ISSN: 2347-6540

International Journal of Latest Research In Engineering and Computing (IJLREC)
Volume 2, Issue 2, March –April, 2014 : Page No. 27-39
www.ijlrec.com

Development of Design Chart for Rigit Pavement By Finite Element Method

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Abstract:- Axisymmetric finite element analysis has been done by varying parameters the thickness of pavement, pressure and elastic modulus of subgrade. The concrete pavement has been idealized as linear elastic material while the subgrade has been idealized as nonlinear material by Drucker-Prager yield criterion. The pavement and the subgrade 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 parameter 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) as well as element stress reduce with increase in pavement thickness. Similarly for a particular elastic modulus of soil the settlement as well as element stress reduce with increase in pavement thickness.

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

INTRODUCTION

Rigid pavements are made up of Portland cement concrete, and may or may not have a base course between the pavement and the subgrade. Because of its rigidity and high tensile strength, a rigid pavement tends to distribute the load over a relatively wide area of subgrade, and a major portion of the structural capacity is supplied by the slab itself. For this reason, minor variations in subgrade strength have little influence upon the structural capacity of the pavement. The rigid pavements are used for heavier loads and can be constructed over relatively poor subgrade.

Rigid pavement with and without base course are used in many countries all around the world. The various layers of the rigid pavement structure have different strength and deformation characteristics which make the layered system difficult to analyze in pavement engineering. On the other hand, subgrade made of the fine-grained soils exhibit nonlinear behavior. Finite element method can be used successfully to solve such problems.

LITERATURE REVIEW

Wang et.al (1972) studied the response of rigid pavements subjected to wheel loadings using linear finite element model. The slab was modeled with medium thick plate elements assuming Kirchoff plate theory. The foundation was considered to be as an elastic half space. Slab stresses and deflections were computed using finite element model with both a continuous foundation and Winkler foundation, and were compared to stresses computed using Westergaard’s equation. In general Westergaard’s solution agreed closely with the finite element method results assuming Winkler foundation.

Huang (1974) presented finite element for rigid concrete paving systems. In this model, the effect of an adjacent slab, connected by shear transfer devices at a transverse joint was considered. The load transfer efficiency was assumed to be perfect. In addition, stresses due to temperature curling were considered. The foundation was modeled as an elastic continuum, and loss of contact was considered. The model was verified by comparison to analytical solutions and the results were found to compare well.

Tabatabaie and Barenberg (1980) developed a more general finite element program called ILLI-SLAB which is still in use today. ILLI-SLAB utilizes the same medium as thick plate elements employed in earlier models. The effect of a bonded or unbonded base can be incorporated using a second layer of plate elements below the slab. The subgrade is modeled as Winkler's foundation . Verification of models developed with ILLI-SLAB was achieved by comparison with theoretical solutions for stresses and displacements. The results compared well.

Huang(1983) extended his earlier models to allow the consideration of multiple slabs and various load transfer devices in a manner similar to ILLI-SLAB. It should be noted that dowels were modeled as having shear stiffness only across the joint i.e bending deformations of the dowels were not considered. The subgrade was modeled as an elastic half space and loss of contact between the subgrade and the slab was considered.

Tayabji et.al (1986) developed the program JSLAB for analyzing pavements resting on a Winkler foundation. The model incorporates features similar to ILLI-SLAB, utilizing plate elements to model the slab and a bonded or unbonded base. Dowels were modeled with modified beam elements that incorporated the effect of shear deformations and elastic support provided by the concrete. As in ILLI-SLAB, aggregate interlock and keyways were modeled with springs

Krauthammer and Western (1988) focus on the relationship between shear transfer capabilities across pavement joints and the effects on the behavior of the pavement. The approach of the present study is to develop a numerical model that could accurately represent the mechanism for shear transfer across reinforced concrete pavement joints and implement it in an existing finite element code. The tool is then used for the analysis of various pavements for which experimental data are available; the model is further refined until the numerical results are in good agreement with the experimental information.

Lee (1999) presents an alternative procedure for the determination of critical stresses. The well-known ILLI-SLAB finite element program was used for the analysis. Prediction models for stress adjustments are developed using a projection persuit regression technique. A simplified stress analysis procedure is proposed and implemented in a user-friendly program to facilitate instant stress estimations.

Hadi and Arfiadi (2001) state that the design of rigid pavements involves assuming a pavement structure then using a number of tables and figures to calculate the two governing design criteria, the flexural fatigue of the concrete base and the erosion of the sub-grade/sub-base. Each of these two criteria needs to be less than 100%. The designer needs to ensure that both criteria are near 100% so that safe and economical designs are achieved. This paper presents a formulation for the problem of optimum rigid road pavement design by defining the objective function, which is the total cost of pavement materials, and all the constraints that influence the design. A genetic algorithm is used to find the optimum design. The results obtained from the genetic algorithm are compared with results obtained from a Newton-Raphson based optimization solver.

Arora (2003) has reported that the Westergaard's analysis is used for design of rigid pavements. The stresses in the concrete slab are determined using Westergaard's theory. Westergaard considered the rigid pavement as a thin elastic plate resting on soil subgrade.The upward reaction at any point is assumed to be proportional to the deflection at that point. The slab deflection depends upon the stiffness of the subgrade and the flexural strength of the slab. Thus the pressure-deformation characteristics of a rigid pavement depend upon the relative stiffness of the slab and the subgrade.

Punmia et.al (2005) have described the development of a design procedure for rigid highway pavement by Portland Cement Association based upon formulae developed by Pickett. The design charts for protected and unprotected corners, based on the formulae by Pickett for the design of highway pavement have been developed. The pavement thickness is obtained based on magnitude of wheel load and given value of modulus of subgrade reaction.

