The Experimental Study on Flexible Pavement on Plastic Silt by Non Linear F.E.M

[1]Sanjeev Gill, [2] Dr.D.K.Maharaj[3] , Dr.Rajiv kumar
[1]Ph.D. Scholar Shri Venkateswara University, Gajraula,
Uttar Pradesh, INDIA

Abstract: **In this research axisymmetric finite element method has been carried out to study of flexible pavement on plastic silt. The asphalt concrete and the base course have been idealized as elastic material. The subgrade has been idealized as nonlinear material by Drucker-Prager yield criterion. The asphalt concrete, base course and subgrade have been discretized as four nodded isoperimetric finite elements. 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 have been obtained. Also the variation of nodal displacement and element stress with decreasing height has been obtained. The pressure vs settlement curve; pressure vs nodal stress curve; pressure vs element stress curve are nonlinear. For all pressure the element stress (Sigy) is more than the element stress (Sigx). For any pressure the nodal deflection is maximum at top and minimum at bottom. Upto certain height the element stress is almost zero for all pressures. After that height the element stress increases with increase in height. The element stress increases with increase in pressure. For any pressure, the nodal deflection is more for lower subgrade modulus than the higher subgrde modulus. The nonlinearity is more in subgrade with lower modulus than in subgrade with higher modulus. For a particular elastic modulus of subgrade the element stress reduces with increase in pavement thickness.**

Keywords: **subgrade modulus Axisymmetric, finite element, element stress, nodal deflection**.

I. INTRODUCTION

Pavements are those which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads. The flexible pavement layers reflect the deformation of the lower layers on to the surface of the layer. Thus if the lower layer of the pavement or soil subgrade is undulated, the flexible pavement surface also gets undulated. The flexible pavements consist of asphalt concrete surface built over a base course and they rest on subgrade. The design of a Flexible pavement is based on the principle that a surface load is dissipated by carrying it deep into the subgrade. Some of the important design Methods for flexible pavements is Group Index Method, California Bearing Ratio Method.

Flexible pavements with asphalt concrete surface courses are used all around the world. The various layers of the flexible pavement structure have different deformation and strength characteristics. Pavement foundation geomaterials, i.e., the fine-grained soils (plastic silt) in the subgrade, exhibit nonlinear behavior. Finite element programs that analyze pavement structures have capability of analyzing nonlinear behavior of subgrade.

II.LITERATURE REVIEW

Rouphail(1985) presents the formulation of a mixed integer linear programming model to determine a minimum cost flexible pavement design. The model identifies the number, type, and thicknesses of paving materials required to meet the structural strength requirements of the pavement system at a minimum initial cost to the highway agency. Policies regarding the designation of minimum and maximum layer thicknesses are accommodated in the model formulation, including the establishment of variable minimum and maximum thicknesses based on the underlying material. In addition, the structural layer coefficients are allowed to vary with the pavement configuration, including the number and type of constituent layers. The model can be used to calculate a marginal cost function which has applications in the selection of cost effective measures designed to strengthen the structural pavement capacity.

Roberts (1987) includes the results of an analytical study of the effects of automobile tire loads on thin asphalt pavements over granular bases. Two different methods of calculating the tire contact pressure are used and the strains induced in the pavement structure are evaluated. The uniform pressure tire model assumes that the tire contact pressure is equal to the tire inflation pressure. The Tielking tire model is a finite element computer program that models and calculates the contact pressure distribution by using the tire carcass properties and the tire load. The contact pressure distributions are used in ILLIPAVE to calculate the strains at various locations in a pavement having a surface of thickness ranging from 2.54 to 10.16 cm and moduli ranging from 345 to 5,516 MPa. A granular base 20.32 cm thick with two different moduli is over a subgrade soil with a modulus of 34.5 MPa. The results are analyzed and the findings indicate that automobile tire loads can produce high pavement strains for certain combinations of surface thickness moduli over weak bases. The best performance occurs when stiff bases are used.

