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# Structural Performance of Flexible Pavements Under Static Loading Using ANSYS FEA

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*Abstract:* This research paper presents a comprehensive structural analysis of flexible pavements using the ANSYS Finite Element Analysis (FEA) simulation package. The primary objective was to evaluate the deformation and stress responses of flexible pavements under applied loads. The methodology involved developing a detailed CAD model of the pavement, meshing it accurately to capture critical features, and applying realistic loading and boundary conditions to simulate various traffic and environmental scenarios. The analysis revealed significant findings, including the identification of maximum normal stress and maximum deformation occurring near the load application zones. Additionally, the study highlighted the distribution of principal elastic strains, indicating potential areas of structural concern, such as cracking or rutting. These insights underscore the importance of robust material selection and design strategies in enhancing pavement durability and performance. The results provide valuable data for optimizing pavement design and maintenance practices, contributing to the development of more resilient and sustainable transportation infrastructure.

***IndexTerms* –Flexible pavement, stability**

## I. INTRODUCTION

The structural behavior of flexible pavements is governed by the interaction between the various layers within the pavement structure. Typically, a flexible pavement consists of multiple layers, including the surface course, base course, subbase course, and subgrade. Each layer serves a specific function, such as providing support, distributing loads, or enhancing drainage. The surface course, often composed of asphalt concrete, serves as the driving surface and provides resistance to wear and environmental factors. Beneath the surface course, the base and subbase courses distribute traffic loads over a larger area and provide structural support. Finally, the subgrade, which is the natural soil foundation of the pavement, must be properly compacted to provide a stable base for the pavement layers. Material selection is crucial in flexible pavement design, as each layer must possess specific properties to withstand the anticipated traffic loads and environmental conditions. For example, asphalt concrete used in the surface course must be flexible yet durable, while the aggregate materials in the base and subbase courses must provide sufficient strength and stability.

## II. LITERATURE REVIEW

Three commonly used techniques are currently employed in the assessment of wind-sensitive structures in wind tunnel practice. Chen and Zhang (2019) demonstrated the efficacy of the Falling Weight Deflectometer (FWD) in assessing flexible pavement performance. Their findings suggest that FWD measurements accurately reflect pavement deflection, providing valuable insights into structural integrity and remaining service life. This study underscores the importance of reliable evaluation techniques for effective pavement management and maintenance.

Newcomb et al. (2020) reviewed the best practices and performance outcomes of Warm Mix Asphalt (WMA) technologies. Their study highlights the environmental and economic benefits of WMA, including reduced energy consumption, lower emissions, and improved workability. By examining various WMA additives and production methods, this research provides valuable insights for implementing sustainable pavement solutions.

Garber and Hoel (2017) explored the use of sustainable materials in pavement construction, focusing on recycled and renewable resources. Their comprehensive review assesses the environmental impact, performance characteristics, and cost-effectiveness of alternative materials such as reclaimed asphalt pavement (RAP), recycled concrete aggregate (RCA), and bio-based binders. The study underscores the importance of integrating sustainable practices into pavement design and construction processes.

Mahmoud and Tighe (2018) provided a comprehensive review of recent advancements in asphalt binder technologies. Their study examined various modifiers, including polymers, rejuvenators, and additives, and their effects on asphalt rheology, durability, and performance. By elucidating the mechanisms of binder modification and their implications for pavement engineering, this research contributes to the development of high-performance asphalt materials.

Shen et al. (2019) conducted a comprehensive review of life-cycle assessment (LCA) methodologies applied to pavement systems. Their analysis encompassed environmental indicators, such as energy consumption, greenhouse gas emissions, and resource depletion, to evaluate the sustainability of different pavement materials and construction techniques. By synthesizing existing LCA studies, this research provides valuable insights for optimizing pavement design and management strategies to minimize environmental impacts.

Wang and Hu (2018) conducted a case study to investigate the effects of heavy traffic loads on flexible pavement performance. Their findings suggest that repeated loading from heavy vehicles accelerates pavement deterioration, leading to increased rutting and fatigue cracking. This research emphasizes the importance of considering traffic characteristics in pavement design and maintenance practices to enhance durability and service life.

## III. OBJECTIVES

The objective of current research is to conducted structural analysis on flexible pavement using ANSYS FEA simulation package. From the analysis, the deformation, stresses on flexible pavement is evaluated.

