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The Behavior Of Rigid Pavement On Loose Sand By Nonlinear Finite Element Method

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ABSTRACT
In this research paper, finite element analysis under axisymmetric condition has been carried out in order to study the behaviour of rigid pavement. The concrete layer and subgrade have been discretized as four noded isoparametric finite elements. The concrete pavement has been considered as elastic medium. The material nonlinearity of the subgrade has been idealized by Drucker-Prager yield criterion. The finite element equations become nonlinear due to the material nonlinearity of the subgrade. These equations have been solved by Full Newton Raphson Method. Based on finite element analysis pressure vs nodal deflection, nodal stress, element stress curves; variation of nodal deflection, element stress with decreasing height have been obtained and studied. The pressure vs nodal deflection, nodal stress, element stress curves are nonlinear. For any pressure the element stress (Sigy) is more than the element stress (Sigx). For all pressures the nodal deflection decreases with decrease in height. For any height, the nodal deflection is less for lower pressure than the nodal deflection for higher pressure. For all pressures the element stress is maximum in the top portion and then it decreases with decreasing height. For any pressure the element stress is more in subgrade with lower modulus than the subgrade with high modulus. For any pressure the nodal deflection is more in subgrade with lower modulus than the subgrade with high modulus. The increase in nodal deflection increases with increase in pressure. The nodal deflection increases with increase in height for both the subgrades. For any height, the nodal deflection is more for subgrade with lower modulus than the subgrade with higher modulus. For any pressure, the nodal deflection for pavement thickness 100 mm is larger than the nodal deflection for pavement thickness 400 mm. This increase in nodal deflection increases with increase in pressure. For any pressure the element stress for pavement thickness 100 mm is more than the element stress for pavement thickness equal to 400 mm. This increase in element stress is seen more at higher pressure.
Keywords: Finite elements, rigid pavement, subgrade, nonlinearity, modulus

INTRODUCTION
Rigid pavements are those which possess note worthy flexural strength or flexural rigidity. The stresses are not transferred from grain to grain to the lower layers as in the case of flexible pavement layers. Rigid pavements are made up of Portland cement concrete-either plain, reinforced or prestressed concrete. The rigid pavement may or may not have a base course between the pavement and the subgrade. Due to its rigidity and high tensile strength, a rigid pavement tends to distribute the load over a relatively wider area of soil, and a major portion of the structural capacity is supplied by the slab itself. The rigid pavements are used for heavier loads and can be constructed over relatively poor subgrade i.e the subgrade with lower strength..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. On the other hand, pavement foundation geomaterials, i.e., the fine-grained soils in the subgrade, exhibit nonlinear behavior. Finite element programs that analyze pavement structures need to employ this kind of nonlinear characterization to more realistically predict pavement responses.

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 continous 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; however the finite element model results assuming a continuous foundation yielded higher stresses and displacements.

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.

Chou (1983) analyzed subgrade contact pressures under rigid pavements using the finite element method for concrete slabs on elastic subgrades. It was found that when the maximum bending stress in the slab is made in agreement in the two analyses, the deflections and subgrade contact pressures are much greater for elastic than for liquid subgrades. Although initial bending stresses in the concrete slab are well below the concrete strengths, excessive subgrade pressures undoubtedly cause large permanent deformations in the subgrade soil, possibly increasing the stresses in the concrete slab rapidly and eventually leading to early failure of the concrete pavement. The computation of large subgrade pressures at slab edges only in pavements with weak subgrade soil supports the Corps of Engineers design practice of reduction of pavement thickness for pavements with high subgrade *k* values, although bending stresses in the concrete slab are only slightly affected by variations in *k* values. Once initial cracking in the concrete slab has occurred, the large contact pressures at slab edges computed for concrete pavements on weak subgrade must have escalated multiple cracking in the concrete slab. The subgrade contact pressures under rigid pavements should be experimentally measured to verify the results computed by the finite element method.

Chou (1983) analyzed stress conditions in concrete pavements using the finite element method for slabs on elastic subgrades. The study consisted of the following parts: (1) The effect of the efficiency of load transfer across the joints; (2) the loading positions that produce the most critical stress and deflection conditions in the pavement; (3) the effect of temperature warping and gaps under the pavement; (4) the nonlinear effect due to the partial contact between the slabs and the supporting subgrade; (5) the stress conditions in the continuously reinforced concrete pavements; and (6) stress and deflection basins in the concrete slabs and the subgrade contact pressures. Implications of the computed results on pavement designs are discussed

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.