Razouki and Al-Muhana (2005) developed stress charts for the quick determination of maximum bending tensile stresses for the case of a concrete pavement slab on a Winkler foundation. The maximum bending moment in the concrete pavement represented by a Westergaard slab on Winkler foundation was obtained analytically by extending the known solution for the case of a uniformly loaded circular segment to the case of multiple circular contact areas. The paper reveals that the effects on the maximum bending tensile stress are quite significant due to the modulus of subgrade reaction, modulus of elasticity of concrete and slab thickness

Darestani et. al (2006) state that the 2004 edition of Austroads rigid pavement design guide has been based on the work of Packard and Tayabji which is known as the PCA method. In this method, a number of input parameters are needed to calculate the required concrete base thickness based on the cumulative damage process due to fatigue of concrete and erosion of subbase or subgrade materials. This paper reviews the 2004 design guide, introduces a design software specially developed to study the guide and highlights some important points. Results of the current study show the complex interdependence of the many parameters.

Long and Shatnawi (2011) address the structural performance of experimental rigid pavements constructed in California. The experimental project consists of seven Portland

Cement concrete pavement sections with various layer structures. Falling weight deflectometer was utilized to conduct deflection testing for back calculation of layer moduli and subgrade reaction moduli, evaluation of joint load transfer capacity, and detection of voids under the slabs. In addition, pavement distress condition was also evaluated as it relates to the integrity of pavement structure. The major findings in this study indicate that thick slab and lean concrete base lower the pavement deflection response and prevent the formation of voids under the slab corners, but lean concrete base has no significant effect on subgrade reaction moduli values

Patil et. al (2012) presented a numerical iterative procedure based on finite element method for analysing the response of pavements. The pavement has been discretized by beam elements. The foundation is modeled by Pasternak's two parameter soil medium. The soil-structure-interaction effect was considered in the analysis. A parametric study has been carried out to understand the pavement response.

Cojocaru et.al (2013) present the results of the research undertaken by them in the frame of the postdoctoral program 4D-POSTDOC. After a short introduction on the actual status of structural design of airport pavements, the modeling and the structural design of airport rigid pavements, constructed with conventional and various recycled materials, using the finite element method, is described. The main objective of this research program was to elaborate a design method which, beside the complex landing gear including six footprint tires, all specific parameters related with the recycled materials and with conventional and reinforce roll compacted concrete technologies are included. Finally, practical design diagrams for structural design of the concrete slabs, including their specific correlation function, used for the construction of the Airbus-A380 runway are presented.

Based on literature review it is found that very few work has been done for rigid pavements by finite element method considering material nonlinearity of subgrade. Very fiew literature has been reported for design chart of rigid pavement. Hence there is lot of scope of development of design chart by finite element method considering the material nonlinearity of subgrade.

FINITE ELEMENT ANALYSIS

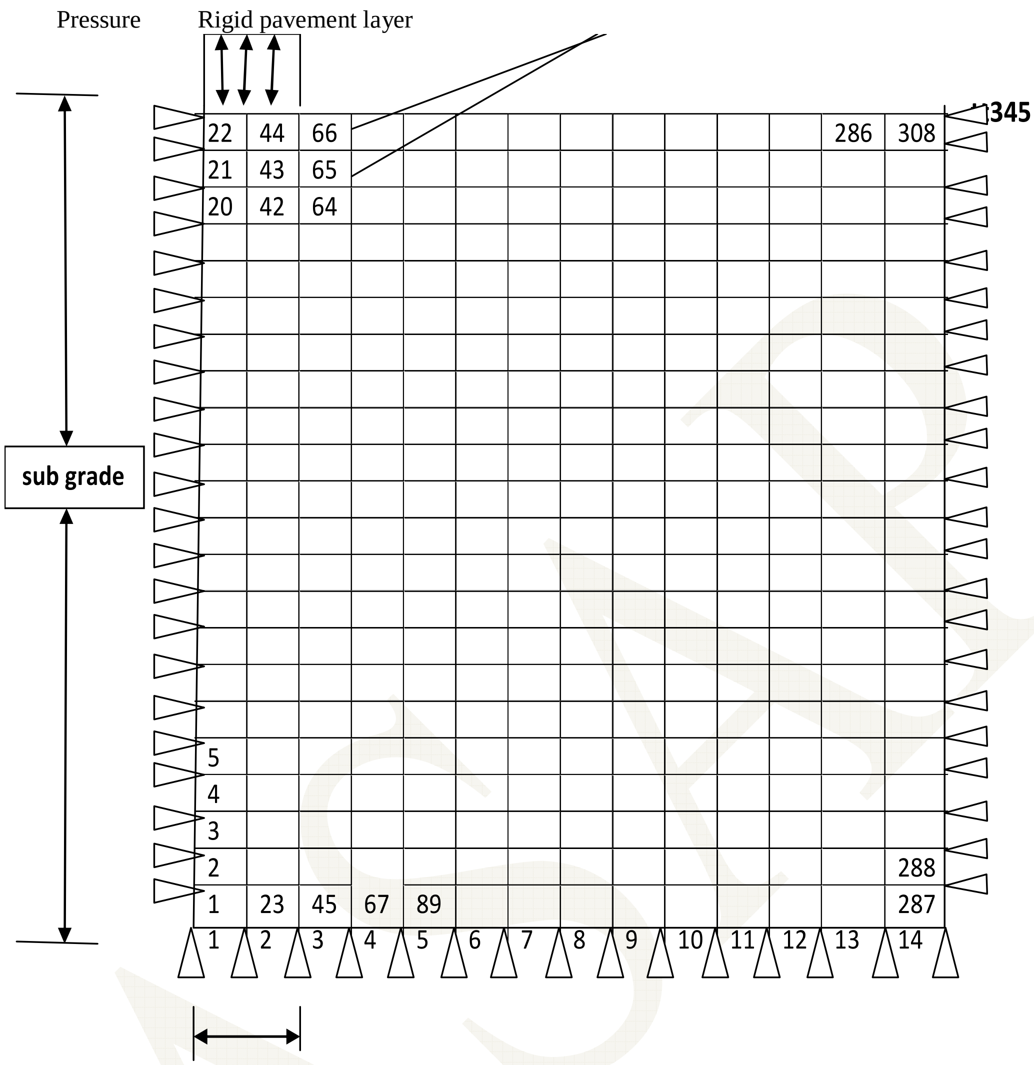
In this research axisymmetric finite element analyses have been done by considering subgrade soil as a nonlinear material. The material nonlinerity has been considered by idealizing the soil by Drucker-Prager yield criterion. The concrete has been idealized as elastic material.Fig.1 shows the finite element discretization considered in this analysis. The concrete pavement and the subgrade have been discretized by four noded isoparametric finite elements. The total number of nodes considered are 345 and total number of elements 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 nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure.The thickness of concrete pavement considered are 100,200,400 and 600 mm. 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 the concrete pavement varies from 100 mm to 600 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 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. In these design charts, the reduction of settlement with increase in thickness is predominant at higher elastic modulus of soil.

