Sensitivity analysis of crack propagation in bituminous pavement layers utilizing a hybrid system that using the Finite Element Method.

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Abstract-

The paper presents results of sensitivity analysis to crack propagation of a pavement bituminous layered structure using the Finite Element Method (FEM). In many developing countries, pavement design still relies on empirical methods, often leading to premature failure or overdesigned pavements. There is a growing need to transition from empirical to semi-mechanistic or mechanistic approaches. Computational tools like finite element (FE) analysis are being effectively used to gain deeper insights, as these tools allow researchers to study the complex behavior of bituminous concrete (BC) materials. BC material is known to exhibit viscoelastic or viscoelasto-plastic behavior, depending on the applied loading and temperature conditions. However, many pavement design tools still consider these materials as purely elastic due to the complexity of the procedures involved. This research aims to develop a simple and practical FEM-based framework to evaluate the structural response of BC materials with viscoelastic characterization, providing an effective tool to predict field behavior using commonly available pavement material tests. The second method, i.e. the extend Finite Element Method was applied, to simulate cracking process of the bituminous layer of a road surface. The pavement model was subjected to static load. Both linear and non-linear material properties of the pavement layers were considered to discuss crack propagation sensitivity in the pavement layers. The main conclusion is that cracking significantly increases as the thickness of the bituminous layer B2 decreases. In contrast, the thickness of the asphalt layer B1 has a much smaller impact on the cracking of the sub grade layer.

Keywords: Transport infrastructure, FEM, Effect of air voids,

1.0 Introduction:

Asphalt pavement cracking presents a significant challenge for road infrastructure development, affecting both worn-out and relatively new roads that adhere to contractor specifications. Cracking in multilayered road pavements is influenced by various factors, including the strength parameters and thickness of the layers, the loads applied, and the production technology used. This study explores the use of a FEM system to predict cracking sensitivity in a sub grade layer (Fig. 1). The system leverages MLP and RBF networks, with input variables comprising asphalt pavement layer parameters and different load modes. In this system, which uses Multilayer Perceptron (MLP) and Radial Basis Function (RBF) networks, the input variables focus on asphalt pavement layer parameters and different load modes. Here's how these neural network models might be applied within this context:

- **Asphalt Pavement Layer Parameters**: This includes data on layer thickness, material properties (e.g., modulus, density, Poisson's ratio), and other structural characteristics of each layer in the pavement. These parameters are critical as they directly influence the stress-strain response of the pavement under load.
- **Different Load Modes**: Different types of loads, such as static, dynamic, and repeated loads, represent real-world stresses on pavement. Variables here might include load magnitude, load duration, frequency, and loading angle. These variables are essential for simulating realistic traffic conditions that the pavement structure would encounter over its lifespan.

Current pavement design procedures in many developing countries still rely on direct and indirect empirical approaches, which can lead to premature pavement failure or over-designed pavements [1]. However, there is a growing recognition of the need to transition from empirical methods to semi-mechanistic or mechanistic pavement design that better suits local requirements. This shift is being increasingly acknowledged by countries such as India. To support this transition, different material characterization tests will be necessary. A crucial aspect to incorporate is the time and temperature dependency of pavement materials. While Dynamic Shear Rheometer (DSR) tests are commonly used to characterize the time/temperature dependency of binding materials, such tests are either not performed or rarely used for mixtures[3]. The authors believe that characterizing the temperature dependency of the mixture is particularly important for countries like India, where significant temperature variations occur across different regions and seasons.

Significant temperature variations can have a major impact on pavement structures, especially affecting the sub grade layer and other asphalt and concrete layers. Here's why these variations matter:

- Temperature changes cause the pavement materials to expand and contract. In regions with extreme temperature fluctuations (e.g., hot days and cold nights, or seasonal changes), this can lead to repeated stress cycles in the pavement layers. Over time, these stresses can result in cracking, especially in the sub grade and asphalt layers, weakening the pavement structure.

