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Development of Design Chart for Flexible Pavement By Finite Element Method

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Abstract:- Axisymmetric finite element analysis has been done by varying different parameters to develop design charts. The parameters varied are thickness of pavement, pressure and elastic modulus of subgrade. The pavement and base course has been idealized as linear elastic material while the subgrade has been idealized as nonlinear material by Drucker-Prager yield criterion. The pavement, base course and soil have been discretized by four noded isoparametric finite elements. First type of design chart has been plotted between thickness of pavement and nodal deflections for various pressures for a particular elastic modulus of soil. Second type of design chart has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of soil.

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 two known parameters, the third parameters can be obtained. From the design charts developed, the effect of thickness, elastic modulus of soil and pressure on nodal deflection and element stress has been studied. For a particular pressure the nodal deflection (settlement) reduces with increase in pavement thickness and is predominant at higher pressure. Similarly for a particular pressure the element stress reduces with increase in pavement thickness. For a particular elastic modulus of soil nodal deflection reduces with increase in pavement thickness. This reduction of settlement increases with decrease in elastic modulus of soil. 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 subgrade.

Keywords: Flexible pavement, subgrade, design chart, finite element method, moduli of subgrade.

INTRODUCTION

The flexible pavements consist of wearing surface built over a base course and they rest on compacted subgrade. 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, Burmister's 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. Finite element method is a versatile tool which can easily solve such type of problems. Design charts provide ready made solution to flexible pavement. In the design chart produced the unknown parameter can be obtained from the known parameters. The design chart can be obtained from the detailed finite element analysis by varying parameters like thickness of pavement, elastic modulus of soil and pressure on pavement. From the results of finite element analysis the design charts can be obtained between nodal deflection or/and element stress and thickness of pavement for various pressure for a particular subgrade. Also the design charts can be obtained between nodal deflection or/and element stress and pavement thickness for various soil moduli for a particular pressure.

LITERATURE REVIEW

Helwany et.al (1998) 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.

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 donot 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.

Arora (2003) have reported various methods for design of flexible pavements. These various methods are Group Index Method, CBR Method, California Resistance Value Method and Mcleod Method. In the Group Index Method, the thickness of base and surfacing is related to the volume of traffic. In CBR Method the curves are plotted between CBR and pavement thickness for light, medium and heavy traffic. California Resistance Value Method uses California Resistance value, called R-value. In Mcleod Method curves are plotted between depth of construction and CBR for traffic conditions

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) 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.

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.

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) present that reliability is an important factor in flexible pavement design to consider the variability associated with the design inputs. In this paper, subgrade 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 subgrade 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.

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 that traditionally being followed and examine the "Design of rigid and flexible pavements by various methods and their cost analysis by each method". 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) 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.

FINITE ELEMENT ANALYSIS

In this research axisymmetric finite element analyses have been done. The asphalt concrete and the base course have been idealized as elastic material. The subgrade has been idealized as a nonlinear material. The material nonlinerity has been considered by idealizing the soil by Drucker-Prager yield criterion. The nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure. Fig.1 shows the finite element discretization considered in the finite element analysis. The asphalt concrete, base course and the subgrade have been discretized by four noded isoparametric finite elements. The total number of elements considered are 308 and the total number of nodes considered are 345. 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 translations, the central nodes have only vertical translation and the right side nodes also have only vertical translation. The thickness of asphalt concrete considered are 100,200,300 and 400 mm. The thickness of base course considered is 450 mm and has been kept the same for various thickness of asphalt concrete. Pressure acts at radius 150 mm.

RESULTS AND DISCUSSIONS

Fig.2 shows the design chart which has been plotted between thickness of pavement and nodal deflections for various pressures for a particular elastic modulus of soil. The thickness of pavement (asphalt concrete) 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 soil is 5000 kN/m^2. It can be seen that for a particular pressure the nodal deflection (settlement) reduces with increase in pavement thickness. This reduction of settlement 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.

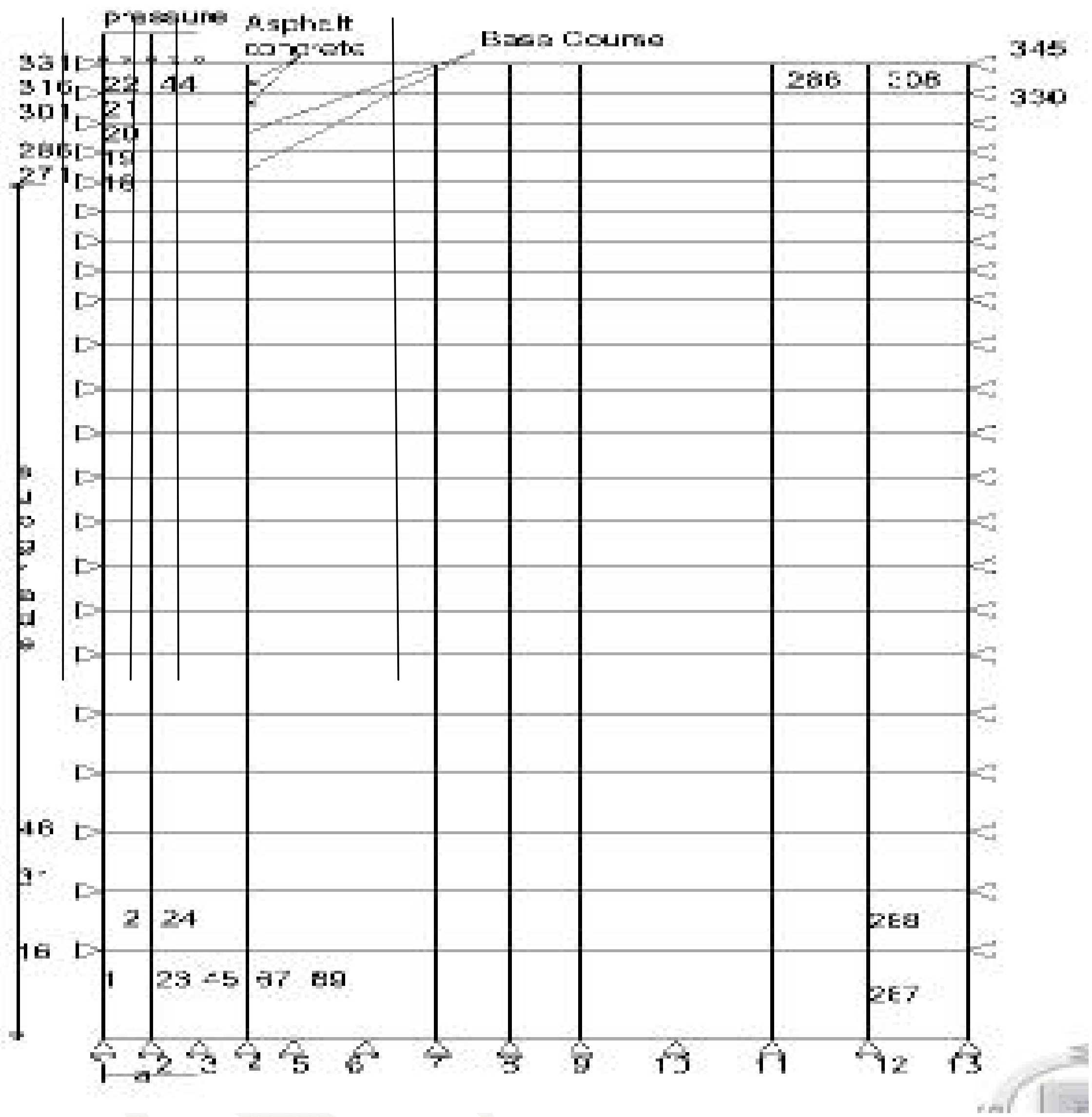

Fig.1 Finite Element Discretization for Flexible Pavement

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

Elastic Modulus	Poisson's Ratio	Cohesion
1. 5000 kN/m^2	0.45	25 kN/m^2
2. 15000 kN/m^2	0.45	30 kN/m^2
3. 25000 kN/m^2	0.45	40 kN/m^2
4. 50000 kN/m^2	0.45	50 kN/m^2

