WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Finite Element Modeling of Concrete Pavents - A State of Art Review

E. Karthik[1], G. Hemalatha[2], G. G. Mahalakshmi[3], B. Murali[4], G. Sasikumar[5]

[1,2,3,4,5]UG Students, Department of civil engineering, GMR Institute of Technology, Rajam, Vizianagaram District, 532127.

A B S T R A C T:

This study encompasses a finite element analysis simulation approach and assessment of ultimate behavior responses of the reinforced concrete slab by using ansys system (ansys) tool. This paper evaluates the effect of various parameters like temperature and stress on a rigid pavements analysis for temperature stresses has been done using both linear and non linear temperature gradient between top and bottom of pavement slab. Here solid 45 and combin14 are used as materials for the analysis of slab. In this study is mainly focused on the finite part by dividing the long panel into very small part and analysis of that part by the above conditions. when compared to the 3D FEM results , the stress levels produced by the westergaards approach are 21.81% greater compared to the 3D FEM elements results for the edge loading case. The westergaard method produces deflection values that are 29.45% higher than the 3D FEM results for the edge loading case. Nonlinear temperature distribution caused higher tensile stresses than the linear distribution of temperature. The difference in tensile stresses resulting from the two distributions was 18.95-23.65%.

Keywords: solid 45 , combin14 , Winkler foundation , TARGE 170 , CONTAC174.

Introduction:

Here introduce the paper, In recent years, cement concrete pavements are being adopted in many new road projects in India in view of their longer services lives, lesser maintenance requirements and smoother riding surface. The current practice of constructing concrete pavement on Indian highways is to provide a granular sub-base over the subgrade to be followed by a Dry lean concrete base with the concrete slab on top which is called rigid pavement. Rigid pavements are those which possess flexural strength & flexural rigidity. The stresses are not transferred from grain to grain to the lower layer as in the case of flexible pavement layers. The rigid pavement are made of Portland cement concrete either plain, reinforced or prestressed concrete. The plain cement concrete slabs are expected to take up about 40kg/cm2flexural stress. Tensile stress are developed due to the bending of the slab under wheel loads & temperature variation. The rigid pavement design is implemented according to calculation settings, which are based on the scheme of a slab resting on the ground and subjected to the action of loads, acting on a limited portion of the slab. The literature provides solutions for calculating the necessary thickness of the slab by calculating the internal stresses induced by load. In general, in rigid pavements, three methods can be used to determine stresses and strains. White topping is a cement concrete overlay constructed on the top of existing Hot Mix Asphalt (HMA) pavement. It isa form of pavement rehabilitation that is designed to extend the life to a deteriorated HMA pavement. The overlay design comprises the determination of thickness and the type of material to be laid over the existing pavement surface so as to extend its longevity for a given period. a three dimensional finite element model for unbonded conventional white topping has been developed. For this, the structural analysis package 'ANSYS' (Version 10) has been used. 3-D brick elementsSOLID45, having 8 nodes with three degrees of freedom per node translations in the nodal x, y and z directions, are used to model the concrete slab as well as the HMA. The sub-grade is modelled as Winkler foundation that consists of a bed of closely spaced, independent, spring elements. Each spring deforms in response to the vertical load applied directly to that spring, and is independent of any shear force transmitted from adjacent areas in the foundation. Spring elements namely COMBIN14 are used to represent the Winkler foundation which has three degrees of freedom at each node-translations in the nodal x, y, and z directions. The interface between the concrete slab and HMA pavement is represented by contact element TARGE 170 and CONTAC174. Contacts between two surfaces are modelled in ANSYS by utilizing the surface to surface contact element TARGE 170 and CONTAC174.Winkler or dense liquid (DL) and elastic solid (ES)subgrade models are used most often in pavement modelling.