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. The reduction of settlement with increase in thickness is predominant at higher elastic modulus of soil. For a particular pressure the element stress reduces with increase in pavement thickness. There is very small reduction in element stress when thickness increases from 400 mm to 600 mm. This reduction of element stress increases with increase in pressure and is predominant at highest pressure. 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. The reduction of settlement with increase in thickness is predominant at higher pressure. 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. In these design charts, the reduction of element stress with increase in thickness is predominant at higher pressure. The design chart has three parameters. For any two parameters, the third parameter can be obtained from the design chart.



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

fig.1 finite element Discretization for rigid pavement without base course

Material Properties

Elastic Modulus of Concrete Pavement = 20000000 kN/m^2, Poisson's Ratio=0.30

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

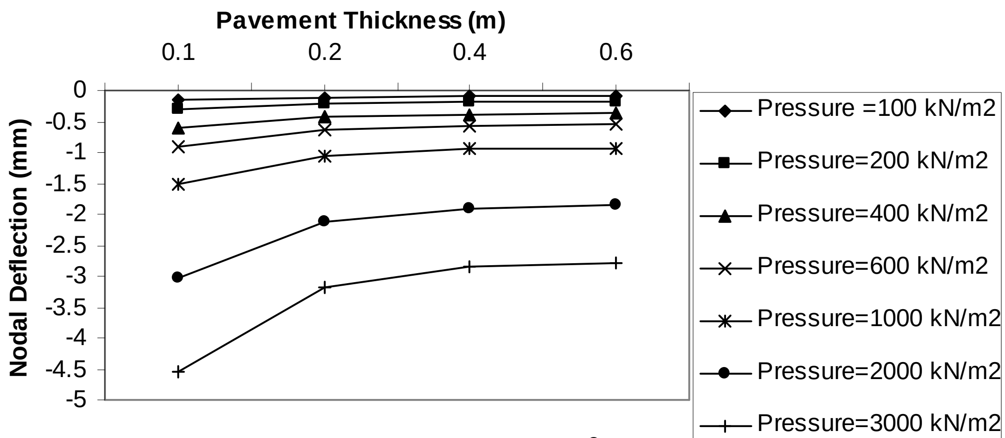


Fig.2 Design Chart (Es=5000 kN/m^2)

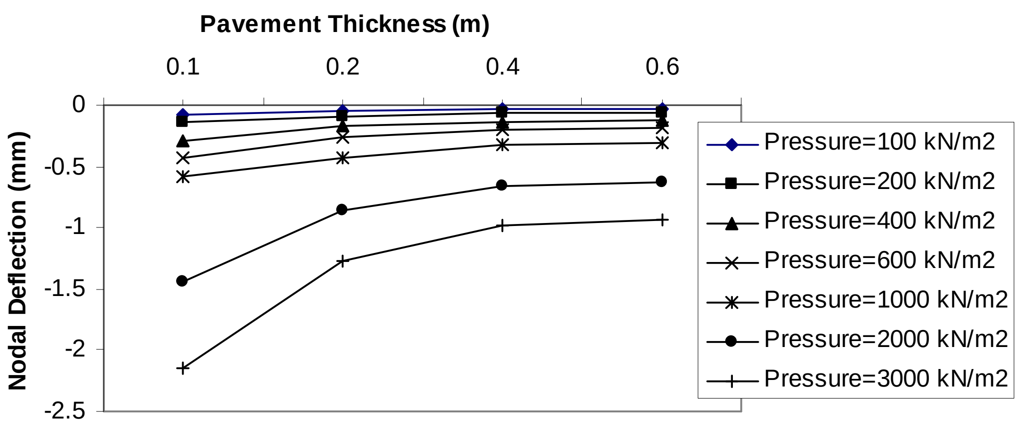


FIG.3 Design Chart (Es=15000 kN/m^2)

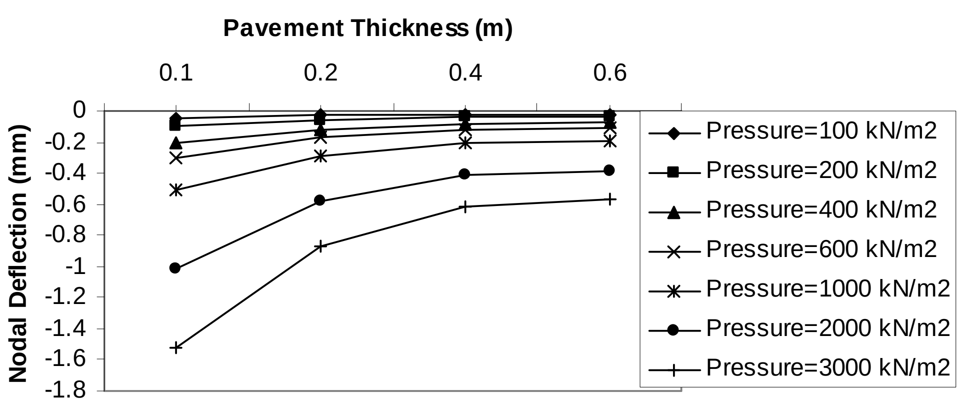


Fig.4 Design Chart (Es=25000 kN/m^2)