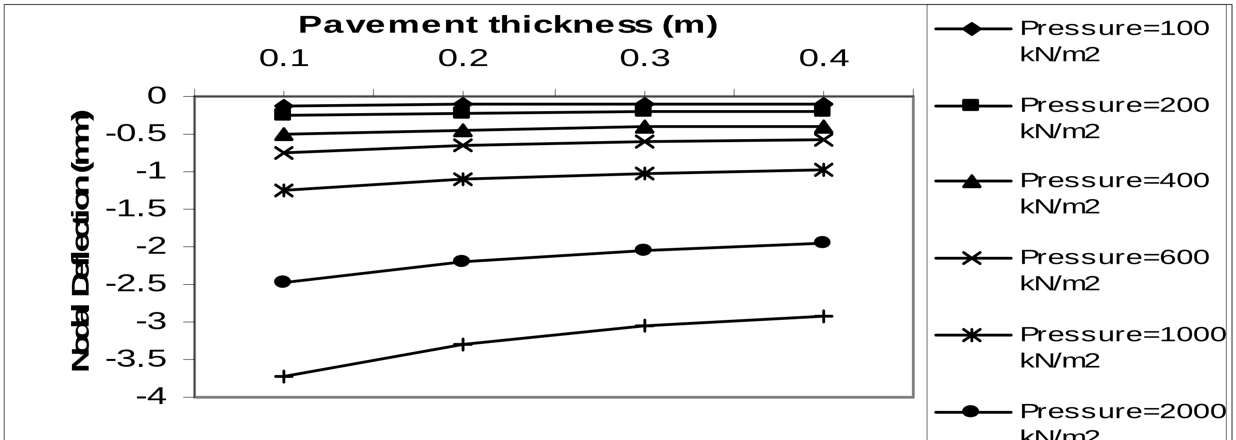

Fig.2 Design Chart (Es=5000 kN/m^2)

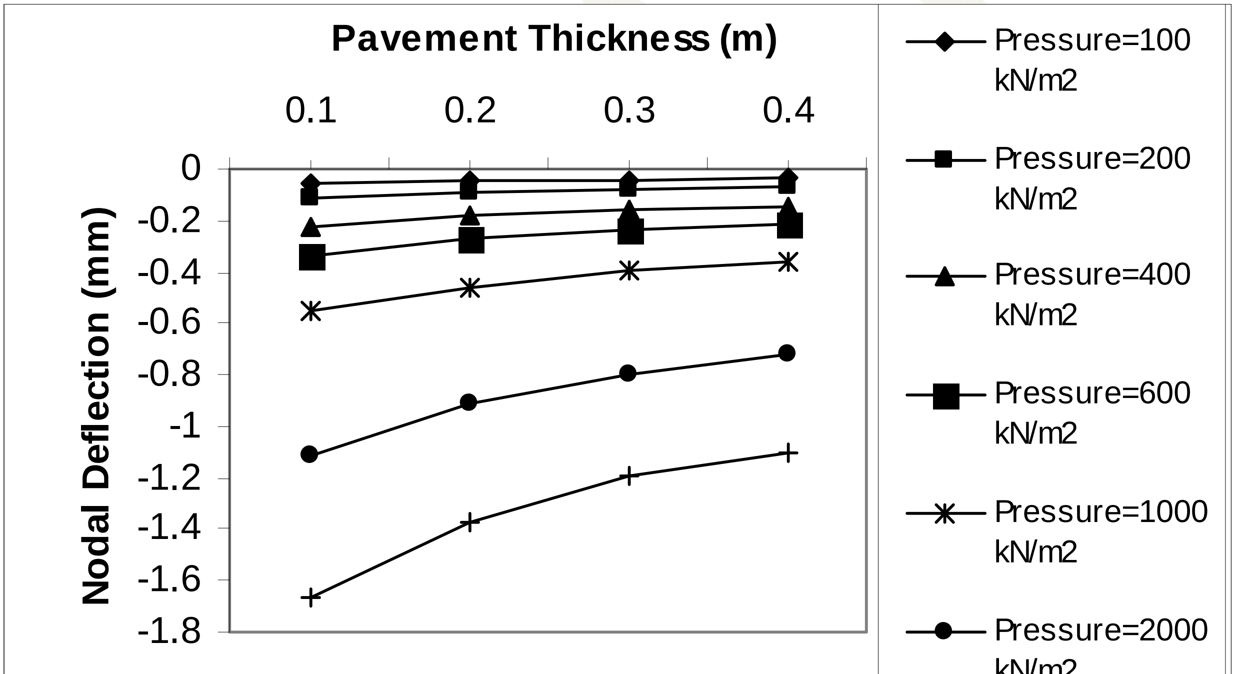

Fig.3 Design Chart (Es=15000 kN/m^2)

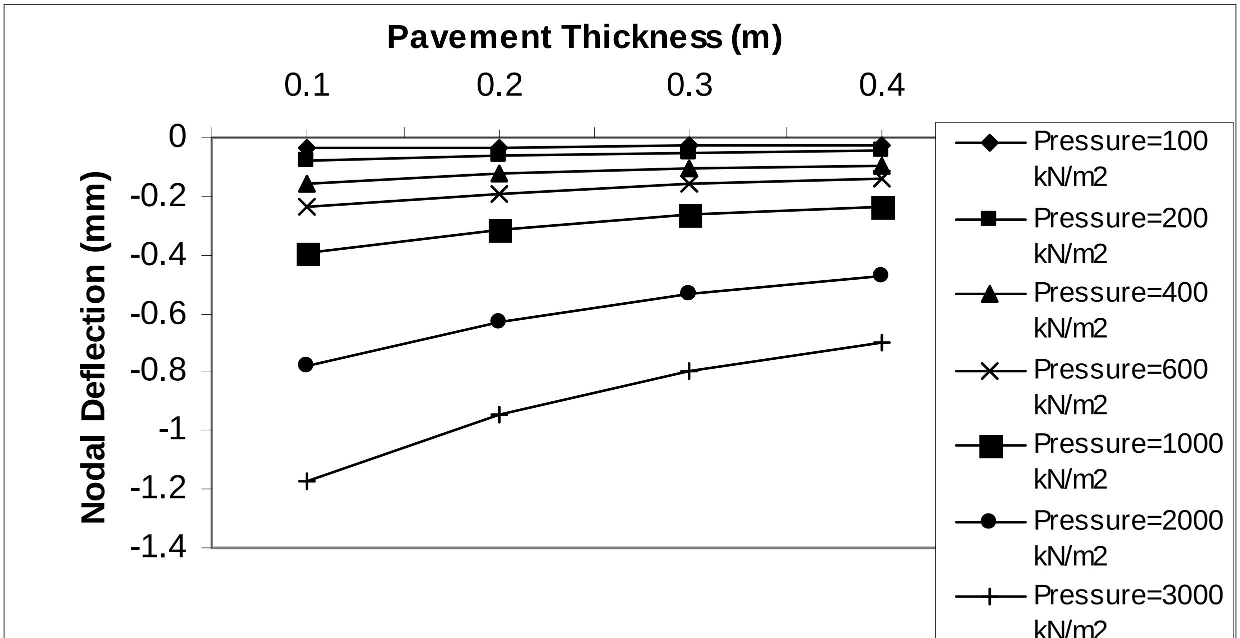

Fig.4 Design Chart (Es=25000 kN/m^2)