In colder climates, significant temperature drops below freezing cause the water in the pavement structure and sub grade to freeze and expand. As temperatures rise, the ice thaws, leading to moisture within the pavement layers. This freeze-thaw cycle is especially damaging to the sub grade, as repeated expansion and contraction can create voids, weaken the soil structure, and cause frost heaves that lead to surface cracking and unevenness.

Fig. 1 Cracked Asphalt

In India, bituminous concrete (BC) pavements, which are multilayer structures with varying material properties, are gaining popularity. According to the Ministry of Road Transport & Highways, India has categorized BC into BC-1 and BC-2 based on aggregate gradations. BC-1 has a nominal aggregate size of 19 mm, while BC-2 has a nominal aggregate size of 13.2 mm. BC-2 contains a higher percentage of fine aggregates (62% passing through a 4.75 mm IS sieve) compared to BC-1 (50% passing through a 4.75 mm IS sieve) [2,6]. Consequently, the minimum binder content specified for BC-2 is higher (5.4%) than for BC-1 (5.2%). Due to its higher percentage of fine aggregates, BC-2 provides a smoother surface than BC-1, which facilitates the fixing of deformation measuring transducers. This smoother surface has motivated its consideration as the top layer in the present study. The different material choices and production processes result in distinct mechanical characteristics and performance outcomes for BC-1 and BC-2. In the context of road construction and pavement engineering, Bituminous Concrete (BC) has indeed been used in India for several decades. However, authors mentioning that it is "gaining popularity" likely reflects recent trends where BC has become the preferred choice for high-quality road surfacing across a wider range of projects and regions in India. Here are some possible reasons why BC might be said to be gaining popularity despite its established history:

In pavement construction, Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) layers are commonly used, each with recommended thicknesses based on function, traffic load, and material properties. A 150 mm BC layer is indeed considered impractical for a few reasons, primarily due to constructability and performance limitations. Here’s a breakdown of typical thicknesses and why 150 mm BC is not advisable:

Bituminous Concrete (BC) Layer:

- Purpose: BC serves as the top, wearing course of the pavement, providing a smooth, durable, and weather-resistant surface.
- Typical Thickness: BC is usually applied in layers of 25–50 mm. Thicker applications are uncommon because BC is designed primarily for surface performance rather than structural support.
- Reasoning: For effective compaction and performance, BC layers are kept thin. Increasing BC thickness (e.g., to 150 mm) would make compaction difficult, leading to an increased risk of voids and reduced durability.

With the recent push for durable, long-lasting infrastructure, there is an increased preference for bituminous concrete due to its superior performance under traffic and environmental stressors. BC offers high resistance to cracking, rutting, and weathering, which aligns with modern requirements for long-lasting pavements, especially for national highways, expressways, and urban roads.

India’s rapid urbanization and the increase in traffic volume and vehicle loads have raised demand for materials that withstand heavy-duty applications. BC, known for its structural strength and load-bearing capacity, is being increasingly specified for major highways, industrial zones, and high-traffic urban areas, thus contributing to its “growing popularity.”

Predicting cracking sensitivity in a sub grade layer is essential in pavement engineering for several key reasons:
Structural Integrity and Load-Bearing Capacity

- The sub grade serves as the foundational layer of a pavement structure, supporting the layers above it (base, sub-base, and surface). If the sub grade is prone to cracking, it compromises the entire pavement system’s load-bearing capacity. Cracks in the sub grade can propagate to the surface layers, accelerating overall pavement deterioration and reducing its structural life.

Prevention of Surface Distress

- Cracks originating in the sub grade layer often worsen under repeated load cycles, eventually reaching and affecting surface layers. This results in visible surface distresses like alligator cracking, rutting, and potholes. Predicting sub grade cracking sensitivity allows engineers to preemptively strengthen the pavement structure, potentially delaying or avoiding such surface issues.

