To Experimental Study of Comparison and Development of Design for Rigid Pavement by Finite Element Method

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***Abstract*— *The development of design have been discussed adopted various types methods use. The Hadi and Arfiadi Method presents a formulation for the optimum rigid road pavement design by genetic algorithm, a new method. The Westergaard's Method determines the stresses in the rigid concrete slab and also the pressure-deformation curve which depend upon the relative stiffness of the slab and the subgrade. Razouki and Al-Muhana also developed stress charts similar to Westergaard's method. 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 The Maharaj and Gill method have performed axisymmetric finite element analysis by varying parameters, the thickness of pavement, pressure and elastic modulus of subgrade. The advantage of this method is that four types of design charts have been presented which other methods have note done. 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. Each of the design charts has three parameters. For two known parameters, the third parameter can be obtained.*

Keywords*— *Rigid pavement, Design Chart, Elastic Modulus of Subgrade, Finite Element Analysis, Thickness of Pavement.

I. 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. 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. The various layers of the rigid pavement structure have different strength and deformation characteristics.

II. LITERATURE REVIEW

Channakeshava et.al (1993) present nonlinear finite element analysis of dowel jointed concrete pavements. The nonlinearities considered are cracking of concrete in tension, compressive yielding of concrete, and loss of support due to lift off of pavements because of temperature gradients. Smeared cracking representation of cracks in concrete and a plasticity based material model are employed. Loss of support due to removal of subgrade material through pumping is considered. Analysis of a doweled joint subjected to shear loading is performed to obtain dowel concrete interface response characteristics. Analyses of plain concrete pavements subjected to self weight, temperature gradients, and static wheel loads are performed with four different extent of loss of subgrade support and two different dowel concrete interface characteristics. The loss of subgrade support may lead to a rapid deterioration of pavements through fatigue, by increasing the tensile stress level in concrete. Faulting of slabs may also be due to loss of support at the far end of the slabs. Softening of the dowel concrete interface stiffness significantly affects the efficiency of the joint in transferring the loads. Nighttime temperature curling further increases the stresses due to lift off of slabs at the ends, while daytime temperature curling is found to be less critical.

Lau et.al (1994) calculates shear stresses at the interface between an existing concrete pavement and an overlay using the finite element method for different loading conditions. The effects of vertical wheel loads, temperature loading, and wheel braking forces are considered. Perfect bonding between the overlay and the pavement is assumed. The pavement overlay slab is modeled using thin plate elements for calculating the stresses due to the vertical wheel load and temperature gradient. In analysis for stresses due to wheel braking loads, the slab is modeled with solid elements. The results are checked against Cerrutti's closed form solution in the case of horizontal wheel braking. The computed shear stresses at the pavement overlay interface for typical values of pavement and overlay thicknesses, wheel loads, and thermal gradients are compared to report values of shear strength of laboratory prepared overlaid specimens. The shear stresses at the interface are found to be small in relation to the interfacial bond strength of laboratory prepared overlaid specimens. The findings suggest that un-bonding in overlay construction in the field is likely to be caused by stress concentrations due to local defects.

Zaman and Alvappillai (1995) developed a finite-element algorithm to analyze the dynamic response of multiple, jointed concrete pavements to moving aircraft loads. In the finite-element idealization, the pavement-subgrade system is idealized by thin-plate finite elements resting on a Winkler-type visco-elastic foundation represented by a series of distributed springs and dashpots. The dowel bars at the transverse joints are represented by plane frame elements. The dowel-pavement interaction effects are accounted for by employing contact elements between the pavement and the dowel bar. Keyed joint or aggregate interlock joint is assumed for the longitudinal joint and is represented by vertical spring elements. The dynamic aircraft-pavement interaction effects are considered in the analysis by modeling the aircraft by masses supported by spring-dashpot systems representing the landing gear of the aircraft. The accuracy of the computer code developed is verified by the available experimental and analytical solutions.

Bright and Mays (1996) analyzed a construction method for rigid pavement utilizing waste plastic for forms to create for stress resulting from application of a standard highway equivalent single axle load (ESAL). The finite-element method is used. The analysis parametrically studied varying slab, base, sub-base, and subgrade thickness and elastic properties and two different tire pressures. Stresses are compared to those in a solid slab under the same loading conditions. Although the stresses in the cellular rigid pavement are higher than in the solid slab, the maximum principal stresses are shown to be within a range that would allow the use of this method for rigid pavement construction. Depending on requirements for load resistance and fatigue criteria, significant savings of material and cost can result. The method reduces material use and the energy required to produce it by approximately 25 and reuses waste product.

