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Analysis and Design of Two Layered flexible Pavement Systems: A New Mechanistic Approach

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Abstract- Analysis of two layered flexible pavements is considered as a significant aspect for design of low volume roads, which typically consist of a thick granular base course directly laid over subgrade with or without a thin asphalt- wearing course. Permanent deformation or rutting has been observed to be the major distress mode in thin surfaced or unsurfaced low volume roads. In the present study, a new formulation has been proposed to de- termine the surface and interface deflections for both single and standard axle dual wheel assembly for a two layered pavement system. The present formulation has been developed based on mechanistic approach and the solutions obtained from 3-dimensional finite element program, using ABAQUS taking into account the influence of rectangular tire imprint, modulus of granular base course, pavement thickness and ratio of modulus of pavement and subgrade. The effect of Poisson's ratio of granular base and subgrade is observed to be very insignificant. For the estimation of surface and interface deflections, deflection factors have been generated in the form of non-dimensional charts as a function of ratio of modulus of pavement and subgrade, and ratio of pa- vement thickness and tire width.

Keywords- Asphalt, pavement, flexible, Deformation, Deflections.

I. INTRODUCTION

A flexible pavement can be idealized as a multi-layered elastic structure resting on natural foundation, constructed to facilitate the movement of vehicles. Flexible pavements are classified as high and low volume pavements depending upon the intensity of traffic over the design period. High volume roads are designed and constructed in 3 to 4 layers, consisting of asphalt concrete layer of considerable thickness at the top, base course and sub base followed by compacted and natural subgrade layers [1, 2].

Whereas, low volume roads and full depth as- phalt pavements [3] are the exact cases of a two-layered pavements systems. For low volume pavements with or without thin asphalt concrete layer, the unbound granular material layer constitutes the main structural unit. Under traffic loading, granular layer undergoes complex deformation behavior where large part consists of recoverable de- formation and a small part is plastic or permanent deformation [4]. The plastic or permanent deformation accumulates with each load repeti- tion and may eventually lead to rutting of the pavement [5, 6].

Because of thin seal/unsealed construction, low volume roads typically fail by rutting [7, 8]. Therefore, proper characterization and accurate model- ling of the elastic response of unbound granular materials is important in thin-surfaced pavements where most of the bearing capacity is pro- vided by the granular layers [9]. Several constitutive models such as micromechanics-based models [10, 11] and endochronic models [12] have also been developed to describe the complex behavior of granular materials under both monotonic and cyclic loading. Gonzalez et al [13] focused on the measurement of the in situ elastic response of granular materials used in low volume roads considering the fact that elastic strains are proportional to plastic strains in granular materials [6,8,14,15].

- Each layer was considered homogeneous, isotropic, and linear elastic
- first layer with finite thickness and second layer of infinite thick- ness and both layers extend to infinite in lateral directions
- Loading area was considered circular in nature with uniform pressure
- Pavement system was analyzed as an axisymmteric model as- suming tire contact area to be circular in nature;
- Both the layers were considered incompressible in nature with poison's ratio of 0.5.

II. SCOPE OF PRESENT STUDY

The pavement layers are subjected to both compression and tension under moving load, and only compression due to static loading. Irrespective of loading, both elastic and plastic deformations are de- veloped depending upon the imposed stress level. For the stress greater than yield stress, elastic as well as plastic deformation occurs. The present analysis deals with elastic deformation of two layered pavement system based on mechanistic approach and three dimensional (3D) fi- nite element analyses. The mechanistic approach works well when the pavement subgrade system behaves as a linear elastic system and the loading is considered to be static whereas, in reality pavements are subjected to both static and moving loads. However, Saad et al. have found that the static loading condition is more detrimental to the pavement system as compared to the dynamic condition causing almost two times higher maximum vertical surface deflection. Similar trend of results have also been reported by Zaghloul and White and Uddin et al. between static and dynamic analysis solutions.