Fig. 1: Slab on Winkler (DL) Foundation Type Area

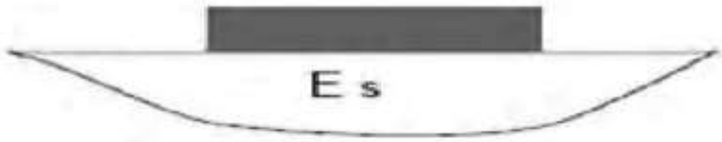


Fig. 2: Slab on Elastic Solid (ES) Foundation

Tables:

properties	**Top layer(PQC)**	**Bottom layer(DLC)**
Modulus of elasticity	3000 N/MM^2	1500N/MM^2
Poisons ratio	0.15	0.25
Coefficient of thermal expansion	$1*10^{-5°C}$	$1*10^{-5°C}$
Reference temperature	35℃	35℃
density	$2.4*10^{-6}$ N/MM^3	$2.4*10^{-6}N/MM^3$
Pavement thickness	150MM	150MM
Subgrade reaction	75 Mpa/m	75 Mpa/m
Dimensions of pavement	4.5m*3.5m	-
Wheel load	120kN	-

Stresses in the rigid pavement:

1.wheel load stresses:

Corner:

$$\boldsymbol{\sigma_c = 3\frac{Q}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]}$$

1.2. interior:

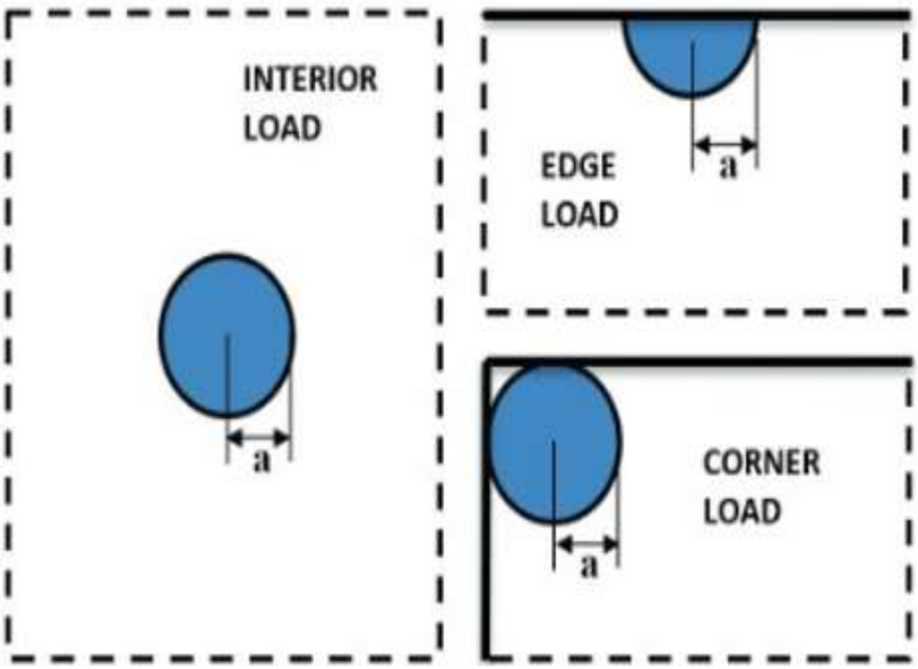
$$\boldsymbol{\sigma_i} = \frac{\mathbf{0.316P}}{\boldsymbol{h^2}}\left[4\ log_{10}\left(\frac{l}{b}\right)+1.069\right]$$

1.3. edge:

$$\boldsymbol{\sigma_i} = \frac{\mathbf{0.572P}}{\boldsymbol{h^2}}\left[4\ log_{10}\left(\frac{l}{b}\right)+0.359\right]$$

1.4. deflection:

$$\Delta=\frac{\mathbf{0.431P}}{\boldsymbol{kl^2}}\left[1-0.82\left(\frac{a}{l}\right)\right]$$



Where,

h = Plain cement concrete overlay thickness = 320mm
k = Modulus of subgrade reaction = 0.12Mpa/mm
b = Radius of equivalent distribution of pressure
S = c/c distance of two tyres in dual wheel assembly
(As per IRC: 58-2002, S=310 mm)
q = Tyre pressure (as per IRC: 58-2002, q= 0.8 Mpa))
P = Design wheel load = 50000N
= half of the single axle load
μ = Poisons ratio for concrete = 015
E = Modulus of elasticity of concrete = 31625Mpa
σ =Load stress
Δ = Deflection in pavement
l = Radius of relative stiffness
a= Radius of load contact areas, assumed circular

$$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$$

$$a = \left[0.8521 \times \frac{P}{q\pi} + \frac{S}{\pi}\left(\frac{P}{0.5227 \times q}\right)^{0.5}\right]^{0.5}$$

Where, b = a, for a/h > 1.724

$$b = (1.6a^2 + h^2)^{0.5} - 0.675\,h$$

2.Temperature stresses:

Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. The variation in temperature across the depth of the slab is caused by daily variation where as an overall increase or decrease in slab temperature is caused by seasonal variation in temperature. Temperature thus tends to produce two types of stress in a concrete pavement these are

2.1.Warping stress (curling stresses)

Whenever the top & bottom surface of a concrete pavement simultaneously possess different temperature, the slab tends to warp down ward or upward inducing warping stress. By the time the top temperature increases to t1 degree, the bottom temperature may be only t2 degree the difference between the top & bottom of the slab would be (t1-t2) = t °C. Assuming straight line variation in temp across the pavement depth the temp at mid depth or average temp of slab would be (t1+ t2) /2.

2.1.1. Interior:

$$St_{(i)} = \frac{E\alpha t}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

here $St_{(i)}$ = warping stress at interior kg/ cm^2

E = modulus of elasticity of concrete kg/ cm^2

α = thermal coefficient of concrete per $^\circ$c

t = temp difference between the top & bottom of the slab in degree c

c_x = coefficient based on l_x /l in desired location

c_y = coefficient based on l_y /l in right angle to the above direction

μ = poisson's ratio (may be taken as 0.15)

2.1.2. Corner:

$$St\ (c) = \frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Here, a is radius of contact & l is the radius of relative stiffness.

2.1.3. Edge:

$$St\ (e) = \frac{C_y E \alpha t}{2}$$

2.2. Frictional stress:

Due to uniform temperature rise and fall in the cement concrete slab, there is an overall expansion and contraction of the slab. Equating total force developed in the cross section of concrete pavement due to movement & frictional resistance due to subgrade restraint in half the length of slab.

$$S_f * h * B * 100 = B * \frac{L}{2} * \frac{h}{100} * w * f$$

$$S_f = \frac{wLf}{2x10^4}$$

Here S_f = Unit stress developed in cement concrete pavement kg/cm^2

w = Unit weight of concrete kg/cm^3 (about 2400 kg/ m^3)

f = Coefficient of sub grade restraint (max value is about 1.5)

L =Slab length, metre

B = Slab width, metre

3. Literature survey's on FE modelling of concrete pavements:

Jundhare et al., (2010) investigated the edge stresses and deflections of a standard white topping overlay that is unbonded and rests on a Winkler foundation. A three-dimensional finite element method analysis is presented in this study. A traditional white topping structure made up of a 320mm thick overlay resting on a 150mm Hot Mix Asphalt layer, which in turn is supported by a well-compacted subgrade, is the subject of the study, which uses a 3D FE modelling approach to analyse it. Axle loading is used in the non-linear static analysis, and ANSYS software (version 10) is used to calculate edge stresses and deflections. The calculated stress values are contrasted with predictions made theoretically using the ALIZE Model and Westergaard's equations. When compared to the 3D FEM results, the stress levels produced by the Westergaard approach are 21.81% greater compared to the 3D FEM results for the edge loading case. When compared to the ALIZE Method, the stress values obtained from the FEM analysis are 2.09% lower. The Westergaard method produces deflection values that are 29.45% higher than the 3D FEM results for the edge loading case.

Qadeer and Harwalkar (2018), discussed the effect of temperature variation on concrete pavement using ANSYS software was presented. Analysis for temperature stresses has been done using both linear and non-linear temperature gradient between top and bottom of pavement slab. The results obtained using the linear temperature gradient has shown reasonable agreement with the results obtained from the three other mechanistic models: given by software KENSLABS, ILLI-SLAB and JSLAB. In this study, a 3-dimensional finite element model for concrete pavement system has been developed. For this, the structural analysis package „ANSYS" (Version 10.0) has been used. A 3-D brick element SOLID 45, having 8 nodes with three degrees of freedom per node translations in the nodal x, y and z directions, were used to model the concrete slab as well as the base. Positive curling temperature gradient yields more stress as compared to negative curling temperature gradient in case of slab length as well as slab thickness. Tensile curling stresses obtained by positive temperature gradient is same as that of those values caused by negative temperature gradient of the same value. Non-linear temperature distribution caused higher tensile stresses than the linear distribution of temperature. The difference in tensile stresses resulting from the two distributions was 18.95 – 23.65%.

