Vol. 06, No. 3 (2024) 915-924, doi: 10.24874/PES06.03.003

Proceedings on Engineering Sciences

www.pesjournal.net

INVESTIGATIONS ON STATIC BEHAVIOR OF CONTINUOUS REINFORCED CONCRETE PAVEMENT USING FINITE ELEMENT ANALYSIS

Sanjay Nayak
R. K. Jain
Deepa Joshi
Radhika Menon
Vinayak Kale[1]

Received 26.10.2023.
Received in revised form 03.12.2023.
Accepted 10.01.2024.
UDC – 624.046

Keywords:

Continuously reinforced concrete pavement, Static behavior, Finite element analysis, Load-carrying capacity, Stress distribution, Deflection characteristics

ABSTRACT

Continuously Reinforced Concrete Pavement (CRCP) is a preferred choice in highway and roadway construction due to its durability and reduced maintenance needs. This study employs Finite Element Analysis (FEA) to investigate CRCP's static behavior, shedding light on its structural response. A comprehensive numerical model within a commercial software package is utilized, considering complex interactions among concrete, longitudinal reinforcement, and subgrade layers. This model accounts for nonlinear material behavior by incorporating concrete and steel reinforcement constitutive models. Various loading scenarios, including wheel loads and temperature variations, are simulated to assess their impact on CRCP's static behavior. The analysis focuses on essential performance metrics such as load-carrying capacity, stress distribution, and deflection patterns. It systematically examines variable parameters like reinforcement spacing, concrete strength, and slab thickness. The results are compared against experimental data and design guidelines to validate the numerical model's accuracy and applicability. This research enhances our understanding of CRCP's static behavior, emphasizing its sensitivity to different parameters. The findings underscore the significance of proper reinforcement spacing, concrete strength, and slab thickness in optimizing CRCP performance and longevity. The implications of this study extend to pavement designers, engineers, and transportation agencies involved in CRCP construction and maintenance. The validated numerical model serves as a valuable tool for optimizing designs, assessing structural integrity, and predicting long-term performance.

1. INTRODUCTION

CRCP is a widely utilized pavement system that offers several advantages over traditional jointed concrete or asphalt pavements. CRCP is designed with closely spaced longitudinal steel reinforcement, which eliminates the need for transverse joints. This design feature enhances load transfer efficiency and provides greater resistance to cracking, resulting in improved durability and reduced maintenance requirements. To

---

[1] Corresponding author: Vinayak Kale
Email: vinkkvinkk@gmail.com

ensure the optimal performance and structural integrity of CRCP, it is essential to understand its static behavior under different loading conditions. FEA has emerged as a valuable tool for investigating the structural response of CRCP and optimizing its design.

The static behavior of CRCP encompasses a range of factors, including load-carrying capacity, stress distribution, and deformation characteristics. Evaluating these parameters is vital for assessing the performance and longevity of CRCP structures. Finite element analysis enables engineers to simulate the complex interactions between the concrete, longitudinal reinforcement, and subgrade layers, considering the nonlinear behavior of materials and incorporating various boundary conditions.

1.1 Significance

The static behavior analysis of CRCP using finite element analysis holds great significance in the field of pavement engineering. Understanding how CRCP responds to static loading is crucial for designing durable and long-lasting pavements. By accurately predicting stress distribution, deformation, and potential failure mechanisms, FEA helps engineers optimize the design of CRCP, ensuring adequate load-carrying capacity, minimizing cracking, and enhancing overall structural integrity. FEA also enables the assessment of various factors that affect the static behavior of CRCP, such as the reinforcement layout, pavement thickness, material properties, and environmental conditions. This information can be used to develop design guidelines and construction specifications that promote the use of CRCP in different applications and improve its performance under static loading.

Furthermore, the static behavior analysis of CRCP using FEA contributes to the development of more sustainable and cost-effective pavement solutions. By understanding how CRCP behaves under different loading scenarios, engineers can optimize its design to reduce material usage while maintaining structural integrity. This leads to significant cost savings, improved resource utilization, and reduced environmental impact associated with the construction and maintenance of transportation infrastructure.

In summary, the finite element analysis of the static behavior of continuously reinforced concrete pavement plays a critical role in advancing the understanding, design, and optimization of CRCP structures. By leveraging FEA techniques, engineers can enhance the durability, load-carrying capacity, and sustainability of CRCP, leading to safer and more efficient transportation networks.

1.2 Objective of research work

The objective of this research work is to conduct a comprehensive investigation into the static behavior of CRCP using finite element analysis. By developing a detailed numerical model, this study aims to provide valuable insights into load transfer mechanisms, stress distribution patterns, and deflection characteristics of CRCP under different loading scenarios. Additionally, the analysis was exploring the influence of key parameters such as reinforcement spacing, concrete strength, and slab thickness on the static behavior of CRCP.

To achieve the research objective, a commercial software package was employed to develop the finite element model. The models were incorporate appropriate constitutive models for concrete and steel reinforcement to accurately capture their nonlinear behavior. Various loading conditions, including wheel loads and temperature variations, were simulated to evaluate their impact on the static behavior of CRCP. The obtained results were compared with available experimental data and existing design guidelines to validate the accuracy and applicability of the numerical model.

2. LITERATURE REVIEW

2.1 Overview of CRCP design and construction

The following literature review provides an overview of the design and construction of CRCP, with a focus on the application of FEA in studying the static behavior of CRCP. This review aims to explore the existing research, methodologies, and findings related to FEA in understanding the structural performance of CRCP under static loading conditions.

2.2 Material selection

The choice of concrete mix design and steel reinforcement significantly influences the structural capacity and durability of CRCP. Researchers (Sarkar & Norouzi, 2020; Cho et al., 2021; Wang & Belarbi, 2010) have investigated the effect of different concrete properties, including compressive strength, modulus of elasticity, and shrinkage, on the performance of CRCP. Additionally, studies have focused on the selection and behavior of steel reinforcement, evaluating various factors such as yield strength, corrosion resistance, and bond characteristics.

