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The behavior of flexible pavement layers under the influence of axle loads with wide-base and conventional conventional dual tires.

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ملخص البحث:

يهدف هذا البحث إلى دراسة الضرر الذي يحدث للرصف المرن نتيجة مرور الشاحنات ذات المحاور المتعددة ذات الأحمال العالية التي بها إطارات عريضة، والتي تم تقديمها لتحل محل الإطارات المزدوجة. تمت الدراسة على عدة محاور تشمل محاور أحادية، ثنائية، ثلاثية، ورباعية، وكلا منها مزودة بإطارات عريضة وإطارات عادية. تم اختيار نوعين من القطاعات الإسفلتية وهما قطاع رقيق (Thin) وقطاع أكثر رقة (Thinner) وتم تمثيل خصائص موادهما لتشمل معظم قطاعات الأسفلت المرن.

تم استخدام برنامج حاسوبي يسمى (KENLAYER Computer Program) لتحليل وحساب التوتر الشد الأفقي في قاع الطبقة العلوية من مزيج الأسفلت الساخن والتوتر الضغطي العمودي في وسط كل طبقة من طبقات الرصف، بالإضافة إلى الطبقات الست المتتالية لتربة القاعدة.

تم استخدام هذه النتائج لحساب الضرر الناتج عن الإجهاد المتكرر (Fatigue) و (عيوب الهبوط تحت مسار العجلات) الناتج عن استخدام الطريق (Rutting) باستخدام نماذج أداء الطريق. تم استخدام نموذج (Strain area) لحساب الضرر الناتج عن الإجهاد المتكرر (Fatigue) ونموذج VESYS لحساب (الهبوط تحت مسار العجلات) (Rutting) في الطبقة الأسفلتية.

تم حساب معامل المحاور لمقارنة التلف الناتج من الإجهاد المتكرر (Fatigue) والانحدار (Rutting) لكلا من المحاور ذات الإطارات العريضة والإطارات العادية. وأظهرت النتائج أن المحاور ذات الإطارات العريضة تسبب ضررا أكبر في الإجهاد المتكرر (Fatigue) والانحدار (Rutting) بالمقارنة مع المحاور ذات الإطارات العادية.

ABSTRACT:

The study focuses on investigating the impact of heavy multiple-axle setups with wide-base tires on flexible pavements.

The researchers considered various axle configurations, including single, tandem, tridem, and quad, equipped with both conventional and wide-base tires. The flexible pavement sections under investigation were categorized as "thin" and "thinner" based on their thicknesses and material properties.

To assess the damage caused by large axle load combinations to these pavement sections, the researchers employed the KENLAYER Computer Program to calculate the pavement response during forward analyses.

This involved measuring the horizontal tensile strain at the bottom of the hot mix asphalt and the vertical compressive strain at the middle of each pavement layer, including the subgrade soils.

The study evaluated two primary types of pavement distress, namely fatigue cracking and pavement surface rutting, using the calculated pavement responses in performance models. The strain area model was used to estimate fatigue damage, while the VESYS rutting model was used for rutting damage.

In comparing the pavement damage caused by axles with conventional and wide-base tires, the researchers computed axle factors for each axle configuration. The results indicated that axles equipped with wide-base tires experienced more significant wear and rutting damage compared to conventional tires.

Overall, the study highlights the potential negative effects of wide-base tires on pavement integrity, particularly in terms of fatigue cracking and rutting, and emphasizes the importance of considering these factors in pavement design and maintenance.

1. Introduction

The economic alliances between nations have led to significant growth in commercial operations, resulting in increased transportation activities on road networks. Heavy vehicles play a crucial role in transporting the majority of freight.

To enhance efficiency and reduce environmental impact, the truck industry has introduced wide-base tires as a replacement for conventional tires.

These wide-base tires offer various benefits, including reduced fuel consumption, lower tire costs and repair expenses, decreased pollution and noise, and a positive impact on tire recycling. Additionally, using wide-base tires improves hauling capacity, ride comfort, handling, braking, and safety.

Researchers have undertaken studies comparing the performance of conventional and wide-base tires after the introduction of the latter.

They focused on various aspects such as contact area, contact stress, pavement responsiveness, and pavement damage impact.

At a constant load, variations in tire inflation pressure primarily influenced contact stresses in the center region of the contact area for two types of wide-base tires (385/65R22.5 and 425/65R22.5). Higher inflation pressure resulted in larger contact pressures in this central region, while the contact pressures in the tire's outer rims remained unaffected.