Guell (1985) presents a comparison of the design thickness of rigid pavement slabs as determined by the AASHTO and PCA methods. The comparison is given for a wide range of truck volumes and axle weights to represent the loadings that are likely to occur on facilities ranging from residential streets to major freeways. The effect of foundation strength on slab thickness is also examined for each design method

According to Kerr et.al (1985) blowups of concrete pavements are caused by axial compression forces induced in the pavements by a rise in temperature and moisture. Although numerous papers and reports have been published on this subject, they have not yet resulted in the development of a generally accepted analysis. The purpose of the study is to establish the blowup mechanism for concrete pavements and to provide an analysis for problems of this type. The analysis presented is based on the assumption that blowups are caused by lift off buckling of the pavement. A "safe" temperature and moisture increase in the pavement was defined; how it is affected by various pavement subgrade parameters is shown

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

According to Larralde and Chen (1987), Highway rigid pavements, such as many of the constructed facilities of the nation, have been deteriorating, some even beyond functional failure, due to excessive loading, environmental effects, and chemical attack of the material components. A method to estimate the mechanical deterioration of highway rigid pavements caused by repetitive traffic loading is presented. In the method presented here, erosion, fatigue, and joint faulting are recognized as mechanisms of failure in highway rigid pavements. A nonlinear analysis with finite elements is used to calculate the repetitive stresses and strains caused by traffic. Decay of slab stiffness and load transfer efficiency, as well as pumping and amount of damage, are obtained as a function of traffic volume and pavement properties

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.

Hadi and Arfiadi (2001) states 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.

Darestani et. al (2006) states 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.

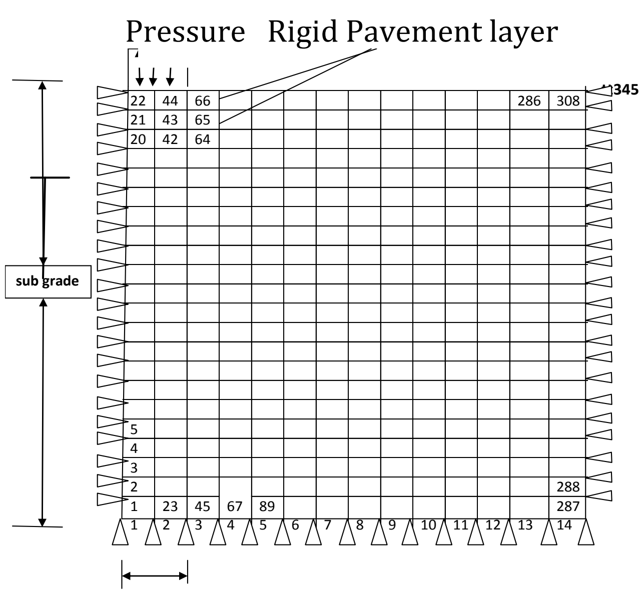
Long and Shatnawi (2011) address the structural performance of experimental rigid pavements constructed in California. The experimental project consists of seven Portland
Cement concrete pavement sections with various layer structures. Falling weight deflectometer was utilized to conduct deflection testing 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

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 has been observed that very few analyses for rigid pavement has been done by finite element method. Hence there is need for finite element analyses of rigid pavement specially considering nonlinear material behaviour of subgrade to understand the behaviour of rigid pavement.

FINITE ELEMENT ANALYSIS

In this research axisymmetric finite element analyses have been done by considering subgrade soil (loose sand) as a nonlinear material. The material nonlinerity 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 pavement concrete has been idealized as linear elastic material. The pavement concrete, the subgrade have been discretized by four noded isoparametric finite elements.
Total number of nodes and elements considered:
The total number of nodes considered = 345
Total number of element considered =308.
Domain Considered:
The horizontal domain considered= 20 times the radius of pressure.
The vertical domain considered = Approximately140 times the radius of pressure.
The boundary conditions considered:
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
Thickness of pavement and base course considered:
The thickness of pavement concrete considered=100 mm and 400 mm.
Pressure varies from 100 to 3000 kN/m^2
Pressure acts at radius 150 mm.



a =Radius of Pressure =150mm(Fig not to scale)
Fig 1Finete Element Discretization for Rigid pavement without Base course

