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A Review of Rutting and Fatigue Analysis of Flexible Pavement Using KENPAVE and IITPAVE

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Abstract

Pavements are an essential component of every roadway system. Pavements are coming apart in the early years of construction due to extreme climatic conditions and premature distresses, although being built for 15-20 years. Furthermore, owing to inadequate quality control during construction, high axle loads, adverse weather conditions, and limited maintenance funds, pavements commonly break early. Understanding the degradation pattern of flexible pavement is required before making a choice to reinforce the pavement. Premature failures in flexible pavement, such as rutting and fatigue, produce significant distresses in the pavement. For developing pavement structures effectively and efficiently, the designers use the new Mechanistic-Empirical (M-E) pavement design technique rather than the previous empirical design approach. The KENPAVE and IITPAVE software provide pavement reactions in terms of stresses and strains, and they have a considerable impact on performance prediction using the M-E design technique. This research analyses the available literature on flexible pavement response analysis utilising KENPAVE and IITPAVE. With KENPAVE and IITPAVE, the selection of pavement materials and pavement performance may be more properly analysed.

Keywords*: - Flexible Pavement, KENPAVE, IITPAVE, Mechanistic-Empirical (M-E)*

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INTRODUCTION

The highways' purpose is to offer a public route for people and vehicles while preserving a reasonable degree of comfort. The environmental variables at each place influence the design of a flexible pavement. One of the flexible pavement design methods based on mechanics theory is the mechanistic empirical technique. For analysing pavement stress, strain, and deflection values, this technique combines mechanical and empirical methodologies. Critical pavement reactions, such as stresses and strains, are derived using multilayer elastic theory and then empirically connected with pavement field performance. These mechanistic parameters are regulated to an appropriate level throughout the design process. Year after year, road infrastructure suffers from increased traffic volume and vehicle axle load. Tyre pressure has a major influence on stresses and strains in higher portions of pavement structures, as well as pavement fatigue and rutting. As a consequence, the road must be able to support the traffic capacity and have sufficient subgrade bearing strength. Road infrastructure that is unable to sustain the weight of traffic moving over it suffers from early breakdowns such as wear and rutting in the pavement layers. As a result, it is critical for pavement design to reduce such early breakdowns. Premature failures occur in road infrastructure that is unable to handle the traffic load flowing over it, such as fatigue and rutting in the pavement layers. As a result, it is crucial for pavement design to reduce such early collapses.

Flexible Pavement Design Software

The design of the flexible pavement necessitates several experimental testing and computations, which may result in numerous mistakes during the design process, resulting in road breakdowns. As a result, the adoption of flexible pavement software helps assure optimal design by reducing the likelihood of road distresses.

Software IITPAVE

IITPAVE Program is mechanistic-empirical software used for flexible pavement design and analysis. The elastic modulus, poisson's ratio, the thickness of various layers, wheel load, and tyre pressure of a vehicle are the input variables utilised in this application to produce stresses and strains at different layers. The results of the IITPAVE software strains (as shown in Figure 1) will be compared to the permissible strains, and if the strains produced are fewer than the allowable standard strains, the pavement thickness is said to be met.