Olita et al, (2020) studies the development of rigid pavement design based on Westergaard's Theory and the requirement for a fresh mathematical formulation to determine stresses under corner loading circumstances. The creation and calibration of a Finite Element model using the ANSYS environment is then covered. The purpose of the research was to address the calculations of the current stress computation under corner loading algorithms. A new mathematical method that accurately determined the maximum tensile stress at the corner of the concrete slabs was found by using the calibrated FE model. The dimensions of the slab L1=1.34 m and L2=2.77 m in length, and h=2.54 cm and 3.38 cm in thickness. According to Westergaard's Theory slab length larger than or equal to 8 times the relative stiffness radius, such dimensions allow considering the slab of infinite length, when it is loaded in the centre and of semi-infinite length in the case of load at the edge. In this study the author used SOLID187 as the finite element used in 3-D modelling. CONTA 174 and TARGE170 elements were also used in the modelling of plate-to ground contact. The mesh of the model was made using the advanced features provided by ANSYS software.

Siddique et al., (2006), performed the finite element analysis of curling stresses and field measurement of curling of a newly built jointed plain concrete pavement. The finite element analysis was performed by using Ansys. the test section was modelled as a three layer system with 300mm concrete slab,100mm treated drainable base,150mm lime treated subgrade. all layers assumed to be linear elastic. The results shows that both upward and downward curling increase as the temperature differential increases. A maximum temperature gradient of 12 degrees C to be reasonable for typical PCC pavements. Curling resulting from a particular positive temperature differential is slightly higher than that resulting from negative temperature differential of the same magnitude.

Maitra et al., (2009), demonstrated the load transfer mechanisms in jointed concrete pavements, specifically focusing on the aggregate interlock and dowel bar system. It highlights that the aggregate interlocking mechanism is effective for narrow joints, while the dowel bar system works well for both narrow and wider joints. To analyze the load transfer efficiency of dowel-jointed concrete pavements, a three-dimensional finite-element model is developed and compared with experimental data. The study presents a generalized expression for estimating the Load Transfer Efficiency (LTE) of a dowel joint. The LTE is shown to depend on parameters such as the radius of relative stiffness, dowel size, dowel spacing, Dead Load (DL), and modulus of dowel support. LTE decreases with an increase in DL and increases with an increase in the modulus of dowel support.

Gupta (2022), evaluated the impact of parameters on short-paneled concrete pavement design characteristics, focusing on sizes ranging from 0.5 m×0.5 m to 2 m×2 m. It uses 2-D and 3-D Finite Element Method (FEM) simulations, considering traffic loading and temperature loading. Results show that 2-D FEM simulations yield higher stresses and deflections for thinner slabs, while 3-D FEM simulations yield similar results for thicker slabs. Increasing slab thickness significantly reduces flexural stresses, while deflection reduction is moderate. The effective modulus of subgrade reaction significantly influences slab deflection.The optimal panel size for practical k-values is 1.0-1.5 m, with a pavement thickness of 130-170 mm. The research includes sensitivity analysis for various parameters, considering both traffic and temperature loading.

Aguirre et al. (2019), explored the mechanistic analysis of rigid pavements has been a subject of extensive research in pavement engineering. Two commonly employed approaches are closed-form solutions and finite element (FE) modelling. However, the accuracy of predicting pavement responses with depth within the pavement foundation structure remains a challenge. Researchers at The University of Texas at El Paso have developed a 3-D FE modelling tool that offers a comprehensive analysis of jointed concrete pavements under various conditions. This tool allows for a more accurate representation of the underlying layers by considering different foundation models, including Winkler foundation, Vlasov foundation, or 3-D FE solid elastic foundation. The 3-D FE model provided a comprehensive assessment of critical stresses and strains in all pavement layers, allowing for a more detailed understanding of pavement behavior. The 3-D FE method proved to be a valuable tool for optimizing pavement structures in terms of layer material properties and Portland cement concrete (PCC) thickness, particularly in handling maximum vehicle loading. The study emphasizes the advantages of the 3-D FE method, which offers a more comprehensive assessment of critical stresses and strains throughout the pavement layers and demonstrates its compatibility with existing industry-standard analysis tools.