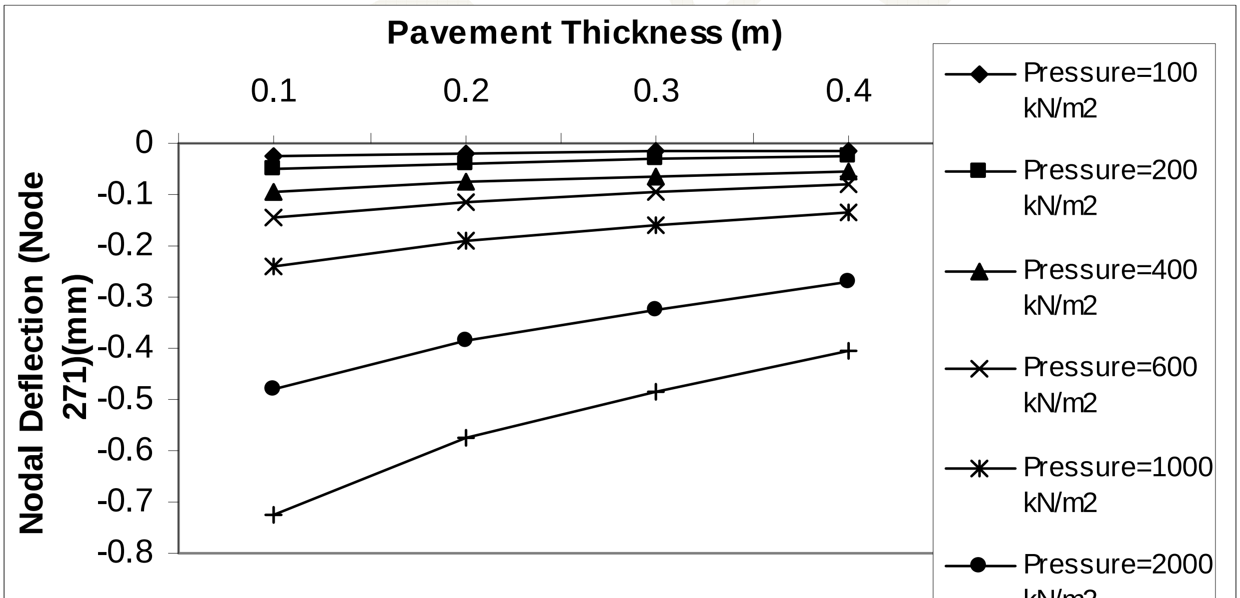

Fig.5 Design Chart (Es=50000 kN/m^2)

Fig.6 shows the design chart which has been plotted between thickness of pavement and element stress for various pressures for a particular elastic modulus of soil. The thickness of pavement (asphalt concrete) 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 soil is 5000 kN/m^2. It can be seen that for a particular pressure the element stress reduces with increase in pavement thickness. This reduction of element stress 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.7, Fig.8 and Fig.9 are similar design charts as for Fig.6. In these design charts, the reduction of element stress with increase in thickness is predominant at higher elastic modulus of subgrade.

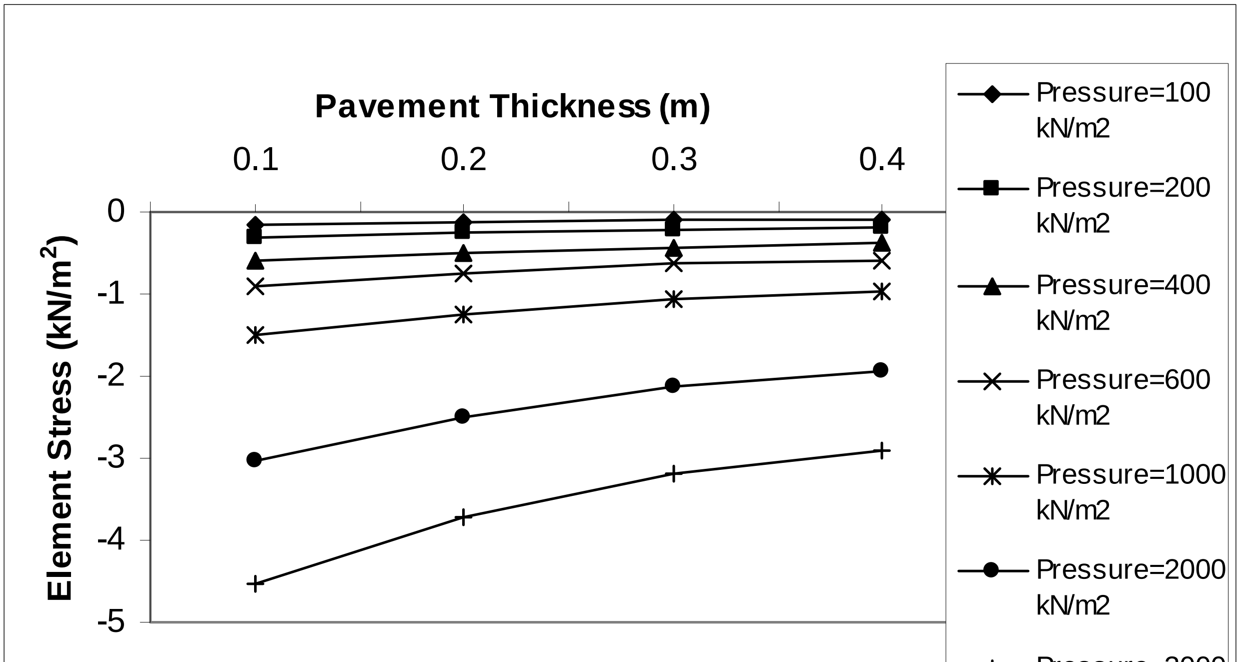

Fig.6 Design Chart (Es=5000 kN/m^2)

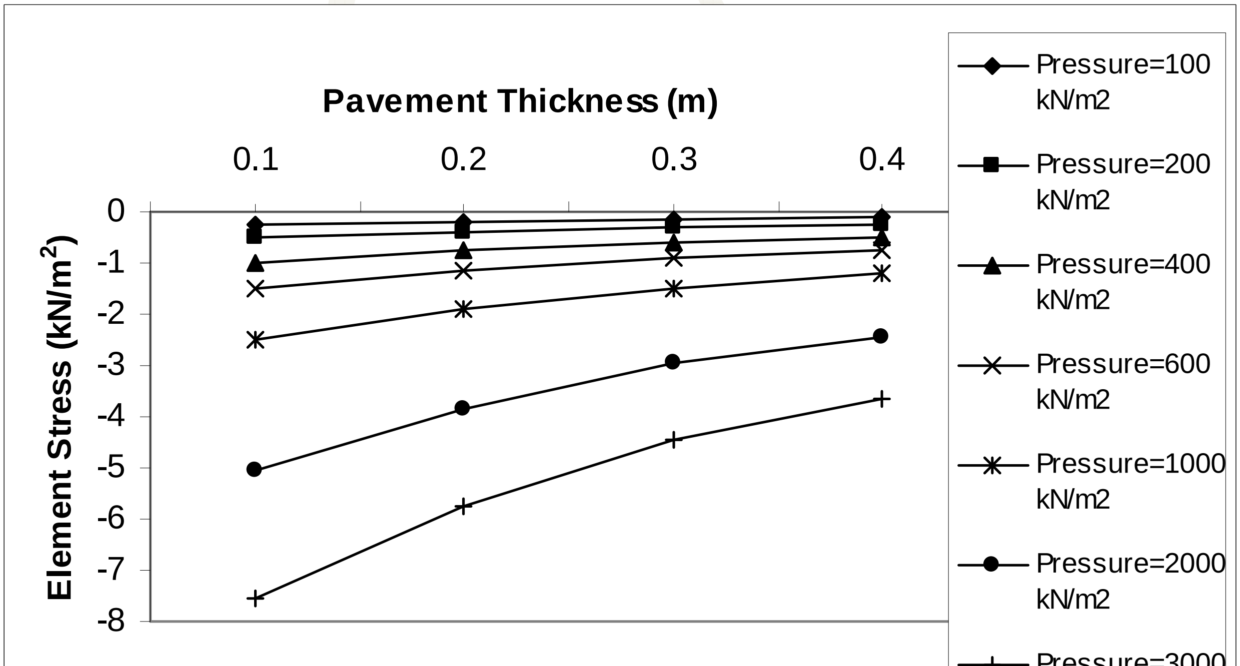

Fig.7 Design Chart (Es=15000 kN/m^2)