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

Properties of Subgrade (Loose Sand):

(1)Modulus of elasticity=10000 kN/m^2, Poisson's Ratio=0.20, Cohesion (C)= 0.0 kN/m^2
$\varphi = \psi = 30^0$

(2) Modulus of elasticity=20000 kN/m^2,Poisson's Ratio=0.30, Cohesion (C)=0.0 kN/m^2
$\varphi = \psi = 33^0$

RESULTS AND DISCUSSIONS

Fig.2 shows the pressure vs nodal deflection curve for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. The initial portion of the curve is linear. After pressure 200 kN/m^2 the pressure vs nodal deflection curve is nonlinear. The nonlinearity of the curve increases with increase in pressure.

Fig.3 shows the pressure vs nodal stress (Sigx) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. The nature of the curve is similar to the curve of Fig.2. The nonlinearity of the curve starts from pressure 200 kN/m^2. The nonlinearity increases with increase in pressure.

Fig.4 shows the pressure vs nodal stress (Sigy) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. The nature of the curve is similar to the curve of Fig.3. Even for this curve, the nonlinearity starts from pressure 200 kN/m^2. In this curve for the same pressure the nodal stress (Sigy) is more than the nodal pressure (Sigx) of curve of Fig.3.

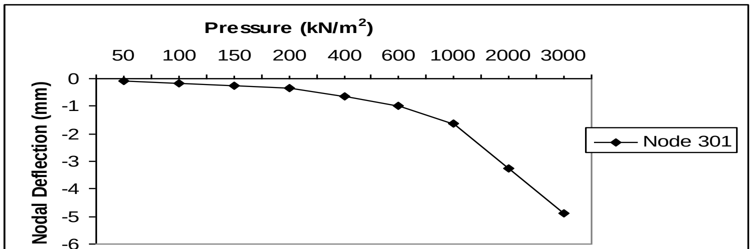


Fig.2 Pressure vs Nodal Deflection Curve, Thickness=400 mm, Es=10000 kN/m^2

Fig.5 shows the pressure vs element stress (Sigx) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. The element stress has been considered for element number 20. This element is a subgrade element just below the rigid pavement element. The nature of the curve is nonlinear.

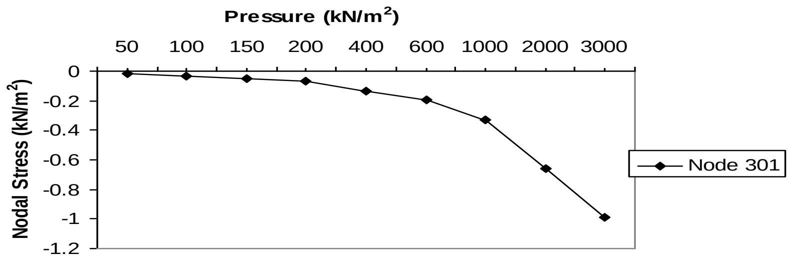


Fig.3 Pressure vs Nodal Stress (Sigx) Curve, Thickness=400 mm, Es=10000 Kn/m^2

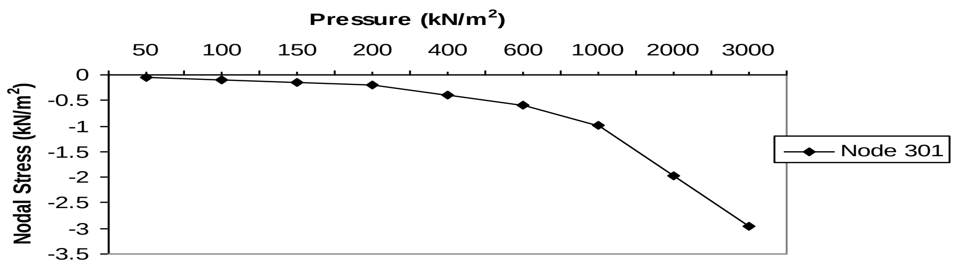


Fig.4 Pressure vs Nodal Stress (Sigy) Curve, Thickness=400 mm, Es=10000 kN/m^2

Fig.6 shows the pressure vs element stress (Sigy) curve for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. The nature of this curve is similar to the curve of Fig.5 i.e the curve is nonlinear. For any pressure the element stress (Sigy) (Fig.6) is more than the element stress (Sigx) of Fig.5. That is, the element stress in y-direction is more than the element stress in the x-direction.