However, at constant inflation pressure, fluctuations in tire load affected the contact stresses in the outer areas of the contact region, with higher loads leading to higher stresses.

Yap (1988) conducted a comparable investigation and found that the highest contact stress was still located in the middle of the contact area.

Comparing tire load increases caused by inflation pressure and subsequent tire load increases for various tire types, wide-base tires exhibited higher contact stresses as inflation pressure increased but showed less increase in stress with tire load. Nonetheless, wide-base tires showed larger vertical contact stresses in both situations.

Myers et al. (1999) studied three contact stress components under different truck tires and found that wide-base tires have higher vertical and transverse contact stresses compared to other types of tires due to their higher load-per-tire ratio.

Vertical contact stresses were not uniformly distributed, with the greatest value occurring at the center of the contact area, roughly 2.3 times the inflation pressure.

Moreover, the maximum vertical stresses of wide-base tires were approximately 1.5 times larger than those of bias ply and radial tires. In terms of transverse stresses, wide-base tires once again outperformed at the center of the contact area, with the maximum transverse stress being approximately one-third of the maximum vertical contact stress. It is essential to note that the relationship between pavement reaction (stress, strain, and deflection) and pavement performance (fatigue, rutting, etc.) is not linear, highlighting the need to measure the pavement damage caused by axles equipped with wide-base tires.

At the Virginia Smart Road Test Facility, ***Al-Qadi et al. (2002)*** conducted tests to compare the pavement responsiveness of conventional dual tires and newly introduced wide-base tires with the same tire pressure. The study found that the wide-base tires induced a similar horizontal strain under the hot mix asphalt layer as the conventional dual tires, resulting in comparable fatigue damage for both tire types. However, the wide-base tires caused stronger vertical compressive stresses on the top hot mix asphalt layers of the tested pavement. As the depth increased, the difference in stresses between the two tire types decreased, becoming negligible at the subbase layer's bottom.

Kim et al. (2005) conducted an evaluation of the stresses generated by wide-base tires and their impact on the pavement's subgrade using two-dimensional and three-dimensional finite element calculations.

The research revealed that wide-base tires induced nearly four times the amount of permanent stresses in the pavement layers compared to conventional tires. This leads to an overestimation of the pavement design life when using Load Equivalency Factor (LEF) values designed for conventional dual tires.

Researchers also analyzed pavement response and predicted pavement damage to assess the influence of wide-base tires on pavement damage.

It was found that the relationship between pavement response and pavement damage is not linear, necessitating a more comprehensive approach to measuring the impact of wide-base tires on the pavement.

Sebaaly and Tabatabaee (1992) investigated the effects of tire pressure, tire type, axle load, and axle design on instrumented test sections under actual truck loading and highway speed. Their findings indicated that wide-base single tires consistently exhibited higher stresses and deflection than conventional dual tires. The fatigue and rutting damage factors for wide-base single tires were observed to range from 1.5 to 1.7 and from 1.2 to 2.0 for single and tandem axles, respectively.

Overall, these studies demonstrate that the use of wide-base tires can significantly affect pavement behavior and damage, emphasizing the importance of considering the specific characteristics of wide-base tire configurations in pavement design and maintenance practices.

2. Damage Calculation Due to Multiple axle loads

To evaluate the fatigue damage caused by traffic loads, ***Matthews et al. (1993)*** conducted various laboratory fatigue experiments, including simple fracture, support fracture, direct axial, diametral, triaxial, fracture tests, and wheel tracking tests.

These experiments were designed as stress-controlled or strain-controlled tests, involving either a single pulse with a rest interval or a constant sinusoidal load. Similarly, laboratory studies have been carried out to predict pavement rutting ***(Ayres, 2002)***, but these trials were also based on a single load pulse. However, in real-world scenarios, the passage of heavy axle group vehicles results in repeated load pulses on the pavement surface.

Due to the absence of laboratory experiments based on multiple pulses, the damage caused by repeated axle loads was not fully understood.