Swarna et al. (2018), studied the Two-lift concrete pavements (TLCPs) are a promising alternative to traditional single-lift concrete pavements, offering reduced material costs, improved durability, and increased sustainability. However, challenges include construction practices and proper bonding between the two layers. A three-dimensional finite element analysis reveals that the cracking of the lower layer of lean concrete is a critical factor in TLCP design. The analysis can help design safe and durable TLCPs. Other topics discussed include recycled concrete or marginal aggregates, deep saw cuts at joints, and the potential for TLCPs to be eco-friendly. Overall, TLCPs offer a promising alternative to traditional single-lift concrete pavements and have the potential to be a more eco-friendly and sustainable solution.

Diallo and Akpinar (2020), evaluated the mechanical behaviour of the pavement under traffic load, this study developed a three-dimensional Finite Element Model of an asphalt concrete overlay on a jointed plain concrete pavement. The goal of this study was to ascertain how the tensile strain at the base of the asphalt overlay was affected by various asphalt concrete thicknesses, asphalt concrete moduli, the interface bond between the asphalt concrete and the Portland cement concrete layer, Portland cement concrete moduli, and joint width. The findings demonstrated that alterations in pavement parameters cause a wide range of differences in the strength of pavement responses .At the base of the overlay, the longitudinal tensile strain ranged in size from 25 to 460 .The pavement responses were primarily influenced by the asphalt concrete thickness, interface contact state, and asphalt concrete modulus factors. Regardless of the thickness of the surface layer, the interface bonding condition was important.

Gupta and Kumar (2014), generated Finite Element Method (FEM) to analyze structural parameters of pavement layers, such as stress, strain, and deflection. It is used to reduce deflections in flexible pavements by varying design configurations. The study found that the subgrade modulus controls excess vertical surface deflection in flexible pavement, while base course and surface layer modulus have minor effects. The FEM and KENLAYER analysis have different results, but discrepancies exist between them. Further research is needed to better understand these discrepancies and improve the accuracy of the KENLAYER program

Al-Ghafri and Javid (2018), studied rigid pavement constructions utilizing human and computer design under various load, material, and temperature regimes. For manual design and computer design, the "Westergaard Method" and "KENPAVE software" were used, respectively. Edge stresses are greater than interior and corner stresses, according to the results of the stress research, and Westergaard method stresses are consistently lower than KENPAVE method stresses. The findings of the sensitivity analysis show that variations in pavement thickness, material properties, and wheel load have a substantial impact on the stresses generated at different slab positions. Traffic load is one of the main factors affecting pavement performance. An estimate of the normal traffic loads that a pavement structure will experience over the course of its lifetime is called equivalent single axle load (ESAL).The Kenpave tool is used to calculate stresses, strains, and deflections at various locations in the pavement structure using traffic loading and material data.

Hu and Walubita (2011), Typically, there are two types of pavements: bituminous (flexible) and concrete (rigid). Due to their inexpensive initial cost, bituminous top pavements are commonly found in many nations. However, in recent years, concrete pavements have gained popularity because to inherent benefits, such as reduced maintenance requirements, longevity, and low life-cycle costs slabs of concrete exposed to creep, vehicle axle load Using the assumptions of homogenous material and constant elastic slab characteristics, Westergaard created closed-form equations. Under circular and semicircular loading, these equations are utilized to calculate the stresses and displacement of the slab at the corner, inside, and edge. For many years, both the original and modified versions of these equations were utilized extensively, such as the Westergaard equation modified by Teller and Sutherland that is found in Appendix-VI of IRC 58

Vishwakarma and Ingle (2020), investigated the Impact of Non-Uniform Soil Subgrade on Critical Stresses in Concrete Pavements This review of the literature looks at the key findings and recommendations made by research looking at the impact of uneven soil subgrade on critical stresses in concrete pavement. The results emphasize the significance of taking soil stiffness, axle loads, and temperature loads into account during pavement analysis and design. The review also highlights the necessity for additional study and the use of finite element (FE) analysis to solve the difficulties brought on by uneven soil subgrades in concrete pavement design. In order to provide a strong and dependable surface for transportation infrastructure, concrete pavement is essential. The quality and consistency of the concrete pavement, among other things, have an impact on how well it performs.

Krishna and Ch. (2022), Investigated the White-Topping as a Sustainable Pavement Maintenance Solution Literature Review Any nation's social, economic, industrial, and cultural development depends heavily on its transportation infrastructure. Pavements must be effective and long-lasting in order to guarantee the timely circulation of people and products. Traditional bituminous pavements need frequent maintenance because they are prone to failures like cracks and rutting. The potential of white-topping, specifically concrete overlays, as a long-term option to lengthen pavement lifespan and save maintenance costs is examined in this paper. Bituminous pavements have a short lifespan and are prone to cracking, rutting, and other types of distress. 1.1 Short lifespan and frequent failures. High maintenance needs: Traditional bituminous overlays necessitate ongoing care and sporadic upkeep to satisfy.

