THE BEHAVIOUR OF FLEXIBLE PAVEMENT BY NONLINEAR FINITE ELEMENT METHOD

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Abstract- In this research, axisymmetric finite element method has been carried out to study the behavior of flexible pavement. The asphalt concrete, base course and sub grade have been discretized as four noded isoparametric finite elements. The asphalt concrete and the base course have been idealized as elastic material. The sub grade has been idealized as nonlinear material by Drucker-Prager yield criteria. The nonlinear finite element equation has been solved by Full Newton Raphson Method. Based on finite element analysis pressure vs settlement curve; pressure vs nodal stress curve; pressure vs element stress curve; variation of nodal displacement with decreasing height and variation of element stress with decreasing height have been obtained. Also the comparison of pressure vs settlement curve and comparison of settlement with decreasing height for different properties of soil have been obtained. It has been found that the pressure vs settlement curve; pressure vs nodal stress curve ; pressure vs element stress curve are linear for small pressure range and then it become nonlinear. More nonlinearity is seen at higher pressure. Hence material nonlinearity must be considered while analysing and designing flexible pavements

Keywords ñ Finite element method, material nonlinearity, pressure, stress, settlement

I. INTRODUCTION

A pavement is defined as a relatively stable crust constructed over the natural soil for the purpose of supporting and distributing the wheel loads and providing an adequate wearing surface. The flexible pavements consist of wearing surface built over a base course and they rest on compacted sub grade. The flexible pavements are able to resist only very small tensile stresses. The design of a flexible pavement is based on the principle that a surface load is dissipated by carrying it deep into the ground through successive layer of granular materials. Some of the design methods for flexible pavements are Group Index Method, California Bearing Ratio Method, North Dakota Method, Bur misterís Design Method and U.S. Navy Plate Bearing Test Method.

Flexible pavements with asphalt concrete surface courses are used all around the world. The various layers of the flexible pavement structure have different strength and deformation characteristics which make the layered system difficult to analyze in pavement engineering. Asphalt concrete in the surface layer is a viscous material with its behavior depending on time and temperature. On the other hand, pavement foundation geomaterials, i.e., the fine-grained soils in the sub grade, exhibit nonlinear behavior. Finite element programs that analyze pavement structures need to employ this kind of nonlinear characterization to more realistically predict pavement responses.

II. LITERATURE REVIEW

Helwany et.(1998) al in their study illustrate the usefulness of finite element method in the analysis of three-layer pavement systems subjected to different types of loading. The method is capable of simulating the observed responses of pavements subjected to axle loads with different tyre pressures. The pavement materials are considered as linear elastic, nonlinear elastic, and viscoelastic. Finite element modeling of pavements has been found extremely useful.

Hadi and Bodhinayake (2003) has undertaken a research study to incorporate the material properties of the pavement layers and the moving traffic load, in the analysis of flexible pavements, using the finite element method. As a preliminary step taken herein in this direction, a pavement structure where field measurements have been carried out when subjected to a cyclic loading, is selected and modeled as a finite element model. The analysis is being carried out using the finite element computer package ABAQUS, when this pavement model is subjected to static and cyclic loading while considering the linear and nonlinear material properties of the pavement layers. The results indicate that displacements under cyclic loading when nonlinear materials are present, are the closest to field measured deflections.

Subagio et.al (2005) discuses a case study for multi layer pavement structural analysis using methods of equivalent thickness. An approximate method has been developed to calculate stresses and strains in multilayer pavement systems by transforming this structure into an equivalent one-layer system with equivalent thicknesses of one elastic modulus. This concept is known as the method of equivalent thickness which assumes that the stresses and strains below a layer depend on the stiffness of that layer.

Das (2007) presents central plant hot mix recycling for design of pavement. Central plant hot mix recycling is one of the popular techniques adopted for recycling of asphalt pavement materials. Varied levels of performances (laboratory as well as field) have been reported of recycled mix compared to the performances of corresponding virgin mixes. Thus, there is a need for conducting performance-related tests before finalizing any recycled mix design. This paper discusses laboratory study conducted on recycled mix design of two different reclaimed asphalt pavement samples, and subsequently develops an integrated mix design structural-design approach for hot recycled mix. The total cost of the asphalt layer construction is estimated considering the constituent proportion and the pavement design thickness so that the desiner can choose the best option.