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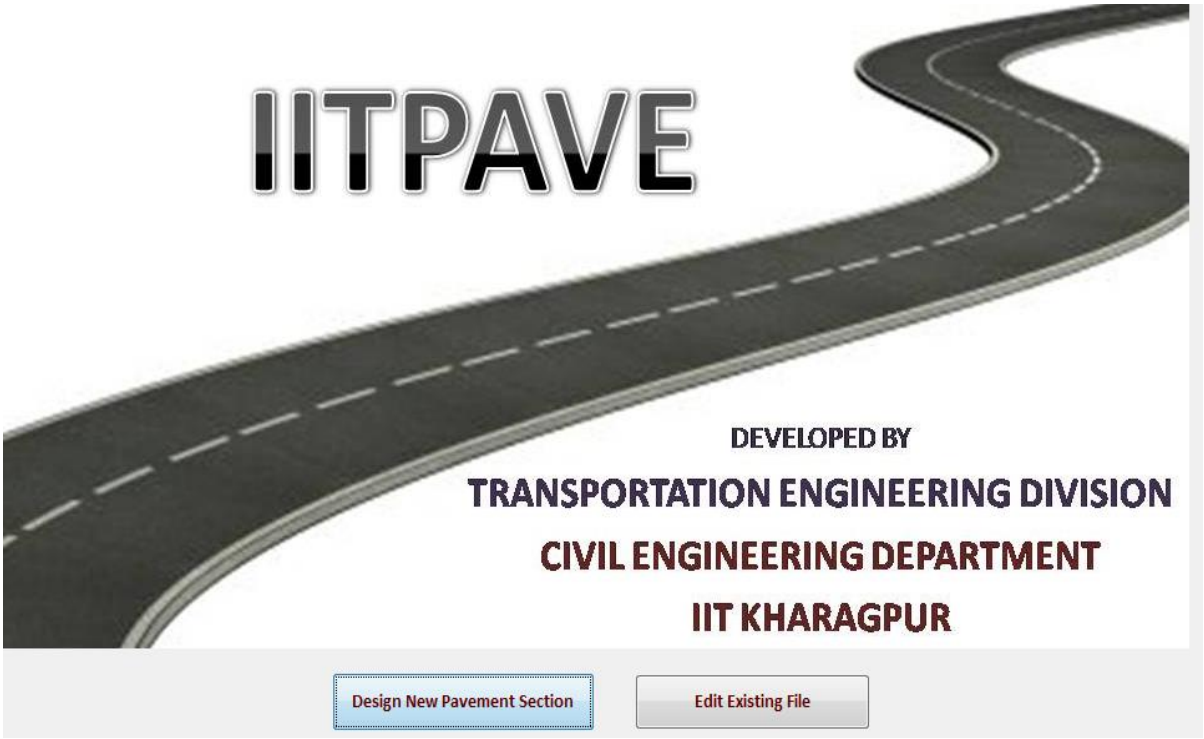


Figure 1: IITPAVE's main screen

KENLAYER Application Software

Yang created the pavement analysis programme KENPAVE at the University of Kentucky (screenshot shown in Figure 2). The software includes the data input interface LAYERINP and the visual tool LGRAPH, as well as KENLAYER and KENSLABS, which are used to analyse flexible and stiff pavements, respectively.

It may be used to analyse the layered pavement in several wheel configurations such as dual-tandem, dual-tridem, single, and dual wheel with linear elastic, nonlinear, and visco-elastic layer behaviour.

The programme calculates stresses, strains, and deflections at 10 various radial coordinates or 19 distinct vertical coordinates, and it can analyse pavements with up to 19 layers.

For tandem and tridem wheel configurations, the superposition and x and y coordinate systems of reference are taken into account. The KENLAYER software uses a fourth order differential equation to solve stresses, strains, and deflections (Omer and Eghan [8]).

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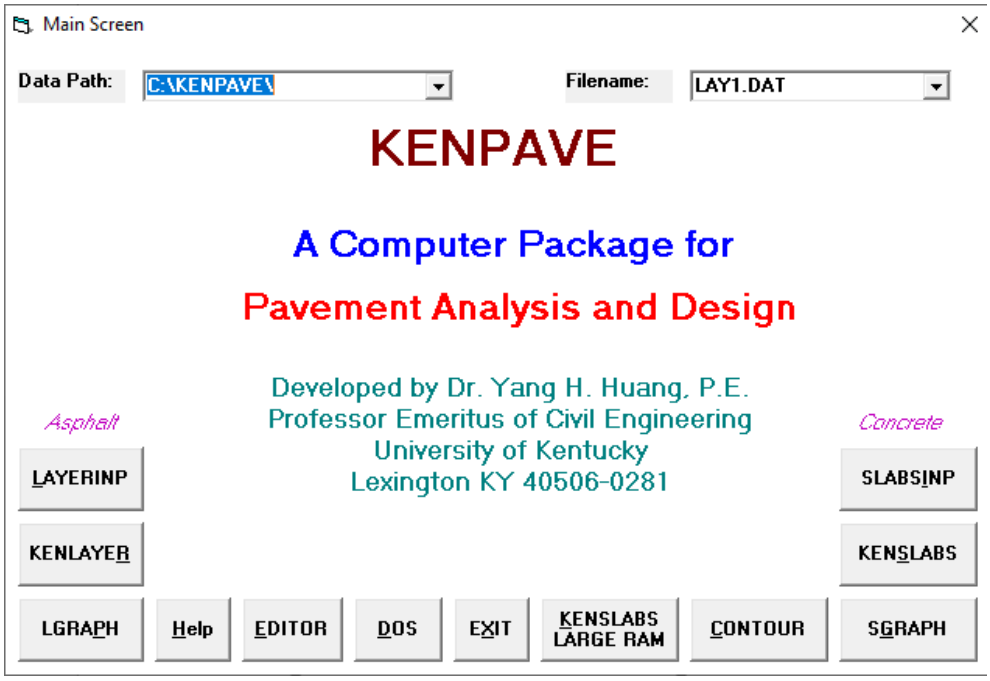