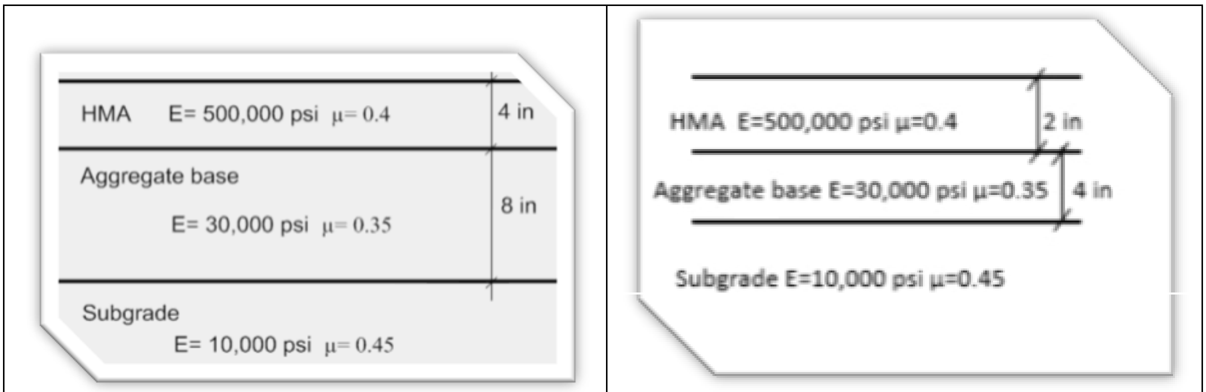
To address this gap, Michigan State University recently conducted extensive laboratory testing that replicated various axle loads for both flexible and rigid pavements.

Salama and Chatti (2011) leveraged this testing data and examined techniques to predict fatigue and rut damage on asphalt concrete pavements subjected to multiple axle loads. Several methods for assessing pavement damage caused by numerous axles were evaluated using the laboratory data, and the level of agreement with the measured laboratory performance served as the assessment criterion. They concluded that the dissipated energy and strain area approaches showed high agreement with laboratory-measured axle parameters for fatigue damage, while the peak strain approach exhibited good agreement with laboratory-calculated axle parameters for rutting damage.

In this study, the strain area and peak strain techniques, validated by Salama and Chatti, will be employed to calculate pavement fatigue and rutting damage, respectively.

The pavement damage will be computed for both thin and thinner pavements with specific thicknesses and material properties. Axle factors for fatigue and rutting damage can be determined using the strain area and peak strain formulas, respectively, as illustrated in the sections below (presumably in the research paper).

These approaches aim to provide a more comprehensive understanding of the impact of repeated axle loads on pavement degradation and performance.



a)Thin section

b) Thinner section

Figure 16: Thicknesses and material properties of thin and thinner pavement sections

2.1.1. Fatigue

Fatigue is one of the most common types of distress experienced by flexible pavements.

It is caused by tensile strain at the bottom of the hot mix asphalt layer, leading to fatigue cracking in the pavement.

In the study conducted *by* ***Huang (1993)***, the KENLAYER computer software will be utilized to calculate the horizontal tensile strain at the bottom of the hot mix asphalt layer under various axle configurations, including single, dual, tridem, and quad axles, equipped with both conventional conventional dual tires and wide-base tires.

The strain area approach has been identified as the most promising method for quantifying fatigue damage.

The strain area approach involves using Equation 1 to calculate the number of fatigue cycles until pavement failure. This approach will be employed to assess the damage caused by different axle configurations compared to the damage caused by a standard axle.

The fatigue strain area model will be utilized to determine the Axle Factors (AF), which allow for a direct comparison of the damage caused by various axles with the damage caused by a standard axle.

By using this approach, researchers can better understand the impact of different axle configurations and tire types on the fatigue performance of flexible pavements.

$$N_f = 18.865 * A_o^{-0.478} \quad (1)$$

Where:

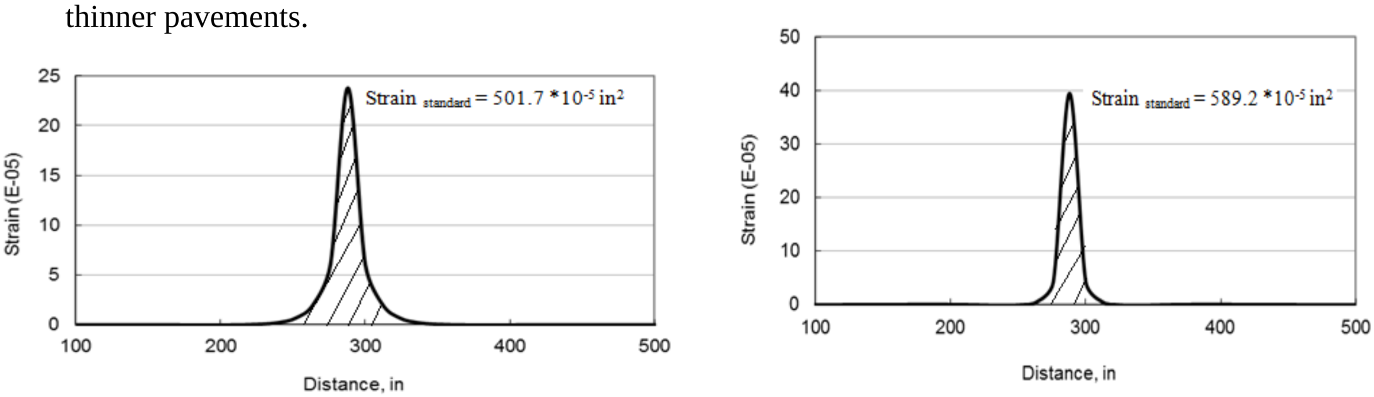
N_f = is the number of cycles to fatigue failure, and