Fig.7 shows the variation of nodal deflection with depth for pressures 100 , 400 and 1000 kN/m^2 for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/m^2. For all pressures the nodal deflection decreases with decrease in height. For any height, the nodal deflection is less for lower pressure (100 kN/m^2) than the nodal deflection for higher pressure (1000 kN/m^2). For pressure 400 N/m^2, the nodal deflection is same above height 20.7 m. Similarly the nodal deflection for pressure 1000 kN/m^2 is same above height 20.7 m.

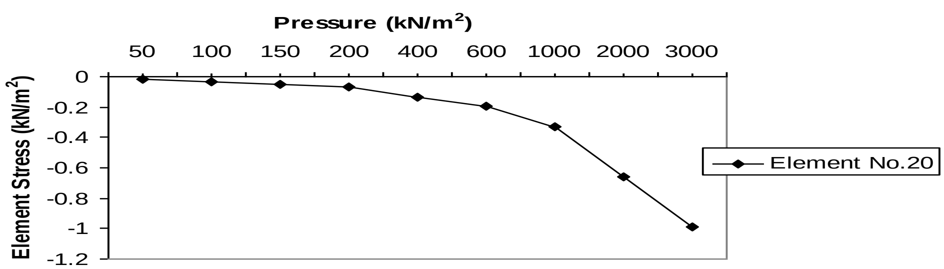


Fig.5 Pressure vs Element Stress (Sigx) Curve, Thickness=400 mm, Es=10000 kN/m^2

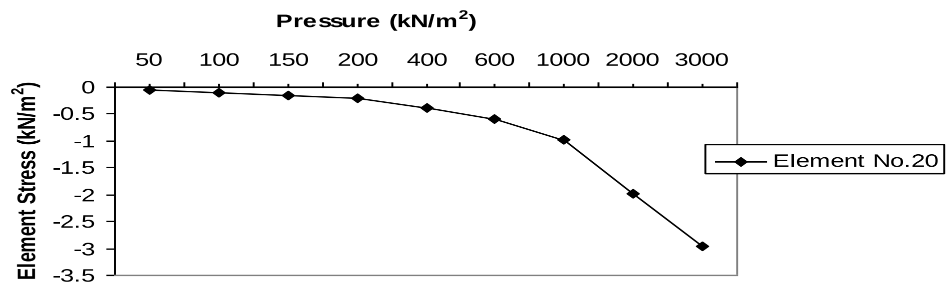


Fig.6 Pressure vs Element Stress (Sigy) Curve, Thickness=400 mm, Es=10000 KN/m^2

Fig.8 shows the variation of element stress with height for pressures 100 , 400 and 1000 kN/m^2 for pavement thickness equal to 400 mm and subgrade modulus equal to 10000 kN/^{2}. For all pressures the element stress is maximum in the top portion and then it decreases with decreasing height. For all pressures, the element stress is almost zero below height 21.0375 m. Above this height, the element stress increases. The increase in element stress is more at higher pressure (1000 kN/m^2) than at lower pressure (100 kN/m^2).

Fig.9 shows the pressure vs nodal deflection curve for pavement of thickness equal to 400 mm for two subgrade moduli, equal to 10000 and 20000 kN/m^2. The nature of both the curves is nonlinear. For any pressure the nodal deflection is more in subgrade with lower modulus than the subgrade with high modulus. The increase in nodal deflection increases with increase in pressure.

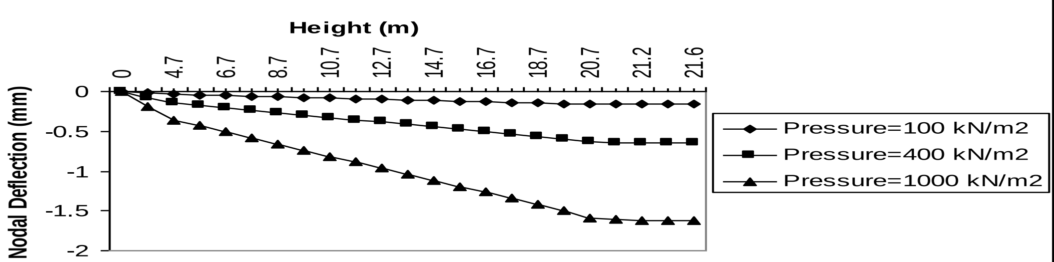


Fig.7 Variation of Nodal Deflection with Depth, Thickness=400 mm, Es=10000 kN/m^2