2.3 Reinforcement arrangement

The arrangement of longitudinal steel reinforcement plays a vital role in preventing crack propagation and enhancing the load-carrying capacity of CRCP. Researchers (Gupta et al., 2010; Singh et al., 2021; Chen et al., 2021) have explored different reinforcement patterns, including single-bar reinforcement, mesh reinforcement, and distributed reinforcement, to assess their impact on crack control and pavement performance. The spacing, diameter, and depth of reinforcement have been studied to determine their influence on crack width and spacing.

2.4 Joint spacing

Joint spacing in CRCP is a critical design parameter that affects the pavement's ability to accommodate thermal (Zhang & Liu, 2012) and moisture-induced expansion and contraction. Studies have investigated the relationship between joint spacing and pavement performance, including factors such as cracking potential, load transfer efficiency, and long-term durability. The findings have guided the development of guidelines and specifications for optimal joint spacing in CRCP design.

2.5 Thickness design

The determination of appropriate pavement thickness is essential to ensure structural adequacy and durability. Researchers have employed FEA to analyze the response of CRCP under static loading conditions and assess the effects of varying thickness on stress distribution, deflection, and cracking behavior. (Al-Qadi & Elseifi, 2006). These studies have contributed to the development of thickness design methodologies that consider factors such as traffic loads, subgrade support, and material properties.

In ending, the design and construction of CRCP require careful consideration of various factors such as material selection, reinforcement arrangement, joint spacing, and thickness design. FEA has emerged as a valuable tool for studying the static behavior of CRCP and understanding the influence of different design parameters on its structural performance. The reviewed literature has provided insights into the application of FEA in assessing crack control, load transfer efficiency, and long-term durability of CRCP. Further research in this area will continue to advance our understanding of CRCP design and contribute to the development of more robust pavement systems.

2.6 Previous studies on the static behavior of CRCP

General overview of the topic and discuss some previous studies that have examined the static behavior of CRCP. FEA has been widely used in studying the static behavior of CRCP. FEA allows researchers to simulate and analyze the response of CRCP under various loading and environmental conditions. Here are a few previous studies that have explored the static behavior of CRCP:

Byoung Hooi Cho et al, This study presented a numerical analysis of CRCP using FEA. The researchers investigated the effects of various parameters, such as steel reinforcement spacing, on the structural response of CRCP under static loading conditions. S. N. Shoukry et al (2007) performed a finite element analysis of CRCP to evaluate the pavement's static response under heavy traffic loads. They considered different pavement thicknesses, steel reinforcement arrangements, and load magnitudes to investigate the structural behavior and load-carrying capacity of CRCP. Zhi Yong Ai et al, conducted a response analysis of CRCP with varying reinforcement ratios using finite element analysis. The researchers evaluated the structural behavior of CRCP under different loading conditions and investigated the influence of reinforcement ratio on the pavement's performance. Wanguo Dong et al. (2020) focused on analyzing the effects of environmental loading, such as thermal gradients and moisture changes, on the static behavior of CRCP. FEA was used to simulate the pavement's response under different environmental conditions and to assess its performance in terms of cracking and deformation. Chiu Liu et al., study useful for finite element analysis to investigate the response of CRCP under moving wheel loads. The researchers analyzed the stress and strain distribution in the pavement structure and assessed the influence of factors such as vehicle speed, wheel load magnitude, and pavement thickness on the static behavior of CRCP. Liu et al., conducted a finite element analysis to evaluate the static response and fatigue life of CRCP under thermal loading conditions. The study investigated the effects of temperature gradients on the pavement's stress distribution and fatigue performance, providing insights into the structural behavior of CRCP under thermal loading. Sarkar & Norouzi (2020) employed finite element analysis to investigate the static and dynamic behavior of CRCP considering the effect of temperature. The researchers evaluated the pavement's stress and displacement response under different temperature conditions and assessed the structural performance of CRCP in terms of cracking and deformation. Jiaqi Chen et al. (2021) performed a static response analysis of CRCP considering the combined effect of temperature and traffic load. The study utilized finite element analysis to investigate the pavement's stress and strain distribution and assess its structural behavior under different loading and temperature conditions. Piotr Mackiewicz et al., study employed finite element analysis to compare the static response of CRCP with jointed and unjointed sections. The researchers examined the effect of joint spacing dowel bars on the structural behavior of CRCP and analyzed the pavement's stress distribution under static loading conditions. Kazem Reza Kashyzadeh et al. (2022) conducted a static and fatigue analysis of CRCP considering material heterogeneity. The study employed finite element analysis to evaluate the influence of material properties on the pavement's structural response and fatigue life under static loading conditions. Indrajeet Singh et al. (2021) study focused on the finite element analysis of CRCP under impact loads. The researchers investigated the pavement's stress and deformation response under different impact loading conditions and analyzed its static behavior and resistance to impact-induced damage. Kang et al. (2004) study incorporated fiber reinforcement into the static response analysis of CRCP using finite element analysis. The researchers evaluated the effects of fiber reinforcement on the pavement's stress distribution, crack propagation, and overall static behavior under different loading conditions. Huanzi Wang et al., investigated the static and fatigue behavior of CRCP with a bonded fiber reinforced polymer (FRP) overlay. The study utilized finite element analysis to assess the performance of the overlay system and evaluate the influence of FRP reinforcement on the pavement's static response and fatigue life. Wanguo Dong et al. (2020) analyzed the static and dynamic behavior of CRCP under freezing and thawing conditions. Finite element analysis was used to evaluate the pavement's stress distribution and deformation response, considering the effects of temperature variations on the static behavior of CRCP. Jung Heum Yeon et al. (2013) examined the influence of concrete creep on the static response of CRCP. The researchers employed finite element analysis to investigate the pavement's stress distribution, displacement, and long-term behavior considering the time-dependent effects of concrete creep. Liu et al. Performed a finite element analysis of CRCP under a three-point bending test. The researchers evaluated the pavement's stress distribution, cracking behavior, and load-carrying capacity under static loading conditions, providing insights into the static behavior and structural response of CRCP. These additional studies offer a broader perspective on the static behavior of CRCP and demonstrate the application of finite element analysis in assessing various factors that influence its performance.