## IV. METHODOLOGY

The methodology process encompasses CAD modeling, meshing, applying loads and boundary conditions. The CAD model of flexible pavement is developed in ANSYS design modeler as shown in figure 1. The model of flexible pavement is developed using sketch and extrude tool.

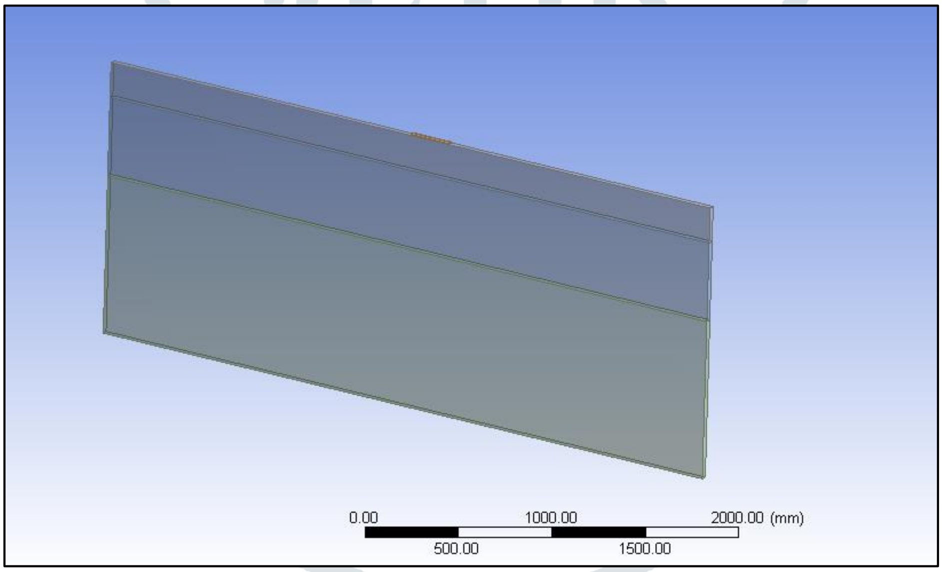

**Figure 1: CAD model of flexible pavement**

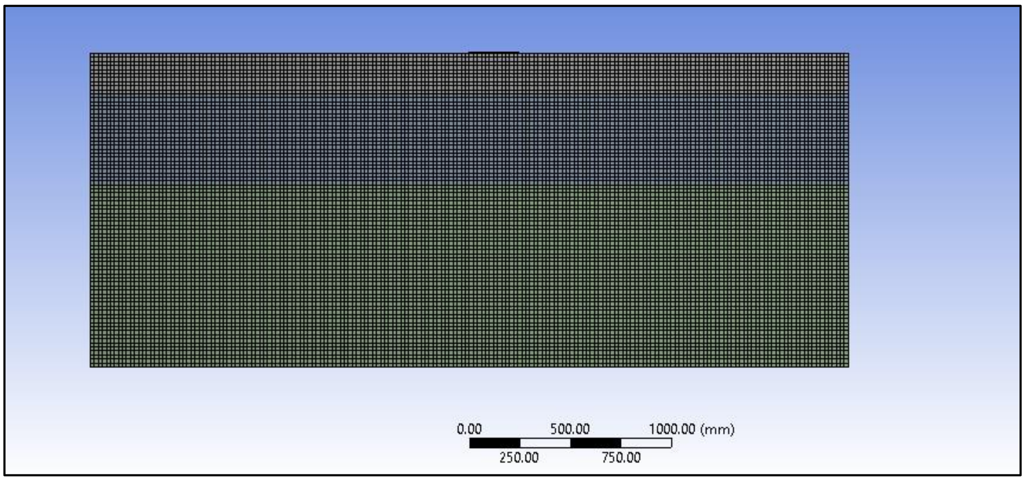

**Figure 2: Meshed model of flexible pavement**

Meshing plays a crucial role in accurately representing the geometry and structural components of the pavement system. The pavement geometry, including layers such as the surface course, base course, subbase course, and subgrade, is discretized into finite elements to facilitate numerical analysis. To ensure computational efficiency and accuracy, an appropriate mesh density is selected, balancing the trade-off between computational resources and solution accuracy. In meshing the pavement geometry, attention is paid to capturing critical features such as layer interfaces, material transitions, and areas of stress concentration, which significantly impact the structural response of the pavement under loading.

