Design of Development for Bitumen Pavement on Sub Grade Plastic Silt Behavior by Finite Element Method

[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 paper axisymmetric finite element analysis has been done for bitumen pavements by varying parameters thickness of pavement, pressure and elastic modulus of subgrade to develop design charts. The asphalt concrete pavement and base course has been idealized as linear elastic material and the subgrade behavior (plastic silt) has been idealized as nonlinear material. The nonlinear behavior of the subgrade behavior (plastic silt) has been idealized by Drucker-Prager yield criterion. The asphalt concrete pavement, base course and subgrade have been discretized by four nodded isoperimetric finite elements. Four types of design charts have been developed. First type of design chart has been plotted between thickness of pavement and nodal deflections for various pressures for a particular elastic modulus of subgrade. Second type of design chart has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of subgrade. The third type of design chart has been plotted between thickness of pavement and nodal deflections for various elastic moduli of subgrade for a particular pressure. Fourth type of design chart has been plotted between thickness of pavement and element stress for various elastic moduli of subgrade for a particular pressure. Each of the design charts has three parameters. For any two parameters known, the third parameter can be obtained from the design chart. For any pressure the nodal deflection reduces with increase in pavement thickness. This reduction of nodal deflection increases with increase in pressure and is predominant at highest pressure. For any pressure the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in pressure. For any elastic modulus of soil the nodal deflection reduces with increase in pavement thickness. For a particular elastic modulus of subgrade the element stress reduces with increase in pavement thickness.**

Keywords: **Axisymmetric Design, finite element, nodal deflection, element stress.**

I. INTRODUCTION

The bituuumen pavements are built with number of layers. The pavements consist of asphalt concrete pavement built over a base course and the base course rests on subgrade. In the design process, it is to be ensured that under the application of load none of the layers is overstressed. This means that at any instance no section of the pavement structure is subjected to excessive deformation to form a localized depression or settlement. In case of flexible pavement, a surface load is dissipated by carrying it deep into the subgrade through asphalt concrete pavement and base course. Commonly used design methods for flexible pavements are Group Index Method, California Bearing Ratio Method, North Dakota Method; Burmister's Design Method and U.S. Navy Plate Bearing Test Method Flexible pavements with asphalt concrete surface course, base course and subgrade are used all around the world. The various layers of the flexible pavement structure become difficult to be analyzed in pavement engineering. Finite element method can easily solve such type of problems. Design charts provide readymade solution to flexible pavement. In the design chart produced the unknown parameter can be obtained from the known parameters

II. LITERATURE REVIEW

Khan(1998) describes the Group Index Method and California Bearing Ratio Method for design of flexible pavements. In Group Index Method the thickness is obtained by first determining the Group Index of soil. The curves are plotted between Group Index of subgrade and thickness for various traffic conditions. In California Bearing Ratio Method, the curves are plotted between California Bearing Ratio Percent and depth of construction.

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.

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. Variabilities 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.

Subagio et.al (2005) discuss 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.

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 analyse 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 tecniques 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 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 specially considering nonlinear behaviour of subgrade. Very fiew 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 specially considering nonlinear material behaviour of subgrade.

III.FINITE ELEMENT ANALYSIS

In this research paper axisymmetric finite element analyses have been done by considering subgrade soil (plastic silt) as a nonlinear material. The material nonlinerity has been considered by idealizing the soil by Drucker-Prager yield criterion. The asphalt concrete as well as the base course have been idealized as linear elastic material. The nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure. Fig.1 shows the finite element discretization considered in this analysis. The asphalt concrete, base and the subgrade have been discretized by four nodded isoperimetric finite elements. The total number of nodes = 345 ,total number of element =308, the horizontal domain = 20 times the radius of pressure, the vertical domain = Approximately140 times the radius of pressure, bottom nodes have no degree of freedom, the central nodes have only vertical degree of freedom, the right side nodes also have only vertical degree of freedom. The thickness of asphalt concrete considered=100,200,300 & 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 from axis of rotation.