According to **Baus and Fogg(1989),** a revised flexible pavement design equation has recently been published by the American Association of State Highway and Transportation Officials. The revised equation contains new input parameters: resilient modulus, *MR*, to characterize subgrade support; reliability, *R* to allow the designer to introduce the concept of risk analysis into the design process; and standard error, *So*, to represent variability in design input values. This paper summarizes the results of a significance study performed using the revised flexible pavement design equation. The study demonstrates the relative importance of design equation input parameters and provides insights into the relative change in required pavement structure thickness resulting from variations or errors in input parameter values. Study results show that variation in subgrade resilient modulus, *MR*, has the most pronounced effect on thickness structural number, *SN*. Variation in the predicted number of 18-kip equivalent single-axle loads, W_{18}, has a lesser effect, and variation in combined standard error, *So*, has a minimal effect on *Sn*. Selection of the highest values for design reliability, *R*, results in significant increases in *Sn*.

Jooste (2002) states that the Semi-Analytical Finite Element Method is an effective method for modeling the load response of structures in which the material properties and problem geometry do not change in one coordinate direction. The method offers considerable savings in computational requirements compared to a full three-dimensional finite element analysis. In this paper, the background to, and theoretical basis of the semi-analytical finite element method is presented. The application of the method to a pavement response evaluation is illustrated. It is shown that there is a good agreement between the results obtained with the theoretical solution and those obtained with the semi-analytical finite element method.

Hadi and Bodhinayake (2003) have 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.

Punmia et. al (2005) have reported stresses in homogeneous mass; elastic deformation under circular load and Burmister analysis for flexible pavement. Charts for vertical deflections have been developed. The design curves by Group Index Method and California Bearing Ratio Method have been developed. In Group Index Method, the curves are plotted between Group Index and thickness. In California Bearing Ratio Method curves are plotted between thickness of construction and California Bearing Ratio.

Subagio et.al (2005) discusses 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 designer can choose the best option.

Das (2008) discusses the reliability issues in bituminous pavement design, based on mechanistic-empirical-approach. Variability's 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 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.

According to Rahman et. al (2011), design of flexible pavement is largely based on empirical methods using layered elastic and two-dimensional finite element analysis. Currently a shift underway towards more mechanistic design techniques to minimize the limitations in determining stress, strain and displacement in pavement analysis. In this study, flexible pavement modeling is done using ABAQUS software in which model dimensions, element types and meshing strategies are taken by successive trial and error to achieve desired accuracy and convergence of the study.

Ameri et. al (2012) have used finite element method to analyses and design pavements. Finite element method is able to analyses 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.

Dilip & Gill et.al (2013) discuss 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 have been done by finite element method especially considering nonlinear behavior of subgrade. Very few literatures are reported for design charts of flexible pavements. Hence there is need for finite element analyses and development of design charts of flexible pavement especially considering nonlinear material behavior of subgrade.

III. FINITE ELEMENT ANALYSIS

Finite element analyses have been done by considering subgrade 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 nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure. The asphalt concrete as well as the base course have been idealized as linear elastic material. The asphalt concrete, base and the subgrade have been discretized by four noded isoparametric finite elements.

The total number of nodes considered = 345

Total number of element considered =308.

The horizontal domain considered= 20 times the radius of pressure.

The vertical domain considered = Approximately140 times the radius of pressure.

Bottom nodes have no translation.

The central nodes have only vertical translation.

The right side nodes also have only vertical translation.

The thickness of asphalt concrete considered=100 mm and 400 mm.

The thickness of base course considered = 450 mm.

Pressure varies from 100 to 3000 kN/m^2

Pressure acts at radius 150 mm.