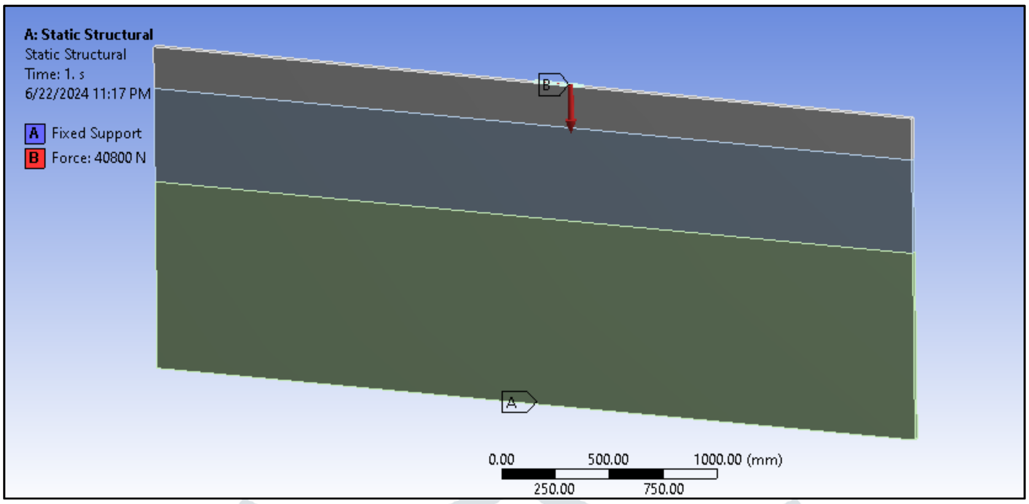

**Figure 3: Meshed model of flexible pavement**

The behavior of flexible pavements using FEA, defining realistic loading and boundary conditions is essential for obtaining meaningful results. Various types of loading scenarios are considered, including static loads from traffic vehicles, dynamic loads from braking and acceleration, and environmental loads such as temperature variations and moisture effects. Boundary conditions are applied to model the interaction between the pavement structure and the surrounding environment, including constraints to represent fixed supports, roller boundaries to simulate the influence of adjacent pavement sections, and thermal boundary conditions to account for temperature gradients within the pavement layers. Once the pavement geometry is meshed, and loading and boundary conditions are defined, the solution stage of the FEA involves solving the system of equations governing the structural behavior of the pavement under the applied loads. The finite element method discretizes the governing equations into a set of algebraic equations, which are then solved iteratively using numerical techniques such as the finite element method or direct solution methods. During the solution stage, the structural response of the pavement, including deflections, stresses, strains, and deformation patterns, is computed at discrete points within the pavement structure.

## V. RESULTS AND DISCUSSION

From the FEA analysis, the normal stress, deformation is evaluated. The induced normal stress is maximum at the zone of load application as shown in figure 4. The maximum induced normal stress is 9.1218MPa as represented in blue colored zone which reduces as we move towards the subgrade layer. The normal stress is minimal on other zones of flexible pavement as represented by dark orange colored zones wherein the magnitude of normal stress is 0.555MPa.