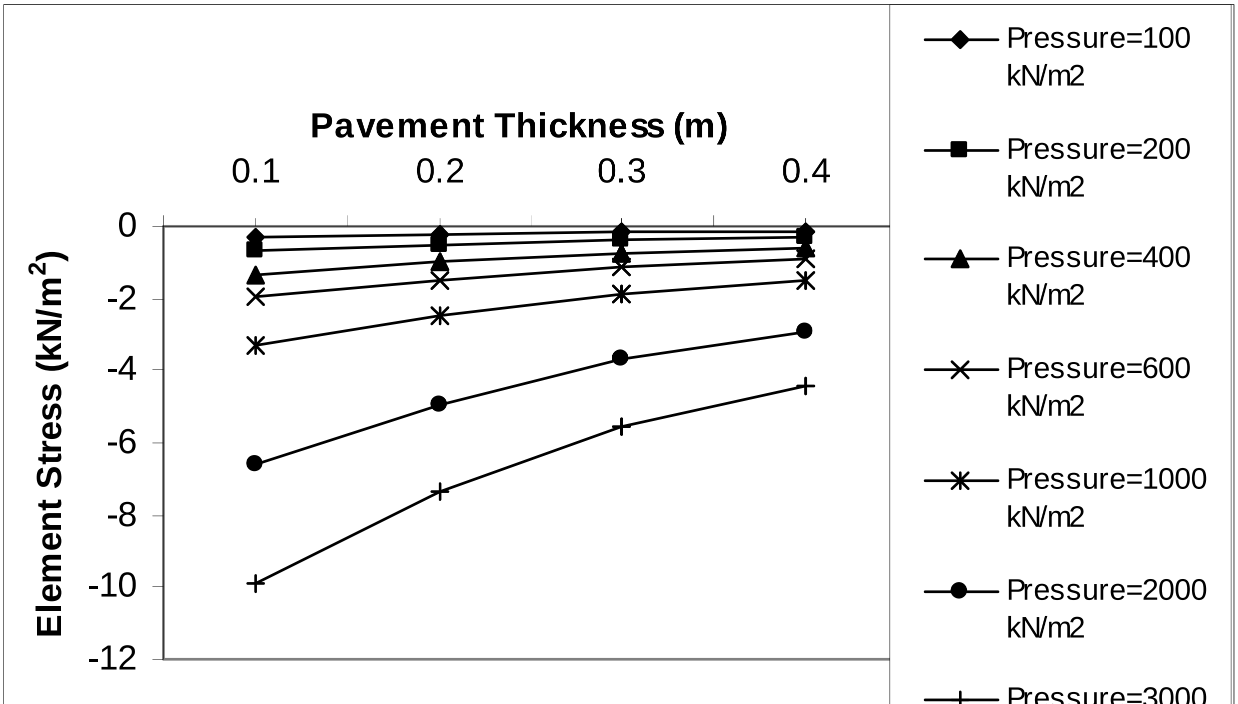

Fig.8 Design Chart (Es=25000 kN/m^2)

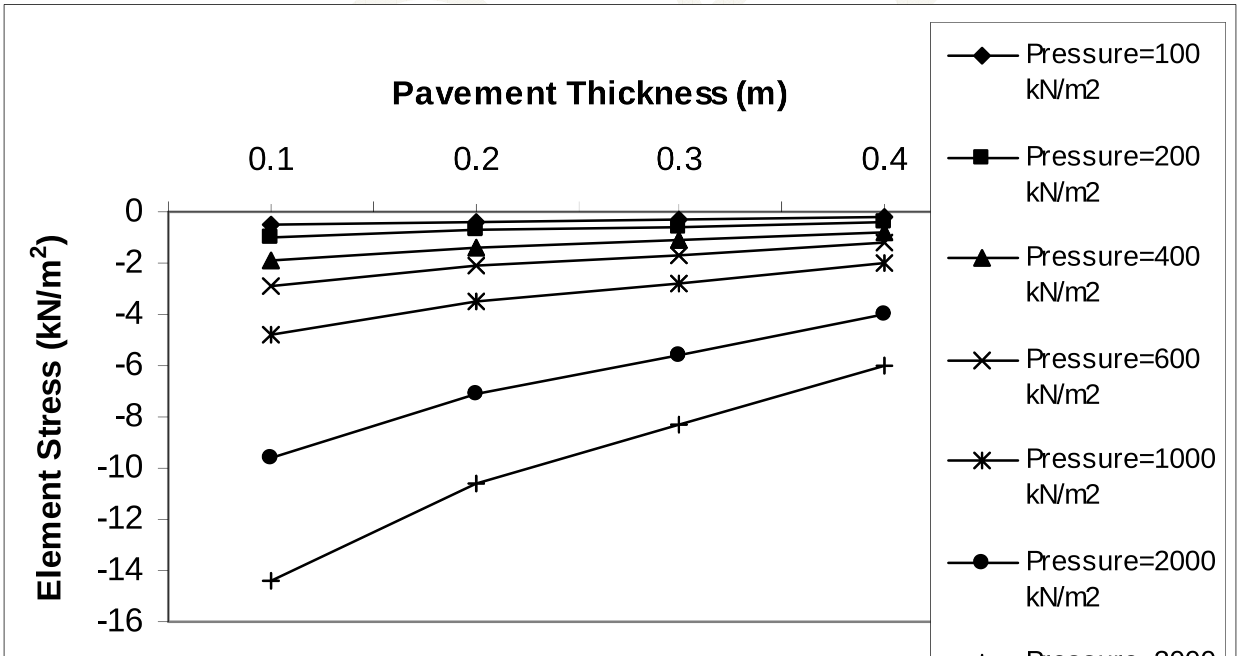

Fig.9 Design Chart (Es=50000 kN/m^2)

Fig.10 shows the design chart which has been plotted between thickness of pavement and nodal deflections 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 50000 kN/m^2 and the pressure is 100 kN/m^2. It can be seen that for a particular elastic modulus of soil the nodal deflection (settlement) reduces with increase in pavement thickness. This reduction of settlement increases with decrease in elastic modulus of soil 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 are similar design charts as for Fig.10.

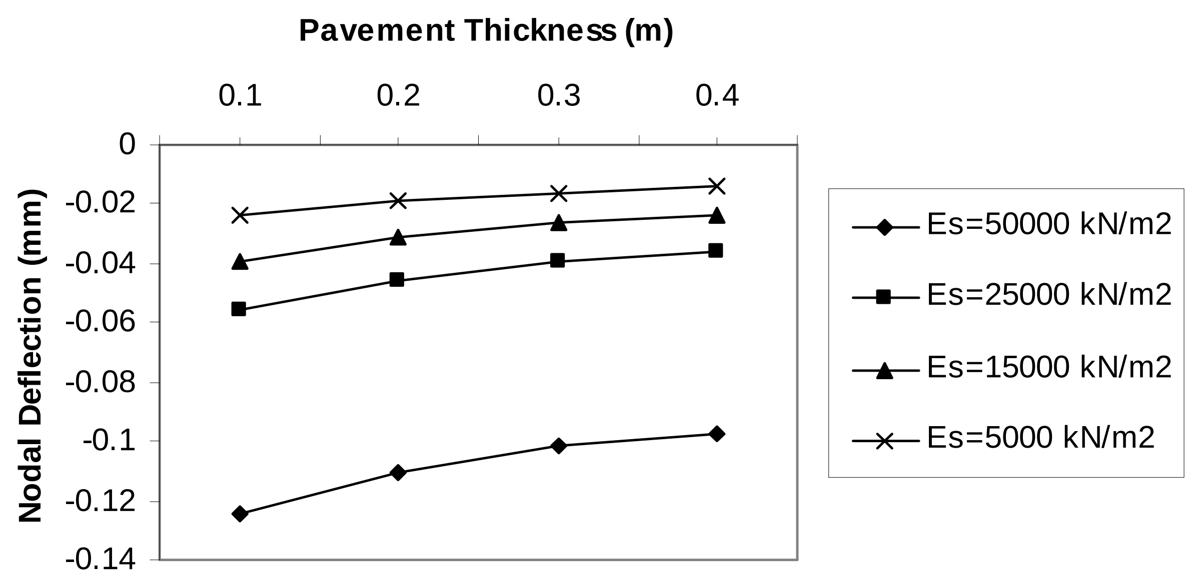

Fig.10 Design Chart (Pressure=100 kN/m^2)