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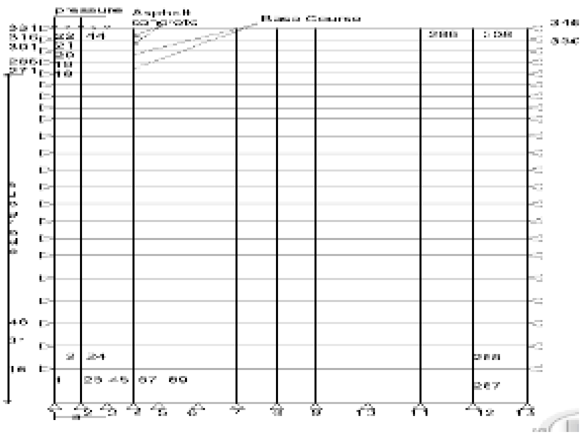
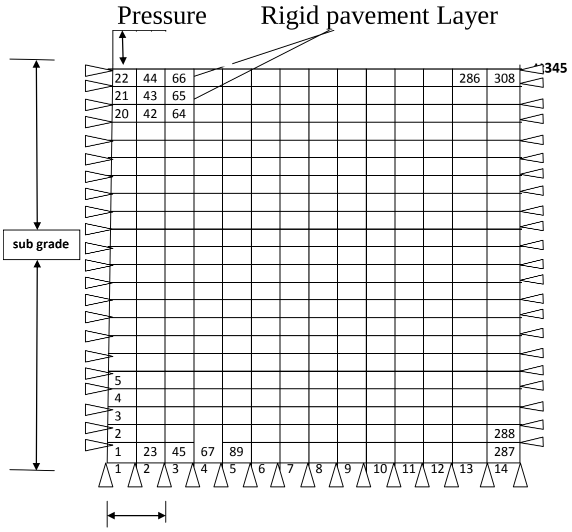


a= Radius of pressure =150mm (fig not scale)

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=10000 kN/m^2, Poisson's ratio=0.30, Cohesion= 10 kN/m^2
$\varphi = \psi = 29^0$
(3) Modulus of elasticity=15000 kN/m^2,Poisson's ratio=0.35, Cohesion (C)=15 kN/m^2
$\varphi = \psi = 31^0$
(4)Modulus of elasticity=20000 kN/m^2, Poisson's ratio=0.35, Cohesion(C)=20 kN/m^2
$\varphi = \psi = 33^0$

IV.RESULTS AND DISCUSSIONS

Fig.2 shows the design chart plotted between thickness of pavement and nodal deflections for different pressures for a particular elastic modulus of plastic silt. The thickness of pavement varies from 100 mm to 400 mm; the pressure varies from 100 kN/m^2 to 3000 kN/m^2 and the elastic modulus of plastic silt is 5000 kN/m^2. It can be seen that for any pressure the nodal deflection reduces with increase in pavement thickness. This reduction of nodal deflection increases with increase in pressure and is predominant at highest pressure. The design chart has three parameters. For any two parameters known, the third parameter can be obtained from the design chart. Fig.3, Fig.4 and Fig.5 are similar design charts as for Fig.2.