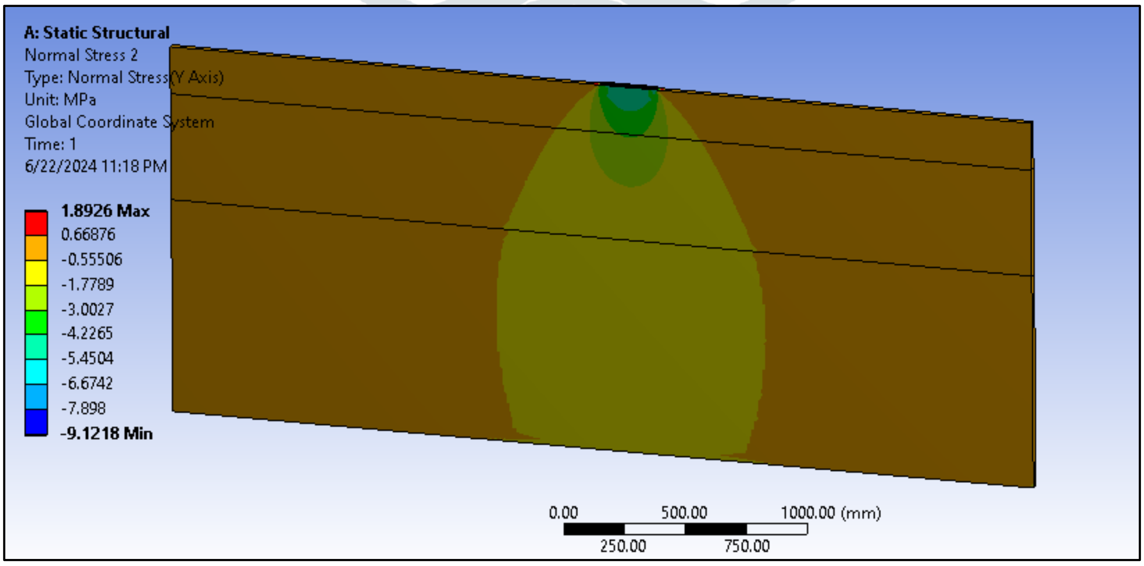

**Figure 4: Induced normal stress on flexible pavement**

The stress contour indicates the distribution of normal stresses across the pavement cross-section. The color gradient represents different stress magnitudes, with red indicating maximum compressive stress and blue indicating maximum tensile stress. The stress distribution shows a high-stress concentration near the surface, likely corresponding to the load application point. This is typical in flexible pavements where the top layers experience the highest stress levels due to direct contact with traffic loads. The topmost layer exhibits the highest stress concentration (green to red zones), suggesting that this area is subjected to significant compressive stress. This is consistent with the surface layer's role in bearing direct traffic loads. The maximum compressive stress near the surface can lead to deformation or potential surface cracking if not properly managed. The stress distribution in these layers shows a gradient from higher compressive stress near the load application zone to lower stress towards the edges. This reflects the load distribution function of the base and subbase layers. These layers are critical for transferring and dissipating loads to prevent excessive stress concentrations in the subgrade.

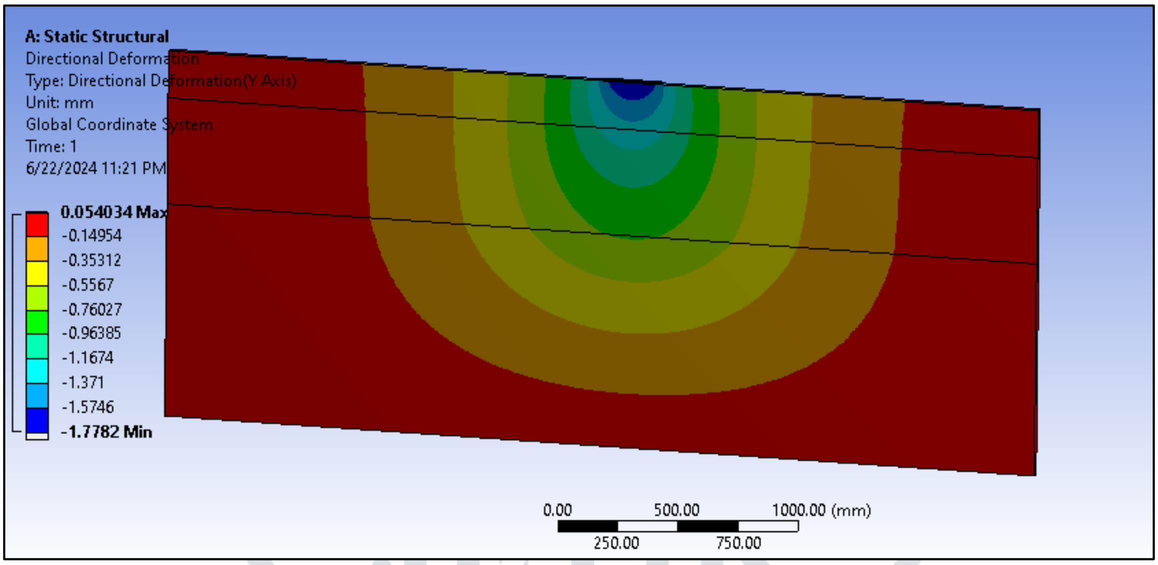

Figure 5: Directional deformation on flexible pavement

The directional deformation plot is obtained for the pavement design as shown in figure 5. The plot shows maximum deformation at the center of pavement wherein the vehicular load is applied. The maximum deformation induced at the zone of load application is nearly 1.7782mm and is lower at the other zones of flexible pavement.