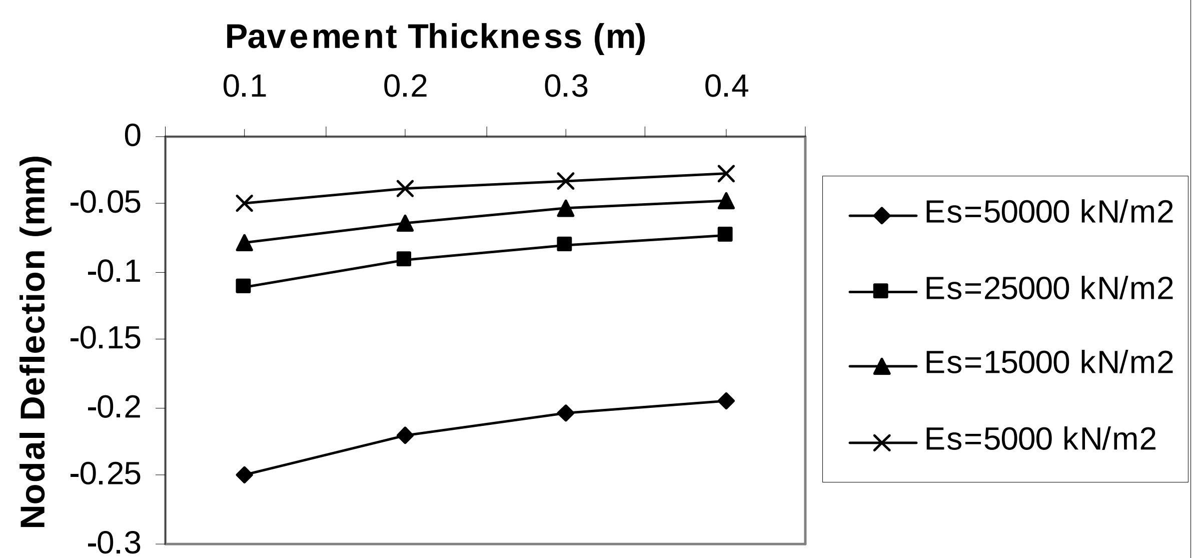

Fig.11 Design Chart (Pressure=200 kN/m^2)

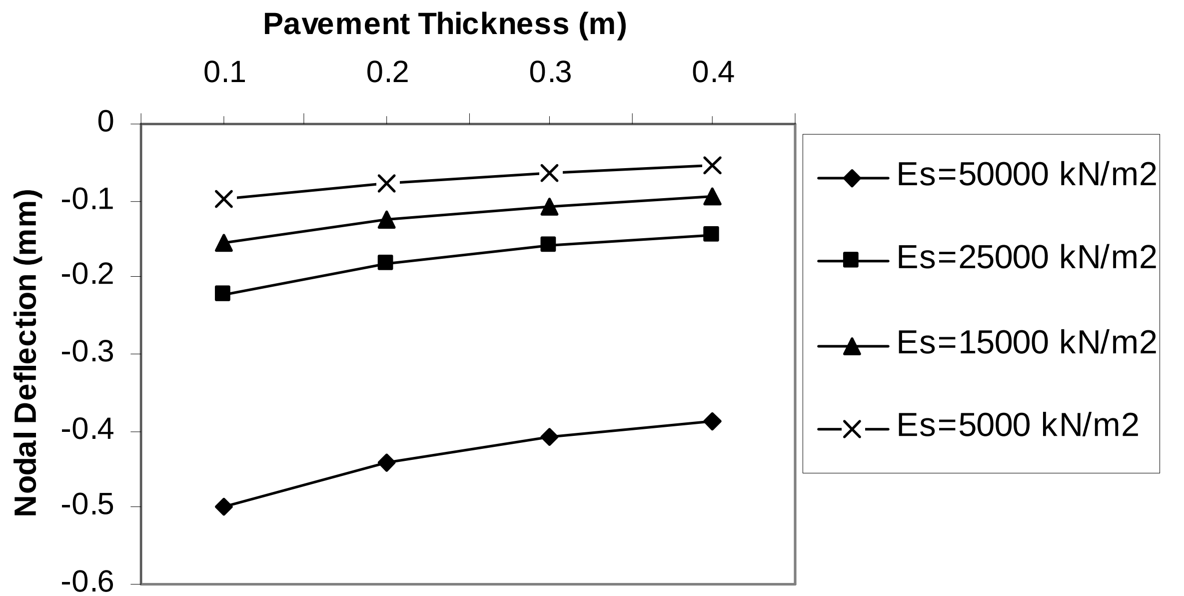

Fig.12 Design Chart (Pressure=400 kN/m^2)

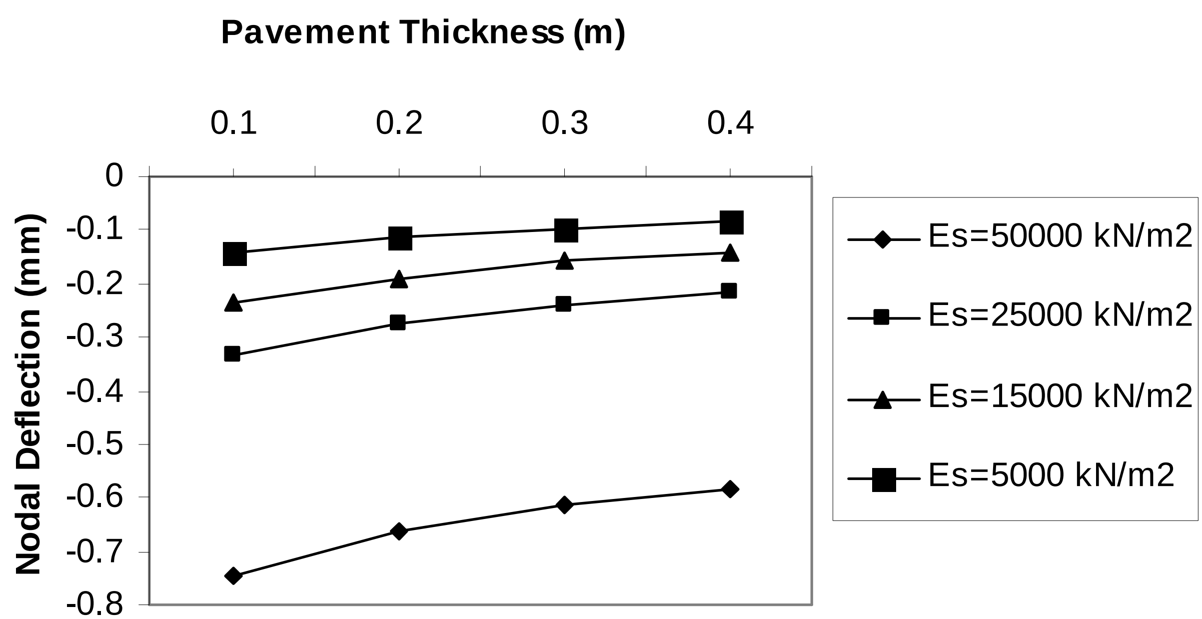

Fig.13 Design Chart (Pressure=600 kN/m^2)