As discussed previously, understanding the behavior of the bituminous concrete (BC) mix is crucial for achieving the expected pavement lifetime. Uncertainties in the mix design phase can significantly reduce this lifetime. To minimize such risks, road agencies in India require testing of these mix samples under controlled laboratory conditions, such as the Marshall stability test and resilient modulus test. However, tests measuring the visco-elastic characterization of the mixture are not mandated. It is well known that asphaltic materials like BC can exhibit visco-elastic or visco-elasto-plastic behavior depending on loading and ambient temperature conditions. Many researchers have studied the visco-elastic behavior of binders and bituminous mixes to analyze flexible pavement. Measuring the properties of BC across a wide range of frequencies and temperatures is essential to capture its viscoelastic behavior[8]. At high temperatures or under slow-moving loads, BC may exhibit purely viscous flow, indicating a tendency toward rutting. In contrast, at low temperatures and under fast-moving loads, BC becomes progressively harder and eventually brittle, making it susceptible to low-temperature cracking. Additionally, BC is prone to fatigue-related problems at normal temperatures, as most vehicular loads are applied at these temperatures. In pavement design, a standard 40 KN single axle load is often used as a baseline, particularly for evaluating the pavement’s structural performance under typical vehicle loads. However, there are scenarios where a 20 KN load may be considered instead, depending on factors like anticipated traffic load, road function, and regional considerations. Here are some potential reasons for choosing a 20 kN load instead of the standard 40 KN.

The characterization of viscoelastic properties is often performed by measuring creep behavior. Creep-related tests are popular because they allow for the determination and separation of the time-independent (elastic strain) and time-dependent (viscoelastic) components of the strain response in a simplified manner. Additionally, parameters obtained from creep tests at low temperatures (m-value) are used to predict the development and propagation of thermal cracking, while those at high temperatures are used to predict rutting in Hot Mix Asphalt (HMA). Once creep compliance is obtained, viscoelastic behavior can be characterized through the time-temperature superposition principle [10]. The tendency of bituminous mixtures to exhibit viscous flow at high temperatures is significant for several reasons, as it directly impacts pavement performance, durability, and safety. Here’s why this behavior matters:

Rutting and Permanent Deformation

- At elevated temperatures, bituminous mixtures soften and start to flow or deform under traffic loads. This viscous flow can lead to rutting a form of permanent deformation in the pavement surface that develops as wheel loads repeatedly press into the softened material. Rutting compromises surface smoothness and can be particularly problematic on heavily trafficked roads, reducing pavement lifespan and increasing maintenance costs.
- When a pavement exhibits excessive viscous flow, it compromises the structural integrity of the pavement layers**.** Layers can shift, leading to an uneven distribution of stress within the pavement. This behavior weakens the overall structure, making the pavement more susceptible to other distresses, such as cracking and fatigue failure.

1.1 Objective:

- The sensitivity analysis aims to identify the key factors that most significantly influence the structural response of the pavement.
- The sensitivity analysis aims to determine how changes in different parameters affect the rate and pattern of crack propagation in the bituminous layered structure.
- Predict the sensitivity of the structural response of bituminous concrete (BC) pavement under various conditions specific to Indian roads.

2. Materials:

In the study, locally available silty sand has been selected as the sub grade material for the pavement. The physical properties and compliance of this material with relevant standards are crucial for ensuring the durability and performance of the pavement structure.

Key Properties of Silty Sand

1. **Free Swelling Index**:
   - **Measurement**: The free swelling index of the silty sand was measured and found to be 12%.
   - **Compliance**: This value is within the specified limit of a maximum of 50% as per IS:2720 Part 40. The free swelling index indicates the material's tendency to swell when exposed to moisture. A lower value suggests that the silty sand has relatively stable volume changes under moisture conditions.
2. **Maximum Dry Unit Weight**:
   - **Measurement**: The maximum dry unit weight of the silty sand, tested according to IS: 2720 Part 8, was found to be 17.91 kN/m³.
   - **Compliance**: This value exceeds the minimum specified value of 17.5 kN/m³. A higher dry unit weight generally indicates better compaction and density, contributing to the stability and strength of the sub grade [12].