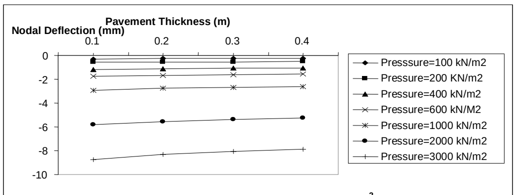


Fig.2 Design on, Plastic Silt, Es=5000 kN/m^2

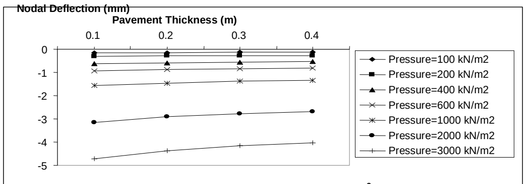


Fig.3 Design on Plastic Silt, Es=10000 kN/m^2

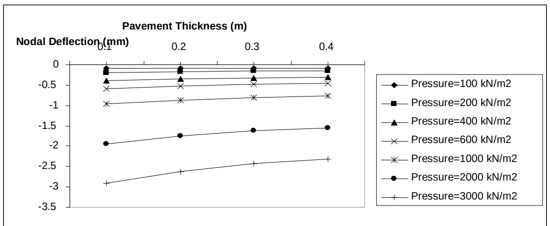


Fig.4 Design on Plastic Silt, Es=15000 kN/m^2

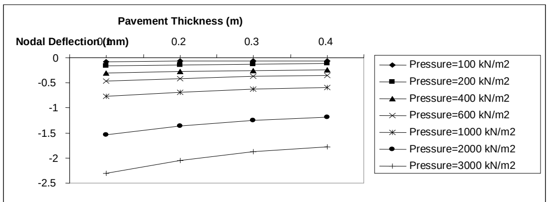


Fig.5 Design on Plastic Silt, Es=20000 kN/m^2

Fig.6 shows the design chart plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of plastic silt. The thickness of pavement varies from 100 mm to 400 mm; the pressure varies from 100 kN/m^2 to 3000 kN/m^2 and the elastic modulus of plastic silt is 5000 kN/m^2. It can be seen that for any pressure the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in pressure. The design chart has three parameters. For any two parameters known, the third parameter can be obtained from the design chart. Fig.7, Fig.8 and Fig.9 are similar design charts as for Fig.6.

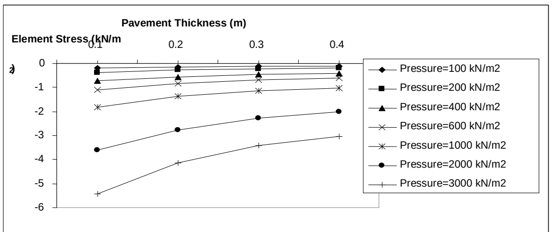


Fig.6 Design on, Plastic Silt, Es=5000 kN/m^2

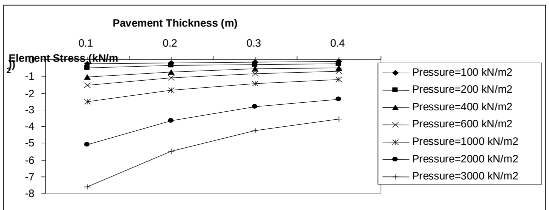


Fig.7 Design on Plastic Silt, E$_s$=10000 kN/m^2

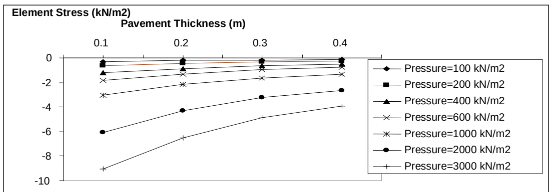


Fig.8 Design on Plastic Silt, Es=15000 kN/m^2

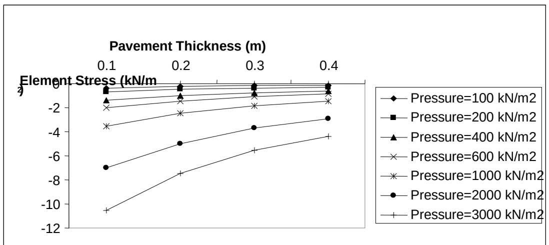


Fig.9 Design on Plastic Silt, Es=20000 kN/m^2

Fig.10 shows the design chart plotted between thickness of pavement and nodal deflections for various elastic moduli of subgrade for a particular pressure. The thickness of pavement varies from 100 mm to 400 mm; the elastic moduli of subgrade vary from 5000 kN/m^2 to 20000 kN/m^2 and the pressure is 100 kN/m^2. It can be seen that for any elastic modulus of soil the nodal deflection reduces with increase in pavement thickness. This reduction of nodal deflection increases with decrease in elastic modulus of plastic silt and is predominant at lowest soil modulus. The design chart has three parameters. For any two parameters, the third parameter can be obtained from the design chart. Fig.10 to Fig.16 is similar design charts as for Fig.10.