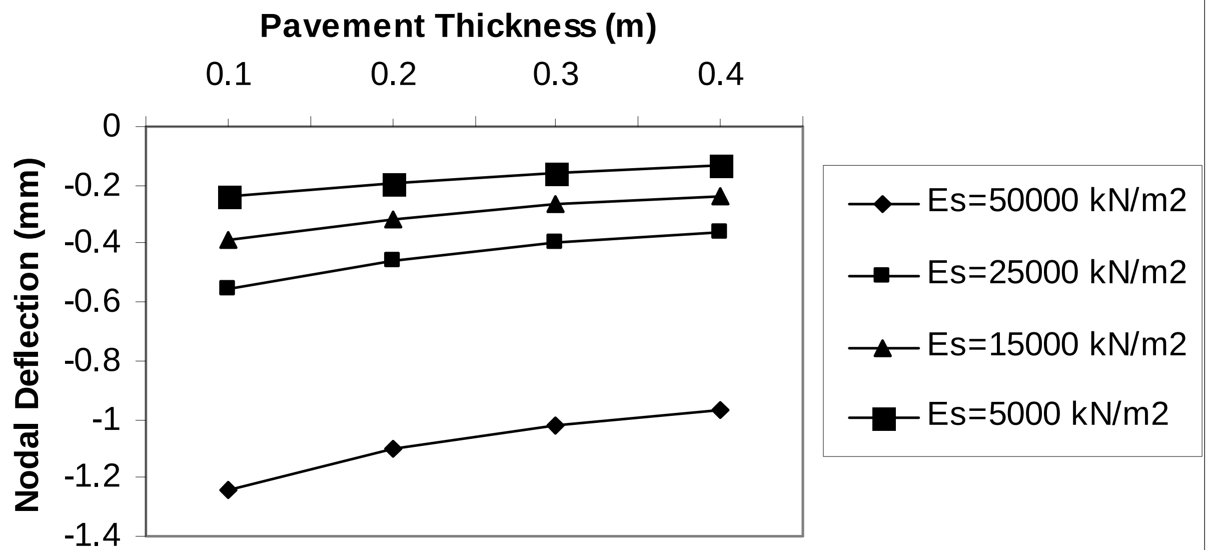

Fig.14 Design Chart (Pressure=1000 kN/m^2)

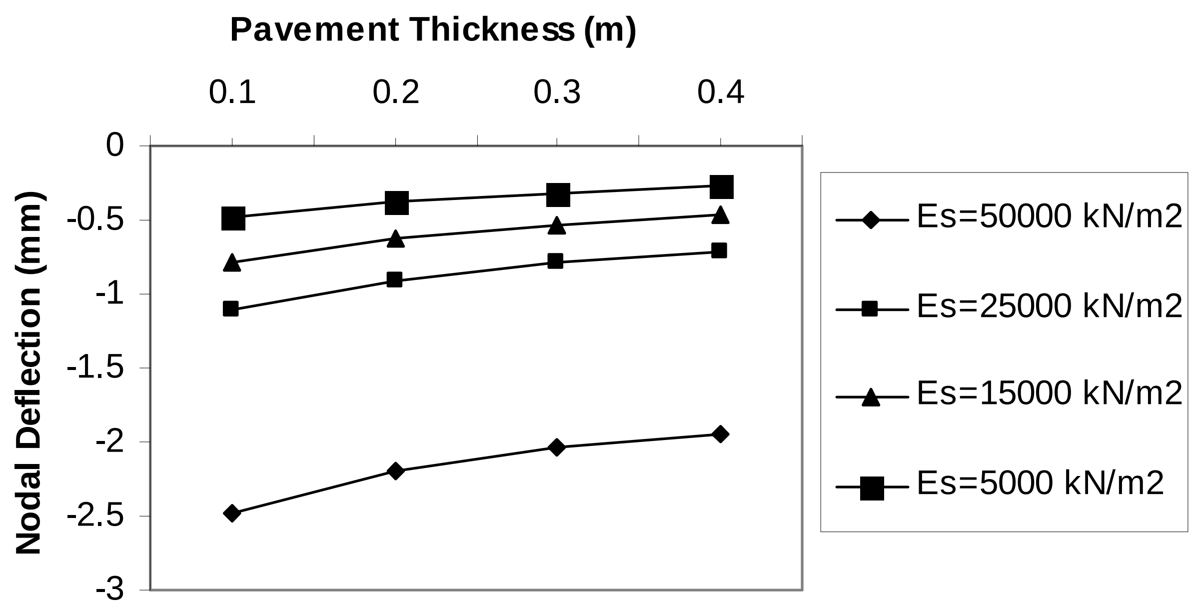

Fig.15 Design Chart (Pressure=2000 kN/m^2)

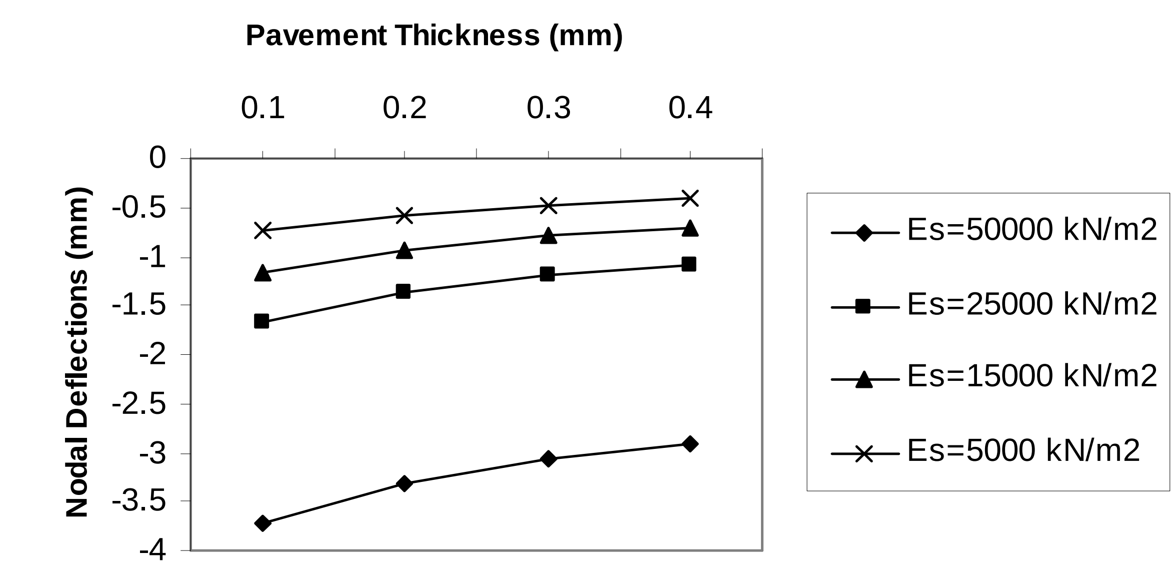

Fig.16 Design Chart (Pressure=3000 kN/m^2)

Fig.17 shows the design chart which has been 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 50000 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 and is predominant at highest soil modulus. The design chart has three parameters. For any two 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.

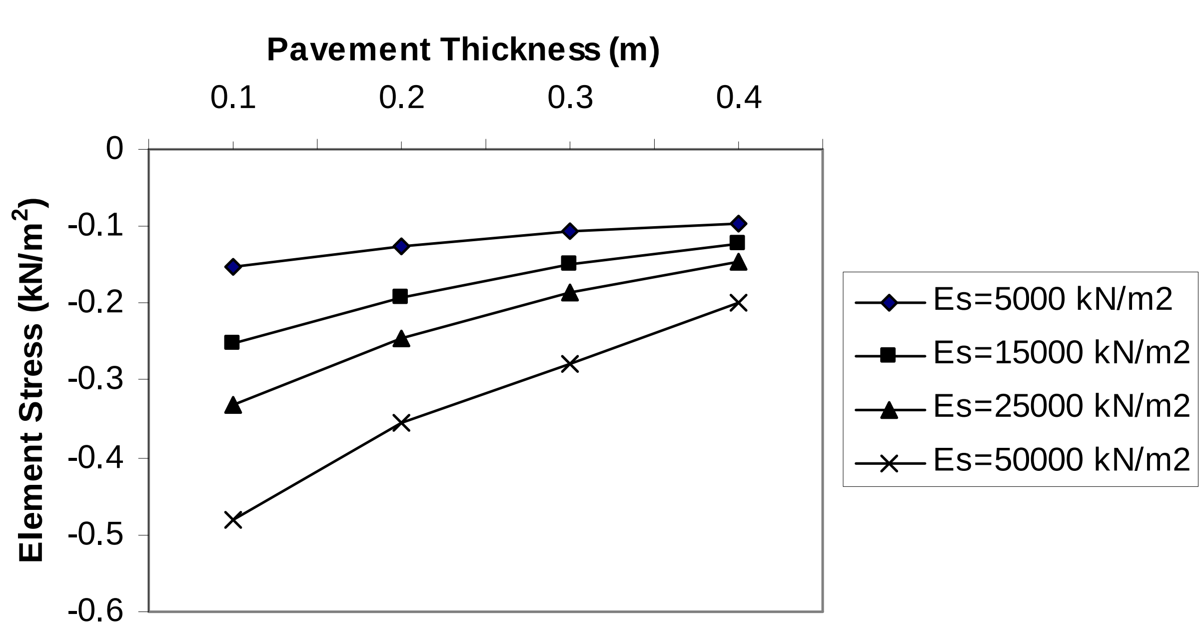

Fig.17 Design Chart (Pressure=100 kN/m^2)