Sahoo and Reddy (2010), used the three-dimensional modelling approaches to improve the precision and dependability of pavement design. The study showed the advantages of using three-dimensional models and detailed analysis processes.

Survateja et al., (2017), Analytical Methods for Stresses in Concrete Pavements: A Review of the Literature For the purpose of building strong and dependable structures, the calculation of stresses in concrete pavements is essential. The stresses induced by single wheel loads with linear temperature variations in concrete pavements have been extensively calculated using Westergaard's theory. The assumption of a liquid or Winkler basis, however, might not fully reflect actual circumstances. Alternative analytical strategies and finite element analysis (FEA) techniques have been developed recently to enhance stress simulations and make them more comparable to real-world situations. This literature review examines the shortcomings of current methods and offers a fresh analytical strategy that includes a layer that breaks bonds and a plausible pavement-foundation interaction.

Parsania et al. (2021), studied the Stresses Analysis in Concrete Pavements with Extended Dry Lean Concrete Bases Concrete pavements are frequently utilized in road infrastructure because they offer tough, long-lasting surfaces for traffic. The Portland Cement Association (PCA) and the Indian Roads Congress (IRC) are two examples of organizations that give recommendations and methodologies for the design of concrete pavements. The borders of the Dry Lean Concrete (DLC) base and the Pavement Quality Concrete (PQC) slab are frequently assumed by these standards to be in the same vertical plane. However, for convenience of building, the base in actual construction extends beyond the concrete slab, which results in differing stress distributions. The available research on the stresses in concrete pavements with extended DLC bases is examined in this literature review.

Suryateja et al. (2018), Modelling White topping Overlay on Winkler Foundation Edge Stresses and Deflections For the purpose of creating strong and long-lasting overlays, it is essential in the field of pavement engineering to accurately anticipate edge stresses and deflections. The Winkler model, which assumes minimal shear resistance of the subgrade relative to its shear capacity, is one regularly used method for modelling the subgrade in pavement analysis. The foundation is depicted in this model as a collection of separate springs. The particular study that is the subject of this literature review uses a three-dimensional finite element method (FEM) to calculate the edge stresses and deflections of an unbonded conventional white topping overlay sitting on a Winkler base. The study compares the obtained stresses using ANSYS software for non-linear static analysis with axle loading.

Memon et al., (2018), done investigation on Polypropylene Fiber Reinforced Concrete for Improving the Performance and Durability of Concrete Pavements Due to their resilience in adverse weather conditions, durability, and capacity to overcome sub-grade problems, concrete pavements are frequently employed in transportation infrastructure. However, a number of variables, including material properties, environmental influences, and vehicular load characteristics, have an impact on the durability and serviceability of rigid pavement constructions. Highway rigid pavements experience fatigue degradation due to the repetitive nature of traffic stresses, which reduces the pavement's stiffness and supporting capacity. The purpose of this study of the literature is to investigate the use of polypropylene fiber reinforced concrete (PFRC) as a potential remedy for problems with concrete pavements.

4. Conclusion:

This study presents the mathematical modeling approach for the linear or nonlinear response of RC slab. From the numerical analysis, it is evident that the proposed numerical models can capture the nonlinear conduct of the RC slab until its failure with reasonable accuracy. This study concludes Positive curling temperature gradient yields more stress as compared to negative curling temperature gradient in case of slab length as well as slab thickness. Tensile curling stresses obtained by positive temperature gradient are same as that of those values caused by negative temperature gradient of the same value. The variation of length of slab does not influence the curling stresses distribution in both the case of positive and negative temperature gradient. But curling stresses increased with increased in slab thickness. Non-linear temperature distribution caused higher tensile stresses than the linear distribution of temperature.