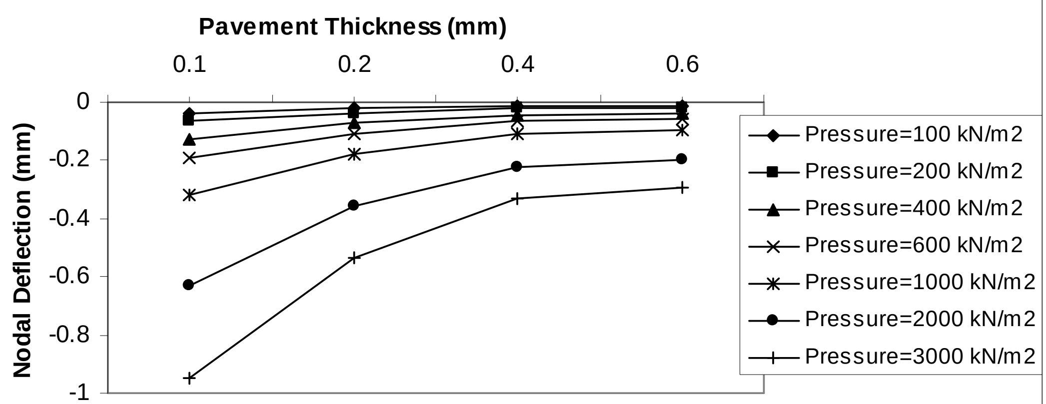


Fig.5 Design Chart (Es=50000 kN/m^2)

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 concrete pavement varies from 100 mm to 600 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. There is very small reduction in element stress when thickness increases from 400 mm to 600 mm. 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 soil

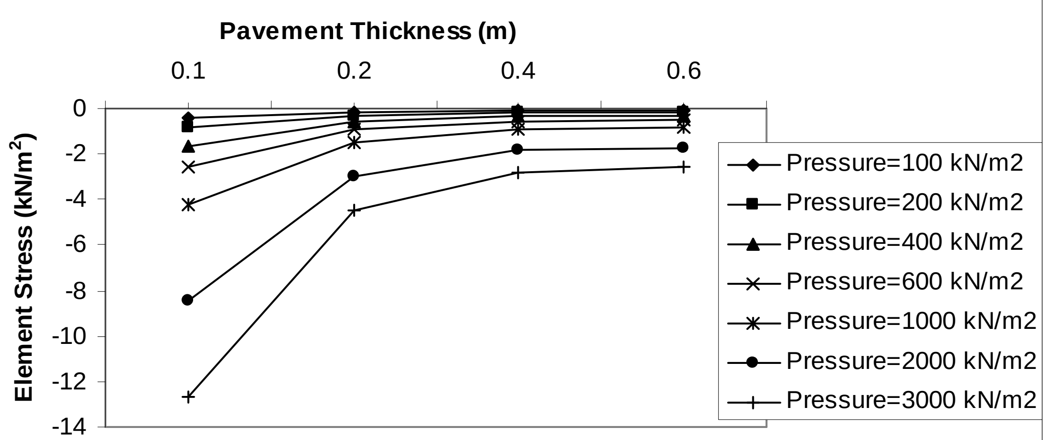


Fig.6 Design Chart (Es=5000 kN/m^2)

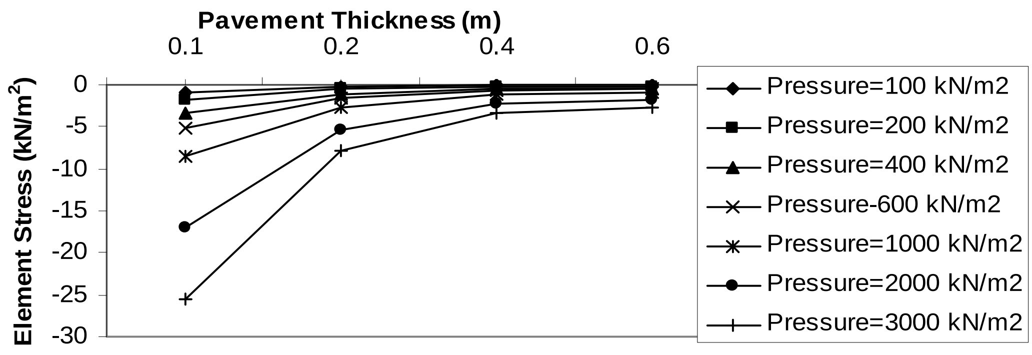


Fig.7 Design Chart (Es=15000 kN/m^2)

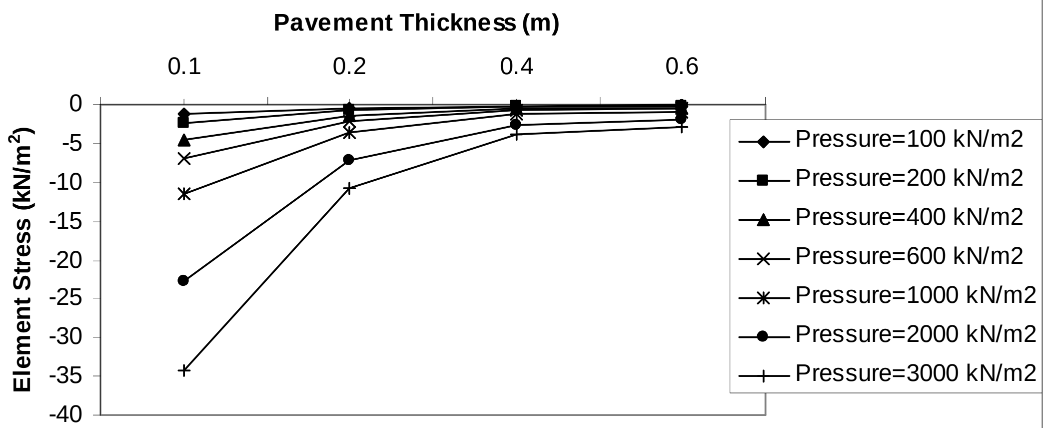


Fig.8 Design Chart (Es=25000 kN/m^2)