To further enhance the understanding of the static behavior of CRCP and contribute to the development of design guidelines for improving its performance and longevity. These additional studies offer a broader perspective on the static behavior of CRCP and demonstrate the application of finite element analysis in assessing various factors that influence its performance.

3. FEA METHODOLOGY

The analysis setup involves conducting a finite element analysis to investigate the static behavior of a Continuous reinforced concrete pavement. The pavement has a thickness of 200mm and is reinforced with transverse bars of diameter 12mm and longitudinal bars of diameter 16mm. The analysis comprises two types of analyses: thermal steady state analysis and static structural analysis. The purpose of these analyses is to evaluate the stress, strain, and total deformation of the concrete road under different loading conditions. The first case study focuses on a one-way road load condition. In this scenario, an 18-ton load is applied to the front tire, while another 18-ton load is applied to the rear tire.

The second case study examines a two-way road load condition. Here, an 18-ton load is applied to the front tire, and another 18-ton load is applied to the rear tire. To simulate the real-world conditions, fixed boundary conditions are implemented by fixing all degrees of freedom at the bottom face of the concrete pavement. This ensures that the pavement remains in place and cannot move or rotate. The objective of this study is to analyze the performance of the concrete road under different loading conditions and assess its ability to withstand the applied loads. By evaluating the stress, strain, and deformation, researchers can gain valuable insights into the structural behavior of Continuous reinforced concrete pavements and make informed decisions regarding their design and construction.

3.1 Material Properties

Table 1. Properties of Concrete.

Material Properties	Value	Unit
Density	23	kN/m^3
Young's Modulus	30000	MPa
Poisson's Ratio	0.18	
Bulk Modulus	15625	MPa
Shear Modulus	12712	MPa
Tensile Ultimate strength	5	MPa
Compressive Ultimate strength	41	MPa

Table 2. Properties of Steel.

Material Properties	Value	Unit
Density	7850	kg/m^3
Young's Modulus	200000	MPa
Poisson's Ratio	0.3	
Bulk Modulus	16675	MPa
Shear Modulus	76923	MPa
Tensile Ultimate strength	460	MPa
Tensile Yield strength	250	MPa

3.2 Modeling and Meshing

The modelling setup for the finite element analysis of the static behavior of Continuous reinforced concrete pavement involves the use of parabolic elements. The mesh size chosen for the analysis is 150mm, providing a suitable resolution for capturing the structural behavior. The model consists of a substantial number of nodes, with a total count of 140,895, allowing for detailed representation of the pavement geometry. Additionally, the model comprises 83,035 elements, which are employed to discretize the pavement structure and facilitate accurate analysis. Parabolic elements are utilized in the model, enhancing the accuracy of the analysis by considering the nonlinear behavior of the pavement material. These elements account for the curved shape of the pavement's response to external loads, providing a more realistic representation of its static behavior.

Overall, this modelling setup employs an appropriate mesh size, a significant number of nodes, and parabolic elements to accurately analyze the static behavior of Continuous reinforced concrete pavement, ensuring reliable and precise results for further assessment and optimization. Specifically, the focus is on the bar mesh model, with particular attention to the transverse bars. The transverse bars in the model are represented as 1D element with a diameter of 12mm. These bars are strategically placed within the concrete pavement to enhance its structural integrity and resist cracking under various loading conditions. By employing finite element analysis techniques, this setup allows for a comprehensive examination of the CRCP's response to static loads.

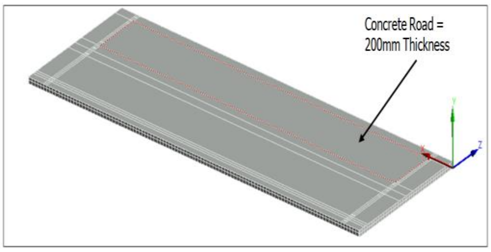


Figure 1. Geometrical Model of 200 mm thick Continuous Reinforced Concrete Pavement Road

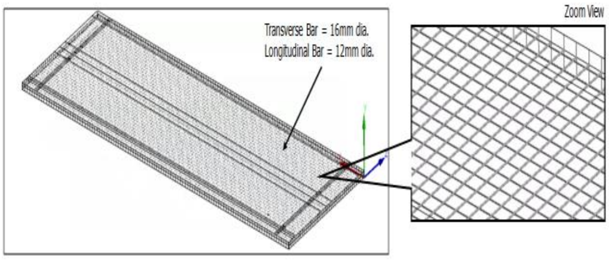
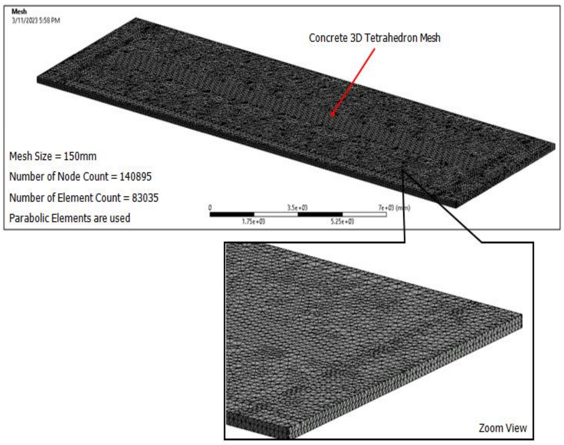