Aggregates and Binder

In addition to the sub grade material, the physical requirements for aggregates used in the granular sub base and base layers, as well as the binder for the bituminous concrete (BC) layer, are essential for overall pavement performance.

1. **Aggregates for Granular Sub base and Base Layers**:
   - **Specifications**: The aggregates must meet specific physical and mechanical properties, such as gradation, shape, and durability, to ensure proper performance in the granular sub base and base layers [13].
   - **Testing**: Common tests include gradation analysis, aggregate impact value (AIV), and aggregate crushing value (ACV) [18].
2. **Binder for Bituminous Concrete (BC) Layer**:
   - **Specifications**: The binder must conform to standards for properties such as viscosity, penetration, and ductility to provide effective adhesion and flexibility in the BC layer.
   - **Testing**: Tests typically include penetration test, softening point test, and ductility test, among others.

Practical Implications

1. **Material Selection**:
   - **Quality Control**: Ensuring that locally available silty sand meets the required physical and chemical properties helps in achieving the desired pavement performance and longevity.
   - **Economic Efficiency**: Utilizing locally available materials can reduce transportation costs and make the project more cost-effective.
2. **Pavement Design**:
   - **Layer Design**: Proper selection and testing of materials for different layers (subgrade, granular sub base, base, and BC layer) are crucial for designing a robust pavement structure that can withstand traffic loads and environmental conditions [18].
3. **Construction and Maintenance**:
   - **Compaction and Stability**: The higher dry unit weight of the sub grade material indicates good compaction, which contributes to the overall stability of the pavement.
   - **Performance Monitoring**: Regular monitoring and testing of aggregates and binder quality during construction and maintenance phases ensure that the pavement continues to perform as intended.

3. Methedology:

3.1 Numerical analysis

Recent advancements in the numerical analysis of crack propagation, particularly in layered materials, have significantly enhanced our understanding of how cracks initiate and propagate in complex structures. These developments are crucial for improving the design and durability of various layered composites, including road pavements.

1. Numerical Analysis Techniques

- **Finite Element Method (FEM)**:
  - **Overview**: FEM is a widely used numerical technique for analyzing crack propagation in layered materials. It divides a complex structure into smaller, manageable elements and solves the governing equations to predict the behavior of each element.

    - **Applications**: FEM is applied to study road pavement structures, enabling detailed simulations of stress and strain distributions and predicting how cracks develop and propagate under different conditions [22].
- **Advances in FEM**:
    - **Enhanced Models**: Recent advancements include more sophisticated FEM models that can accurately simulate crack behavior in multi-layered composites. These models account for material properties, loading conditions, and environmental effects.
    - **Higher Resolution**: Improved mesh generation and computational techniques allow for higher resolution simulations, providing more accurate predictions of crack propagation.

2. Layered Composites

- **Metallic Layers**:
    - **Studies**: Research on crack propagation in metallic layered composites has explored various failure mechanisms and the impact of different loading conditions and material properties.
    - **Applications**: These studies are relevant for applications in aerospace, automotive, and structural engineering, where metallic composites are used for their strength and durability [18].
- **Ceramic Layers**:
    - **Studies**: Crack propagation in ceramic layered composites has been investigated to understand how these materials, which are often brittle, behave under stress.
    - **Applications**: Research in this area is important for industries where ceramics are used for their hardness and wear resistance, such as in cutting tools and armor.

3. Temperature Effects

- **Influence on Crack Behavior**:
    - **Crack Initiation and Propagation**: Temperature effects play a significant role in crack initiation and propagation in layered composites. Temperature variations can alter material properties, such as stiffness and thermal expansion, which in turn affect crack behavior.
    - **Studies**: Recent studies have focused on how temperature fluctuations impact the mechanical response of layered materials, including the effects of thermal cycling and temperature gradients.