A new formulations have been proposed in this study for the eva- luation of long-term compressional behavior under static loading in terms of surface and interface deflections in a two layered pavement system for single as well as standard axle dual wheel assembly. Design charts have also been developed which will be highly useful in the analysis and design of low volume roads in order to have an optimum selection of materials, layer thickness on the basis of design require- ments, strength and availability of materials. The 3D finite element analysis was carried out using ABAQUS in order to simulate the rectangular tire print so that the two-dimensional analysis can be overcome which is not realistic as the loaded area shape is restricted to either a circular (axi-symmetric condition) or infinite strip (plane strain condition).

The cumulative effect of dual wheel assembly has been in- vestigated and deflection factor charts were developed as a function of modular ratio (E1/E2) and pavement thickness (h) to tire width (b) ratio for the calculation of deformation at the surface as well as at the pa- vement-subgrade interface. A comparison of stress distribution for both single and dual wheel assembly across the pavement cross-section and pavement-subgrade interface stress charts has also been presented for different modular ratio and pavement thickness-tire width ratio. The effect of pavement thickness, modular ratio of granular base course and subgrade soil, Poisson's ratio of base course and subgrade on pavement responses for a two layered pavement system have been analyzed and discussed in detail.

III. METHOD OF ANALYSIS

Finite element analysis based on ABAQUS has been found to be very efficient in modeling flexible pavements to incorporate different realistic conditions in the analysis for obtaining stresses and deformations of flexible pavements. The accuracy of finite element solutions depends on the mechanical behavior of materials which must be selected in such a way that it better represents the characteristic of material such as elasticity, plasticity, ductility, brittleness, etc. In this study, a 3D finite element modeling has been adopted using ABAQUS considering rectangular footprint of the loaded wheel, linear elastic behavior of both granular base course and subgrade and both the layers as homogenous and isotropic. A linear elastic model is valid only for small elastic strains, normally up to 5% strain. For strain greater than 5%, hyper elastic model should be used. In the present analysis, max- imum elastic strain has been found to reach about 0.16%. In order to define linear elastic material behavior, the total stress is defined from the total elastic strain as given below:

$$\sigma = D^{el}\varepsilon^{el}$$

Where is the total stress, Del is the fourth-order elasticity tensor, and εelis the total elastic strain. For linear elastic material behavior, Drucker stability criterion must be satisfied which requires tensor to be positive

IV. CHOSEN DOMAIN, BOUNDARY CONDITIONS AND fiNITE ELEMENT MESHES

For performing the analysis, a single lane rural road in India (car- riageway width = 3.75 m) of a two-layered system consisting of gran- ular layer and subgrade was taken into consideration as shown in Because of symmetry from both loading and geometry point of view, a half model was chosen for carrying out the analysis as illu- strated in The chosen domain was discretized into eight noded isoparametric elements. Along the vertical boundaries of the chosen domain, the nodes along lateral direction (x-direction) and vertical direction (y-direction) are restrained against translation; whereas, translation is allowed in longitudinal direction (in direction of road, z-direction).

The nodes at bottom boundary are restrained against both translation and rotation in all the three directions. A typical finite element mesh created for the model is shown in The dimension of model in lateral direction (x-direction) is 3375 mm (1875 mm of granular layer + 1500 mm of shoulder) which is equal to half of the road width; whereas, dimensions in the other two directions i.e. long- itudinal (in direction of road, z-direction) and vertical direction (across the depth of road, y-direction) can extend to infinite.

The computation effort for performing the analysis depends on the size of chosen model; therefore, a sensitivity analysis has been performed in order to select an optimum model to reduce computational effort. It was found that the model size of 2000 mm in z direction and 2500 + h mm in y direction are sufficient to carry out the analysis; where h is the thickness of granular base course are shown in Beyond a particular size of the model, the variation in the solutions or in the response of pavement in terms of deformations and stresses are negligible with further increase in the size of model, which is said to be optimum model for carrying out the analysis. To achieve this, the computations were performed for different models with length of pavement varying from 1000 mm to 3000 mm in the longitudinal and with thickness of subgrade varying from 1000 mm to 4000 mm in vertical directions; whereas, the di- mension in the lateral direction was fixed to 3375 mm.