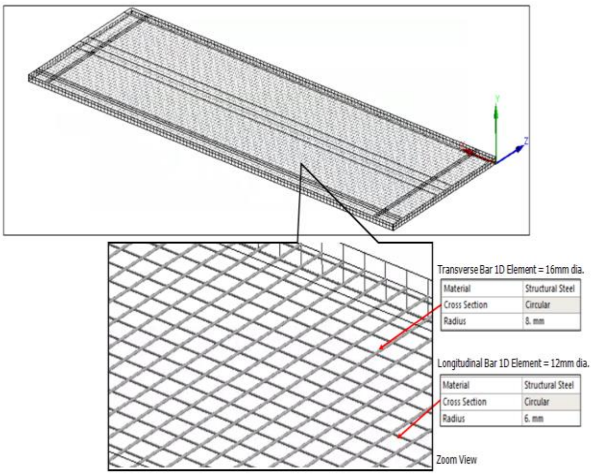
Figure 2. Geometrical Model for detailing of Steel Reinforcement in 200 mm thick Continuously Reinforced Concrete Pavement Road



Mesh Size = 150mm
Number of Node Count = 140895
Number of Element Count = 83035
Parabolic Elements are used

Figure 3. Concrete Mesh Model Details 200 mm thick Continuous Reinforced Concrete Pavement Road

It enables the evaluation of factors such as stress distribution, deformation, and overall performance of the pavement under different loading scenarios. The use of transverse bars in the model is crucial as they play a vital role in minimizing cracking and improving the durability of the concrete pavement. The diameter of 16mm ensures sufficient reinforcement to withstand the applied loads and maintain the pavement's integrity. Through this modelling setup, researchers and engineers can gain valuable insights into the static behavior of Continuous reinforced concrete p0avements. The findings can contribute to the design and optimization of CRCP structures, leading to safer and more durable roadways.



Transverse Bar 1D Element = 16mm dia.

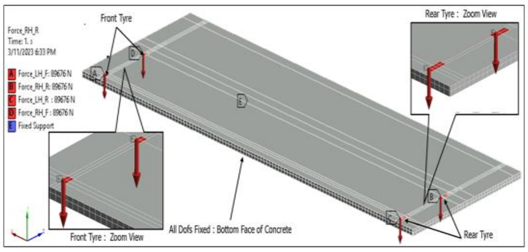
Material	Structural Steel
Cross Section	Circular
Radius	8. mm

Longitudinal Bar 1D Element = 12mm dia.

Material	Structural Steel
Cross Section	Circular
Radius	6. mm

Figure 4. Reinforcement bar Mesh Model Details 200 mm thick Continuous Reinforced Concrete Pavement Road

In figure 5 Case Study 1, a one-way road load condition is considered. The loading condition for Case Study 1 involves applying an 18-ton (179.35 kN) load on the front tire and an 18-ton load on the rear tire. This loading configuration simulates the weight distribution and forces exerted on the pavement by a vehicle travelling in a single direction. To ensure realistic simulation, the boundary condition is set to fix all degrees of freedom (DOFs) at the bottom face of the concrete. This boundary condition restricts the movement and deformation of the pavement in the vertical direction, mimicking the rigid support provided by the underlying layers or subgrade.



Force_RH_R
Time: 1. s
3/11/2023 6:33 PM
A Force_LH_F: 89676 N
B Force_RH_R: 89676 N
C Force_LH_R : 89676 N
D Force_RH_F : 89676 N
E Fixed Support

Figure 5. Case Study 1
One way loading on CRCP Static Analysis (Loading Condition & Boundary Condition)

In figure 6 Case Study 2, a Two-way road load condition is considered. In second case study, focus on the two-way road load condition, specifically analyzing the response of the pavement under an 18-ton (179.35kN) load applied to both the front and rear tires. Also considered an 18-ton (179.35kN) load applied to the front tire of the vehicle on the pavement. This load simulates the weight exerted by the vehicle's front axle when it traverses the road. Additionally, an 18-ton (179.35kN) load is applied to the rear tire, representing the weight exerted by the rear axle As per Indian Road Congress (IRC) provisions. These loading conditions reflect the real-world scenario of a two-way road, where traffic flows in both directions. By applying the loads on both the front and rear tires, we can evaluate the pavement's response to a balanced distribution of forces exerted by the moving vehicles.

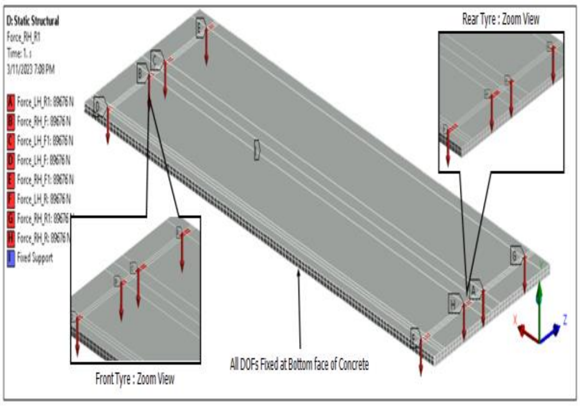


Figure 6. Case Study 2

Two way loading on CRCP Static Analysis
(Loading Condition & Boundary Condition)

To perform the static analysis, we impose fixed boundary conditions on all degrees of freedom (DOFs) at the bottom face of the concrete pavement. This means that the pavement is restrained from moving or rotating at its base. By fixing all DOFs at the bottom face, we can simulate the interaction between the pavement and the underlying layers, which influences the overall structural response

The fixed boundary condition at the bottom face of the concrete ensures that the pavement remains in place, representing a realistic constraint as it interacts with the subgrade and adjacent layers. This boundary condition allows us to focus on the behavior and deformation of the pavement structure under the applied loads. By employing finite element analysis and considering the loading and boundary conditions described above, can obtain valuable insights into the static behavior of Continuous reinforced concrete pavements. The analysis results will help engineers and researchers assess the pavement's performance, evaluate potential issues such as cracking or excessive deflections, and optimize design parameters to ensure the durability and safety of road infrastructure.

