asphalt interlayer bond shear strength. SASW method is also found to be reasonably suitable for anomaly and crack detection of the asphalt layer.