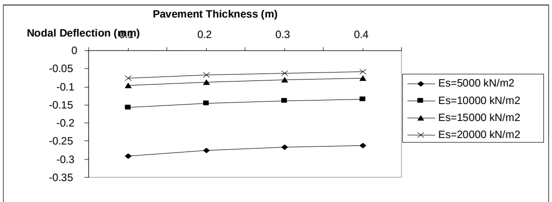


Fig.10 Design on Plastic Silt, Pressure=100 kN/m^2

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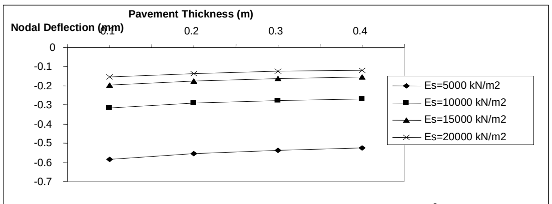

Fig.11 Design on Plastic Silt, Pressure=200 kN/m ^{2}

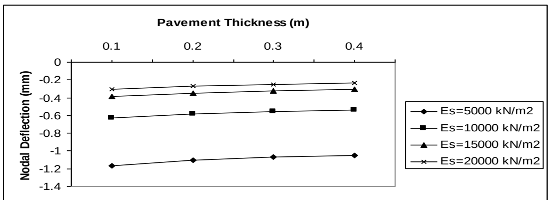

Fig.12 Design Chart, Plastic Silt, Pressure=400 kN/m ^{2}

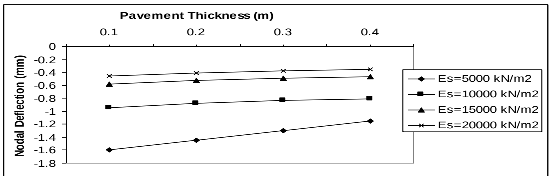

Fig.13 Design Chart, Plastic Silt, Pressure=600 kN/m ^{2}

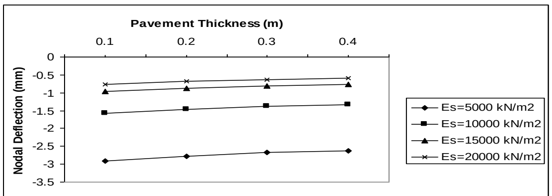

Fig.14 Design Chart, Plastic Silt, Pressure=1000 kN/m ^{2}

Fig.11 shows the pressure vs element stress curve for flexible and rigid pavements for pavement thickness equal to 100 mm and base course equal to 450 mm. Both the pavements have same element stress upto pressure 200 kN/m ^{2}. Above pressure 200 kN/m ^{2} the flexible pavement has more element stress than the rigid pavement and is maximum at maximum pressure. However this increase is comparatively small due to increase in base course thickness. Fig.12 shows the variation of nodal deflection with decreasing height. Upto height equal to 19 m both pavements have same deflection. Above height 19 m the flexible pavement has more deflection than rigid pavement. This is maximum at maximum height.