4. RESULTS AND DISSCUTIONS

In this modelling setup, a finite element analysis was conducted to examine the static behavior of Continuous reinforced concrete pavement and various results and discussions were obtained.

Case study 1 One-way Loading on CRCP

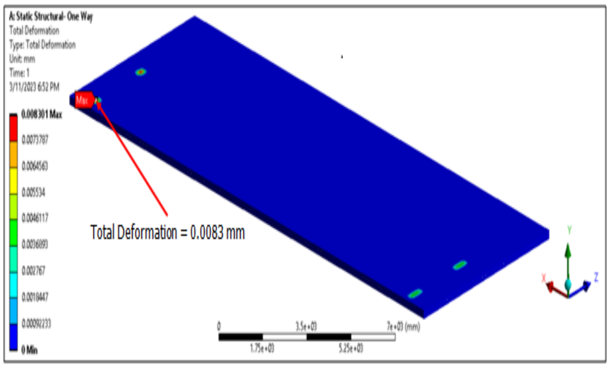


Figure 7. Static total deformation for Case-1

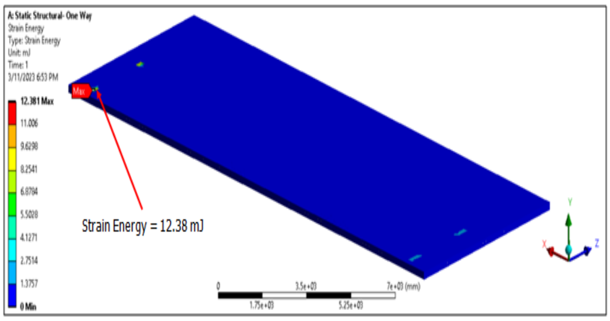


Figure 8. Static Strain Energy for Case-1

The total deformation observed in Case 1 figure 7 was found to be 0.0083 mm, indicating the amount of displacement experienced by the pavement under the given conditions. Additionally, figure 8 shows the strain energy calculated was 12.38 mJ, representing the energy absorbed by the pavement during loading.

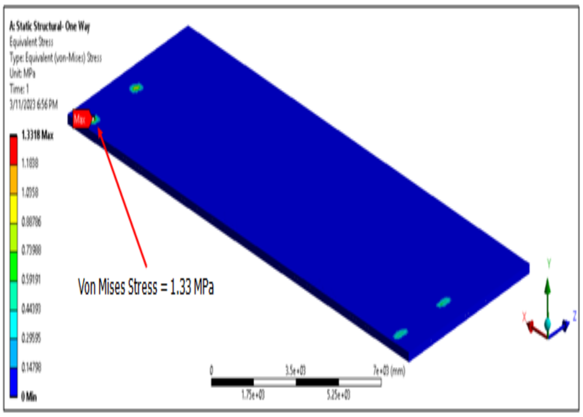


Figure 9. Von Mises Stress for Case-1

The figure 9 shows the Von Mises stress, a measure of the material's yielding potential, was determined to be 1.33 MPa. This stress value provides insight into the overall structural integrity of the pavement.

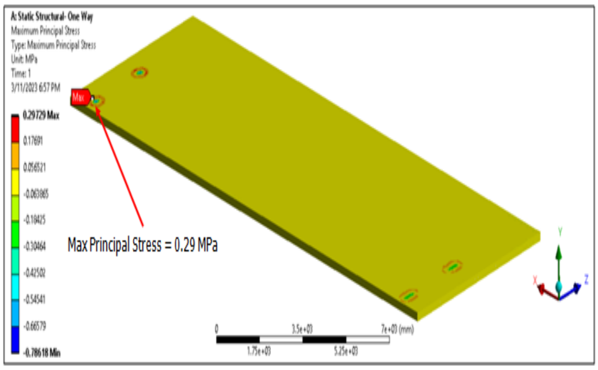


Figure 10. Maximum Principal Stress for Case-1

Furthermore, figure 10. Shows the maximum principal stress recorded was 0.29 MPa, indicating the highest stress magnitude experienced within the pavement structure. This information is crucial for assessing the material's resistance to failure under different loading scenarios.

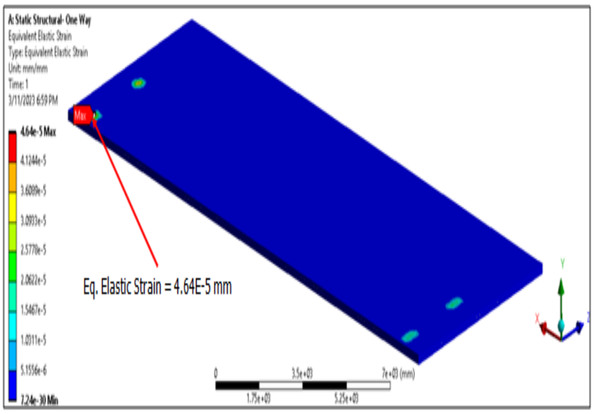


Figure 11. Maximum Principal Elastic Strain for Case-1

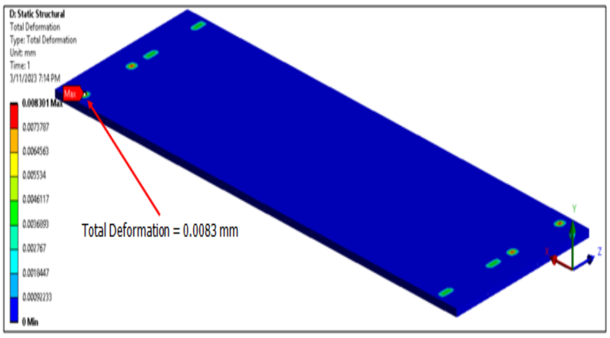


Figure 12. Static total deformation for Case-2

It provides crucial information regarding potential areas of stress concentration and vulnerability to cracking. Figure 11 shows The equivalent elastic strain in the pavement was found to be 4.92E-5 mm. This parameter represents the strain experienced by the material within the elastic limit. It helps determine the pavement's ability to recover its original shape after the load is removed. The maximum principal elastic strain observed in the pavement was 1.02E-5 mm. This strain component represents the maximum tensile or compressive strain experienced by the material. It is a significant factor in assessing the pavement's susceptibility to deformation and potential failure. These results and discussions serve to analyze and evaluate the static behavior of Continuous reinforced concrete pavement, aiding in the understanding of its performance under various loading conditions.