Das (2008) discusses the reliability issues in bituminous pavement design, based on mechanistic-empirical-approach. Variabilityís of pavement design input parameters are considered and reliability, for various proposed failure definitions, of a given pavement is estimated by simulation as well as by analytical method. A methodology has been suggested for designing a bituminous pavements for a given level of overall reliability by mechanistic empirical pavement design approach.

Beiabih and Chandra (2009) have compared the cost of flexible and rigid pavements. It is necessary to ensure that they are designed for same traffic loading. A total of 90 flexible pavements and 63 rigid pavements are designed and their costs compared. The costs include the construction cost and a fixed maintenance cost. Mathematical expressions are developed to relate the cost of pavements with soil CBR and traffic in million standard axles. Flexible pavements show wider range of variation in cost with respect to design parameters of traffic and soil CBR. The overall variation in cost of rigid pavements is comparatively small. It is observed that flexible pavements are more economical for lesser volume of traffic.

Tarefder et. al (2010) presents that reliability is an important factor in flexible pavement design to consider the variability associated with the design inputs. In this paper, sub grade strength variability and flexible pavement designs are evaluated for reliability. Parameters such as mean, maximum likelihood, median, coefficient of variation, and density distribution, function of sub grade strength are determined. Design outputs are compared in terms of reliability and thickness using these design procedures. It is shown that the AASHTO provides higher reliability values compared to the probabilistic procedure. Finally, the reliability of the flexible pavement design is evaluated by varying hot mix asphalt properties. Alternative designs are recommended for the existing pavement thickness by modifying material and subgrade properties to mitigate different distresses.

Ameri et. al (2012) has used finite element method to analyses and design pavements, Finite element method is able to analyse stability, time dependent problems and problems with material nonlinearity. In this paper, a great number of the prevalent pavements have been analyzed by means of two techniques : Finite element method and theory of multilayer system. Eventually, from statistical viewpoint, the results of analysis on these two techniques have been compared by significance parameter and correlation coefficient. The results of this study indicate that results of analysis on finite elements are most appropriately compiled with results came from theory of multilayer system and there is no significant difference among the mean values in both techniques.

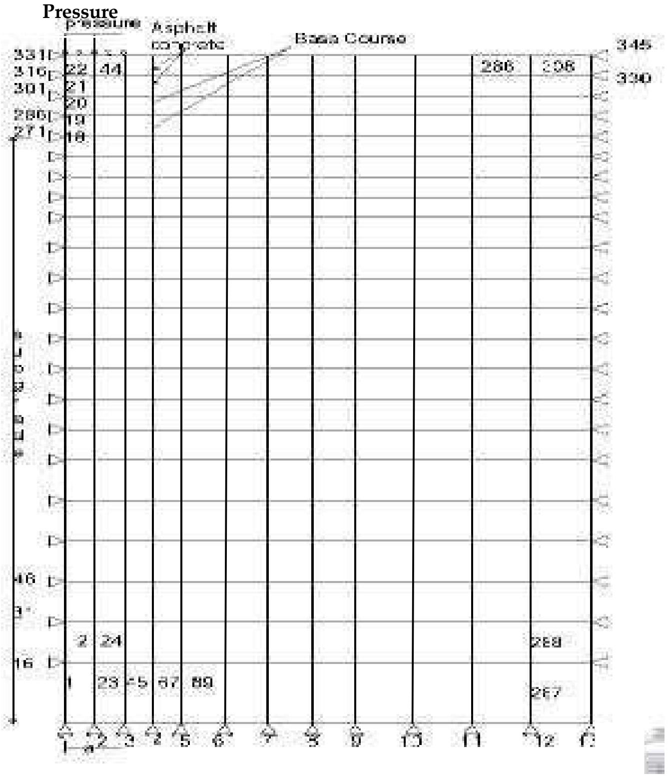
Jain et. al (2013) discuss about the design methods that traditionally being followed and examines the ìDesign of rigid and flexible pavements by various methods and their cost analysis by each methodî. Flexible pavements are preferred over cement concrete roads as they have a great advantage that these can be strengthened and improved in stages with the growth of traffic and also their surfaces can be milled and recycled for rehabilitation. The flexible pavement is less expansive also with regard to initial investment and maintaince. Although rigid pavement is expansive but less maintenance and have good design period. It is observed that flexible pavements are more economical for lesser volume of traffic. The life of flexible pavement is near about 15 years whose initial cost is less needs a periodic maintenance after a certain period and maintenance costs very high. The life of rigid pavement is much more than the flexible pavement of about 40 years, approximately 2.5 times life of flexible pavement whose initial cost is much more than flexible pavement but maintenance cost is very less.