Fig.2: KENPAVE's main screen

REINFORCEMENT AND MODIFIERS' EFFECT ON PAVEMENT PERFORMANCE

The impact of reinforcing and material qualities of multiple layers of pavement is addressed in this part utilising software such as KENPAVE and IITPAVE.

Visvanathan et al. [19] investigated static loads on a coir reinforced low volume road. Several field experiments were conducted to ascertain the increased elastic modulus values, with the Plate Load test results serving as the basis for analysis. For damage analysis, the KENPAVE programme was employed. When coir geotextiles were utilised as reinforcements, aggregate layer thickness was drastically reduced when compared to unreinforced parts. Geotextiles with greater mass per unit area, better tensile strength, and smaller aperture size have been demonstrated to enhance reinforced section performance.

Reddy et al. [12] created a Low-Volume Road (LVR) using Bitumen-Emulsion-treated Recycled Concrete Aggregate (RCA) bases. To optimise the thickness of each layer, the KENPAVE programme was utilised to calculate stress and strain. The largest vertical compressive stresses are found in the dual wheel system's centre. Researchers discovered that cement treated mixes with 75 percent RCA and 100 percent RCA may be utilised for base/sub-base layer materials, particularly for Low Volume Roads (LVRs), and that

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using cement-treated bases/subbases with RCA can result in a thickness decrease.

Hafez et al. [4] examine the effect of employing recycled plastic Polyethylene Terephthalate (PET) as a soil reinforcement material on the Resilient modulus (MR) of a clayey soil, which is a common soil in Egypt's delta area. The damage analysis was done using KENLAYER software on a typical flexible pavement section with a 10.16 cm (4 in.) asphalt layer above a 25.4 cm (10 in.) granular base layer sitting on a subgrade layer. As an alternate way for increasing the performance of the pavement construction, recycled plastic bottles were employed for strengthening the subgrade. The resilient modulus (MR) of the plastic waste reinforced subgrade rises until a particular level of PET content is reached, after which the MR decreases as the PET concentration increases. The universal model can predict subgrade MR values. The addition of 0.6 percent PET to the subgrade layer improves the fatigue and rutting life of the pavement. Figure 3 depicts the horizontal tensile strain at the bottom of the bituminous layer of the original and reinforced sections, while Figure 4 depicts the vertical strain at the top of the subgrade layer of the original and reinforced sections. When compared to the original section beneath the centre line of wheel load, the horizontal tensile strain at the bottom of the bituminous layer was reduced by 3.25 percent in reinforced subgrade with 0.6 percent plastic content. Similarly, the vertical compressive strain in the reinforced subgrade was reduced by 12.7 percent beneath the wheel load centerline. This research demonstrates that reinforced subgrade may be modelled using the KENPAVE programme.

Chandak et al. [2] sought to determine the optimal composition of employing wastes such as crumb rubber, plastic, and e-waste to replace bitumen and aggregates in rural roads. A few laboratory experiments on modified mixes were carried out in order to determine the feasibility and ideal waste content for village road building. The subgrade strength in the study region was estimated using the California Bearing Ratio (CBR) test. The IITPAVE programme was used to analyse the performance of the study area's rural roads based on the appropriateness of identified wastes in the bituminous layer. Using the IITPAVE programme, the design charts were made based on using wastes for rural roads in Karad, District - Satara, India.

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Gonwala et al. [3] investigated the influence of industrial waste such as Electric Arc Furnaces (EAF) slag Ground Granulated Blast Furnace Slag (GGBFS) in the base or subbaselayer. By altering the composition, several trail combinations of EAF slag+Cement and EAF slag+GGBFS were evaluated to identify an ideal blend. The IITPAVE Software was used to calculate the pavement thickness with the best mix and to ensure that the critical stresses are within the permissible range. The utilisation of industrial waste on Indian rural roads provides a sustainable waste management solution.