4. Applications in Road Pavement Structures

- **Road Pavement Analysis**:
    - **FEM in Pavement Structures**: Numerical analyses using FEM are increasingly applied to investigate road pavement structures. These analyses help in understanding the performance of different pavement layers under traffic loads and environmental conditions.
    - **Crack Propagation in Pavements**: By simulating the behavior of pavement layers, engineers can predict how cracks will develop and propagate, leading to more effective design and maintenance strategies.
- **Advancements**:
    - **Improved Models**: Advances in FEM models for road pavements include better representation of material properties, loading conditions, and environmental effects, providing more accurate predictions of pavement performance.
    - **Design Optimization**: Enhanced numerical analyses contribute to optimizing pavement design, improving durability, and reducing maintenance costs.

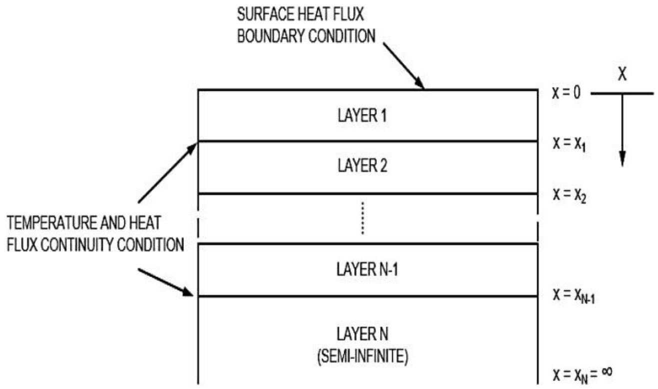


Fig. 2 Layer system used in the numerical analysis.

3.2 **Material modeling**

Material characterization of bituminous concrete

The Generalized Kelvin Model (GKM) and Generalized Maxwell Model (GMM) are two prominent models used to characterize the linear viscoelastic properties of bituminous mixes. Both models utilize series of decaying exponentials, also known as Dirichlet or Prony series, to describe the material's relaxation modulus and creep compliance. Here's a detailed overview of each model:

1. Generalized Kelvin Model (GKM)

- **Description**:
  - **Structure**: The GKM, also known as the Kelvin-Voigt model, incorporates a combination of springs (elastic elements) and dashpots (viscous elements) arranged in parallel.
  - **Behavior**: It represents materials that exhibit both elastic and viscous behavior. The parallel arrangement allows the model to capture the instantaneous elastic response and the time-dependent viscous response of the material.
- **Mathematical Representation**:
  - **Relaxation Modulus**: The relaxation modulus in the GKM is described by a series of decaying exponentials. It is often represented as:

$$\mathbf{E\ (t) = E_0} + \sum_{i=1}^{n} \boldsymbol{Eie - \frac{t}{Ti}}$$

Where E_0 is the initial modulus,E_i are the relaxation moduli for different components, and T_i are the relaxation times.

Applications:

- **Bituminous Mix**: The GKM is used to model the time-dependent behavior of bituminous mixes, particularly to describe how the material's stiffness evolves over time under load.

2. Generalized Maxwell Model (GMM)

- **Description**:
    - **Structure**: The GMM, also known as the Maxwell model, consists of a series of springs and dashpots arranged in series.
    - **Behavior**: This model is used to capture the time-dependent deformation of materials that exhibit a combination of elastic and viscous behavior, where the series arrangement allows for the prediction of creep and relaxation behavior over time.

3.3 FE modeling of bituminous concrete pavement

Finite Element (FE) modeling has been widely used for predicting the response of bituminous concrete pavements under various conditions. This technique enables detailed simulations of how pavements perform under different loading conditions and material characteristics. Here's a summary of the current state and research gaps in FE modeling for pavement response prediction:

1. Historical Development

- **Early Models**:
    - **Origins**: FE modeling for pavement response has been established for several decades, with numerous researchers developing models to simulate how pavements react to various loads, contact pressures, and material properties.
    - **Geographic Focus**: Much of the early work has been concentrated in European countries, where models have been tailored to specific load classes, contact pressures, and material properties prevalent in those regions.
- **Research Contributions**:
    - **Diverse Conditions**: Researchers have investigated different scenarios, including varying load classes and contact pressures, to understand how pavements perform under different conditions.
    - **Material Properties**: Models have been developed to account for the specific material properties used in European pavements, including bituminous mixes, sub grades, and base layers.