A_o = is the initial area under the strain curve for a standard axle or any axle or truck.

and

$$\begin{aligned} AF &= \text{Damage of axle / Damage of the standard axle} \\ &= N_{f\ \text{std axle}} / N_{f\ \text{axle or truck}} \\ &= (A_{o\ \text{std axle}} / A_{o\ \text{axle or truck}})^{-0.478} \quad (2) \end{aligned}$$

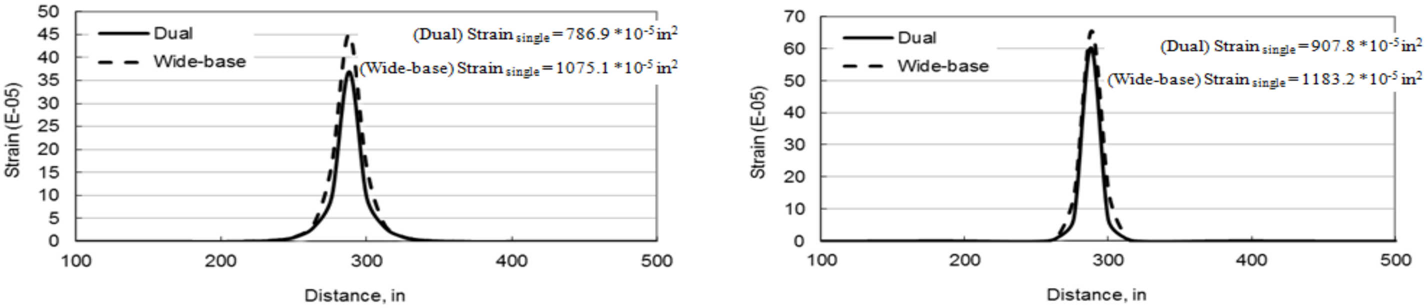
Figure 1.2 shows the area under the tensile strain curve for the standard axle for thin and thinner pavements.



Standard axle (Thin pavement) Standard axle (Thinner pavement)

Figure 1.2 Area under the tensile strain curve for standard axle

Figure 1.3 shows the area under the tensile strain curve for the single axle 13 ton for both conventional dual and wide-base tires for thin and thinner pavements**.**



Single axle 13 ton (Thin pavement) Single axle 13 ton (Thinner pavement)

Figure 1.3 Area under the tensile strain curve for single axle 13 ton

To calculate the Axle Factor for any axle we can use the following equation.

(Dual) $AF = (A_{o\ \text{std axle}} / A_{o\ \text{axle}})^{-0.478} = (501.7 * 10^{-5} / 786.9 * 10^{-5})^{-0.478} = 1.24$ (thin)

(Wide-base) $AF = (A_{o\ \text{std axle}} / A_{o\ \text{axle}})^{-0.478} = (501.7 * 10^{-5} / 1075.1 * 10^{-5})^{-0.478} = 1.44$ (thin)

(Dual) $AF = (A_{o\ \text{std axle}} / A_{o\ \text{axle}})^{-0.478} = (589.2 * 10^{-5} / 907.8 * 10^{-5})^{-0.478} = 1.23$ (thinner)

(Wide-base) $AF = (A_{o\ \text{std axle}} / A_{o\ \text{axle}})^{-0.478} = (589.2 * 10^{-5} / 1183.2 * 10^{-5})^{-0.478} = 1.40$ (thinner)

