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THE BEHAVIOUR OF RIGID PAVEMENT BY NONLINEAR FINITE ELEMENT METHOD

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Abstract- In this research, axisymmetric finite element method has been carried out to study the behavior of rigid pavement. The concrete layer, base course and sub grade have been discretized as four noded isoperimetric finite elements. The top concrete pavement and the base course have been considered as elastic medium. The material nonlinearity of the sub grade has been idealized by Drucker-Prager yield criterion. The finite element equations become nonlinear due to the nonlinear behavior of the sub grade. The nonlinear finite element equations have been solved by Full Newton Raphson Method. Based on finite element analysis pressure vs settlement, nodal stress, element stress curves; variation of nodal deflection, element stress with decreasing height and variation of deflection in horizontal direction have been obtained. Also comparison of pressure vs settlement, element stress, variation of nodal deflection, element stress with decreasing height have been made for rigid pavement with base course and rigid pavement without base course. It has been found that the pressure vs settlement, nodal stress, element stress curves are nonlinear. Hence material nonlinearity considered represents the actual behavior of the rigid pavements. The settlement obtained in the horizontal direction is almost uniform which shows the rigid behavior of the pavement. The variation of nodal deflection with depth and the element stress with depth are nonlinear. The comparison shows that the deflection and element stress of rigid pavement with base are less than the that of rigid pavement without base. When compared, the nodal deflection with depth is more for rigid pavement without base course than the rigid pavement with base course. The stress in rigid pavement with base course is more than the stress in rigid pavement without base.

Keywords: Finite element method, material nonlinearity, pressure, stress, deflection.

I. INTRODUCTION

A pavement is defined as a relatively stable crust constructed over the natural soil for the purpose of supporting and distributing the wheel loads and providing an adequate wearing surface. Rigid pavements are made up of Portland cement concrete, and may or may not have a base course between the pavement and the sub grade. Because of its rigidity and high tensile strength, a rigid pavement tends to distribute the load over a relatively wide area of soil, and a major portion of the structural capacity is supplied by the slab itself. For this reason, minor variations in sub grade 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, 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.

II. 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 Westergaardís equation. In general Westergaardís 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 Winklerís foundation . Verification of models developed with ILLI-SLAB was achieved by comparison with theoretical solutions for stresses and displacements. The results compared well.

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.

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) presents 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.

III. 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 nonlinear finite element equation has been solved by Full Newton Raphson Iterative Procedure. The concrete as well as the base course have been idealized as linear elastic material. Fig.1 shows the finite element discretization considered in the finite element analysis. The concrete, base course and the subgrade have been discretized by four noded isoparametric finite elemnts. The total number of nodes considered are 345 and total number of element considered are 308. The horizontal domain of discretization considered in the analysis is about 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 thickness of concrete pavement considered is 100 mm and the thickness of base course considered is 450 mm. The pressure acts at radius 150 mm

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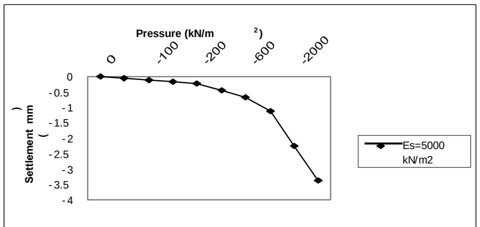
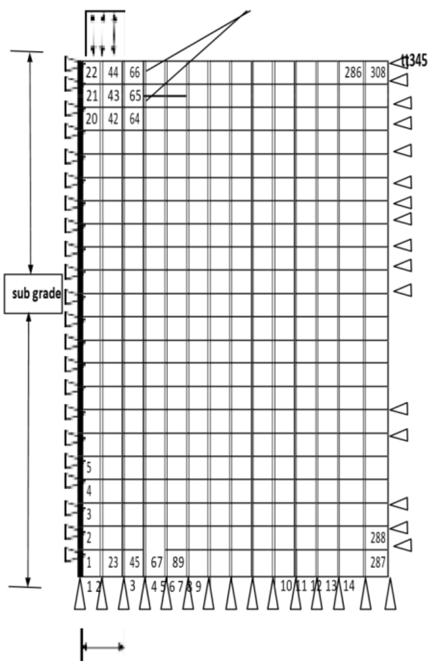


Fig.2 Pressure vs Settlement Curve

Pressure Rigid pavement layer



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

Fig.1(a). Finite Element Discretization for Rigid Pavement without Base course **Material Properties**

