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Comparative Mechanistic Evaluation of Flexible Pavement Responses Using Linear, Nonlinear and Viscoelastic Analysis through KENPAVE

Syed Azam[1]
[1] Assistant Professor,
Department of Civil Engineering
MVJCE, Bengaluru, India,

Vidhya A Carmel[2]
[2] Assistant Professor,
Department of Civil Engineering
MVJCE, Bengaluru, India,

***Abstract* - Flexible pavement design in India is generally performed using IRC:37-2012 guidelines and validated using IIT-Pave software under linear elastic assumptions. However, actual pavement behavior is influenced by nonlinear characteristics of granular layers, viscoelastic response of bituminous materials, and moving vehicular loads. The present study evaluates the mechanistic response of flexible pavements considering linear, nonlinear, viscoelastic stationary load, and viscoelastic moving load conditions using KENPAVE software. A study stretch between Elwala and K.R. Nagara in Mysuru district, Karnataka, was selected for analysis. Traffic surveys, axle load surveys, and geotechnical investigations were conducted for pavement design. Pavement responses such as horizontal tensile strain, vertical compressive strain, and vertical stress were evaluated under single, tandem, and tridem axle configurations. Results indicate that nonlinear and viscoelastic analyses provide more realistic pavement responses compared to conventional linear elastic analysis. The study also demonstrates that increased vehicle speed reduces detrimental strain effects on pavement layers. The findings highlight the importance of incorporating realistic material behavior and moving load effects in mechanistic pavement design.**

Keywords - Flexible pavement; KENPAVE; IIT-Pave; Viscoelastic analysis; Nonlinear analysis; Mechanistic pavement design; Moving load analysis; Pavement strain analysis.

I. INTRODUCTION

Road transportation infrastructure plays a significant role in the economic and social development of a country. In India, flexible pavements are extensively adopted due to lower construction cost, ease of maintenance, and riding comfort. Conventional pavement design procedures are generally based on IRC:37-2012 guidelines and rely on linear elastic assumptions for pavement materials.

The IIT-Pave software recommended by IRC is widely used for evaluating stresses and strains in flexible pavements. However, conventional mechanistic analysis has certain limitations. Bituminous layers are treated as linear elastic even though asphaltic materials exhibit viscoelastic behavior. Similarly, granular layers are assumed to possess constant elastic modulus throughout their depth despite their nonlinear stress-dependent characteristics. In addition, vehicular loading is generally considered static, whereas field loading conditions are dynamic due to moving traffic.

To address these limitations, the present study investigates flexible pavement behavior using KENPAVE software by incorporating:

- Linear elastic analysis
- Nonlinear granular layer analysis
- Viscoelastic analysis under stationary load
- Viscoelastic analysis under moving load conditions

The study focuses on evaluating critical pavement responses including horizontal tensile strain, vertical compressive strain, and vertical stress under different axle configurations.

Objectives of the Study

The primary objectives of the study are:

1) To conduct traffic, axle load, and geotechnical investigations along the selected highway stretch.
2) To design flexible pavement using IRC:37-2012 guidelines.
3) To analyze pavement responses using IIT-Pave and KENPAVE software.
4) To evaluate linear, nonlinear, and viscoelastic pavement behavior.
5) To study the influence of vehicle speed on pavement response.

II. LITERATURE REVIEW

Several researchers have investigated mechanistic pavement behavior using analytical and finite element approaches.

- Karagöz (2004) evaluated linear and nonlinear granular behavior in flexible pavements using KENPAVE and SAP90 software. The study reported lower strain values in KENPAVE compared to finite element analysis.
- Jawed Qureshi (2006) compared KENPAVE and ANSYS for evaluating flexible pavement performance under nonlinear and viscoelastic conditions. The study concluded

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that three-dimensional finite element modeling better represents actual pavement behavior.

- Daba S. Gedafa (2006) compared pavement performance using KENPAVE and HDM-4 software. The analysis indicated higher design life prediction using KENPAVE.
- Jawed Qureshi (2007) studied the effect of moving loads on flexible pavements and observed that lower operating speeds produce higher detrimental pavement strains.
- Muniandy et al. (2013) compared KENPAVE and CHEV PC software and reported variations in predicted pavement strains and pavement life.

Previous studies indicate that realistic modeling of material behavior and moving loads significantly affects pavement response prediction. However, limited studies have integrated linear, nonlinear, viscoelastic stationary, and viscoelastic moving-load analyses for Indian highway conditions. The present study attempts to bridge this gap.

III. METHODOLOGY

A. *Study Area*

The selected project stretch extends from Elwala to K.R. Nagara along SH-117 in Mysuru district, Karnataka, with a total length of approximately 21.2 km. The corridor traverses predominantly plain terrain and agricultural land.

B. *Traffic Survey*

A seven-day classified traffic volume count survey was conducted in accordance with IRC:9-1972 guidelines. The average daily traffic (ADT) observed along the corridor was approximately 5118 vehicles/day with a commercial vehicle count of 440 CVPD.