Masad et.al (1996) presents the finite-element study of the effect of temperature variation on plain-jointed concrete pavements. Temperature variation causes curling and thermal-expansion stresses. Curling stresses result from temperature gradients through a slab depth. Thermal-expansion stresses are induced due to uniform changes in temperature that cause the slab to expand. The developed three-dimensional (3D) model consists of four slabs separated by longitudinal and transverse joints. The interaction between the ground and the concrete slab along with interaction at the joints were modeled using interface elements. These elements gave the model the capability to solve for partial contact between curled slabs and the ground to investigate the effect of compressive stresses that may develop at the joints during curling, and to study the influence of friction between slabs and the ground. The data obtained using the finite-element model has shown reasonable agreement with the results obtained from three computer models: KENSLABS, ILLI-SLAB, JSLAB, and the analytical solution proposed by Bradbury. The best correlation was obtained with JSLAB. The model was used to perform parametric studies on curling and thermal-expansion stresses to study the effect of superposition of both stresses and to address the effect of uniform temperature changes on joint opening. Another simpler model using nine layers across the depth of a pavement slab was used to introduce the effects of nonlinear temperature distribution. The results of the parametric studies are presented and compared with other solutions. The arithmetic addition of positive curling stresses and thermal-expansion stresses were less than those stresses obtained by superposition. In some cases, the calculated joint openings were higher than the allowable joint opening. Nonlinear temperature distribution caused higher tensile stresses than the linear distribution of temperature.

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

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 sub base 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) 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.

Maharaj and Gill (2014) performed axisymmetric finite element analysis 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. Four types of design charts have been developed.

Based on literature review it is found that very few literatures have been reported on design charts of rigid pavements. Important design charts have been discussed in the following section.

III. METHOD FOR RIGID PAVEMENT

3.1 Razouki and Al-Muhana Method

Razouki and Al-Muhana 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

3.2 Hadi and Arfiadi Method

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.

3.2.1 Westergaard's Method

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 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

3.2.2 Gill and Maharaj Method

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.

Typical design charts have been shown in Figs. in the following section.

Fig.6 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 from100 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.7, Fig.8 and Fig.9 are similar design charts as for Fig.6. In these design charts, the reduction of settlement with increase in thickness is predominant at higher elastic modulus of soil.

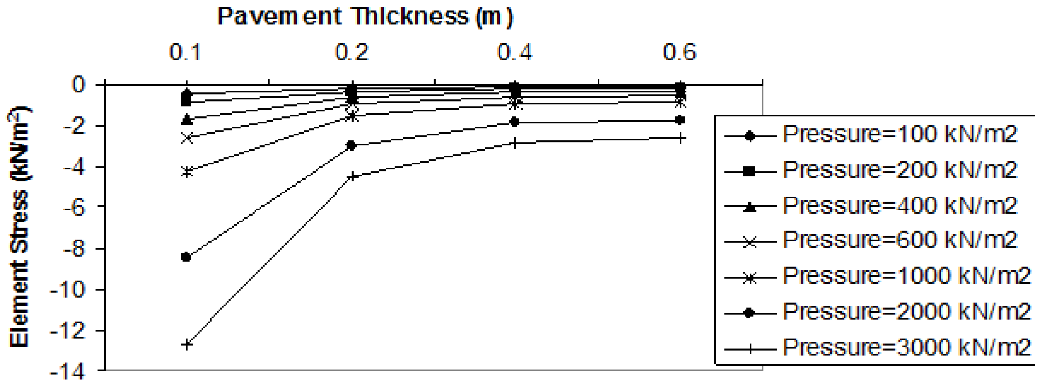

FIG. 1: DESIGN CHART (E_s=5000kN/m^2)