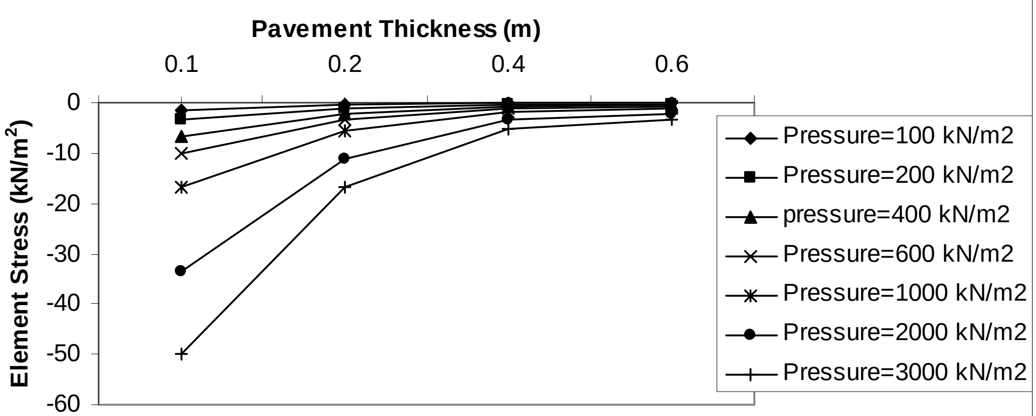


Fig.9 Design Chart (Es=50000 kN/m^2)

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 concrete pavement varies from 100 mm to 600 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 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. In these design charts, the reduction of settlement with increase in thickness is predominant at higher pressure.

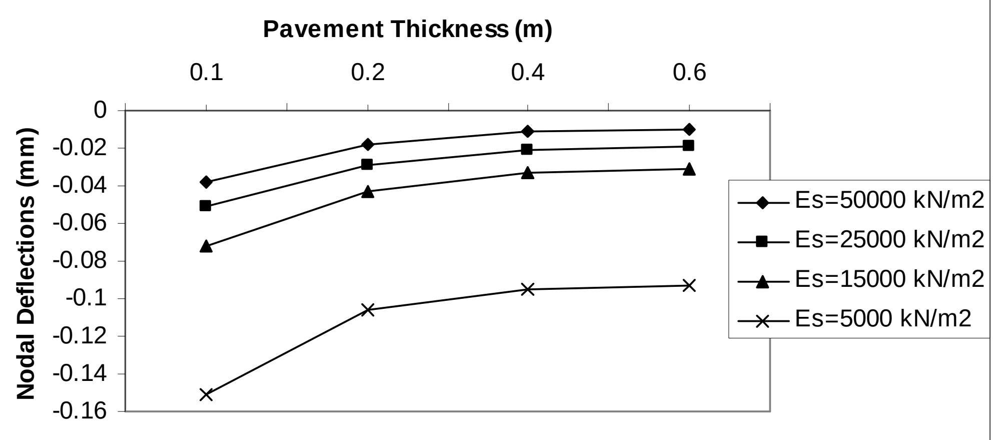


Fig.10 Design Chart (Pressure=100 kN/m^2)

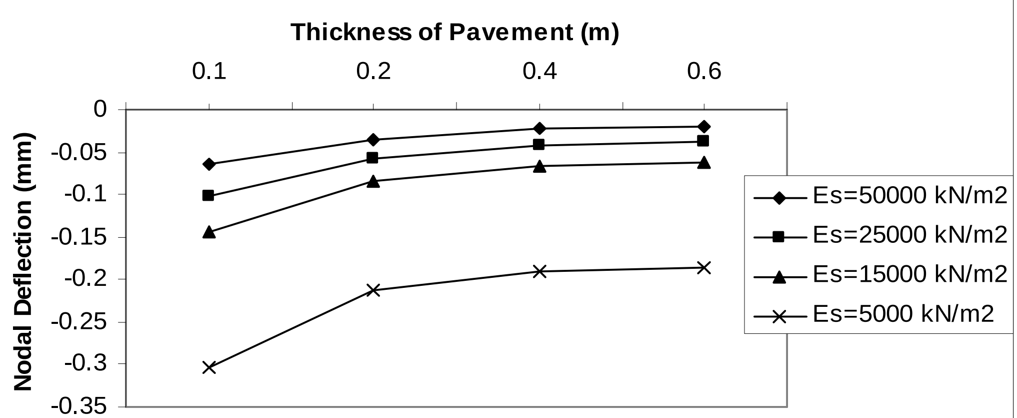


Fig.11 Design Chart (Pressure=200 kN/m^2)

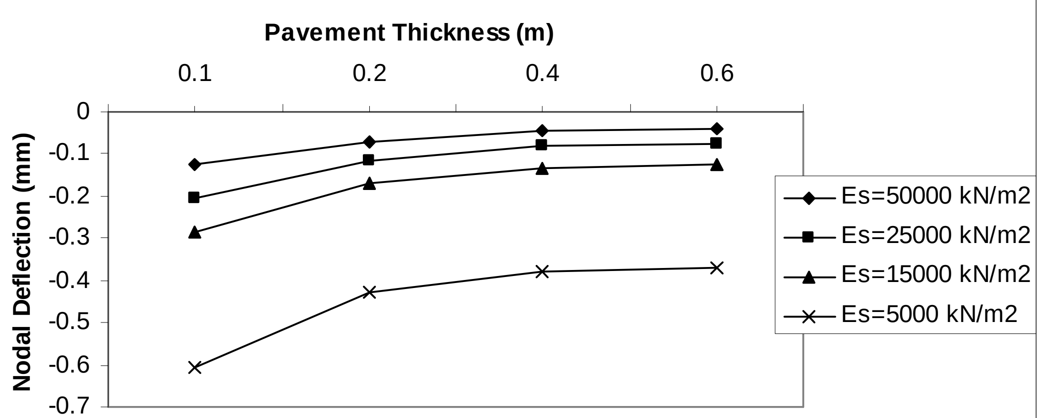


Fig.12 Design Chart (Pressure=400 kN/m^2)