A traffic growth rate of 5% was adopted as per IRC recommendations due to limited historical traffic data availability.

C. *Axle Load Survey*

Axle load surveys were conducted for LCVs, buses, and multi-axle vehicles in both traffic directions. Vehicle Damage Factor (VDF) values were computed using IRC:37-2012 equivalency equations.

The adopted average VDF for pavement design was 3.80.

D. *Soil Investigation*

Subgrade soil investigations were carried out at multiple locations along the corridor. Based on CBR evaluation, a design CBR value of 18.25% was adopted.

E. *Pavement Design*

Flexible pavement design was performed using IRC:37-2012 mechanistic-empirical guidelines. The adopted pavement composition consisted of:

- 35 mm Bituminous Concrete (BC)
- 40 mm Dense Bituminous Macadam (DBM)
- 250 mm Granular Base
- 180 mm Granular Sub-base

The total pavement thickness adopted was 505 mm.

F. *Software Analysis*

1) *IIT-Pave Analysis*

The designed pavement section was initially evaluated using IIT-Pave software to verify allowable tensile and compressive strain criteria.

2) *KENPAVE Analysis*

KENPAVE software was used to perform:

- Linear elastic analysis
- Nonlinear analysis
- Viscoelastic stationary load analysis
- Viscoelastic moving load analysis

Single axle, tandem axle, and tridem axle loading configurations were considered.

- Maximum horizontal tensile strain occurred near the bituminous layer.

IV. LINEAR ELASTIC ANALYSIS

Linear elastic analysis was carried out by assuming constant elastic modulus values for all pavement layers.

The following observations were obtained:

- Vertical compressive stress decreased with increase in pavement depth.
- Maximum horizontal tensile strain occurred near the bituminous layer.
- Maximum vertical compressive strain occurred near the interface between granular layer and subgrade.
- Strain patterns remained similar for different axle configurations.

V. NONLINEAR ANALYSIS

In nonlinear analysis, the granular layers were modeled using varying elastic modulus values with depth to simulate realistic stress-dependent behavior.

The nonlinear analysis revealed:

- Reduction in horizontal tensile strain compared to linear analysis.
- Lower vertical compressive strain values.
- More realistic stress distribution within granular layers.
- Improved representation of actual pavement behavior.

The results confirmed that assuming constant modulus values for granular layers may overestimate pavement strains.

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VI. VISCOELASTIC ANALYSIS

A. Viscoelastic Stationary Load Analysis

The bituminous surface layer was modeled as a viscoelastic material using Kelvin model-based creep compliance relationships.

The viscoelastic stationary analysis showed:

- Lower stresses and strains compared to linear analysis.
- Time-dependent pavement response behavior.
- More realistic prediction of asphalt layer performance.

B. Viscoelastic Moving Load Analysis

KENPAVE moving load analysis was performed considering a design speed of 60 km/h.

The moving load analysis demonstrated:

- Significant reduction in tensile and compressive strains with increasing vehicle speed.
- Lower detrimental effect of moving loads at higher speeds.
- Influence of load duration on pavement response.

The results highlight the importance of considering dynamic traffic loading in mechanistic pavement design.

VII. RESULTS AND DISCUSSION

Comparative analysis of linear, nonlinear, viscoelastic stationary, and viscoelastic moving load conditions revealed distinct variations in pavement response.

The major findings are summarized below:

I. Linear elastic analysis produced the highest strain values among all analysis methods.

II. Nonlinear analysis generated comparatively lower strains due to realistic modeling of granular layer behavior.

III. Viscoelastic analysis provided more practical representation of asphaltic layer response.

IV. Moving load analysis indicated reduced pavement damage at higher vehicle speeds.

V. Vertical stress consistently decreased with increase in pavement depth for all analyses.

VI. The effect of axle configuration on response trends was comparatively less significant than material characterization.

The study demonstrates that conventional linear elastic assumptions may not accurately represent actual pavement performance under field conditions.

VIII. CONCLUSIONS

Based on the mechanistic evaluation carried out using KENPAVE and IIT-Pave software, the following conclusions are drawn:

I. Nonlinear and viscoelastic analyses provide more realistic pavement response predictions compared to conventional linear elastic analysis.

II. Linear analysis resulted in maximum horizontal tensile and vertical compressive strains.

III. Nonlinear analysis produced comparatively lower strains due to stress-dependent granular layer behavior.

IV. Viscoelastic moving load analysis demonstrated that higher vehicle speeds reduce detrimental pavement strains.

V. Dynamic load consideration significantly influences pavement response behavior and should be incorporated in advanced mechanistic pavement design.

VI. Vertical compressive stress decreases with increase in pavement depth irrespective of loading condition.

VII. KENPAVE software effectively models realistic pavement material behavior and can be used for advanced flexible pavement evaluation.

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