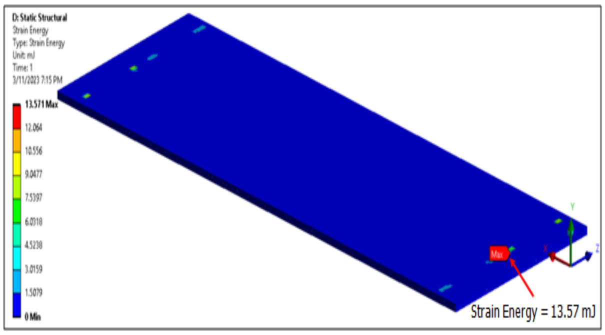


Figure 13. Strain Energy for Case-2

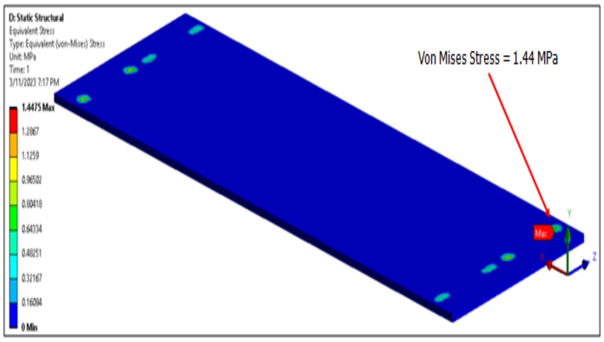


Figure 14. Von Mises Stress for Case-2

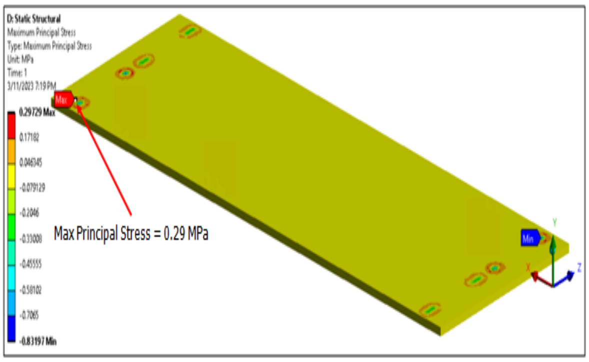


Figure 15. Maximum Principal Stress for Case-2

The results obtained from the finite element analysis provide valuable insights into the static behavior of the Continuous reinforced concrete pavement under the two-way road load condition. The low values of total deformation, Von Mises stress, and maximum principal stress indicate that the pavement is able to effectively distribute the load and maintain its structural integrity. The calculated strain energy indicates that the pavement possesses sufficient resistance against deformation and cracking.

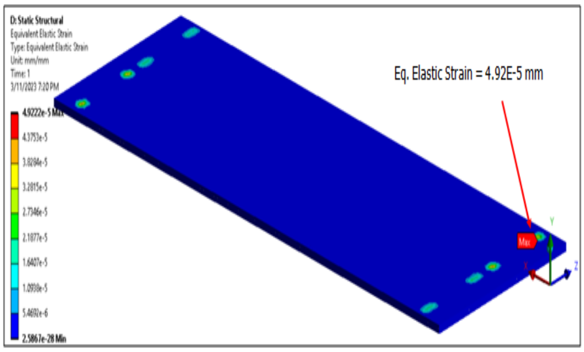


Figure 16. Maximum Principal Elastic Strain for Case-2

The low values of equivalent elastic strain and maximum principal elastic strain further validate the pavement's ability to recover its shape within the elastic limit.

Under the one-way road load condition, the total deformation of the pavement is calculated to be 0.0083 mm. This deformation indicates the amount of displacement experienced by the pavement under the applied load. Comparing the results of the two-way road load condition, finds that the total deformation remains the same at 0.0083 mm. This suggests that the load configuration does not significantly affect the overall deformation of the pavement.

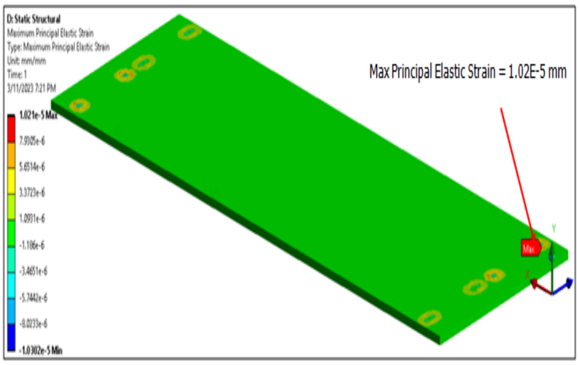


Figure 17. Maximum Principle Elastic Strain for Case-2

Moving on to the strain energy, which represents the amount of energy stored in the pavement due to the applied load, we observe a slight increase from 12.38 mJ in the one-way condition to 13.57 mJ in the two-way condition. This indicates that the two-way load configuration results in a slightly higher energy storage within the pavement compared to the one-way load configuration. The Von Mises stress is a measure of the stress state within the pavement material, taking into account both normal and shear stresses.

Table 3. Observations.