References:

1. Jundhare, D.R., Khare, K.C. and Jain, R.K., 2010, December. Study of edge stresses and deflections in whitetopping overlay on winkler foundation. In *Indian geotechnical conference* (pp. 877-880).***c***

2. Qadeer, M.I.K.M.A. and Harwalkar, A.B., Mechanistic Analysis of Rigid Pavement for Temperature Stresses Using Ansys.

3. Olita, S., Diomedi, M. and Ciampa, D., 2020. Alternative formula for rigid pavement stress calculation in corner load conditions. *The Baltic Journal of Road and Bridge Engineering*, *15*(5), pp.59-79.

4. Siddique, Z., Hossain, M. and Meggers, D., 2006. Curling and curling stresses of new concrete pavements. In *Airfield and Highway Pavement: Meeting Today's Challenges with Emerging Technologies* (pp. 671-682).

5. Maitra, S.R., Reddy, K.S. and Ramachandra, L.S., 2009. Load transfer characteristics of dowel bar system in jointed concrete pavement. *Journal of Transportation Engineering*, *135*(11), pp.813-821.

6. Gupta, A., 2022. Analytical investigations on short-paneled concrete pavements using finite element analysis. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, *46*(2), pp.1755-1770.

7. Aguirre, N., TaghaviGhalesari, A. and Carrasco, C., 2019, July. A comparison of concrete pavement responses using finite element method with foundation springs and 3-D solid elements. In *International Airfield and Highway Pavements Conference 2019* (pp. 81-90). Reston, VA: American Society of Civil Engineers.

8. Swarna, S.T., Reddy, K.S., Reddy, M.A. and Pandey, B.B., 2018. Analysis of stresses due to traffic and thermal loads in two-lift bonded concrete pavements by finite element method. *Advances in Civil Engineering Materials*, *7*(2), pp.207-222.

9. Diallo, A.O. and Akpinar, M.V., 2020. Mechanistic Responses of Asphalt Concrete Overlay Over Jointed Plain Concrete Pavement Using Finite Element Method. *The Baltic Journal of Road and Bridge Engineering*, *15*(5), pp.80-93.

10. Gupta, A. and Kumar, A., 2014. Comparative structural analysis of flexible pavements using finite element method. *International Journal on Pavement Engineering & Asphalt Technology*, *15*(1), pp.11-19.

11. Al-Ghafri, I.H. and Javid, M., 2018. Comparative analysis of rigid pavement using Westergaard method and computer program. *Journal of Soft Computing in Civil Engineering*, *2*(2), pp.19-30.

12. Hu, X. and Walubita, L.F., 2011. Effects of layer interfacial bonding conditions on the mechanistic responses in asphalt pavements. *Journal of Transportation Engineering*, *137*(1), pp.28-36.

14. Vishwakarma, R.J. and Ingle, R.K., 2020. Effect of non-uniform soil subgrade on critical stresses in concrete pavement. In *Transportation Research: Proceedings of CTRG 2017* (pp. 805-817). Springer Singapore.

15. Krishna, U.S.R. and Ch, N.S.K., 2022. Analytical modelling of ultra-thin white topping cement concrete overlay on bituminous concrete pavement using ANSYS. *World Journal of Engineering*, (ahead-of-print).

16. Sahoo, U.C. and Reddy, K.S., 2010. Effect of nonlinearity in granular layer on critical pavement responses of low volume roads. *International Journal of Pavement Research and Technology*, *3*(6), p.320.

17. Survateja, S., Reddy, M.A. and Pandey, B.B., 2017. Analysis and design of concrete pavements: A new approach. *Indian Highways*, *45*(12).

18. Parsania, V., Solanki, U.J. and Zala, L.B., 2021, August. Different Analysis of Rigid Pavement Subjected to Multi Axle Load and Temperature Effect. In *Journal of Physics: Conference Series* (Vol. 2007, No. 1, p. 012018). IOP Publishing.

19. Suryateja, S., Reddy, M.A. and Pandey, B.B., 2018. Effect of extended dry lean concrete base on flexural stresses in concrete pavements. In *Journal of the Indian Roads Congress* (Vol. **79, No. 2).**

20. Memon, I.A., Jhatial, A.A., Sohu, S., Lakhiar, M.T. and Hussain, Z., 2018. Influence of fibre length on the behaviour of polypropylene fibre reinforced cement concrete. *Civil Engineering Journal*, *4*(9), pp.2124-2131.

21. Mackellar, A., 2017. *The effect of concrete strength and fibre content on the fatigue performance of Ultra Thin Continuously Reinforced Concrete Pavement (UTCRCP)* (Doctoral dissertation, University of Pretoria).