Elastic Modulus of Concrete Pavement= 20000000 kN/m^2,

Poissonís Ratio=0.30

Elastic Modulus of Base Course = 207000 kN/m^2,

Poissonís Ratio=0.40

Elastic Modulus of Subgrade = 5000 kN/m^2,

Poissonís Ratio=0.45

Cohesion of Subgrade =25 kN/m^2

Fig.5 shows the pressure vs element stress (sigx) curve. The element considered is the element number 18. This element is the first element located centrally below the base. The curve is linear upto 200 kN/m^2 and then become nonlinear. At pressure 400 kN/m^2 it shows nonlinearity. As pressure increases nonlinearity also increases. Fig.6 shows the pressure vs element stress (Sigy) curve. The range in magnitude of the element stress (Sigy) is more than the range of element stress (Sigx). The nature of this curve is similar to the pressure vs element stress (Sigx) curve. This curve also consists linear and nonlinear portion showing the elastic and nonlinear behaviour.

IV. RESULTS AND DISCUSSIONS

Fig.2 shows the pressure vs deflection (settlement) curve. The initial portion of the curve is linear and then it become nonlinear.The curve is linear upto pressure 200 kN/m^2 and then it is nonlinear. The nonlinearity of the curve increases with increase in pressure. In the initial portion of the curve the pressure is directly proportional to deflection. After that the increase in deflection (settlement) is more than the increase in pressure.

Fig.3 shows the pressure vs Nodal Stress (sigx) curve. The pressure is negative while the nodal stress is positive. The curve is linear in the initial portion upto 200 kN/m^2 and then it bends in the upward direction. This is because the nodal stresses are positive. At higher pressure the bend is more than at lower pressure. The nonlinear curve shows that the nonlinear model considered in the analysis i.e the Drucker- Prager model simulates correctly the material nonlinearity.

Fig.4 shows the pressure vs nodal stress (sigy) curve. The nature of the curve is similar to the pressure deflection curve. In this case the curve bends downward direction. The range of magnitude of nodal stress (sigx) is more than the magnitude of nodal stress (sigy). Even this curve is linear for small pressure and then at high pressure the curve becomes nonlinear. The Drucker-Prager model considered for material nonlinearity correctly simulates the subgrade.

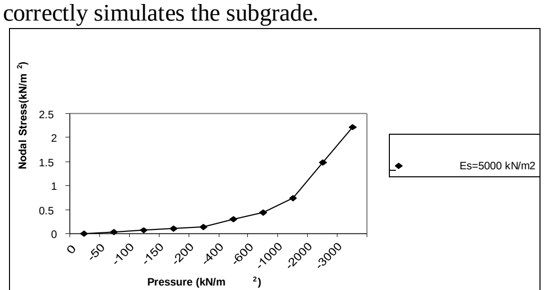


Fig.3 Pressure vs Nodal Stress (Sigx) Cur e

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Fig.7 shows the variation of deflection (settlement) in the horizontal direction from centre towards right direction for a height 21 m. The deflection is same for the radius of pressure range and then the deflection (settlement) decreases. It is minimum at the extreme right end. At the centre the deflection is 3.3734 mm and remains same upto radius of pressure range of 0.150 m and then it decreases and at the end it is 2.6182 mm.