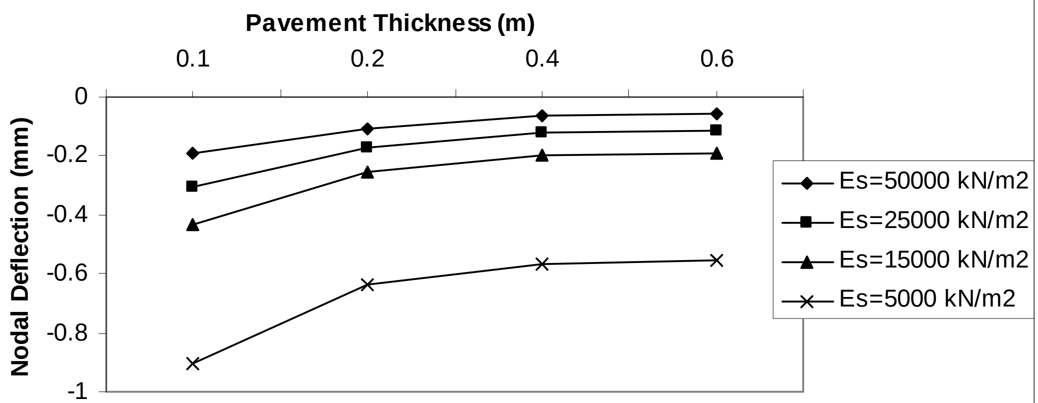


Fig.13 Design Chart (Pressure=600 kN/m^2)

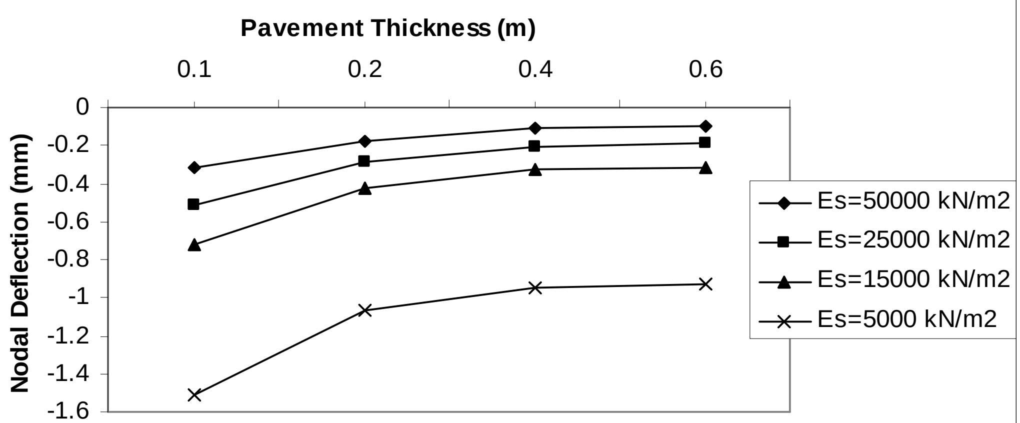


Fig.14 Design Chart (Pressure=1000 kN/m^2)

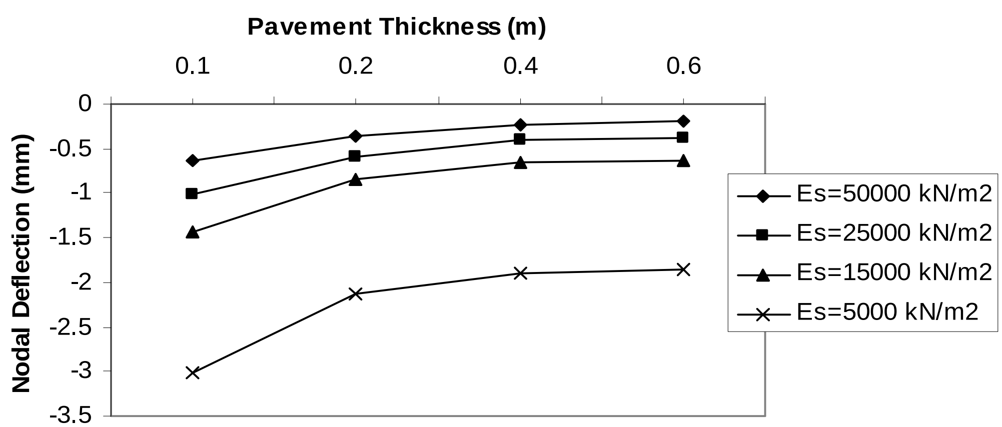


Fig.15 Design Chart (Pressure=2000 kN/m^2)

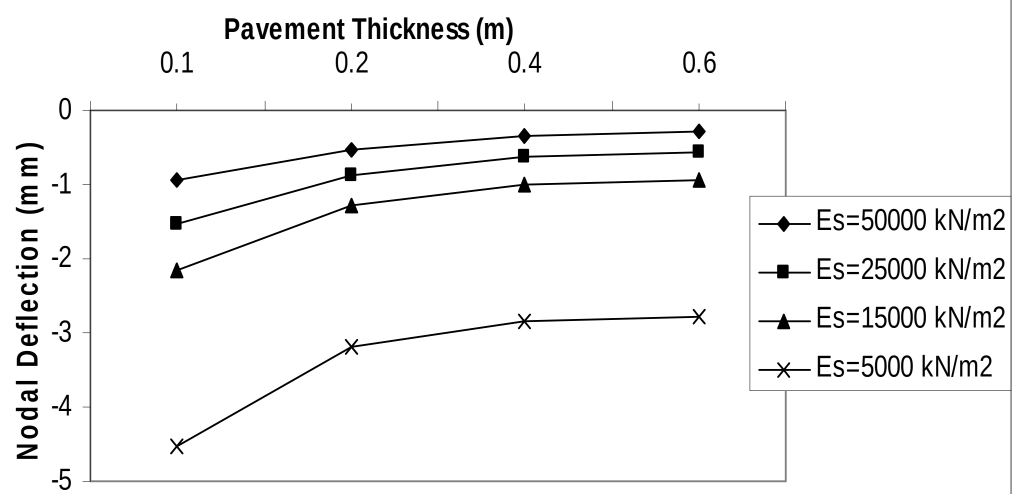


Fig.16 Design Chart (Pressure=3000 kN/m^2)

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 concrete pavement varies from 100 mm to 600 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.