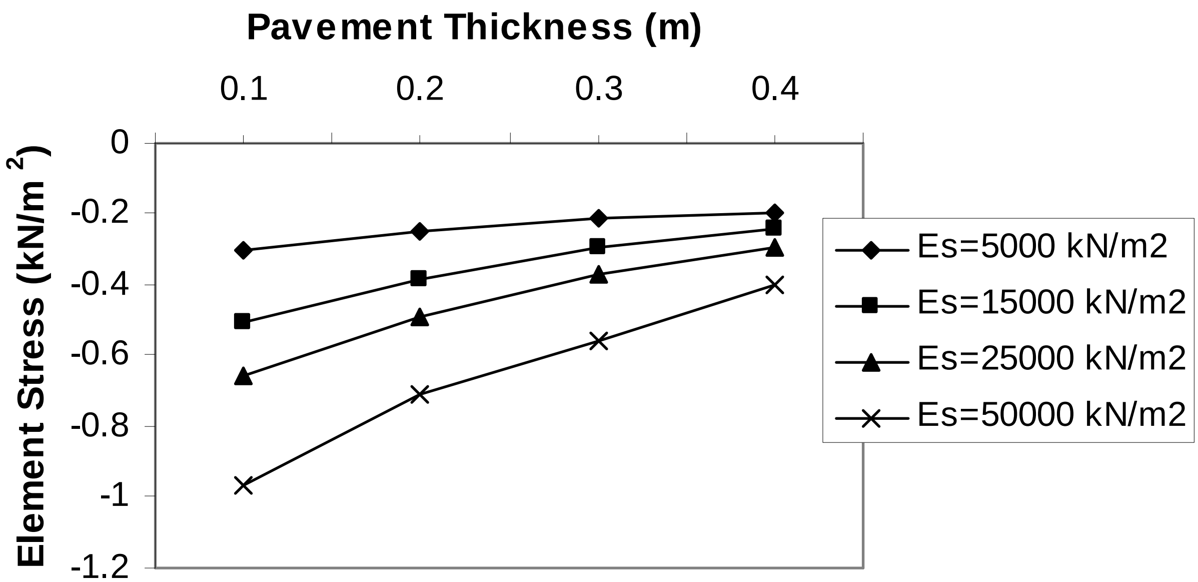

Fig.18 Design Chart (Pressure=200 kN/m^2)

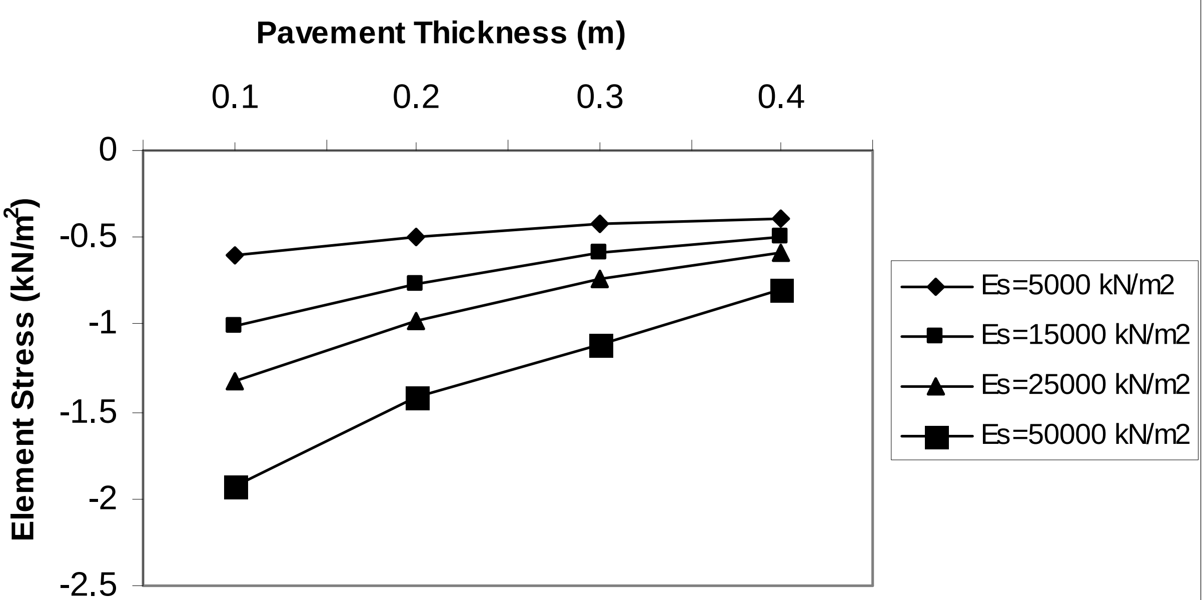

Fig.19 Design Chart (Pressure=400 kN/m^2)

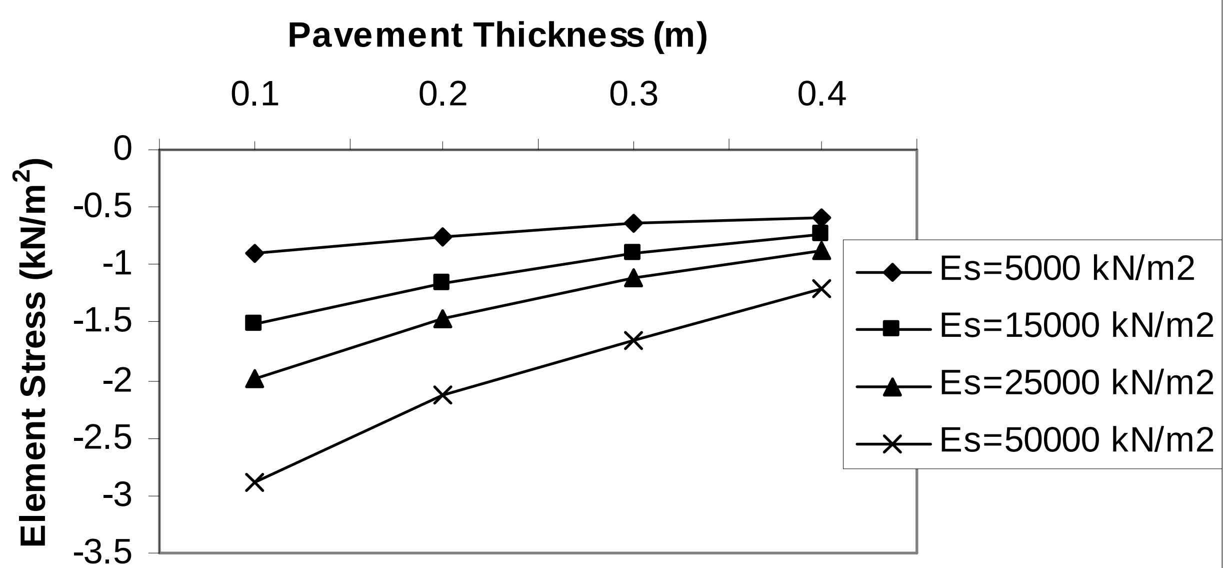

Fig.20 Design Chart (Pressure=600 kN/m^2)