2. Research in Developing Countries

- **Limited Studies**:
    - **Focus**: There is a notable gap in FE modeling studies for developing countries like India, Bangladesh, and Sri Lanka. These regions often experience mixed traffic with a wide range of load classes and contact pressures, which are not always well-represented in existing models.
    - **Challenges**: The variability in material properties due to different sources and conditions in these countries poses additional challenges for accurate pavement response prediction.
- **Material Variability**:
    - **Characterization**: Materials used in pavement layers in developing countries can vary significantly based on local availability and sources. Accurate characterization of these materials is essential for reliable FE modeling.
    - **Model Adaptation**: Existing models may not directly apply to the diverse conditions found in developing countries, necessitating adaptation and recalibration to reflect local conditions accurately.

Pavement structure

In this study, the focus is on Linear Viscoelastic (LVE) material characterization of bituminous mix for sensitivity analysis of pavement response. In India, pavement design follows linear elastic theory as outlined in the guidelines for flexible pavement design (IRC: 37–2018). The pavement structure consists of a 150 mm bituminous concrete (BC) layer (including dense bituminous macadam), a 300 mm aggregate base layer, a 350 mm granular subbase layer, and a 500 mm compacted subgrade layer. The top surface of the 150 mm BC layer was used to model the contact area for tire loading. A 20 kN tire load was assumed to be uniformly distributed over the contact area at the tire-pavement interface. The contact area was estimated using a standard contact pressure of 560 kPa [24].

This contact area was represented as a rectangle with two semi-circles at the ends, as shown in Fig. 3(a). The shape was then converted to an equivalent rectangle, as suggested by Huang, with an area of 0.5227 L^2 and a width of 0.6 L. The dimensions of the contact area were determined using the tire load and contact pressure. For FE model validation, the contact area was subjected to a uniformly distributed contact pressure of 560 kPa over the entire area.

4. Results and discussion

4.1 Numerical Analysis

The numerical analysis of a multi-layer asphalt pavement structure was conducted using FEM, focusing on various aspects of pavement response, including crack propagation. Here's a detailed summary of the methodology and findings:

1. Model Description

- **2D Model**:
  - **Structure**: The model included a multi-layer asphalt pavement structure consisting of bituminous layers, sub base, sub grade layers, and fills. This setup allowed for an in-depth analysis of pavement behavior under various conditions.
  - **Layers**: Each layer was characterized by its specific material properties, with the bituminous layers being particularly critical for understanding crack propagation.

2. Extended Finite Element Method (X-FEM)

Crack Propagation Analysis:

- The analysis of crack propagation was performed using the extended finite element method (X-FEM), which is well-suited for modeling complex crack growth in materials.
- **Traction-Separation Rule**: A triangular traction-separation rule was used to describe the cracking process. This rule helps in capturing the relationship between the traction (stress) and separation (displacement) of the material at the crack interface.