Reddy and Ramu[13] concentrated on the production of high modulus bituminous mixtures utilising hard grade bitumen and Polyphosphoric Acid (PPA) as a modifier. The researchers discovered that high-grade bitumen is more resistant to high temperatures and plastic deformation, and its robust modulus is double that of virgin bitumen. The hard grade bituminous mix has better Marshall stability and indirect tensile strength than the standard mix. Using IITPAVE and the IRC: 37-2018 criteria, a pavement section for 300 msa was developed. When comparing the high grade bituminous mix to the ordinary mix, a 40 mm decrease was noted in the pavement section.

Harish [5] created the flexible pavement by mixing alternative materials such as cementitious and salvaged asphalt, and he used the programme IITPAVE to analyse the crucial reactions. A road length surrounding Bangalore was chosen for this purpose, and the subgrade qualities of the soil were investigated. Cementitious Base and cementitious Sub-base of aggregate interlayer for crack relief, cementitious base and sub-base with Stress Absorbing Membrane Interlayer (SAMI) at the interface of base and bituminous layer, Foamed bitumen/bitumen emulsion treated Recycled Asphalt Pavement (RAP) or fresh aggregates, and cementitious sub-base were used. The portion was then developed, analysed, and compared to the standard granular base and granular subbase. The research demonstrates that employing varied composition materials in pavement construction improves serviceability when compared to conventional granular base and granular sub-base. When compared to alternative designs across all compositions, cemented base and subbase with SAMI resulted in a considerable reduction in stresses, thickness, and expense, as well as improved serviceability.

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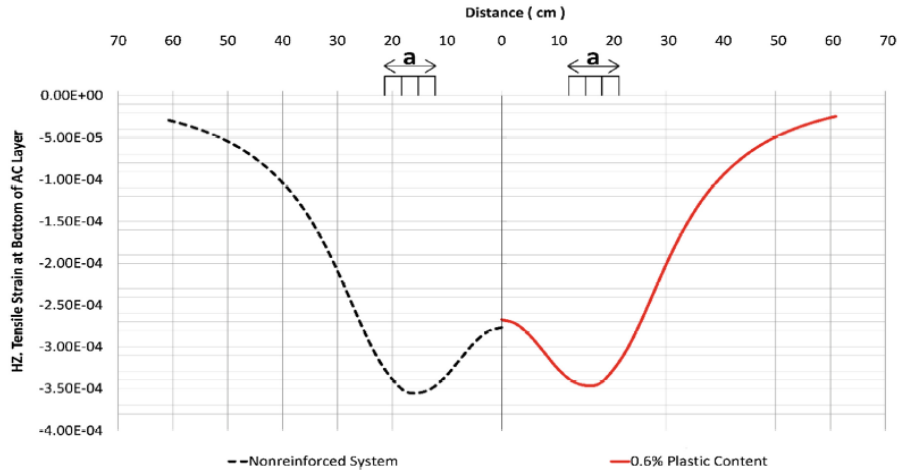


Figure 3: Comparison of horizontal tensile strain at the bottom of the AC layer in the original and reinforced portions (Source: [4])

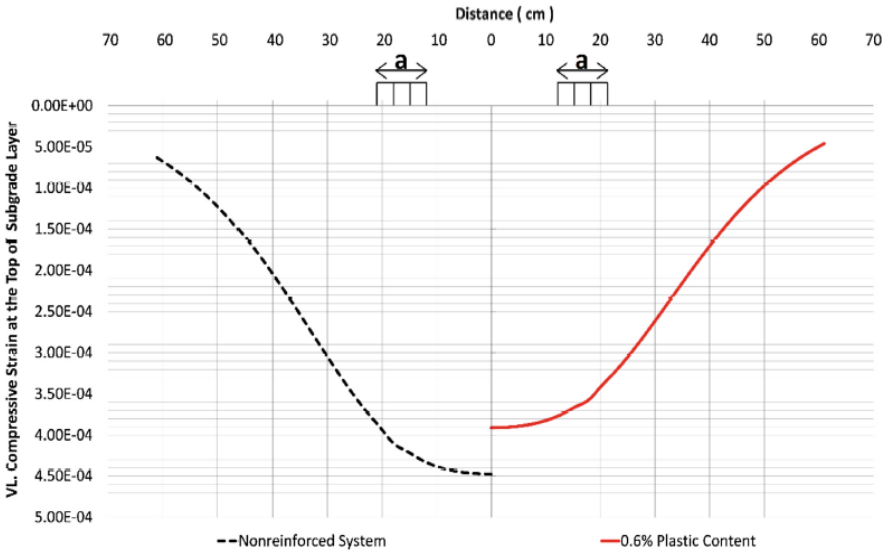


Figure 4 shows a comparison of vertical strain at the top of the subgrade layer in the original and reinforced portions (Source: [4])

EFFECT OF VARIATION IN PAVEMENT LAYER THICKNESS AND RESILIENT MODULUS ON PAVEMENT RESPONSE

In terms of rutting and cracking, **Sahis et al. [15]** discovered that granular layer thickness is more sensitive to pavement performance than bituminous layer thickness.