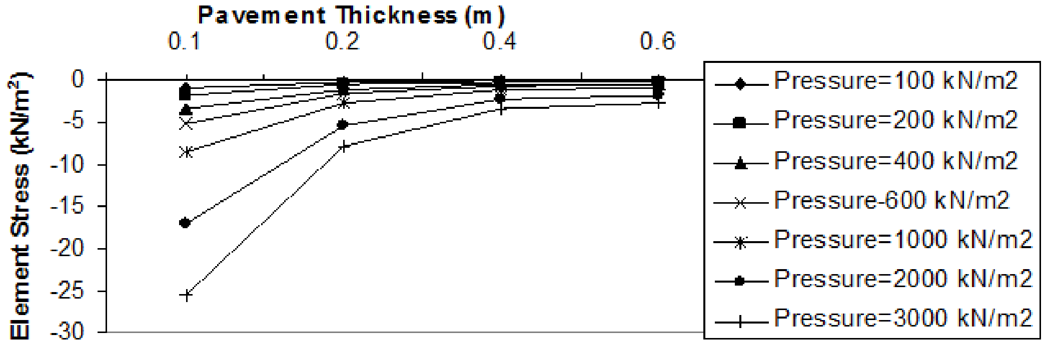

FIG. 2: DESIGN CHART (E_s=15000kN/m^2)

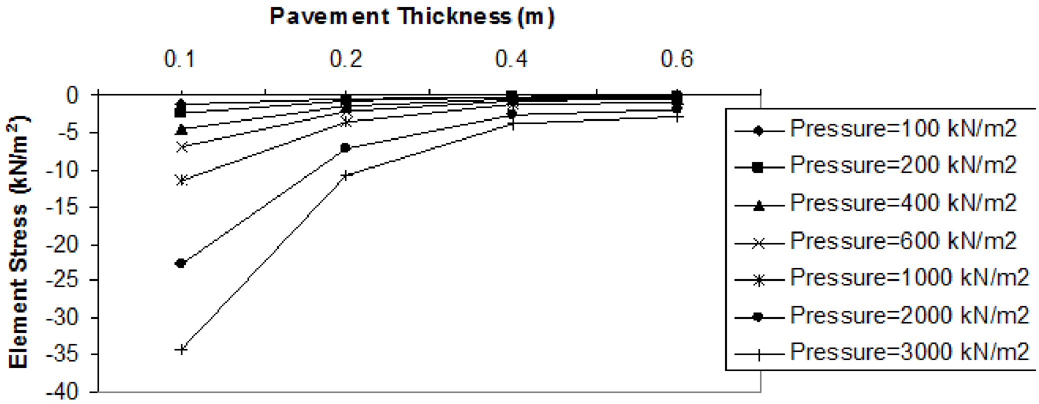

FIG. 3: DESIGN CHART (E_s=25000kN/m^2)

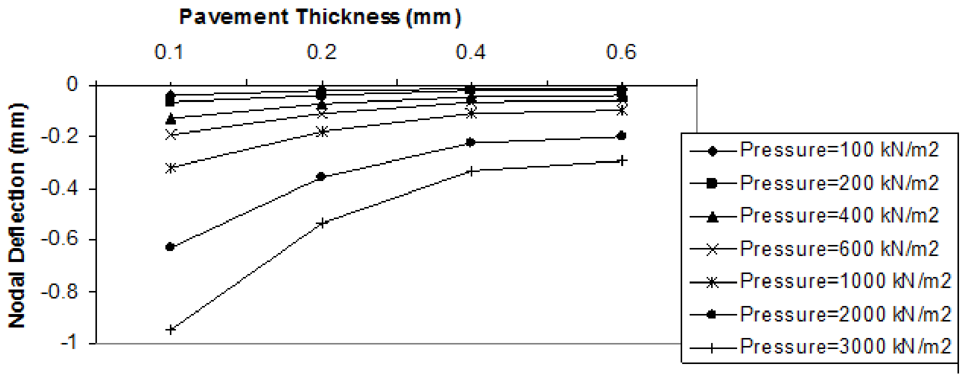

FIG. 4: DESIGN CHART (E_s=50000kN/m^2)
(AFTER MAHARAJ AND GILL, 2014)