Figure 3 a and b show the Axle Factors (AFs) calculated from the strain area method for single 13 ton, tandem 26 ton, tridem 39 ton and single 10 ton, tandem 20 ton, tridem 30 ton and quad axle 40 ton with dual and wide-base tires for both thin and thinner pavements. The results show that the fatigue damages increasing with the increased axle configurations (from single axle to tandem or tridem or quad axles) because the area under the tensile strain pulse is increasing with the increased axle configurations, and the fatigue damages increasing with an average of 9.83 % and 5.65 % with increased axle loads from 10 ton to 13 ton at single axle for thin and thinner pavements respectively, and the fatigue damages increasing with an average of 9.72 % and 5.55 % with increased axle loads from 20 ton to 26 ton at tandem axle for thin and thinner pavements respectively, and the fatigue damages increasing with an average of 9.98 % and 5.8 % with increased axle loads from

from 30 ton to 39 ton at tridem axle for thin and thinner pavements respectively, because the area under the tensile strain pulse is increasing with the increased axle loads. and the results show that the wide-base tires impose more fatigue damage for both thin and thinner pavements because the area under the tensile strain pulse with wide-base tire more than the area under the tensile strain pulse with conventional dual tire with the increased axle configurations see Figure 1.3. The wide-base tire cause more fatigue damage in the thinner pavement since the thin hot mix asphalt do not provide enough protection for the sublayers especially the aggregate base to sustain the heavy axle loads.

2.1.2. Rutting

Rutting is another significant distress type experienced by flexible pavements. It is primarily caused by the vertical compressive strain in the pavement layers.

In the study, the KENLAYER computer program will be utilized to calculate the vertical compressive strain at various positions within the pavement layers.

These positions include the middle of the hot mix asphalt (HMA) layer, the apparent middle of the base layer, and the middle of the subsequent six subgrade layers, each with a thickness of 40 inches.

The calculations will continue until the vertical compressive strain becomes negligible and does not result in any permanent deformation due to the applied truckload.

To determine the total rutting at the pavement surface, which includes rutting in the HMA layer, base layer, and subgrade, the most appropriate model is the VESYS rutting model.

This model takes into account the cumulative effect of rutting at different layers of the pavement structure and provides a comprehensive assessment of the overall rutting damage.

By using the KENLAYER program to calculate the vertical compressive strain and the VESYS rutting model to assess the total rutting, researchers can effectively evaluate the impact of different axle configurations and tire types on the rutting performance of flexible pavements.

This data will help in understanding the extent of rutting damage caused by various axles and aid in making informed decisions for pavement design and maintenance.

model which has this capability, Moavenzadeh, 1974.

Equation 3 shows the form of the model.

$$.\rho_p = h_{AC} \frac{\mu_{AC}}{1\text{-}\alpha_{AC}} \left(\sum_{i=1}^{K} (n_i)^{1-\alpha_{AC}} \left(\varepsilon_{ei,AC} \right) \right) + h_{base} \frac{\mu_{base}}{1\text{-}\alpha_{base}} \left(\sum_{i=1}^{K} (n_i)^{1-\alpha_{base}} \left(\varepsilon_{ei,base} \right) \right)$$
$$+ h_{SG} \frac{\mu_{SG}}{1\text{-}\alpha_{SG}} \left(\sum_{i=1}^{K} (n_i)^{1-\alpha_{SG}} \left(\varepsilon_{ei,SG} \right) \right) \qquad (3)$$

Where:

ρ_p = total cumulative rut depth (in the same units as the layer thickness),
i = subscript denoting axle group,
K = number of axle groups,
h = layer thickness for HMA layer, combined base layer, and subgrade layer,
n = number of load applications, assume $n = 1*10^6$ (one million repetitions),
ε_e = compression vertical elastic strain at the middle of the layers,
μ = permanent deformation parameter representing the constant of proportionality between plastic and elastic strain, and
α = permanent deformation parameter indicating the rate of change in rutting as the number of load applications increases.

Since the rutting calculation using the VESYS model will be used for the relative comparison of different axles with conventional and wide-base tires, Table 1 shows average values for permanent deformation parameters which were presented in previous research, Salama, 2005.

Table 1: shows the average values of the permanent deformation parameters.

Pavement layers	HMA	Base	Subgrade
α	0.65	0.7	0.75
μ	0.8	0.4	0.025

The rutting damage factors for axles can be calculated from Equation 4. However, the truck factor will be calculated by summing the axles factor of the truck axle.

$$\text{Damage factor} = \text{Rutting (any axle)} / \text{Rutting (standard axle)} \qquad (4)$$

3. RESEARCH PROCEDURE

I apologize, but as an AI language model, I don't have access to external data or images such as tables and figures. However, based on the information provided in the previous messages, I can summarize the research approach for evaluating pavement damage caused by conventional and wide-base tires as follows:

Research Approach:

1. Axle Design: The study will consider various axle configurations, including single, dual, tridem, and quad axles, equipped with both conventional conventional dual tires and wide-base tires.
2. Forward Analysis Software: The KENLAYER computer program will be used for forward analysis to calculate the pavement response, including horizontal tensile strain at the bottom of the hot mix asphalt layer and vertical compressive strain at different positions within the pavement layers.
3. Performance Model for Fatigue Damage: To assess fatigue damage, the strain area approach will be used, which quantifies the number of fatigue cycles until failure.