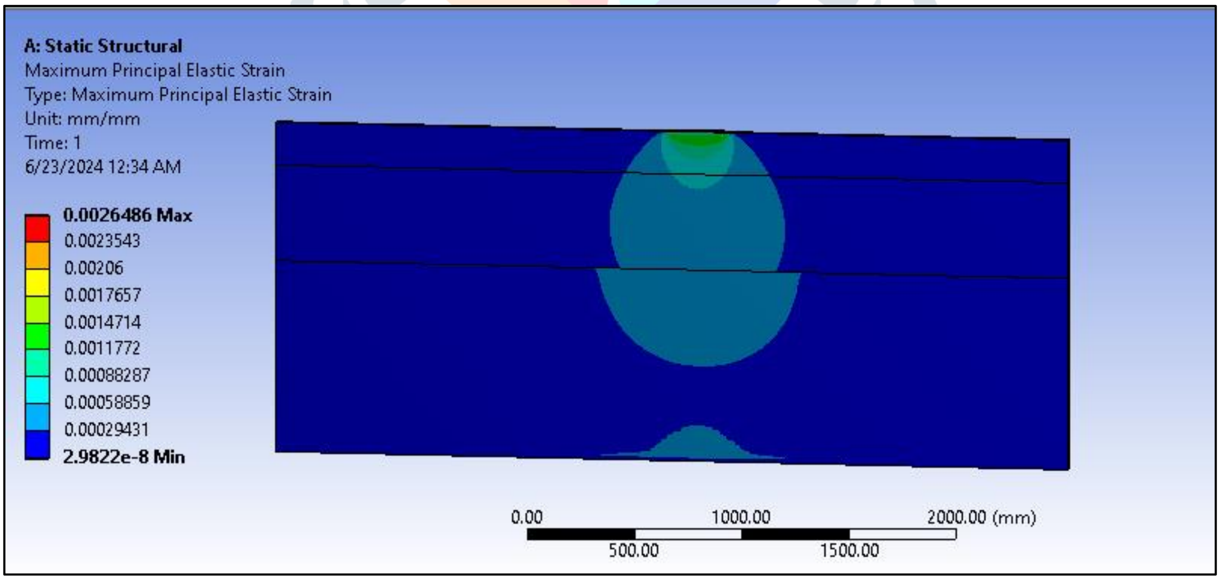

Figure 6: Maximum principal elastic strain on flexible pavement

The strain contour illustrates the distribution of maximum principal elastic strain across the pavement cross-section. The color gradient indicates varying strain magnitudes, with red representing the highest strain and blue the lowest. A significant concentration of strain is observed near the load application area, which diminishes as the distance from the load application point increases. The topmost layer exhibits the highest strain concentration (green to red zones), suggesting that this area undergoes significant deformation under applied loads. This is typical for the surface course, which directly interacts with traffic loads. High strain in the surface course indicates potential areas where cracking or rutting might initiate if the strain exceeds the material's elastic limit. The strain distribution in these layers shows a gradient from higher strain near the surface to lower strain towards the subgrade. This reflects the role of the base and subbase in dissipating the applied loads and reducing the strain transmitted to the subgrade. Moderate strain levels in these layers are essential for load distribution but should be monitored to prevent excessive deformation.

# VI. CONCLUSION

The FEA analysis of flexible pavement using ANSYS provided comprehensive insights into the structural behavior under various loading conditions. The investigation focused on evaluating deformation, normal stresses, and principal elastic strains within the pavement structure. The results indicated that the maximum normal stress, approximately 9.1218 MPa, occurred near the load application zone on the surface course, diminishing through the base and subbase layers to minimal levels in the subgrade. This stress distribution underscores the critical role of the surface layer in bearing direct traffic loads and the importance of the base and subbase layers in load dissipation. Furthermore, the directional deformation analysis revealed significant deformation at the center of the pavement, where vehicular loads were applied, with a maximum value of approximately 1.7782 mm. This observation highlights the necessity for robust material selection and structural design to mitigate potential surface deformation and cracking. The maximum principal elastic strain analysis showed a high concentration near the load application area, indicating areas susceptible to cracking or rutting if the strain exceeds material limits. The study demonstrated that flexible pavements are subject to high stress and strain concentrations at the surface layer, necessitating careful material selection, design considerations, and maintenance strategies to enhance pavement durability and performance. The findings provide valuable data for optimizing pavement design and improving the resilience of transportation infrastructure.

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