The thickness of the granular layer necessary to prevent rutting and fatigue reduces as the thickness of the bituminous layer increases, and vice versa.

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Researchers discovered that the coordinates of the junction point of the curves in terms of the bituminous and granular layer, as illustrated in Figure 5, would be the optimal thickness of the pavement section. The deflection of the pavement section computed using Odemark's-technique Boussinesq's was found to be in excellent agreement with findings obtained for comparable sections utilising KENPAVE and IITPAVE software.

Rind et al. [14] investigated rutting and fatigue distresses in a flexible pavement using KENLAYER software. The NHA (N-55) length of road in Sehwan, Pakistan, was utilised as the reference pavement, and the researchers changed the bituminous course thicknesses by 25%. On 20 cross-sections, the KENLAYER programme was used to analyse rusting and fatigue early failures. As the thickness of the asphaltic wearing course and base course grew, the micro stresses decreased and the allowed for the number of loading repetitions increased, and vice versa.

Srikanth[17] investigated the influence of surface layer thickness and modulus of elasticity on pavement performance using the programme KENPAVE. Researchers evaluated the effects of vertical compressive stress and horizontal tensile strain on pavement performance using modulus of elasticity (E) and thickness (h) as primary factors. The findings revealed that as surface thickness grows, compressive and tensile micro stress decreases. Surface thickness changes may assist to ease pavement strain while also lowering expenses.

Priyanka et al. [11] utilised the KENPAVE software programme to analyse low-volume roads. The robust modulus of subgrade and granular layers was calculated using the equation from IRC: 37-2012. Damage analysis yielded tensile and compressive stresses, fatigue and rutting lifetimes, and damage ratios using the KENPAVE programme. According to the research, the resilient modulus (MR) of pavements would be lowered under severe situations of complete or partial submergence in heavy rainfall conditions. When the MR value was lowered, vertical displacement rose around 1.3-4 times, fatigue life and rutting life decreased by 58-98 percent and 72-100 percent, respectively, compared to the standard values.

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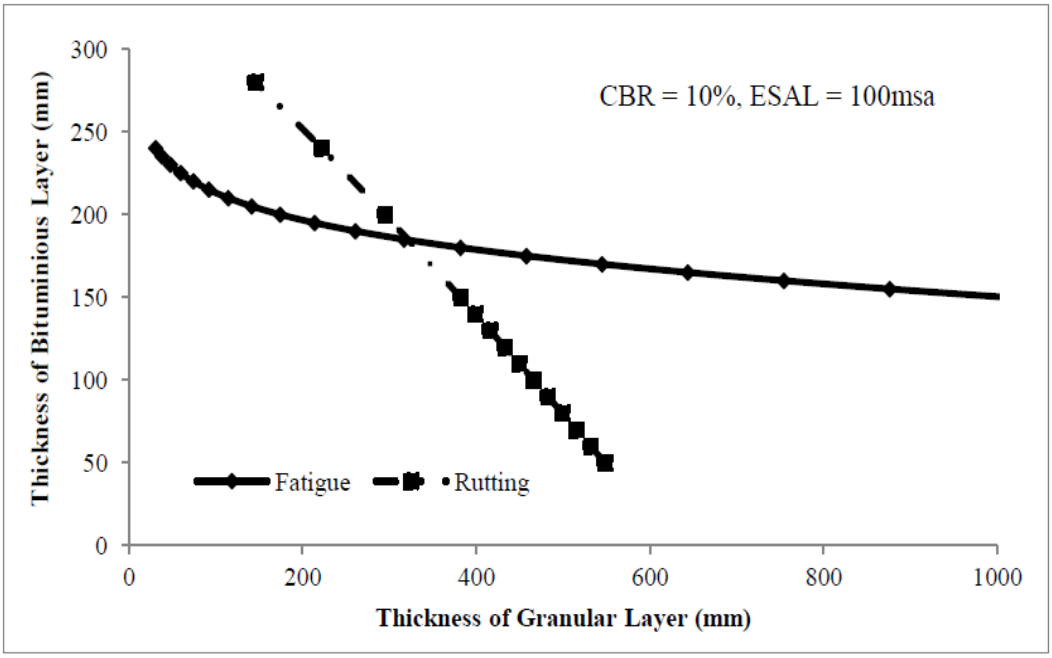