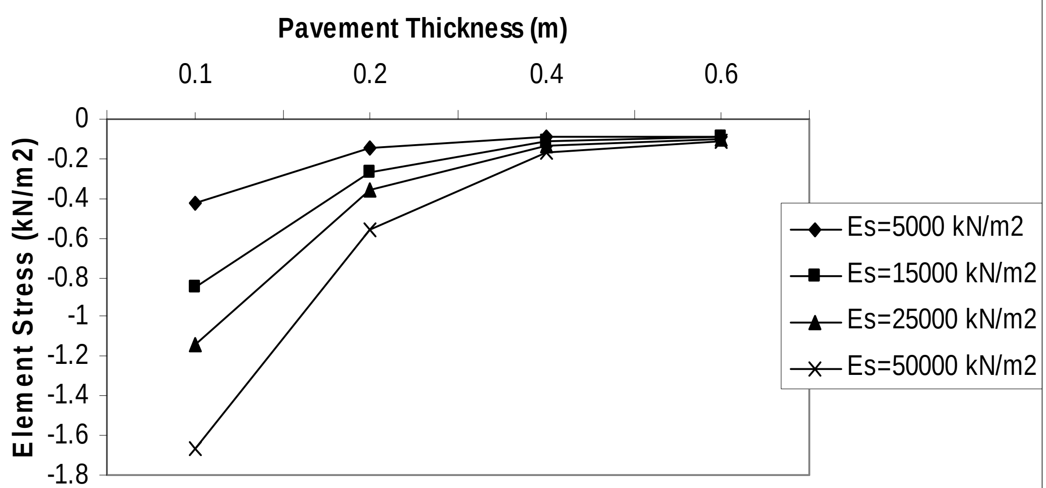


Fig.17 Design Chart (Pressure=100 kN/m^2)

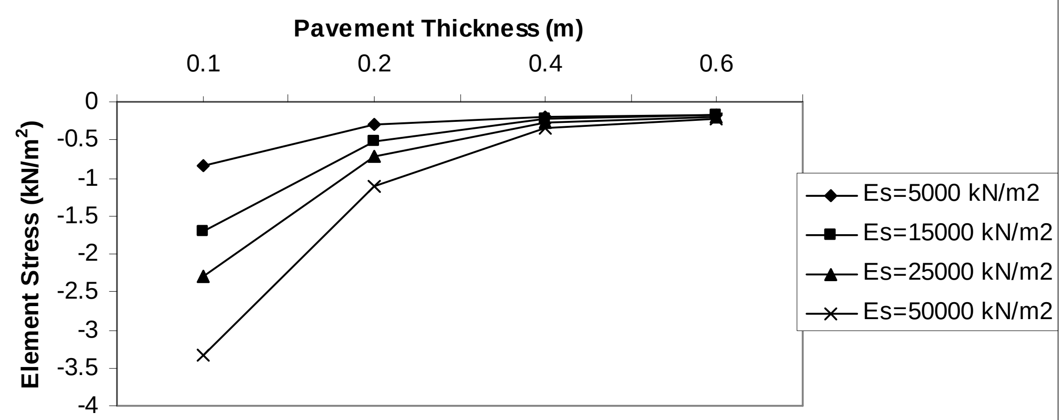


Fig.18 Design Chart (Pressure=200 kN/m^2)

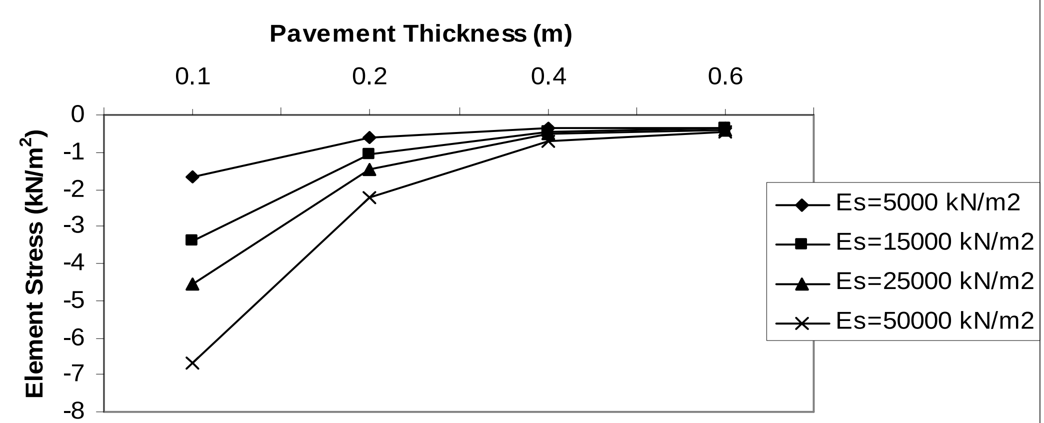


Fig.19 Design Chart (Pressure=400 kN/m^2)