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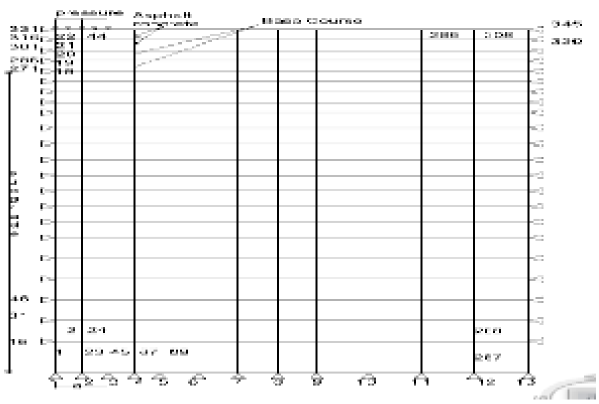
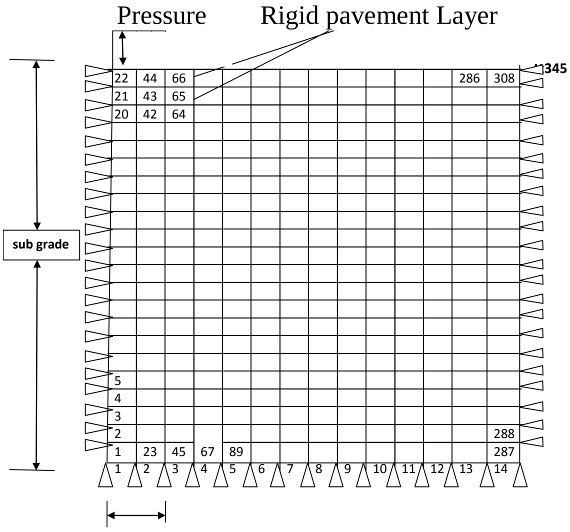


a= Radius of pressure =150mm (fig not scale)

Fig.1.(a) Finite Element Discretization for Flexible Pavement



a = Radius of pressure =150mm(fig not scale)

Fig.1.(b) Finite Element Discretization for Rigid Pavement

Material Properties

Elastic Modulus of Asphalt Concrete = 2759000 kN/m^2, Poisson's Ratio=0.35
Elastic Modulus of Base Course = 207000 kN/m^2, Poisson's Ratio=0.40
Properties of Subgrade (Plastic Silt):
(1)Modulus of elasticity=5000 kN/m^2, Poisson's Ratio=0.30, Cohesion (C)= 7.5 kN/m^2
$\varphi = \psi = 27^0$
(2) Modulus of elasticity=15000 kN/m^2,Poisson's Ratio=0.35, Cohesion (C)=15 kN/m^2
$\varphi = \psi = 31$

IV.RESULTS AND DISCUSSIONS

Fig.2 shows the pressure vs nodal deflection curve for flexible pavements for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2. The nodal deflection is considered for node 271. The initial portion of the curve is linear. From pressure equal to 200 kN/m^2 the curve becomes nonlinear. The curve becomes more nonlinear at high pressure.

Fig.3 shows the pressure vs nodal stress (sigx) curve for pavement thickness equal to 400 mm and modulus of subgrade equal to 5000 kN/m^2. The initial portion of curve is linear upto pressure 200 kN/m^2 and then it becomes nonlinear. The nonlinearity of the curve increases with increase in pressure. The nodal stress is considered for node 271.

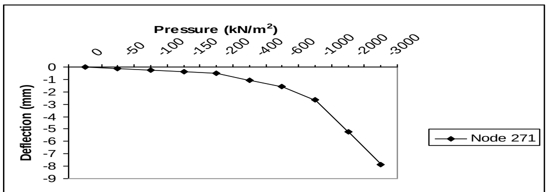


Fig.2 Pressure vs Nodal Deflection Curve, Thickness=400 mm, Es=5000 kN/m^2

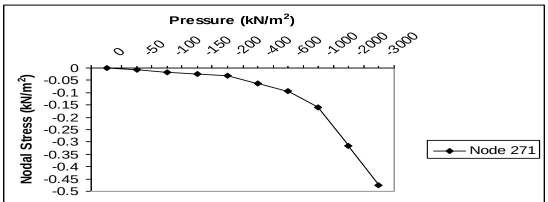


Fig.3 Pressure vs Nodal Stress (Sigx) Curve , Thickness =400 mm, Es=5000 kN/m^2

Fig.4 shows the pressure vs nodal stress (Sigy) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2. The nature of the curve is similar to Fig.3 i.e the initial portion of the curve is linear and then it becomes nonlinear and maximum nonlinearity is seen at high pressure. Sigy is the nodal stress in y direction.

Fig.5 shows the pressure vs element stress (Sigx) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2. The nature of the curve is similar to the nodal stress curve. The initial portion of the curve is linear and then it becomes nonlinear.