Figure 5: Variation in bituminous and granular layer thickness due to fatigue and rutting (Source: [15])

AXLE LOAD'S EFFECT ON PAVEMENT PERFORMANCE

This section discusses the influence of axle load and arrangement on responsiveness.

Sahis et al. [15] investigated the relationship between axle load and layer thickness. The rate of rise in bituminous layer thickness was observed to be slower when axle load repeats increased over 50 msa.

However, the change in granular layer thickness with axle load repetitions was found to be much larger for lower subgrade CBR than for higher CBR subgrade. However, on subgrades with lower to greater CBR, the variance in bituminous layer thickness was shown to grow dramatically with increasing axle load repetitions.

Tajudin and Priyatna[18] used the KENPAVE software to analyse the flexible pavement mechanical response to axle configurations and tyre changes based on a field study done on Cipularang Highway Km. 97. Each tyre load is calculated by dividing the axle load by the number of tyres. Rutting damage was assessed using vertical compressive strain at the top of the subgrade, whereas fatigue damage was assessed using horizontal

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tensile strain at the bottom of the bituminous layer.

Elastic modulus, poisson's ratio, pavement layer thickness, and load condition were all required data inputs. To identify the critical reaction induced by axle and tyre arrangement, the responses at different positions along the transverse direction were compared.

The number of allowable repetitions (NR) and (Nf) is inversely proportional to the horizontal strain value, which means that as the horizontal strain value increases, the number of vehicle repetitions required to cross the road without rutting fatigue decreases. It can also be seen that the pavement will not sustain groove damage because the actual repetition value is less than the NR and Nf.

The greatest strain value is near the centre of a single axle single tyre. At the tyre radius, single axle dual tyres incur the most strain. Tandem and tridem axle dual tyres have the highest strain values between the tyres. Both axle arrangement and vehicle loads impact the important mechanistic factors.

Pandey et al. [9] investigated the impact of increasing axle load on the service life of bituminous pavement in terms of rutting and fatigue damage. The three-dimensional Finite Element Model (FEM) of bituminous pavement was created using ANSYS Mechanical APDL finite element software. By comparing it to the FEM model, the surface deflection produced by KENPAVE was validated. The validated model was subjected to dynamic loading conditions in order to determine the pavement response at various axle loads under real-time truck loading. Using the most damaging vehicle speed, the critical strains causing fatigue and rutting damage in pavement were calculated.

The critical strains measured were incorporated into the Asphalt Institute's Rutting and Fatigue models to estimate the service life of bituminous pavement. The FEM method was used to investigate the effect of vehicle speed on critical mechanistic parameters.

The effect of increased axle load on pavement service life is being evaluated in order to design a policy to penalise heavy cars depending on the level of damage they produce on the pavement. Figures 6 and 7 show that greater axle load situations and slow-moving traffic conditions create significant pavement deterioration.

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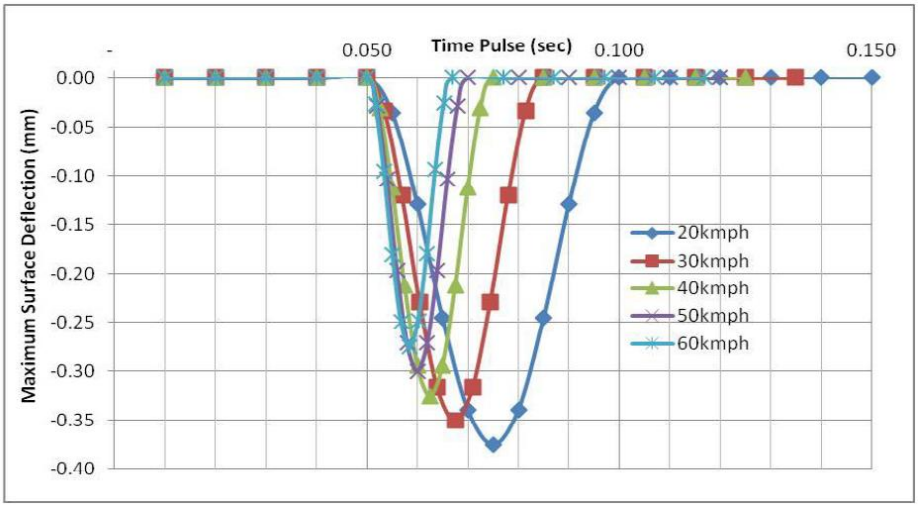