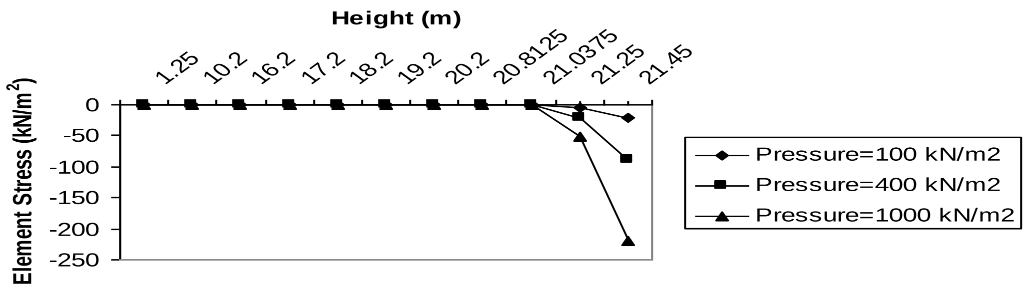


Fig.8 Variation of Element Stress (Sigy) with Depth, Thickness=400 mm, Es=10000 kN/m^2

Fig.10 shows the variation of nodal deflection with decreasing height for pavement thickness 400 mm and pressure 1000 kN/m^2 for two subgrade moduli equal to 10000 and 20000 kN/m^2. The nodal deflection increases with increase in height for both the subgrades. For any height, the nodal deflection is more for subgrade with lower modulus (10000 kN/m^2) than the subgrade with higher modulus (20000 kN/m^2).

Fig.11 shows the pressure vs nodal deflection curve for subgrade of modulus 10000 kN/m^2 for pavement thickness 100 and 400 mm. Both the curves of thickness 100 and 400 mm are nonlinear. For any pressure, the nodal deflection for pavement thickness 100 mm is larger than the nodal deflection for pavement thickness 400 mm. This increase in nodal deflection increases with increase in pressure.

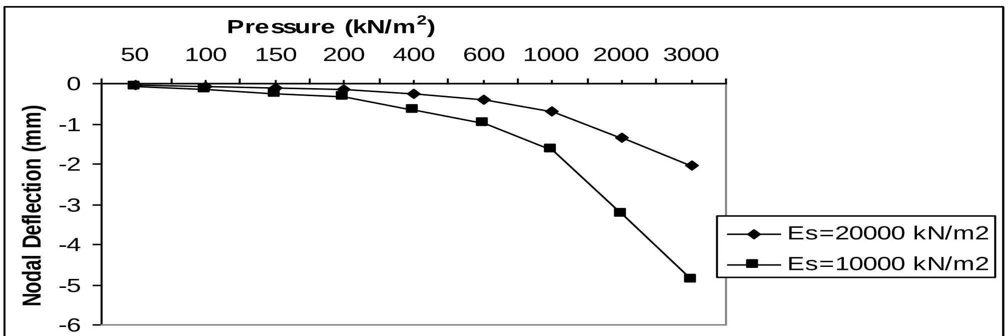


Fig.9 Pressure vs Nodal Deflection Curve, Thickness=400 mm

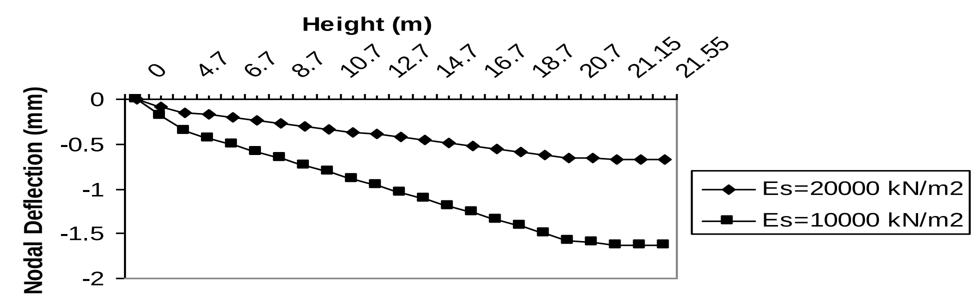


Fig.10 Variation of Deflection with Depth, Pressure=1000 kN/m², Thickness=400 mm

Fig.12 shows the pressure vs element stress curve for subgrade modulus equal to 10000 kN/m² for pavement thickness 100 and 400 mm. Both the curves are nonlinear. For any pressure the element stress for pavement thickness 100 mm is more than the element stress for pavement thickness equal to 400 mm. This increase in element stress is seen more at higher pressure. This is because in case of thicker pavement the maximum pressure is taken by the pavement itself.