Fig.6 shows the pressure vs element stress (Sigy) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2. The nature of the curve is similar to Fig.5. Comparison of Fig.5 and Fig.6 shows that for all pressure the element stress (Sigy) is more than the element stress (Sigx

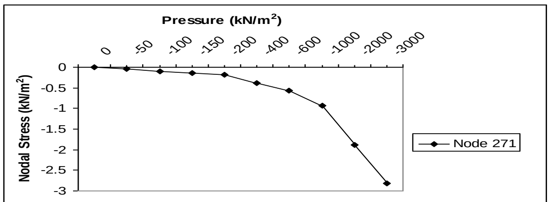


Fig.4 Pressure vs Nodal Stress (Sigy) Curve , Thickness=400 mm, Es=5000 kN/m^2

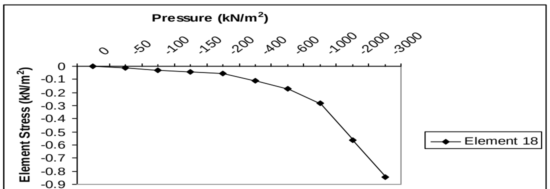


Fig.5 Pressure vs Element Stress (SigX) Curve, Thickness=400 mm, Es=5000 kN/m^2

Fig.7 shows the variation of nodal deflection with decreasing height for pressure 100 kN/m^2, 400 kN/m^2 and 1000 kN/m^2 for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2. For any pressure the nodal deflection with decreasing height decreases. It is maximum at top and minimum at bottom. When compared with pressure, the nodal deflection at any height is maximum for pressure 1000 kN/m^2 and minimum for pressure 100 kN/m^2. The nodal deflection for pressure 400 kN/m^2 is in between the nodal deflections for pressure 100 kN/m^2 and pressure 1000 kN/m^2.

Fig.8 shows the variation of element stress with increasing height for pavement thickness equal to 400 mm and subgrade modulus equal to 5000 kN/m^2 for pressures 100 , 400 and 1000 kN/m^2. Upto height 21 m the element stress is almost zero for all pressures. After 21 m height the element stress increases with increase in height. The element stress increases with increase in pressure. The element stress is maximum for highest pressure and minimum for lowest pressure.

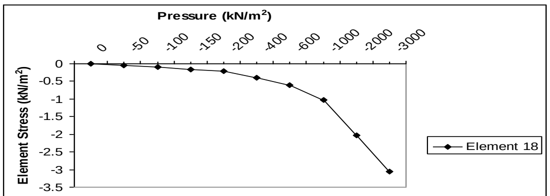


Fig.6 Pressure vs Element Stress (Sigy) Curve, Thickness=400 mm, Es=5000 kN/m^2

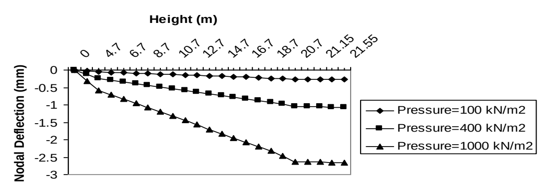


Fig.7 Variation of Nodal Deflection with Depth Thickness=400 mm Es=5000 kN/m^2

Fig.9 shows the pressure vs nodal deflection curve for pavement thickness 400 mm for two subgrade moduli of soil. For any pressure, the nodal deflection is more for lower subgrade modulus than the higher subgrde modulus. The nature for both the curves is nonlinear. The nonlinearity is more in subgrade with lower modulus than in subgrade with higher modulus.

Fig.10 shows the variation of nodal deflection with increasing height for two subgrades with modulus 5000 kN/m^2 and 15000 kN/m^2. The nodal deflection increases with increasing height. For any height the nodal deflection is more in subgrade with lower modulus than the soil with higher modulus.

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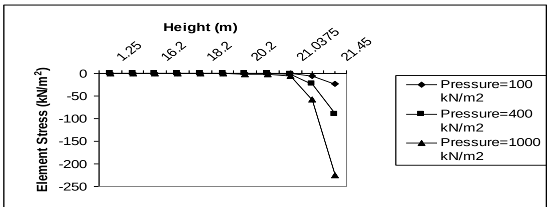

Fig.8 Variation of Element Stress (Sigy) with Depth, Thickness=400 mm, Es=5000 kN/m^2