Fig.13 shows the variation of element stress with decreasing height. Upto height equal to 20 m both pavements have same element stress. Above height 20 m the flexible pavement has more element stress

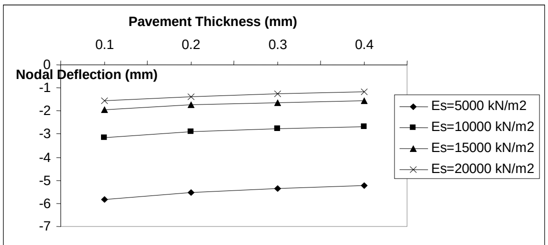

Fig.15 Design on , Plastic Silt, Pressure=2000 kN/m ^{2}

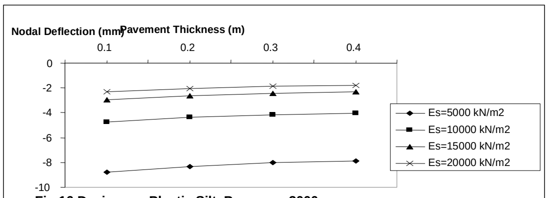

Fig.16 Design on Plastic Silt, Pressure=3000 kN/m ^{2}

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 vary 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.

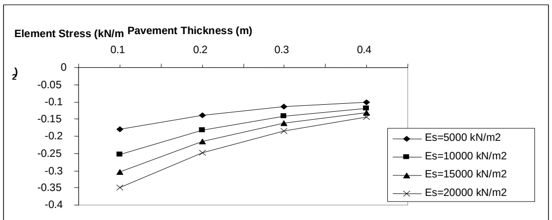

Fig.17 Design on Plastic Silt. Pressure=100 kN/m ^{2}

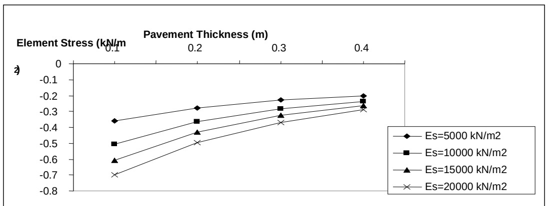

Fig.18 Design on , Plastic Silt, Pressure=200 kN/m ^{2}

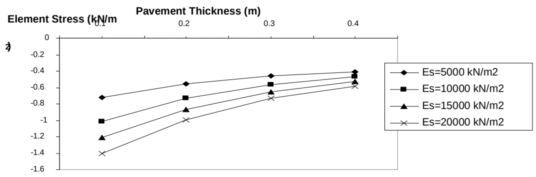

Fig.19 Design on Plastic Silt, Pressure=400 kN/m^2

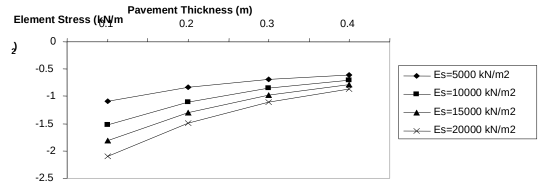

Fig.20 Design on Plastic Silt, Pressure=600 kN/m^2

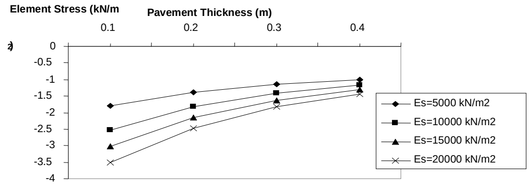

Fig.21 Design on Plastic Silt, Pressure=1000 kN/m^2

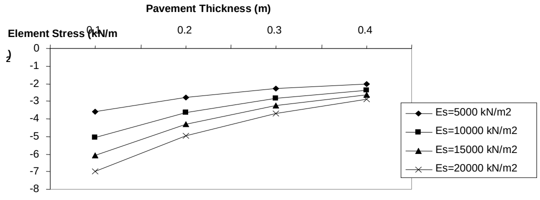

Fig.22 Design on , Plastic Silt, Pressure=2000 kN/m^2

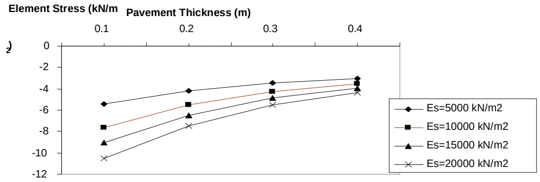

Fig.23 Design on , Plastic Silt, Pressure=3000 kN/m^2

V.CONCLUSIONS

The design has three parameters. For two parameters known, the third parameter can be obtained from the design. For any pressure the nodal deflection reduces with increase in pavement thickness. This reduction of nodal deflection increases with increase in pressure and is predominant at highest pressure. For any pressure the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in pressure. For any elastic modulus of subgrade the nodal deflection reduces with increase in pavement thickness. This reduction of nodal deflection increases with decrease in elastic modulus of plastic silt (subgrade) and is predominant at lowest modulus of subgrade. For a particular elastic modulus of soil the element stress reduces with increase in pavement thickness.

REFERENCES

[1] Arora, K.R. (2003) Soil mechanics and Foundation Engineering, Standard Publishers Distributors, Delhi

[2] Ameri, M., Salehabadi, E.G., Nejad, F.M. and Rostami, T. (2012) Assesment of Analytical Techniques of Flexible Pavements by Finite Element Method and Theory of Multi-Layer System, Journal Basic Applied Science Research, Vol.2, No.11, pp.11743-11748.