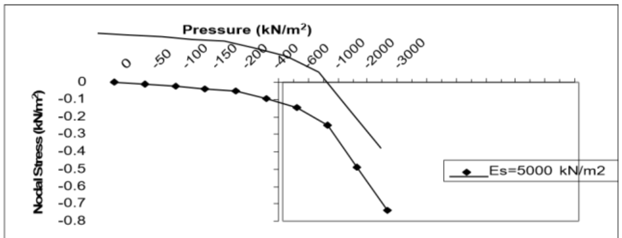

Fig.4 Pressure vs Nodal Stress (sigy) Curve

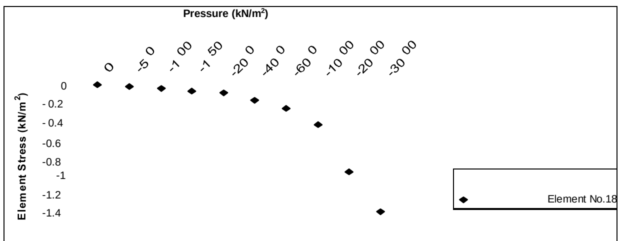

Fig.5 Pressure vs Element Stress (Sigx) Curve

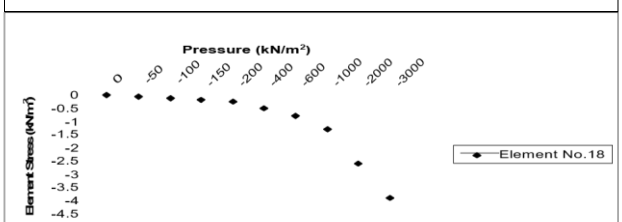

Fig.6 Pressure vs Element Stress (Sigy) Curve

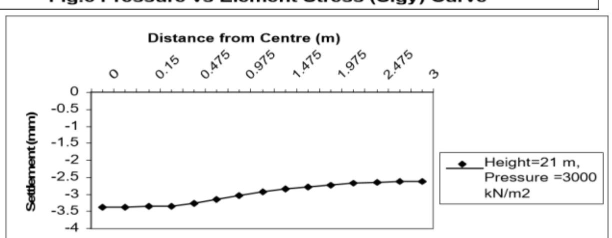

Fig.7 Variation of Settlement in Hor. Direction

Fig.8 shows the variation of deflection (settlement) with depth for two pressures equal to 400 kN/m^2 and 1000 kN/m^2. The deflection is maximum in the top portion and then it decreases with depth. In the top portion upto 21 m the variation is nonlinear for both the curves and then it shows linear variation. For any depth the deflection is more for the 1000 kN/m^2 pressure than the deflection for 400 kN/m^2 pressures.

Fig.9 shows the variation of element stress (sigy) with depth for three different pressures. The stress is same for all the three curves for height equal to 20.5 m. Above this height the stress is different for the three curves. The variation of element stress is nonlinear for all the three curves. The value$_2$ of element stress is maximum for pressure 1000 kN/m and minimum for pressure 100 kN/^{2} while the value is in between the two for pressure equal to 400 kN/m^2.

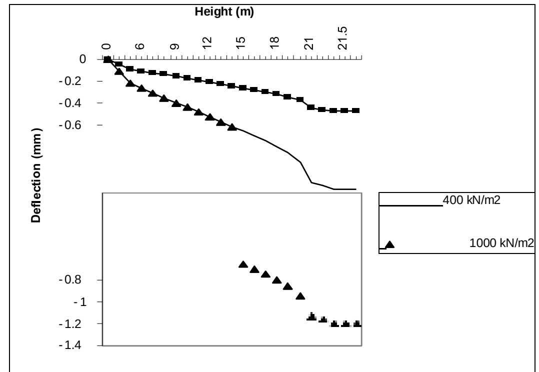

Fig.8 Variation of Deflection with Depth

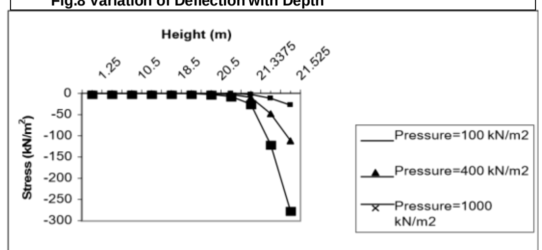

Fig.9 Variation of Element Stress with Depth

Fig.10 shows the pressure vs deflection (settlement) curve for rigid pavement with base and rigid pavement without base at node just on the subgrade. At any pressure the deflection (settlement) is more for the the rigid pavement without base than the rigid pavement with base. This indicates that providing the base is important to reduce the settlement of the rigid pavement.

Fig.11 shows the pressure vs element stress (sigx) curves. The curves are for rigid pavement with base and rigid pavement without base. It can be seen that for any pressure the element stress for rigid pavement without base is more than the element stress for rigid pavement with base. This increase in element stress is more at high pressure than at lower pressure. The nature of both the curves is nonlinear. This nonlinearity increases more with increase in pressure.

Fig.12 shows the pressure vs element stress (sigy) curves. The stress in element for rigid pavement with base is less than the stress for rigid pavement without base. The natures of both the curves are nonlinear. This nonlinearity increases with increase in pressure.