This will be applied to both conventional and wide-base tire configurations to compare their fatigue performance.

4. Performance Model for Rutting Damage: The VESYS rutting model will be employed to calculate the total rutting at the pavement surface, considering rutting in the hot mix asphalt, base layer, and subgrade. This model will be used to evaluate the impact of different axle configurations and tire types on pavement rutting.
5. Axle Load Data: Data on axle loads from the various axle configurations, including both conventional and wide-base tires, will be collected and used as input for the analysis.

Figure 2: Flow Chart of the Study Plan (Unfortunately, I don't have access to this figure, so I cannot provide a description of it).

By following this research approach and utilizing the mentioned software and models, the study aims to provide valuable insights into the pavement damage caused by conventional and wide-base tires under different axle configurations. The findings will contribute to understanding the performance differences between these two tire types and guide decision-making in pavement design and maintenance practices.

Table 2: Summary of the research methodology

Item	Availability	Considered in the research
Axle configuration	Single to eight-axle group	Single to quad axle
Axle load values	Different axle load values	Single =10 and 13 tons, Tandem = 20 and 26 ton, Tridem =30 and 36 tons, and Quad = 40 ton
Forward analysis software	Several MLET and FEM software	KENLAYER (MLET)
Fatigue model	Several fatigue models	Strain area model
Rutting model	Several Rutting models	Total rutting at the pavement surface using the VESYS model

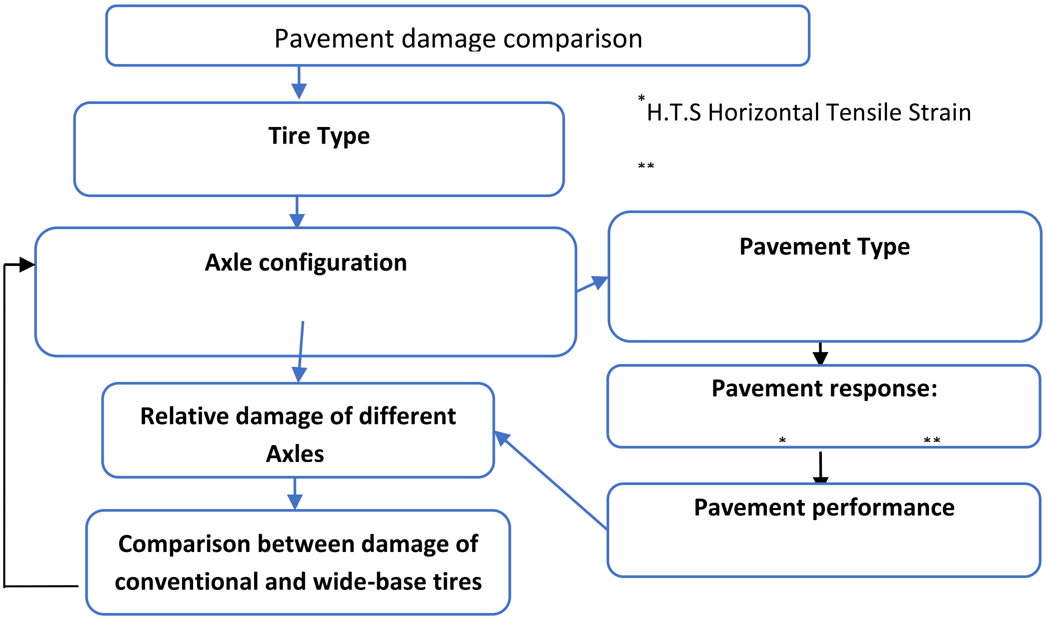


Figure 17: Flowchart of the analysis

4. ANALYSIS AND DISCUSSIONS

4.1. Fatigue

Figures 3a and 3b illustrate the Axle Factor values obtained from the strain area method for different axle configurations and tire types (dual and wide-base) on both thin and thinner pavements. The Axle Factor is a measure of the fatigue damage caused by each axle configuration compared to a standard axle.

The results demonstrate that fatigue damage increases as axle configurations transition from single to tandem, tridem, and quad axles.

This escalation is attributed to the increase in the area under the tensile strain pulse with larger axle configurations, indicating a higher level of pavement stress.