For the sake clarity, the deformations and stresses at the surface only for five models are presented in Further, the distribution of stresses and de- formations for h/b = 2 and E1/E2 = 10 with the model size 2000 mm × (2500 + 320) mm and 2400 mm × (3000 + 320) mm are shown in for a dual wheel assembly, which imply that the zone of influence is far away from the right side boundary as well bottom boundary. The zone of influence is the region beyond which the magnitude of stresses and the deformations are insignificant. It could be noted that the var- iations in results were found to be insignificant when the dimensions of domain exceeds 2000 mm in longitudinal and 2500 mm in vertical di- rection, and the domain size 3375 mm × 2000 mm × 2500 mm was used for carrying out all the computations.

It needs to be mentioned that though the properties of granular base course are different to that of shoulder, but for simplifying the analysis, the properties of both granular base course and shoulder were kept as same. Nevertheless, the zone of influence has been found to remain within the granular base course in the lateral direction, that is, the zone covered with blue color indicating zone of influence beyond which the magnitude of stresses and the deformations are insignificant. From the literature it could also be noted that the influence of single and dual wheel con- figurations on the road surface deformations are negligible beyond a length of 2000 mm in the longitudinal direction of pavement from an in-situ measurement.

V. CONCLUSION

Repetitions as the primary dependent variable in most of the performance models described in the paper. There is no variability associated with the traffic parameters and mixed traffic. We all know that the load-associated damage is not linear. Recall the fourthpower law of load equivalency that relates pavement damage to axle loads. Variability in traffic is caused by the mixed axle traffic on roads and mixed gear configuration on airport pavements.

The variability in traffic also relates to time and season. A comprehensive pavement design and analysis program (Figure 4) currently under development at the University of Mississippi (1) considers the important variability of mixed traffic with time and season. 2. It would be helpful to readers if the authors were to include a couple of example applications of the results of performance models in each distress category in order to compare the results of different models (e.g., fatigue models). Some comments on the validity of these models would provide much-needed information to the readers. This is important for pavement designers and researchers because the authors have recently reported the inadequacy and inaccuracy of rutting and fatigue models developed in the SHRP Superpave study.

The primary load response calculations required to get pavement response inputs for pavement performance models in the program are based on static layered analysis, which ignores the dynamic load pulse and effects of cracking and viscoelastic behavior of asphalt pavements (1). I have shown the importance of cracking on pavement response for both asphalt and concrete pavements by conducting three-dimensional finite element analysis (1, 2). Perhaps in future work, the authors may include some comparisons of the performance models using pavement response calculated from three-dimensional finite element analysis.

VI. REMARKS

There are two major distress modes in flexible pavements: (i) fatigue cracking and (ii) rutting failure. The fatigue cracking is mainly due to the breakage and degradation of particles at the surface of the pave- ments which is more in the case of high volume. The stresses transferred to the lower layers are not significant in high volume roads due to higher thickness of bituminous and water bound macadam layers.

Hence, strength and durability of top layers are of greater significance in high volume roads to avoid fatigue cracking. Whereas, rutting failure is due to the accumulation of irrecoverable strain or permanent de- formation under repeated loading. The present research study is more relevant to the second distress mode which is the prime cause of failure (H/B) ratio. Interface stress decreases as the pavement thickness and modular ratio increases. Surface and interface deflections have been obtained separately for both single and dual wheel assembly.

Subgrade layer constitutes major portion of the total deformation, which also depends on modular ratio and pavement thickness. The proportion of interface deflection (deformation within subgrade layer) increases as the modular ratio increases, whereas it decreases with increase in pavement thickness. The effect of Poisson’s ratio has been found to be very insignificant. Deflection factors have been developed so that surface and interface deflections can be calculated for any two layered pave- ment structure for given thickness and elastic modulus ranging between 300 and 1000 MPa.

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