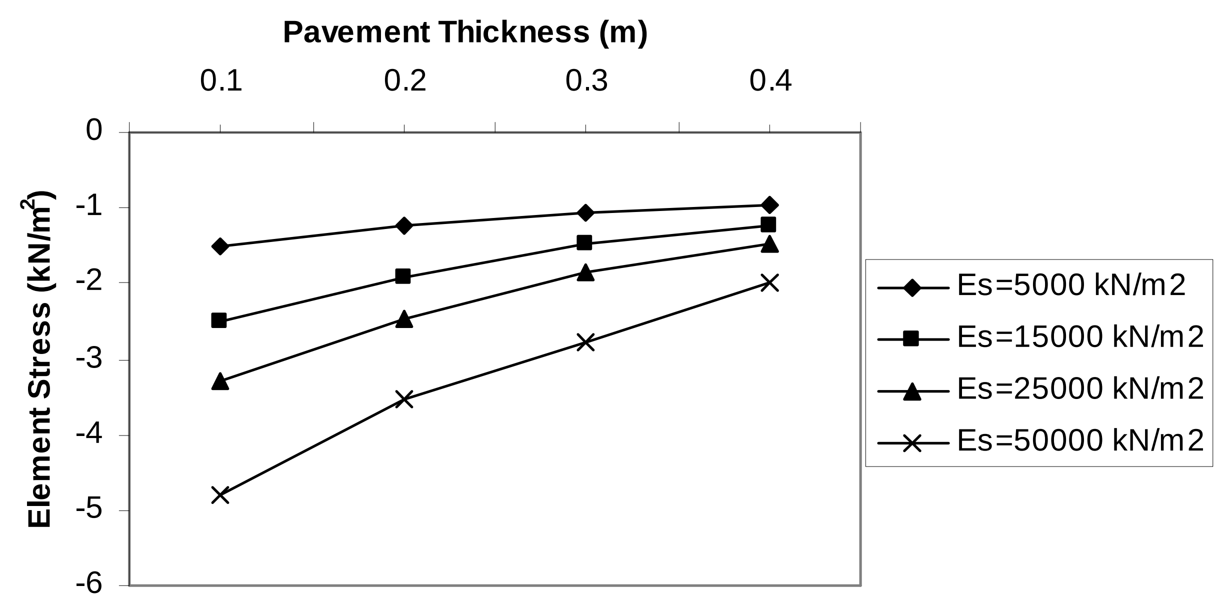

Fig.21 Design Chart (Pressure=1000 kN/m^2)

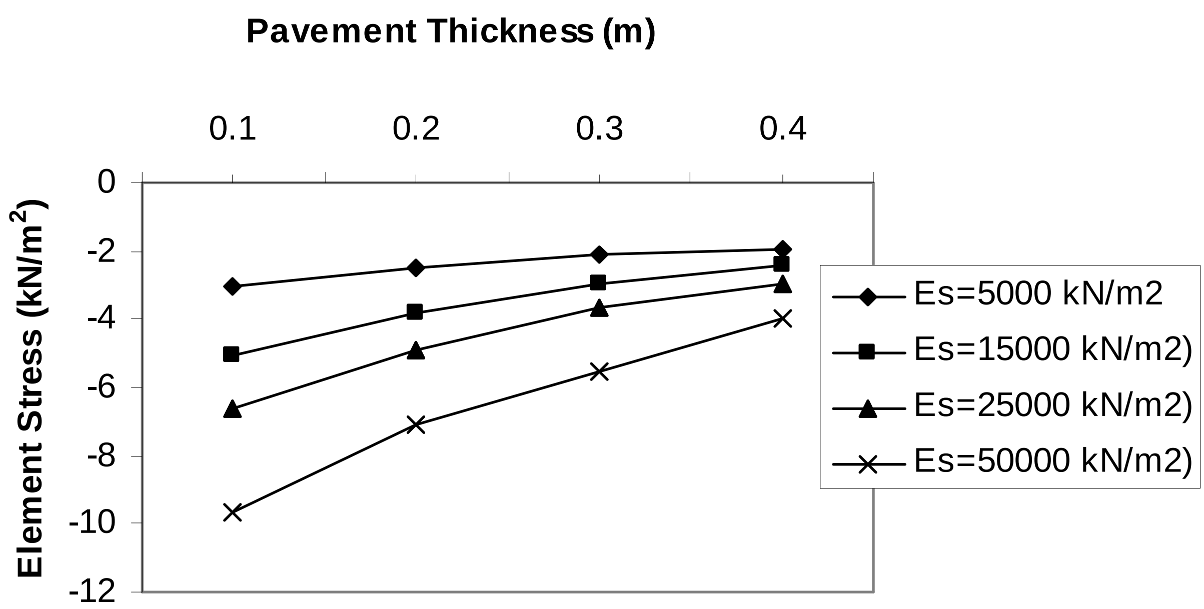

Fig.22 Design Chart (Pressure=2000 kN/m^2)

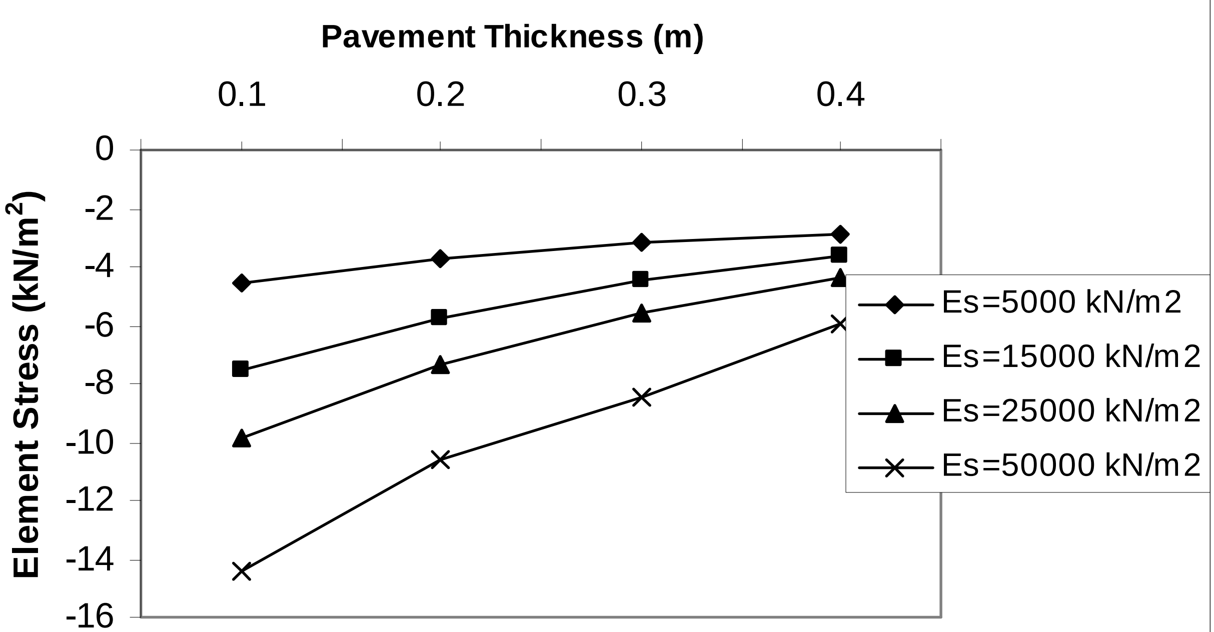

Fig.23 Design Chart (Pressure=3000 kN/m^2)

CONCLUSIONS

For a particular pressure the nodal deflection (settlement) reduces with increase in pavement thickness. This reduction of settlement increases with increase in pressure and is predominant at highest pressure. Similarly for a particular pressure the element stress reduces with increase in pavement thickness. This reduction of element stress increases with increase in pressure and is predominant at highest pressure. In these design charts, the reduction of element stress with increase in thickness is predominant at higher elastic modulus of soil. For a particular elastic modulus of soil the settlement reduces with increase in pavement thickness. This reduction of settlement increases with decrease in elastic modulus of soil and is predominant at lowest soil modulus. 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 and is predominant at highest soil modulus. The reduction of element stress with increase in thickness is predominant at higher pressure. Each design chart has three parameters. For any two parameters known, the third parameter can be obtained from the design chart.

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