Dilip et.al (2013) discusses the uncertainty in material properties and traffic characterization in the design of flexible pavements. This has led to significant efforts in recent years to incorporate reliability methods and probabilistic design procedures for the design, rehabilitation, and maintenance of pavements. This study carries out the reliability analysis for a flexible pavement section based on the first-order reliability method and second-order reliability method techniques and the crude Monte Carlo Simulation. The study also advocates the use of narrow bounds to the probability of failure, which provides a better estimate of the probability of failure, as validated from the results obtained from Monte Carlo Simulation.

Based on literature review it has been observed that very few analyses for flexible pavement has been done by finite element method. Hence there is need for finite element analyses of flexible pavement especially considering nonlinear material behavior.

III. FINITE ELEMENT ANALYSIS

In this research axisymmetric finite element analyses have been done by considering sub grade soil as a nonlinear material. The material nonlinearity has been considered by idealizing the soil by Drucker-Prager yield criterion. Fig.1 shows the finite element discretization considered in this analysis. The asphalt concrete and the base course have been idealized as elastic material. The nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure. The asphalt concrete as well as the base have been idealized as linear elastic material. Fig.1 shows the finite element discretization considered in the finite element analysis. The asphalt concrete, base and the sub grade have been discretized by four noded isoperimetric finite elements. The total number of nodes considered are 345 and total number of element considered are 308. The horizontal domain of discretization considered in the analysis is 20 times the radius of pressure. The vertical domain considered in the analysis is approximately 140 times the radius of pressure. The boundary conditions considered in the analysis are such that the bottom nodes have no degree of freedom, the central nodes have only vertical freedom and the right side nodes also have only vertical degree of freedom. The thickness of asphalt concrete considered is 75 mm and the thickness of base course considered is 250 mm. Pressure acts at radius 150 mm.



a = radius of pressure = 150mm
(diagram not to the scale)

Fig. 1 Finite Element Discretization For Flexible Pavement

Elastic Modulus of Asphalt Concrete = 2759000 kN/m^2, Poissonís Ratio=0.35
Elastic Modulus of Base Course = 207000 kN/m^2, Poissonís Ratio=0.40
Elastic Modulus of Subgrade = 5000 kN/m^2, Poissonís Ratio=0.45
Cohesion of Sub grade =25 kN/m^2

IV. RESULTS AND DISCUSSIONS

Fig.2 shows the pressure versus deflection ie pressure vs settlement curve. The initial portion of the curve is linear which shows the linear elastic behavior of the pressure vs settlement curve. The curve is linear up to pressure 200 kN/m^2 .After that it becomes nonlinear. The nonlinearity of the curve increases with increase in pressure. In this figure the nonlinearity is more after pressure 600 kN/m^2. The nodal settlement is at the node 271which is the node at top of sub grade.

Fig.3 shows the variation of nodal stress (sigx) with increase in pressure . The initial portion of the curve is linear up to pressure 200 kN/m^2 . After 200 kN/m^2 the pressure vs nodal stress curve become nonlinear. The nonlinearity increases with increase in pressure. The increase in nonlinearity means that the nodal stress increase is more than the pressure increase. The nonlinearity of the pressure vs nodal stress curve shows that the material nonlinearity considered in the finite element analysis simulates the actual behavior.