Static Analysis Results	**One Way Road Load Condition**	**Two Way Road Load Condition**
Total Deformation	0.0083 mm	0.0083 mm
Strain Energy	12.38 mJ	13.57 mJ
Von Mises Stress	1.33 MPa	1.44 MPa
Max Principal Stress	0.29 MPa	0.29 MPa
Eq. Elastic Strain	4.64E-5 mm	4.92E-5 mm
Max Principal Elastic Strain	9.9E-6 mm	1.02E-5 mm

Under the one-way road load condition, the Von Mises stress is calculated to be 1.33 MPa, while in the two-way condition, it slightly increases to 1.44 MPa. This indicates that the two-way load configuration leads to a slightly higher stress concentration within the pavement material compared to the one-way configuration.

Considering the maximum principal stress, which represents the maximum stress magnitude experienced by the pavement, we find that it remains constant at 0.29 MPa for both the one-way and two-way road load conditions. This suggests that the load configuration does not have a significant effect on the maximum stress experienced by the pavement.

Examining the equivalent elastic strain, which represents the deformation of the pavement within the elastic range, we find that it decreases slightly from 4.92E-5 mm in the one-way condition to 4.64E-5 mm in the two-way condition. This indicates that the two-way load configuration results in a slightly lower elastic deformation within the pavement compared to the one-way configuration.

Finally, analyzing the maximum principal elastic strain, which represents the maximum elastic deformation experienced by the pavement, we observe an increase from 9.9E-6 mm in the one-way condition to 1.02E-5 mm in the two-way condition. This suggests that the two-way load configuration leads to a slightly higher maximum elastic deformation within the pavement compared to the one-way configuration.

5. CONCLUSIONS

Based on the finite element analysis conducted on the static behavior of CRCP under one-way and two-way road load conditions, the following conclusions can be drawn:

1. Both one-way and two-way road load conditions resulted in a total deformation of 0.0083 mm. This indicates that the CRCP design and construction can effectively withstand the applied load without excessive deformation.
2. The strain energy values for both road load conditions were found to be 12.38 mJ and 13.57 mJ, respectively. This suggests that the CRCP has sufficient energy absorption

capacity to withstand the applied load and prevent failure.

3. The Von Mises stresses observed in the CRCP were 1.33 MPa and 1.44 MPa for one-way and two-way road load conditions, respectively. These stress values are within an acceptable range and indicate that the CRCP can resist the applied load without experiencing significant stress concentrations.
4. The maximum principal stresses for both road load conditions were 0.29 MPa, further indicating that the CRCP can effectively distribute the load and minimize stress concentrations.
5. The equivalent elastic strains were found to be 4.92E-5 mm and 4.64E-5 mm for one-way and two-way road load conditions, respectively. These values demonstrate the ability of the CRCP to deform elastically and recover its original shape after the load is removed.
6. The maximum principal elastic strains observed were 9.9E-6 mm for one-way and 1.02E-5 mm for two-way road load conditions. These small strain values suggest that the CRCP maintains its structural integrity even under high load conditions.

In conclusion, based on the finite element analysis, it can be stated that the CRCP design and construction exhibit favorable static behavior under both one-way and two-way road load conditions. The pavement demonstrates adequate deformation resistance, energy absorption capacity, stress distribution, and elastic recovery, ensuring its durability and longevity.

References:

Ai, Z. Y., Wang, X. K., Wang, X. M., Ye, Z., & Yang, J. J. (2023). Dynamic behaviours of continuously reinforced concrete pavement on a layered transversely isotropic saturated subgrade under moving loads. *International Journal for Numerical and Analytical Methods in Geomechanics*. https://doi.org/10.100

Alae, M., Ling, M., Haghshenas, H. F., & Zhao, Y. (2021). Three-dimensional finite element analysis of top-down crack propagation in asphalt pavements. *Engineering Fracture Mechanics, 248*, 107736. https://doi.org/10.1016/j.engfracmech.2021.107736

Al-Qadi, I. L., & Elseifi, M. A. (2006). Mechanism and modeling of transverse cracking development in continuously reinforced concrete pavement. *International Journal of Pavement Engineering, 7*(4), 341-349. https://doi.org/10.1080/10298430600799067

Chen, J., Dan, H., & Ding, Y. (2021). New innovations in pavement materials and engineering: A review on pavement engineering research 2021. *Journal of Traffic and Transportation Engineering (English Edition), 8*(6), 815-999. https://doi.org/10.1016/j.jtte.2021.10.001

Cho, B. H., Won, M., & Nam, B. H. (2021). Layer composition of continuously reinforced concrete pavement optimized using a regression analysis method. *Journals Infrastructures, 6*(4), 56. https://doi.org/10.3390/infrastructures6040056

Cho, Y. K., Kim, S. M., Chung, W., Kim, J. C., & Oh, H. J. (2014). Effect of steel ratio on behavior of continuously reinforced concrete railway track under environmental loads. *KSCE Journal of Civil Engineering, 18*(6), 1688-1695. https://doi.org/10.1007/s12205-014-1559-y

Dong, W., Liu, C., Bao, X., Xiang, T., & Chen, D. (2020). Advances in the deformation and failure of concrete pavement under coupling action of moisture, temperature, and wheel load. *Materials, 13*(23), 5530. https://doi.org/10.3390/ma13235530

Gupta, S., & Degrande, G. (2010). Modelling of continuous and discontinuous floating slab tracks in a tunnel using a periodic approach. *Journal of Sound and Vibration, 329*(8), 1101-1125. https://doi.org/10.1016/j.jsv.2009.10.037

Hussein, M. F. M., & Hunt, H. E. M. (2006). Modelling of floating slab tracks with continuous slabs under oscillating moving loads. *Journal of Sound and Vibration, 297*(1-2), 37-54. https://doi.org/10.1016/j.jsv.2006.03.026