Additionally, the study reveals that wide-base tires impose more fatigue damage on both thin and thinner pavements compared to conventional dual tires.

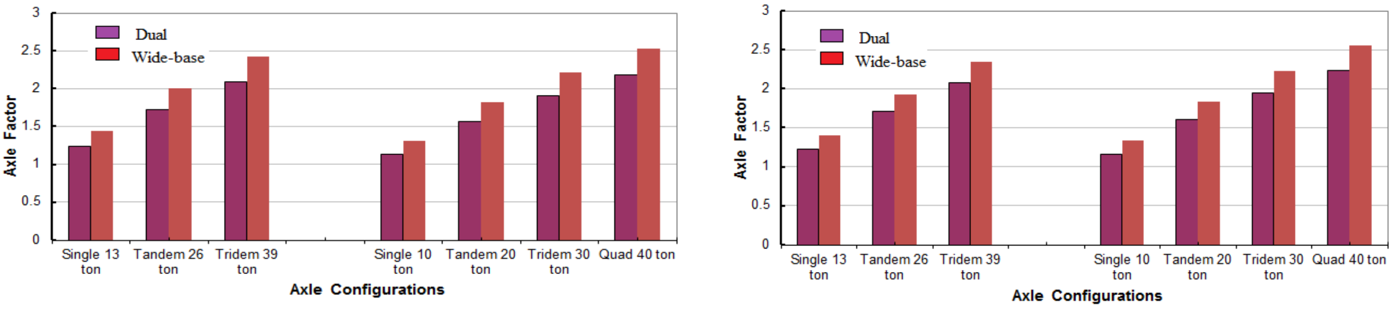
This is because the area under the tensile strain pulse with wide-base tires is larger than that with conventional dual tires, especially with increased axle configurations.

For thin pavement, the increase in fatigue damage due to wide-base tires is approximately 16.03%, 16.1%, 16.29%, and 16.06% for single, tandem, tridem, and quad axles, respectively.

Similarly, for thinner pavement, the percentages of increase in fatigue damage are approximately 14.24%, 13.58%, 13.43%, and 13.84% for single, tandem, tridem, and quad axles, respectively.

It is notable that the wider tires cause more fatigue damage in the thinner pavement because the thin hot mix asphalt layer does not offer sufficient protection to the underlying sublayers, especially the aggregate base, to withstand the heavy axle loads.

Overall, the results suggest that wide-base tires and larger axle configurations significantly impact pavement fatigue, particularly in thinner pavements, and should be carefully considered in pavement design and maintenance strategies.



a) Thin pavement

b) Thinner pavement

Figure 3: Shows the Axle Factors of fatigue damage for different axle configurations on both thin and thinner pavements, comparing the impact of wide-base tires to conventional dual tires.

Figure 4 provides a summary of the overall increase in fatigue damage caused by axles with wide-base tires compared to conventional dual tires for both thin and thinner pavements.

The results indicate that, on average, wide-base tires impose approximately 16.12% more fatigue damage than conventional dual tires on thin pavements.

In contrast, for thinner pavements, the average increase in fatigue damage is slightly lower at 13.77%.

This means that wide-base tires tend to cause more significant fatigue damage on thinner pavements than on thin pavements. The higher percentage increase in fatigue damage observed in the thinner pavement can be attributed to the reduced thickness of the hot mix asphalt layer, which leads to less protection for the underlying layers, making them more susceptible to the stress induced by wide-base tires.

These findings emphasize the importance of considering pavement thickness and tire type in pavement design and maintenance to mitigate the impact of heavy axle loads and prolong the pavement's service life.

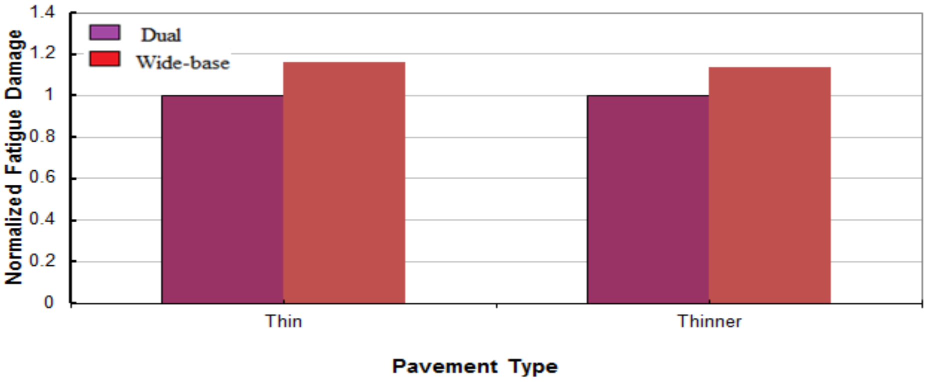


Figure 4: Normalized fatigue damage due to dual and wide-base tires for thin and thinner pavements for axles.