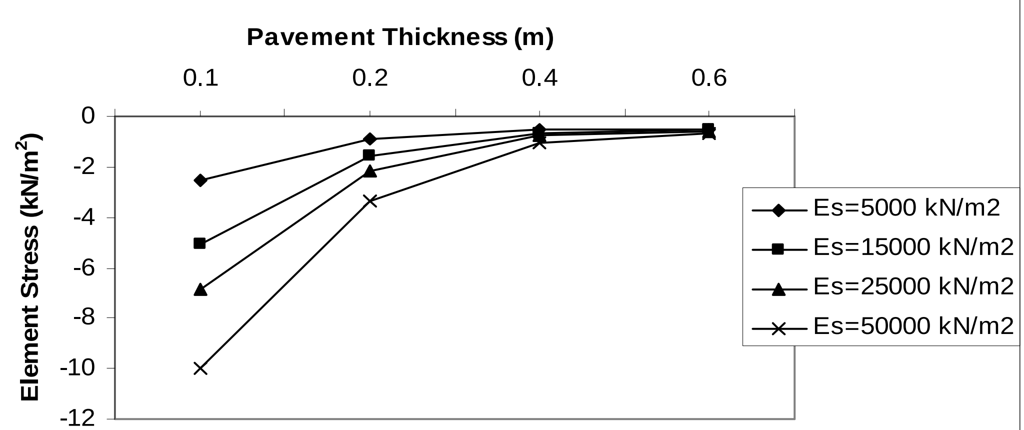


Fig.20 Design Chart (Pressure=600 kN/m^2)

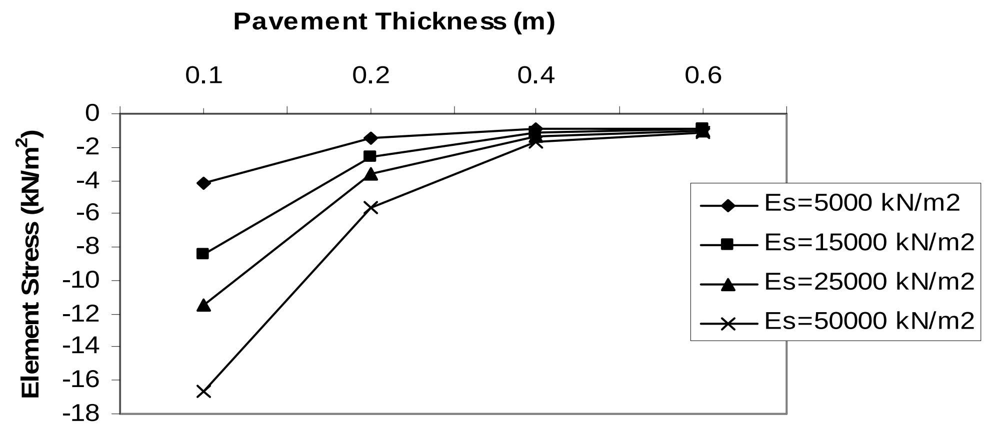


Fig.21 Design Chart (Pressure=1000 kN/m^2)

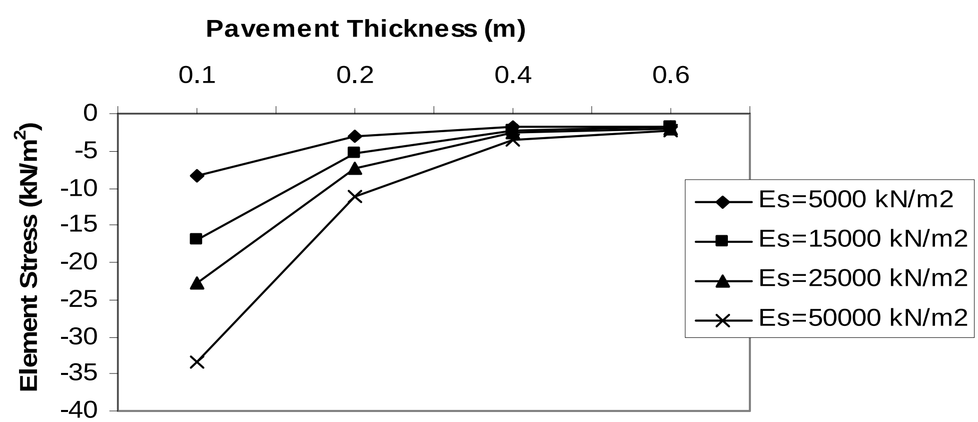


Fig.22 Design Chart (Pressure=2000 kN/m^2)

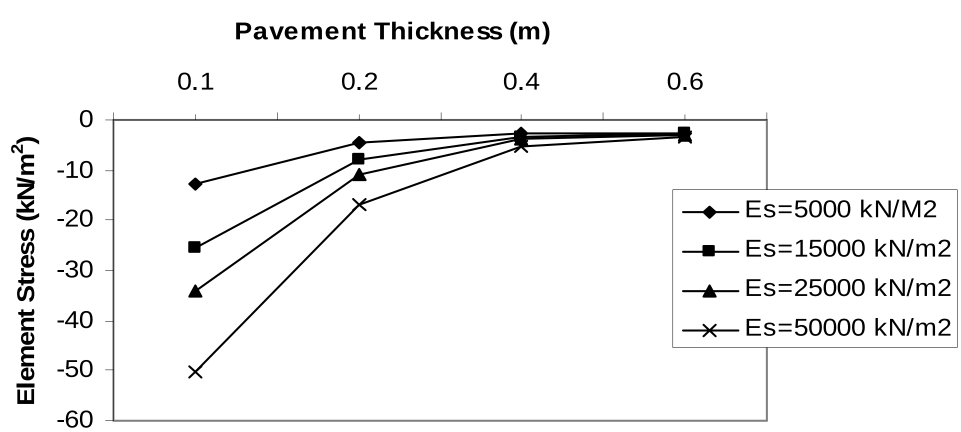


Fig.23 Design Chart (Pressure=3000 kN/m^2)

ACKNOWLEDGEMENTS

The first author acknowledges his chairman Trilochan Singh as well as Dean, Sachin Chawla for their moral support and wife and sons Ashish and Manish for their inspiration. The second author acknowledges his chairman, Er.L.D.Singhal for his moral support and wife and his loving son Dhruv Gill for their inspiration.

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