[3] Das, A. (2007) Pavement Design with Central Plant Hot-Mix Recycled Asphalt Mixes, Construction and Building Materials, Vol.21, No.5, pp.928-936

[4]Das, A.(2008) Reliability Considerations of Bituminous Pavement Design by Mechanistic-Empirical Approach, the International Journal of Pavement Engineering, Vol.9, No.1, pp. 19-31.

[5] Dilip, D., Ravi, P. and Babu,G. (2013) System Reliability Analysis of Flexible Pavements, Journal Transportation Engineering, Vol.139, No.10, pp. 1001-1009.

[6] Hadi, M.N.S. and Arfiadi (2001) Optimum Rigid Pavement Design by Genetic Algorithms, Computers and Structures, Vol.1, No.5

[7] Huang, Y.H. and Deng, X.J.(1983) Finite Element Analysis of Jointed Concrete Pavements, Journal of Transportation Engineering, Vol.109, No.5,pp.689-705.

[8] Jain, S., Joshi,Y.P., Golia, S.S. (2013) Design of Rigid and Flexible Pavements by Various Methods and Their Cost Analysis of Each Method, International Journal of Engineering Research and Applications, Vol.3, No.5 pp.119-123.

[9] Krauthammer, T. and Western, K.L.(1988) Joint Shear Transfer Effects on Pavement Behaviour, Journal of Transportation Engineering, Vol.114, No.5, pp.505-529.

[10] Long,B.and Shatnawi, S.(2011) Structural Evaluation of Rigid Pavement Sections, Road Materials and Pavement Design, Vol.1, No.1, pp.97-117

[11] Subagio, B. Cahyanto, H., Rahman, A. and Mardiyah, S.(2005) Multilayer Pavement Structural Analysis Using Method of Equivalent Thickness, Case Study: Jakarta-Cikampeck Toll Road , Journal of the Eastern Asia Society for Transportation Studies, Vol.6,pp.55-65.

[12] Tabatabaie,A.M. and Barenberg (1980) Structural Analysis of Concrete Pavements, Transportation Engineering Journal, ASCE, Vol.106,No.5,pp.832-849.

[13] Tarefder, R., Saha, N. and Stormont, J.(2010) Evaluation of Subgrade Strength and Pavement Designs for Reliability, Journal Transportation Engineering, Vol.136, No.4, pp. 379-391.

[14] Tyabji, S.D.and Colley, B.E.(1986) Analysis of Jointed Concrete Pavements, Technical Report FHWS-RD-86-041, FHWA.

[15] Khan, I.H.(1998) A Textbook of Geotechnical Engineering, Pentice Hall of India Private Limited, New Delhi.

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