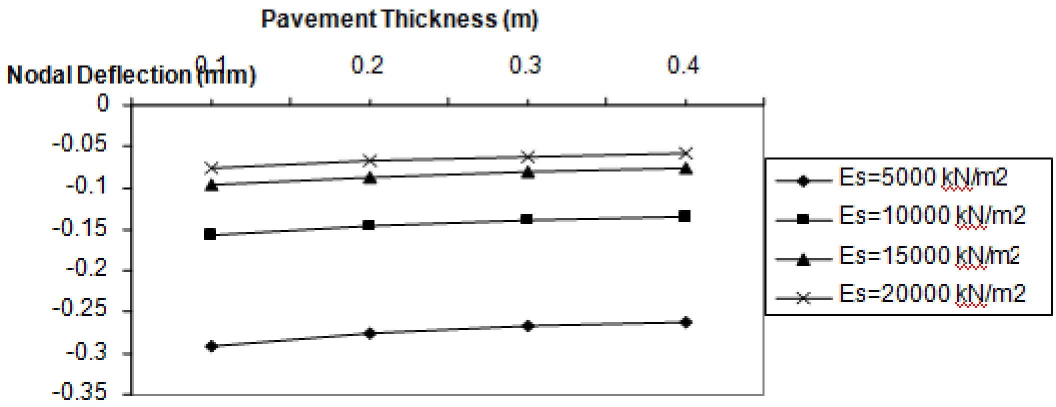

FIG. 6: DESIGN CHART, PRESSURE=100 kN/m^2

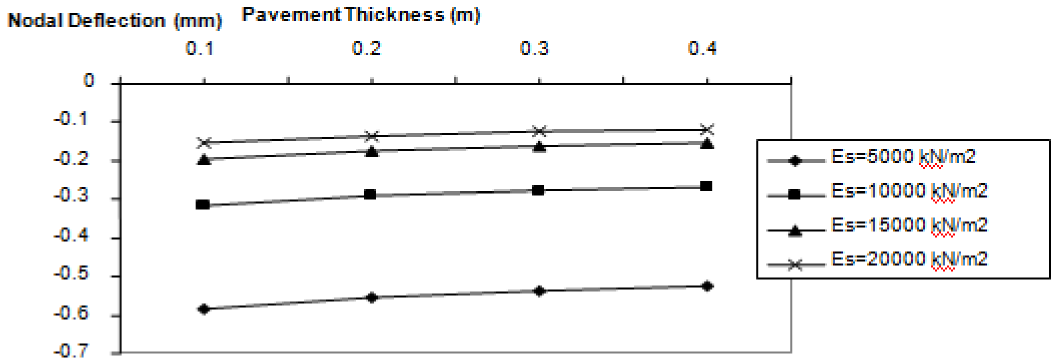

FIG.7: DESIGN CHART, PRESSURE=200 kN/m^2

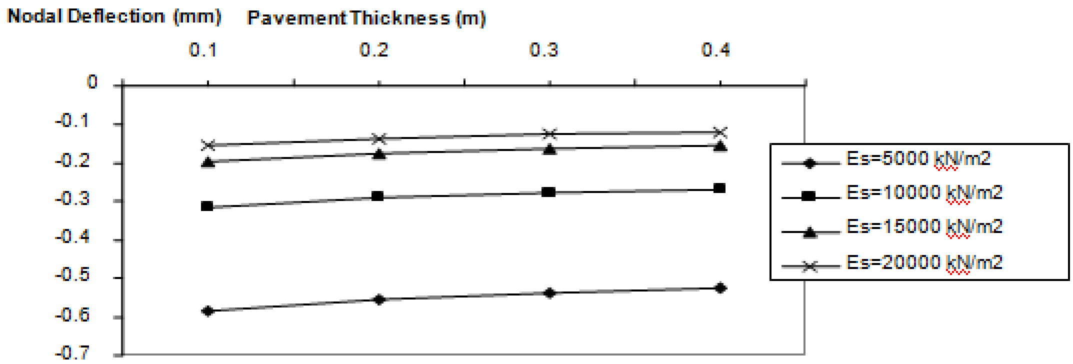

FIG.8: DESIGN CHART, PRESSURE=400 kN/m^2

IV. CONCLUSION

The advantage of the Hadi and Arfiadi Method is that it presents a formulation for the problem of optimum rigid road pavement design by genetic algorithm a new method. The advantage of Westergaard's Method is that the stresses in the rigid concrete slab are determined by this method and also the pressure-deformation curve which depends upon the relative stiffness of the slab and the subgrade are presented. Razouki and Al-Muhana also developed stress charts similar to Westergaard's method. 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 The Maharaj and Gill method have performed axisymmetric finite element analysis by varying parameters the thickness of pavement, pressure and elastic modulus of subgrade. 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. The design charts has three parameters of each layers. Two are same parameters; the third parameter can be obtained.

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