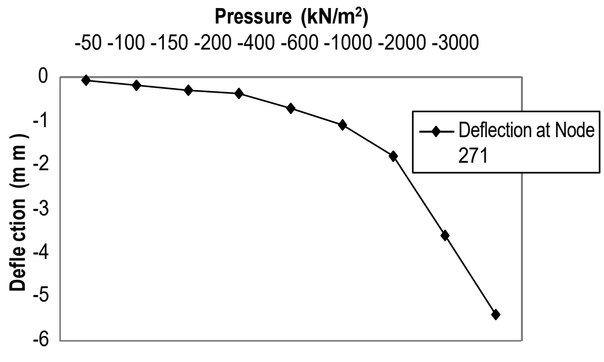


Fig.2 Pressure vs Deflection Curve

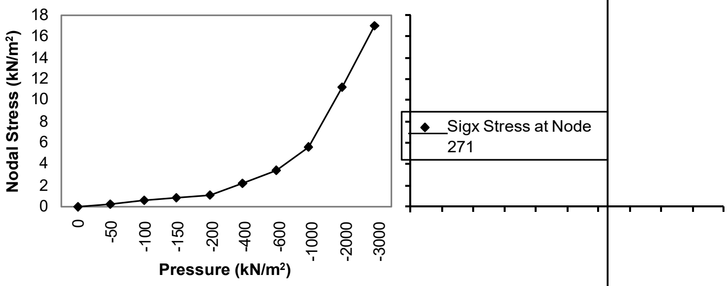


Fig.3 Pressure vs Nodal Stress Curve

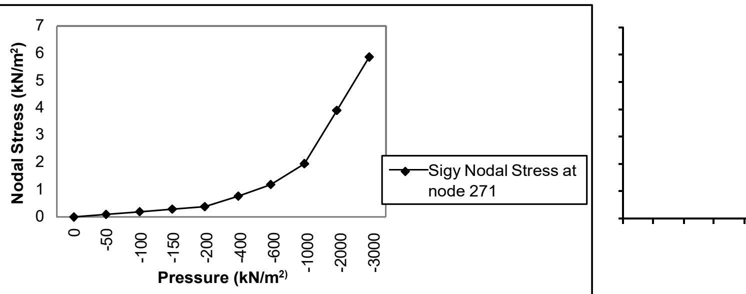


Fig.4 Pressure vs Nodal Stress Curve

Fig.4 shows the pressure vs nodal stress (sigy) curve. The initial portion of the curve shows the linear elastic behavior ie. the pressure vs nodal stress curve is linear. This means that the increase in pressure and nodal stress is directly proportional. The curve then becomes nonlinear. In the nonlinear case the increase in pressure and increase in nodal stress is not proportional. In nonlinear case the increase in pressure is less than the increase in nodal stress.

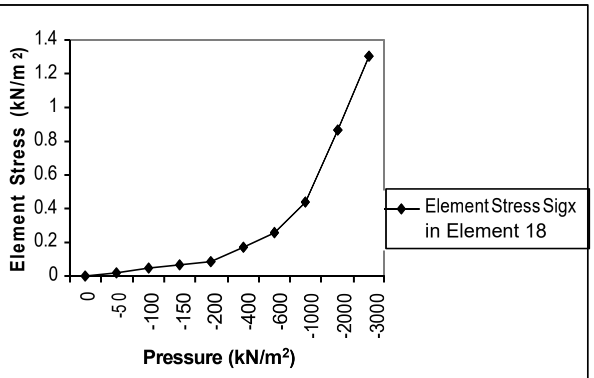


Fig.5 Pressure vs Elment Stress Curve

Fig.5 shows the variation of pressure vs element stress (sigx). The element considered is the element number 18. This element is the first element considered in sub grade. This element is below the base element 19 . The curve between pressure and element stress is nonlinear. This indicates that even increase in element stress is more than the increase in pressure.

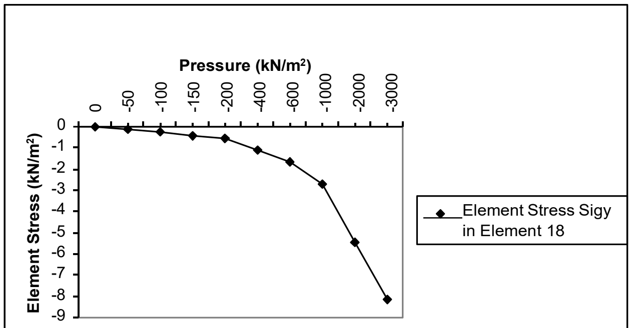


Fig.6 Pressure vs Element Stress Curve

Fig.6 shows the variation of element stress with increase in pressure. The curve is linear in initial portion and then it becomes nonlinear. The stress is considered in element 18 which is the first element of subgrade. This element is below the element 19 of the base. The increase in element stress (sigy) with increase in pressure in this case is more than the element stress (sigx). The curve bends downward due to the negative value of the element stress (sigy).

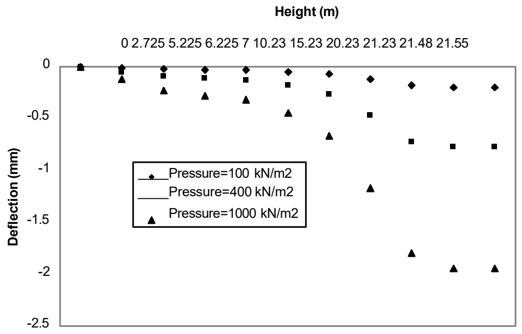


Fig.7 Variation of Deflection with Height

Fig.7 shows the variation of settlement. The settlement is maximum at top and decreases with depth. The settlement variation is similar for all pressures. With increase in pressure the settlement increases from top to bottom. The value of settlement at any depth is more for high pressure than the low pressure.

