Abstract

The continuous increase in loading and the extreme temperature have increased the challenges of constructing longer-lasting, superior performing roads. It is important to understand the potential damage to the service life of roadways due to changes in the intensity of these parameters. One way to study the influence can be field evaluation of the structural response of the pavement to collect realistic data for computing loss to fatigue life of the asphalt layer and rutting life of the subgrade layer. However, it is labor-intensive and time-consuming. The other way of study may be an analytical or numerical analysis of asphalt pavement under field conditions. The later analysis requires large-scale experimentation to obtain material properties of various layers under varying field conditions.

To minimize the cost and time required, the current practice of pavement analysis and design, especially in developing economies like India, is based on layered elastic theory, which considers linear elastic properties of materials in various layers of asphalt pavement. The loading is assumed uniform and distributed over a circular area to make analysis easy. In reality, neither materials in various layers respond linear elastically, nor is the loading uniform at the pavement surface. Past studies have shown that asphalt mixes are viscoelastic material, while materials' response in unbound granular layers is nonlinear stress dependent. So, material characterization based on linear elastic theory may underestimate or overestimate its strength. Thus, extensive laboratory tests were realized to capture these complex behavior of pavement materials. These material characterization tests were categorized into different phases.

The initial phase of the study is based on the experimental determination of linear elastic properties of materials in different layers of the asphalt pavement. Whereas later phases

considered viscoelastic properties of asphalt mixes and nonlinear stress-dependent responses of unbound materials. The linear elastic properties were determined first to study the difference in pavement response when complex material behavior like viscoelastic mixes and stress-dependent unbound materials are considered. The resilient modulus (M_r) of asphalt mixes (SMA-1, SMA-2, BC-1, and BC-2) has been evaluated at a wide range of temperatures to consider average and extreme temperature conditions in various regions of India. The soaked California bearing ratio (CBR) test was conducted on unbound granular materials (UGMs) to evaluate its M_r properties using empirical relations as specified in IRC:37. The resilient modulus test data are used to characterize linear elastic properties of the materials.

The linear viscoelastic material characterization of dense graded asphalt mix (BC-2) is based on the creep compliance test at three different air voids of 4, 5, and 6% and three different test temperatures of 5, 15, and 25^{o} C. The creep compliance test captures the dynamic response of the material. The Generalized Kelvin Model (GKM) has been used to analyze the creep behaviour of BC-2 mixes. Model parameters are determined by a series of constraint optimization processes using the least square approach.

The study of the nonlinear stress dependent response of UGMs is based on repeated load triaxial compression testing. Variations in M_r values with the change in stress (cyclic stress) in the material were evaluated. The k-ϴ model, Uzan model, and NCHRP model have been used to describe the response of UGMs in base and granular sub-base (GSB) layers. The NCHRP model showed the best fit of M_r data while the k-ϴ model predicts these M_r values least reliably. The Bilinear model was used to explain the stress-dependent response of soil material. It fits the experimental data of fine-grained cohesive soil reasonably well; however, a significant difference in predicted and experimental data was found for non-cohesive soils. Advanced solution methods are often required to consider these nonlinear constitutive models for pavement analyses. The numerical modelling techniques, like finite element (FE) analysis are equipped with built-in nonlinear constitutive models to account for the nonlinear stress dependent behaviour of unbound granular layers as well as the viscoelastic behaviour of the asphalt layer. These benefits of FE method have been used in present study also.

The 3-dimensional FE model of the tire-pavement system was developed in ABAQUS to evaluate pavement response and its life subjected to different loading, material properties, and environmental conditions. A solid tire model of a single rubber material is constructed to simulate nonuniform contact stress distribution at the tire-pavement interface. The hyper-elastic material modelling technique has been used to explain the behaviour of rubber material in solid tires. The FE model has been validated using the results obtained from 3D Move analysis and Boussinesq close form solution under similar conditions of loading and material properties of various layers in the asphalt pavement. The two results were found to be in close agreement with each other.

The FE analysis of the asphalt pavement system has been categorized into four simulation stages. The first simulation stage is based on linear elastic properties of materials and uniform loading conditions. It also considers the assumed shapes of the contact area (circular, square, rectangular, and rectangle with semi-circular ends). The results indicated that the response of the pavement is not significantly affected by changes in the shape of the contact area.

The second stage of FE simulation considers linear elastic properties of the materials in various layers of asphalt pavement and nonuniform loading applied through realistic tires.

The parameters of increasing concern, like overloading and temperature have been considered to study its damaging effect on the critical mechanistic parameters and pavement life. An overload of 25% (with respect to a standard load of 40 kN on a single tire) reduced subgrade rutting life by 62.42% and asphalt fatigue life by 32.53%.

The third simulation stage considers linear viscoelastic (LVE) properties of asphalt mixes (BC-2), linear elastic properties of UGMs, and nonuniform loading conditions. The LVE simulation predicted higher deformation and normal compressive strain, while lower horizontal tensile strain in the pavement compared to linear elastic analysis under static loading conditions. The study concluded that the linear elastic approach overestimates material stiffness. The fourth simulation stage considers nonlinear stress-dependent behavior of UGMs keeping other parameters similar to third simulation stage. The study showed that the linear elastic properties of UGMs overestimate the material stiffness. Therefore, the analysis approach must be revised for better reliability and accuracy.