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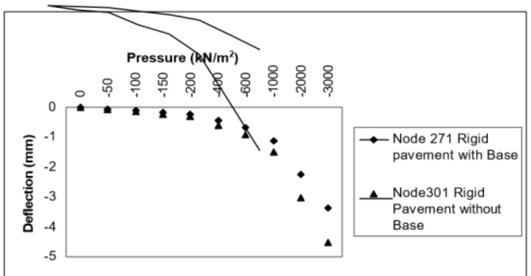

Fig.10 Comparison of Pressure vs Deflection

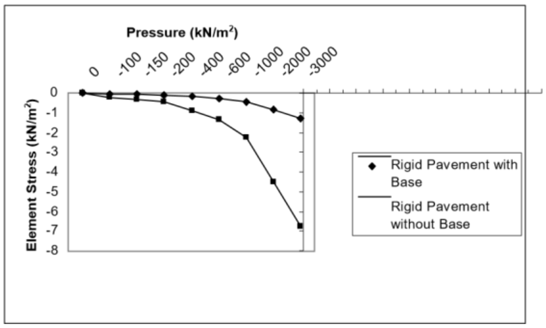

Fig.11 Pressure vs Element Stress (Sigx) Curve

Fig.13 shows the variation of nodal deflection with depth ie decreasing height for pressure 400 kN/m^2. The nodal deflection is more in the top portion and then decreases with decrease in depth. The nodal deflection is more for rigid pavement without base than the nodal deflection for rigid pavement with base. Hence if the deflection (settlement) is to be reduced for rigid pavement without base, the base course must be

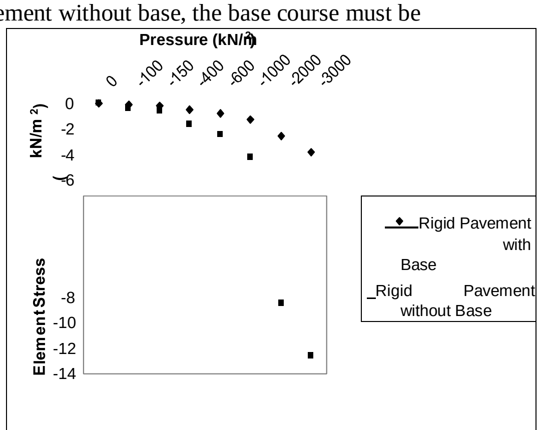

Fig.12 Pressure vs Element Stress (gy)

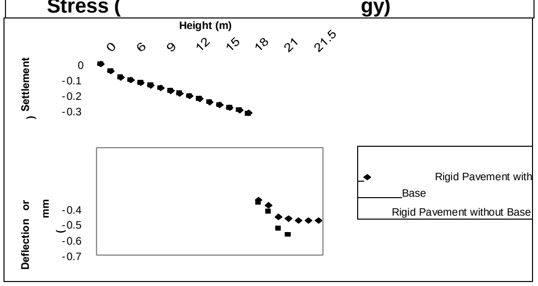

Fig.13 Variation of Deflection with Depth

(Pressure=400 kN/m²)

Fig. 14 shows the depth vs element stress curve for pressure 1000 kN/m^2. The curves for rigid pavement with base and the rigid pavement without base are nonlinear. The stress for both the curves decreases with decrease in height. Below depth 20.5 m the stress in both the cases is negligible. The stress in rigid pavement with base is more than the stress in rigid pavement without base.

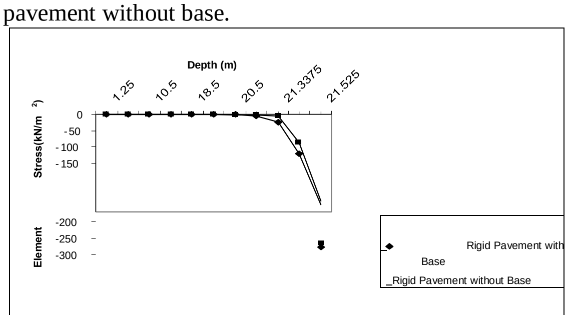

Fig.14 Variation of Element Stress with Depth

(Pressure 1000 kN/m²)

V. CONCLUSIONS

It has been found that the pressure vs settlement, nodal stress, element stress curves are nonlinear. Hence material nonlinearity considered represents the actual behaviour of the rigid pavements. For same height the value of deflection (settlement) is more for higher pressure than for lower pressure. The variation of deflection (settlement) with decreasing height is nonlinear The element stress is maximum in the top element and then it decreases in elements with decreasing height. The settlement obtained in the horizontal direction is almost uniform which shows the rigid behaviour of the pavement. The variation of nodal deflection with depth and the element stress with depth are nonlinear. The comparison shows that the deflection and element stress of rigid pavement with base course are less than that of rigid pavement without base. Hence to reduce settlement (deflection) base course must be provided. When compared, the nodal deflection with depth is more for rigid pavement without base course than the rigid pavement with base course. The stress in rigid pavement with base course is more than the stress in rigid pavement without base.

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