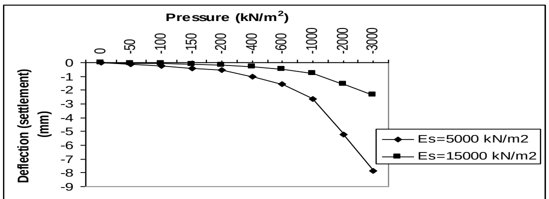

Fig.9 Pressure vs Nodal Deflection Curve,Thickness=400 mm

Fig.11 shows the variation of pressure vs nodal deflection curve for two pavement thickness equal to 100 mm and 400 mm and subgrade modulus equal to 5000 kN/m^2. The nature of both the curves is nonlinear. At any pressure the nodal deflection is more for pavement with thickness 100 mm than the pavement with thickness 400 mm.

Fig.12 shows the pressure vs element stress curve for pavement thickness equal to 100 mm and 400 mm for subgrade modulus equal to 5000 kN/m^2. For any pressure the element stress is more in pavement of thickness 100 mm than pavement with thickness equal to 400 mm. This is because the pavement with higher thickness (400 mm) takes more load than the pavement with lower thickness (100 mm).

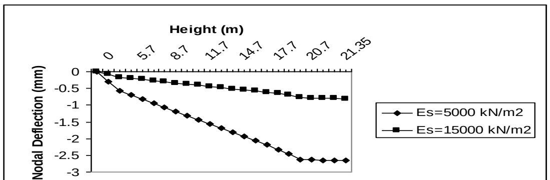

Fig.10 Variation of Nodal Deflection with Depth, Thickness=400 mm, Pressure=1000 kN/m^2

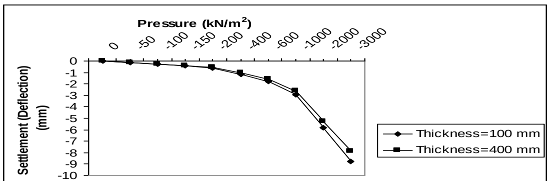

Fig.11 Pressure vs Nodal Deflection Curve, Es=5000 kN/m^2

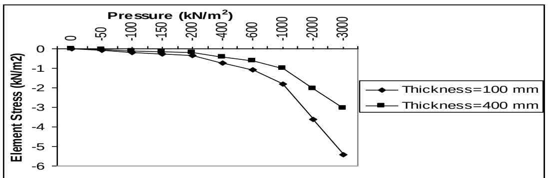

Fig.12 Pressure vs Element Stress(Sigy) Curve, Es=5000 kN/m^2

Fig.17 shows the design chart plotted between thickness of pavement and element stress for various elastic moduli of subgrade for a particular pressure. The thickness of pavement (asphalt concrete) varies from 100 mm to 400 mm; the elastic moduli of subgrade varies from 5000 kN/m^2 to 20000 kN/m^2 and the pressure is 100 kN/m^2. It can be seen that for a particular elastic modulus of soil the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in elastic modulus of soil. The design chart has three parameters. For any two known parameters, the third parameter can be obtained from the design chart. Fig.18 to Fig.23 are similar design charts as for Fig.17. In these design charts, the reduction of element stress with increase in thickness is predominant at higher pressure.

V.CONCLUSIONS

The load vs nodal deflection curve and the pressure vs nodal stress curve are linear upto pressure 200 kN/m^2 and then they become nonlinear. The curve becomes more nonlinear at high pressure. The pressure vs element stress curve is initially linear and then it becomes nonlinear. For all pressure the element stress (Sigy) is more than the element stress (Sigx). For any pressure the nodal deflection with decreasing height decreases. It is maximum at top and minimum at bottom. When compared with pressure, the nodal deflection at any height is maximum for pressure 1000 kN/m^2 and minimum for pressure 100 kN/m^2. Upto height 21 m the element stress is almost zero for all pressures. After 21 m height the element stress increases with increase in height. The element stress increases with increase in pressure. The element stress is maximum for highest pressure and minimum for lowest pressure. For any pressure, the nodal deflection is more for lower subgrade modulus than the higher subgrade modulus. The nonlinearity is more in subgrade with lower modulus than in subgrade with higher modulus. The nodal deflection increases with increasing height. For any height the nodal deflection is more in subgrade with lower modulus than the soil with higher modulus.

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