Kang, Y. J., Park, J. S., Yoon, K. Y., & Han, S. Y. (2004). Experimental study on fatigue strength of continuously reinforced concrete pavements. *Magazine of Concrete Research, 56*(10), 605-615. https://doi.org/10.1680/macr.2004.56.10.605

Kashif, M., Naseem, A., Iqbal, N., De Winne, P., & De Backer, H. (2021). Numerical evaluation of early-age crack induction in continuously reinforced concrete pavement with different saw-cut dimensions subjected to external varying temperature field. *Applied Science, 11*(1). https://doi.org/10.3390/app11010042

Kashyzadeh, K. R., Souri, K., Bayat, A. G., Jabalbarez, R. S., & Ahmad, M. (2022). Fatigue life analysis of automotive cast iron knuckle under constant and variable amplitude loading conditions. *Applied Mechanics, 3*(2), 517-532. https://doi.org/10.3390/applmech3020030

Kim, S. M., & Won, M. C. (2004). Horizontal cracking in continuously reinforced concrete pavements. *ACI Structural Journal, 101*(6), 784-791.

Kim, S. M., Won, M. C., & McCullough, B. F. (1998). Numerical modeling of continuously reinforced concrete pavement subjected to environmental loads. *Transportation Research Record, 1629*(1), 76-89. https://doi.org/10.3141/1629-10

Kim, S. M., Won, M. C., & McCullough, B. F. (1998). Numerical modeling of continuously reinforced concrete pavement subjected to environmental loads. *Transportation Research Record, 1629*(1). https://doi.org/10.3141/1629-10

Kim, S. M., Won, M. C., & McCullough, B. F. (2000). Three-dimensional analysis of continuously reinforced concrete pavements. *Transportation Research Record, 1730*(1), 43-52. https://doi.org/10.3141/1730-06

Liu, C., McCullough, B. F., & Oey, H. S. (2000). Response of rigid pavements due to vehicle-road interaction. *Journal of Transportation Engineering, 126*(3), 237-242. https://doi.org/10.1061/(ASCE)0733-947X(2000)126:3(237)

Liu, K., Zhang, X., Wang, Y., Han, S., Luo, Z., Hao, J., & Zhang, J. (2023). Laboratory investigation on early-age shrinkage cracking behavior of partially continuous reinforced concrete pavement. *Construction and Building Materials, 377*, 131125. https://doi.org/10.1016/j.conbuildmat.2023.131125

Mackiewicz, P. Finite-element analysis of stress concentration around dowel bars in jointed plain concrete pavement. *Journal of Transportation Engineering*. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000768

Ouzaa, K., & Benmansour, M. B. (2014). Cracks in continuously reinforced concrete pavement. *Arabian Journal for Science and Engineering, 39*(6), 8593-8608.

Roesler, J. R., Hiller, J. E., & Brand, A. S. (2016). Continuously reinforced concrete pavement manual: Guidelines for design, construction, maintenance, and rehabilitation. *Federal Highway Administration*.

Sarkar, A., & Norouzi, R. (2020). Evaluating curling stress of continuous reinforced concrete pavement. *Structural Journal, 117*(1). https://doi.org/10.14359/51720197

Shoukry, S. N., Fahmy, M., & Prucz, J. (2007). Validation of 3D-FE analysis of rigid pavement dynamic response to moving traffic and nonlinear temperature gradient effects. *International Journal of Geomechanics, 7*(1). https://doi.org/10.1061/(ASCE)1532-3641(2007)7:1(16)

Singh, I., Dev, N., Pal, S., & Visalakshi, T. (2021). Finite element analysis of impact load on reinforced concrete. *Emerging Technologies and Applications for Green Infrastructure*, Lecture Notes in Civil Engineering, *203*. https://doi.org/10.1007/978-981-16-7160-9_26

Vandenbosschea, J. M., Nassiri, S., Ramireza, L. C., & Sherwood, J. A. (2012). Evaluating the continuously reinforced concrete pavement performance models of the mechanistic-empirical pavement design guide. *Road Materials and Pavement Design, 13*(2), 235-248.

Wang, H., & Belarbi, A. (2010). Static and fatigue bond characteristics of FRP rebars embedded in fiber-reinforced concrete. *Journal of Composite Materials, 44*(13). https://doi.org/10.1177/0021998309355845

Yeon, J. H., Choi, S., Ha, S., & Won, M. C. (2013). Effects of creep and built-in curling on stress development of Portland cement concrete pavement under environmental loadings. *Journal of Transportation Engineering, 139*(2), 147-155. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000451

Zhang, Y., & Liu, H. (2012). Finite element analysis of thermal stress for continuous reinforced concrete pavement (CRCP). *Journal of Highway and Transportation Research and Development (English Edition), 6*(2), 1-110. https://doi.org/10.1061/JHTRCQ.0000118

Sanjay Nayak
J.S.P.M.S. Rajshree Shahu College of Engineering, Tathawade, Pune
Maharashtra, India – 411033.
sanjay.nayakphd@gmail.com
ORCID 0009-0001-2506-5439

R. K. Jain
J.S.P.M.S. Rajshree Shahu College of Engineering, Tathawade, Pune
Maharashtra, India – 411033
jainrb20@gmail.com
ORCID 0000-0002-0216-5437

Deepa Joshi
Department of Civil Engineering, Dr. D. Y. Patil Institute of Technology, Pimpri,
Pune-411018
joshi.deepa13@gmail.com
ORCID 0000-0002-7730-5625

Radhika Menon
Mathematics, Dr. D. Y. Patil Institute of Technology, Pimpri,
Pune-411018
Radhika.menon@dypvp.edu.in
ORCID 0000-0002-0389-9037

Vinayak Kale
Department of Civil Engineering, Dr. D. Y. Patil Institute of Technology, Pimpri,
Pune-411018
vinkkvinkk@gmail.com
ORCID 0000-0001-8218-7857