Figure 6: Maximum surface deflection at various vehicles (Source: [9])

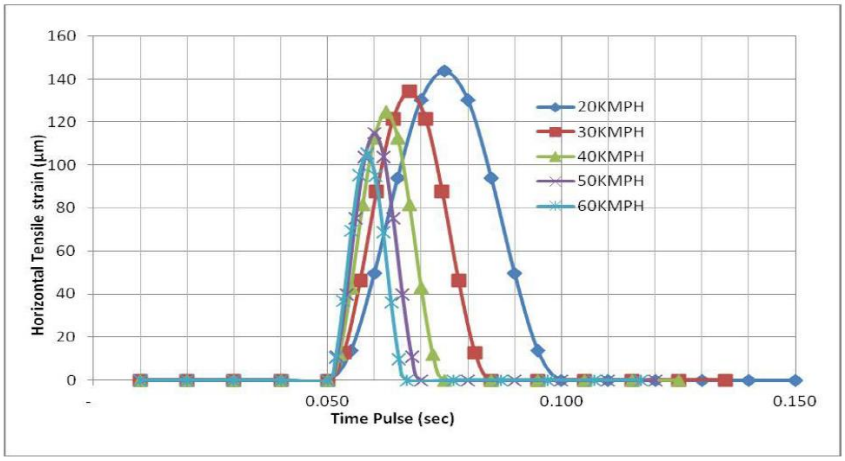


Figure 7: Maximum horizontal critical strain at various vehicle speeds.

PAVEMENT RESPONSE VALIDATION

This part examines the literature to verify the pavement reaction from other software. Some articles compare the genuine answer to the responses from IITPAVE and KENPAVE, and its accountability is validated using economic software.

Singh et al. [16] use the prominent characteristics of KGPBACK, IITPAVE, and HDM-4 to anticipate, compare, and analyse the overlay to be supplied over the existing pavement of the National highway in the state of Haryana, India.

The current Falling Weight Deflectometer (FWD) approach was utilised by the researchers to measure the deflection of the pavement on three chosen areas that were classified as H-1, H-2, and H-3 depending on the pavement condition.

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KGPBACK software was used to compute the elastic moduli of each layer utilising FWD deflection data. The elastic moduli of section H-3 were determined to be the best, whilst section H-1 was the lowest, indicating the influence of the pavement quality on the elastic modulus.

The overlay thickness was discovered to change depending on the previous pavement's elastic modulus. It was predicted using the IITPAVE software. The provided overlay thickness was validated by the HDM-4 software, and a significant reduction in ravelling, rutting, cracking, and roughness distress values was observed. The modelling of bituminous overlay maintenance improved the conditions of all pavement portions, and the Indian Highway Roads' lifespan may be extended.

Mohan and Kumar [7] worked with flexible pavement analysis using IITPAVE software and project economic analysis using HDM-4 software. In this study, researchers wanted to gather data from the field relating to traffic studies and subgrade soil CBR values, as well as design the flexible pavement in accordance with IRC: 37-2012 recommendations. The IITPAVE programme was then used to validate the results. The Madhugiri-Chikkabbalapur portion of NH-234 was chosen for the research. Using the IITPAVE and HDM-4 software, the optimum technical and economic choices for road sections are determined. At both sites, the actual horizontal tensile and vertical compressive stresses are within the permitted limits.

As a result, the anticipated pavement thickness is accurate, and the planned pavement is safe. The economic assessment of a road project utilising HDM-4 software yields economic indicators such as Economic Internal Rate of Return (EIRR) and Economic Net Present Value (ENPV) (ENPV).

Patil et al.[10] emphasise the relevance of KGP Back software, which is used to revise pavement thickness. The researchers chose NH-218 (Bijapur to Hubballi) as the study route. The FWD test was performed at the designated sites, and the test results were analysed using KGPBACK software in accordance with IRC: 115-2014, and the design was validated using IITPAVE software. The fatigue and rutting equations from IRC: 37-2012 were used to calculate the allowable strains, which were then compared to the calculated strains from IITPAVE. Based on the KGPBACK and

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IITPAVE results, a new pavement thickness was proposed.