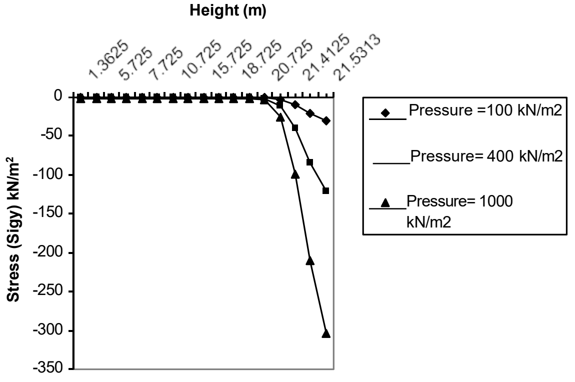


Fig.8 Variation of Element Stress (Sigy) with Height

Fig.8 shows the variation of element stress (sigy) with height for various pressures. The element stress is more at initial height and then decreases with decrease in height. This decrease is up to height 20.725m. The variation in element stress is similar for all pressure. The value of element stress (sigy) at a height is more at high pressure than at low pressure.

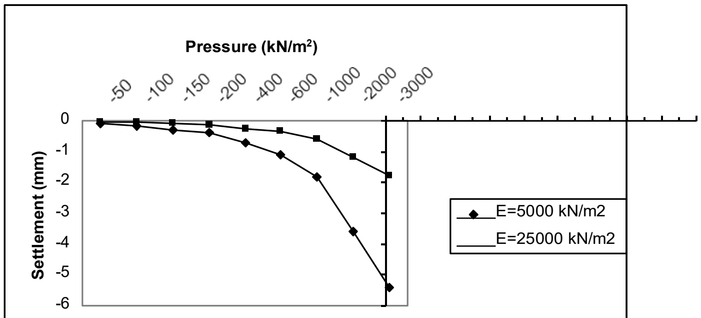


Fig.9 Pressure vs Deflection Curve

Fig.9 shows the pressure vs settlement curves for two moduli of sub grade. The pressure settlement curves are nonlinear for both the cases. At a pressure the settlement is more for sub grade with lower modulus of elasticity than the sub grade with higher modulus of elasticity. Hence the sub grade with higher modulus of elasticity is preferred.

Fig.10 shows the variation of settlement with height for two moduli of elasticity. The settlement is maximum in the top portion and then decreases with decrease in height. For a particular height the settlement is more for a sub grade having lower modulus of elasticity than for sub grade having higher modulus of elasticity. The variation of settlement with decreasing height is nonlinear for both sub grades having different modului of elasticity.

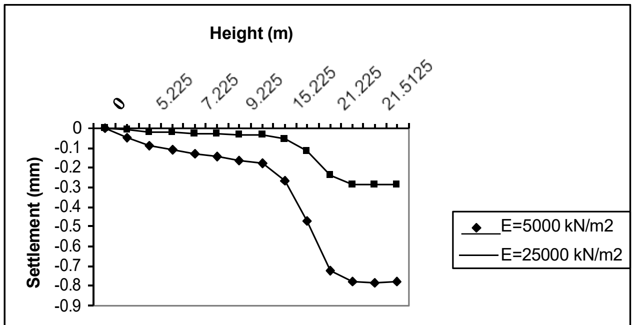


Fig.10 Variation of Settlement with Depth

V. CONCLUSIONS

Pressure vs settlement curve is linear for small range of pressure ie up to 200 kN/m^2. Then it becomes nonlinear. This nonlinearity is more at high pressure. The pressure vs nodal stress curve follows the similar trend. The curve is in the upward direction. This is because the pressure is negative and stress positive. The pressure vs element stress (sigx) has similar curve as the pressure vs nodal stress curve. The pressure vs element stress (sigy) curve is similar to the pressure vs settlement (deflection) curve. The deflection is maximum at the top and then decreases with decreasing height. For same height the value of deflection (settlement) is more for higher pressure than for lower pressure. The variation of deflection (settlement) with decreasing height is nonlinear. The element stress is maximum in the top element and then it decreases in elements with decreasing height. At the same pressure the settlement is more in sub grade with lower elastic modulus than sub grade with high elastic modulus. The variation of settlement with decreasing height is nonlinear. At any height the settlement is more in soil with lower elastic modulus than in soil with higher elastic modulus.

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