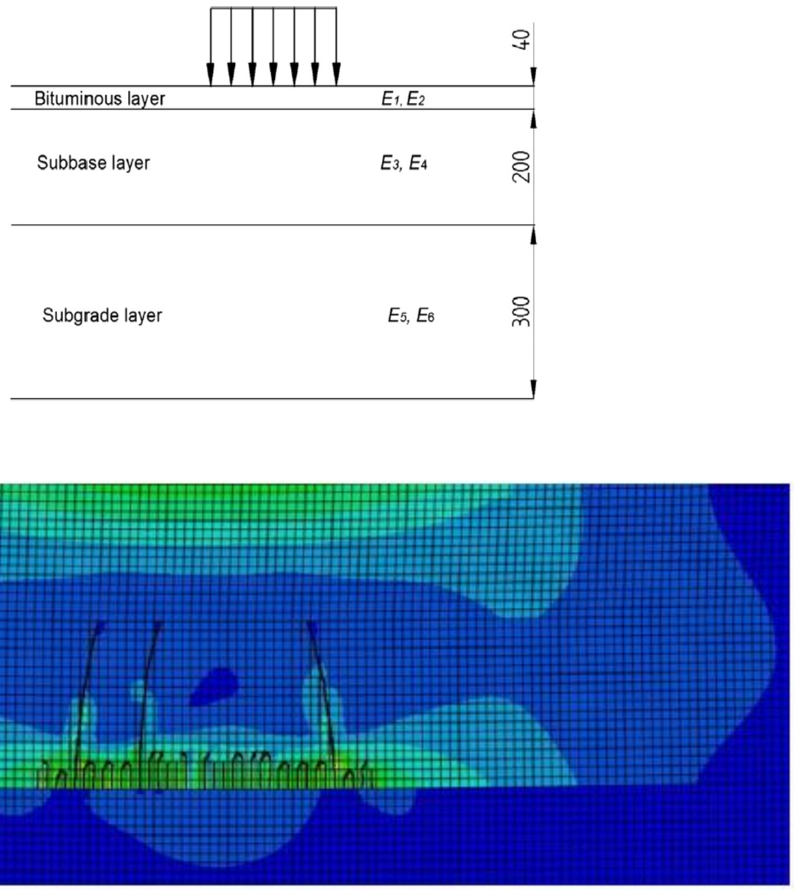
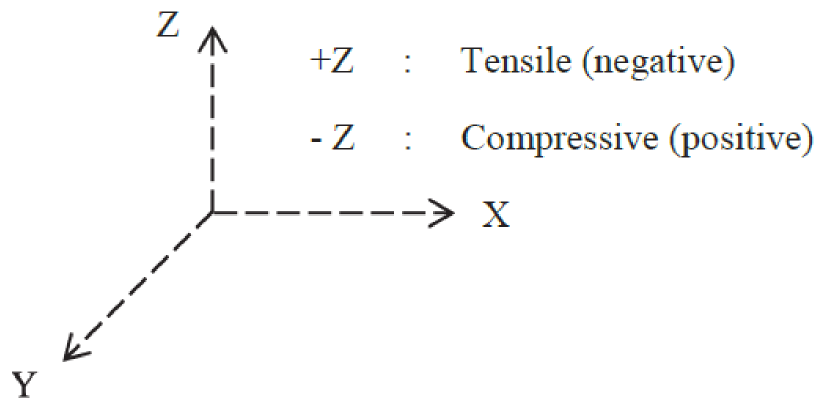


Fig. 3 Layer System and Crack propagation paths using FEM

4.2 Bituminous concrete pavement response

After evaluating the Prony series coefficients and the resilient modulus of unbound granular layers, the bituminous concrete pavement was modeled for structural response analysis. The pavement response, obtained using the FEM-based tool, was first validated with 3D Move Analysis, a continuum-based finite layer approach software developed by the University of Nevada, Reno. The FE model was validated based on the elastic properties of the bituminous mix.

A validated model was then used to predict pavement response in terms of normal compressive stress (σz), normal compressive strain (εz), and vertical deformation. These responses were estimated at zero radial distance from the axle load (r = 0) and vertically downward along the pavement depth (z). In this context, compressive stress is considered positive. Tensile stress as negative. A similar sign convention for strain has been followed. The sign convention used in the study is shown below.



The structural response analysis of bituminous concrete pavement was conducted using the finite element method (FEM), and the model was validated with an alternative tool. Here's a summary of the methodology and findings:

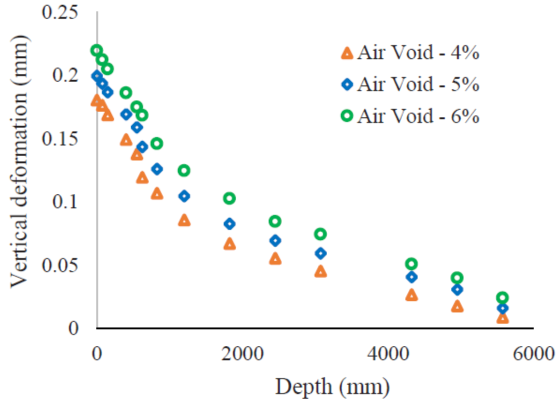
1. Model Development and Validation

- **Prony Series Coefficients and Resilient Modulus**:
  - **Prony Series**: The Prony series coefficients were evaluated to capture the time-dependent viscoelastic behavior of the bituminous concrete. These coefficients describe the relaxation modulus of the bituminous mix.
  - **Resilient Modulus**: The resilient modulus of unbound granular layers was also determined, which is essential for accurately modeling the pavement response.
- **Pavement Modeling**:
  - **FE-Based Tool**: The bituminous concrete pavement was modeled for structural response analysis using the FEM, ABAQUS software. This tool allows for detailed simulations of how the pavement responds to various loading conditions.
- **Validation with 3D Move Analysis**:
  - **Validation Software**: The FE model developed in ABAQUS was validated using 3D Move Analysis, continuum-based finite layer approach software developed by the University of Nevada, Reno.
  - **Elastic Properties**: The validation focused on comparing the elastic properties of the bituminous mix to ensure that the ABAQUS model accurately represents the pavement behavior.

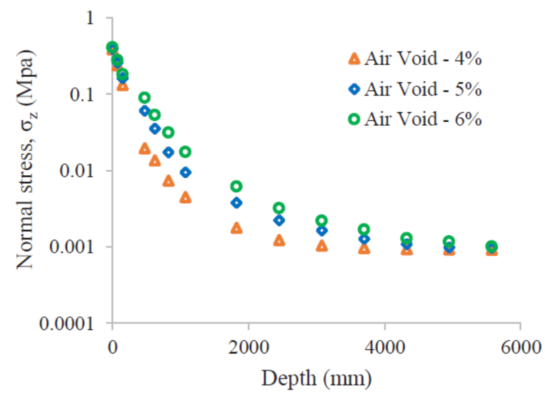
2. Pavement Response Analysis

- **Predicted Responses**:
  - **Normal Compressive Stress (σz)**: The model predicted the normal compressive stress within the pavement structure. Compressive stress was considered positive.
  - **Normal Compressive Strain (εz)**: The normal compressive strain was estimated to understand how the pavement deforms under loading.
  - **Vertical Deformation**: The vertical deformation of the pavement was analyzed to assess the overall structural response.
- **Analysis Conditions**:
  - **Zero Radial Distance (r = 0)**: Responses were estimated at zero radial distance from the axle load, focusing on the direct impact of the load.

- **Vertical Direction (z – z)**: The analysis considered the vertical direction along the pavement depth to capture how stresses and strains vary with depth.



(A)



(B)

Fig. 4. (a) Pavement deformation vs. vertical depth (b) Normal compressive stress vs. pavement depth.

5. Conclusions

The presented test method explores the application of a FEM system for evaluating road pavement behavior. Preliminary analyses indicate that this system effectively investigates cracking in road pavements. Based on these studies, the system could potentially be used to assess other phenomena in similar layered materials or rheological behaviors. The method offers the ability to estimate how various parameters of road pavement impact sensitivity to cracking. It has been observed that cracking increases significantly with a decrease in the thickness of bituminous layer B2, while the thickness of layer B1 has a much smaller effect on the cracking of the sub grade layer. Future studies will examine the impact of additional road pavement parameters on cracking and other strength characteristics of constructed pavements. The effect of temperature on pavement cracking will also be investigated.

Accurate characterization of the mechanical properties of bituminous concrete (BC) mixes is crucial for predicting the lifetime expectancy of flexible pavements, especially under Indian design specifications. Current standard specifications mainly treat BC material as elastic. To accurately determine these mechanical behaviors, resilient modulus tests are recommended. However, several studies have reported that characterizing BC material solely with elastic properties introduces uncertainty in predicting its expected lifetime.

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