Armilli et al. [1] investigated the mechanical behaviour of materials in order to determine the distress parameters of flexible pavements. The ANSYS pavement design software was used to analyse and evaluate the mechanical behaviour of a conventional pavement with hot bituminous surface, foamed base pavements, and cold recycled emulsified with new overlay.

The findings of this ANSYS were validated using KENPAVE and IITPAVE. Although the tensile strain and vertical displacement values in ANSYS were somewhat lower, the linear elastic analysis in both KENPAVE and IITPAVE matched well. The research was expanded to include a cost-benefit analysis of both recycled and conventional mixes.

Pandey et al. [9] investigated the effect of increased axle load on rutting and fatigue life of flexible pavement. The 3D model was created using ANSYS, and the resulting response was validated using KENPAVE. Figure 8 depicts the surface deflection at different distances acquired using KENPAVE and ANSYS.

Khan et al. [6] compared the findings of KENLAYER and General Study of Multi-layered Elastic Systems (GAMES) for the analysis and design of asphalt roadway pavement. The programmes are equal for analysing any flexible pavement; the KENLAYER software is used to determine the pavement's reactions, whilst the GAMES software is used to simulate asphalt pavements with several layers and loads with layer interface slip with more precision.

The GAMES computer programme model delivers 68 percent greater vertical deflection outcomes than the KENLAYER software. Pavement deflection data analysis in this project demonstrates that the modulus values have been lowered, which reflects the decline in the capacity and capability of the pavement. Both pieces of software are capable of analysing and designing asphalt pavements. Using some theoretical analysis, the design traffic load application expanded its accumulative applicable application for the design of traffic load. The KENLAYER programme idealises a more realistic technique to finding and producing separate Layered elastic analysis results for three-layered elastic pavements.

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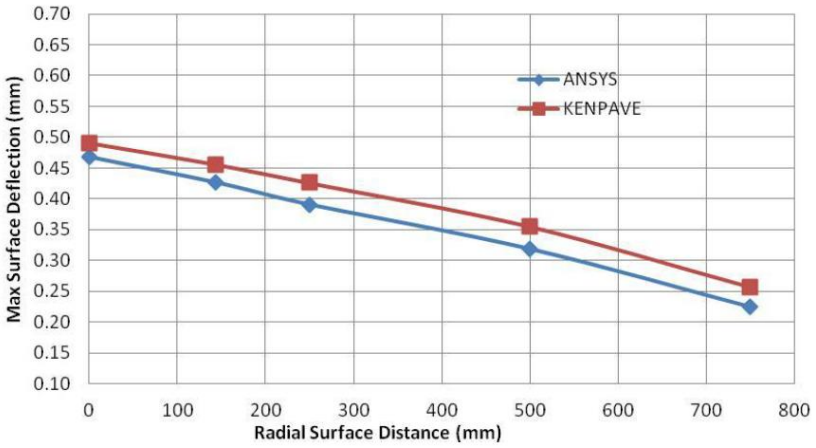


Figure 8: Surface deflection at different radial distances (Source:[9])

CONCLUSION

This study looks at how the mechanistic approach response may be used to evaluate pavement performance. Based on the pavement studies examined in this paper, it is possible to conclude that layered elastic analysis is a good approximation of actual pavement responses under both static and dynamic wheel loads. The layered elastic method is suitable for predicting pavement responses under a wide range of environmental and loading conditions. Direct measurement of pavement responses has limitations, as evidenced by various research studies. The precise pavement reaction cannot be described due to the limits of both theoretical modelling and actual measurement. Nonetheless, the software KENPAVE and IITPAVE can be used for flexible pavement response analysis. The following are some particular findings based on the **KENPAVE and IITPAVE software analyses.**

- By increasing the thickness of the pavement layer, critical mechanistic parameters such as horizontal tensile strain and vertical compressive strain can be reduced, extending the pavement's rutting and fatigue life.

- The robust modulus values of the pavement decline under heavy rains, lowering rutting and fatigue life. • The analysis demonstrates significant distresses at high axle loading and slow-moving traffic situations.

- Reinforced sections can increase pavement life and decrease material consumption. • The KENPAVE and IITPAVE can be used to validate other software.

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