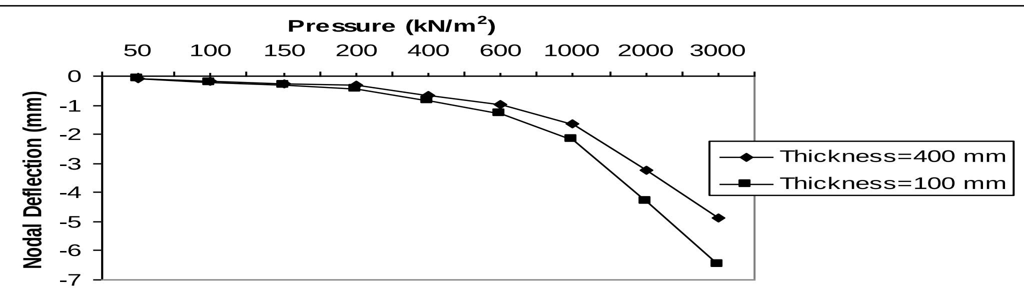


Fig.11 Pressure vs Nodal Deflection Curve, Es=10000 kN/m²

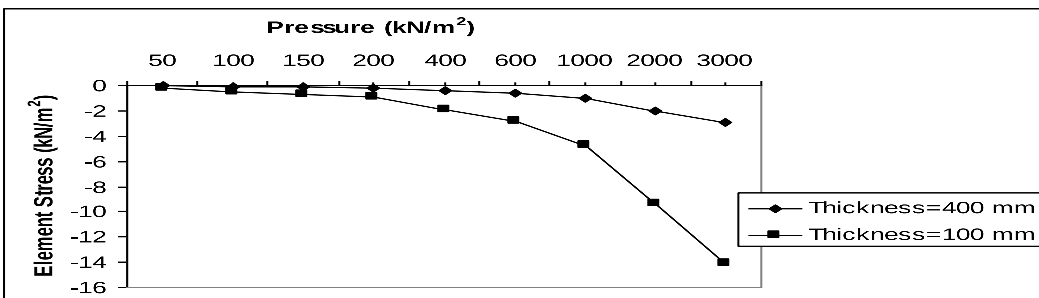


Fig.12 Pressure vs Element Stress (Sigy) Curve, Es=10000 kN/m²

CONCLUSIONS

In the pressure vs nodal deflection curve the initial portion of the curve is linear. After that the curve is nonlinear. The nonlinearity of the curve increases with increase in pressure. The pressure vs nodal stress (Sigx & Sigy) curves are nonlinear. In this curve for the same pressure the nodal stress (Sigy) is more than the nodal pressure (Sigx). The
pressure vs element stress (Sigx & Sigy) curves are nonlinear. For any pressure the element stress (Sigy) is more than the element stress (Sigx). For all pressures the nodal deflection decreases with decrease in height. For any height, the nodal deflection is less for lower pressure than the nodal deflection for higher pressure. For all pressures the element stress is maximum in the top portion and then it decreases with decreasing height. For all pressures, the element stress is almost zero below height 21.0375 m. Above this height, the element stress increases. The increase in element stress is more at higher pressure than at lower pressure. For any pressure the element stress is more in subgrade with lower modulus than the subgrade with high modulus. For any pressure the nodal deflection is more in subgrade with lower modulus than the subgrade with high modulus. The increase in nodal deflection increases with increase in pressure. The nodal deflection increases with increase in height for both the subgrades. For any height, the nodal deflection is more for subgrade with lower modulus (10000 kN/m^2) than the subgrade with higher modulus (20000 kN/m^2). For any pressure, the nodal deflection for pavement thickness 100 mm is larger than the nodal deflection for pavement thickness 400 mm. This increase in nodal deflection increases with increase in pressure. For any pressure the element stress for pavement thickness 100 mm is more than the element stress for pavement thickness equal to 400 mm. This increase in element stress is seen more at higher pressure.

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