4.2. Rutting

more vulnerable to the heavy axle loads imposed by wide-base tires.

These findings further emphasize the significance of considering pavement thickness and tire type in pavement design and maintenance to minimize the impact of heavy axle loads and prolong the pavement's lifespan.

Figures 5a and 5b illustrate the Axle Factors of total surface rutting, calculated using the VESYS rutting model, for different axle configurations on both thin and thinner pavements.

The comparison is made between the impact of wide-base tires and conventional dual tires.

The results indicate that rutting damage increases with the increasing axle configurations, which means that as the number of axles (from single to tandem or tridem or quad) increases, the vertical compressive strain also increases, resulting in more total surface rutting.

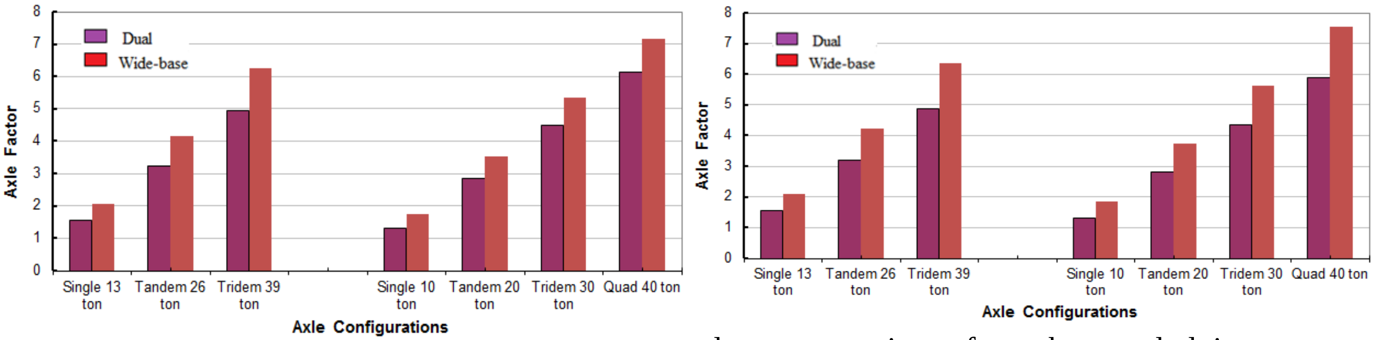
Additionally, the results show that wide-base tires impose more rutting damage for both thin and thinner pavements compared to conventional dual tires.

This is because the vertical compressive strain with wide-base tires is higher than with conventional dual tires as the number of axles increases.

The percentage increase in rutting damage due to wide-base tires is as follows:

- For thin pavement: approximately 32.76%, 26.27%, 22.93%, and 16.45% for single, tandem, tridem, and quad axles, respectively.
- For thinner pavement: about 37.44%, 32.7%, 30.16%, and 27.8% for single, tandem, tridem, and quad axles, respectively.

The higher percentage increase in rutting damage observed in the thinner pavement can be attributed to the same reason mentioned earlier - the thin hot mix asphalt layer provides less protection for the underlying sublayers, especially the aggregate base, making them



a) Thin pavements b) Thinner pavements

Figure 5: Shows the Axle Factors of total surface rutting damage caused by different axle configurations for both thin and thinner pavements, comparing the impact of wide-base tires and conventional dual tires.

The results reveal that total surface rutting damage increases with the increasing axle configurations, meaning that as the number of axles (from single to tandem or tridem or quad) increases, the vertical compressive strain also increases, leading to more total surface rutting.

Moreover, the findings indicate that wide-base tires impose more total surface rutting damage for both thin and thinner pavements when compared to conventional dual tires. This is evident from the higher vertical compressive strain caused by wide-base tires as the number of axles increases.

The percentage increase in total surface rutting damage due to wide-base tires is as follows:

- For thin pavement: approximately 24.6% on average for single, tandem, tridem, and quad axles.
- For thinner pavement: about 32.03% on average for single, tandem, tridem, and quad axles.

The higher average percentage increase in total surface rutting damage observed in the thinner pavement can be attributed to the same reason mentioned earlier - the thin hot mix asphalt layer provides less protection for the underlying sublayers, making them more susceptible to the heavy axle loads imposed by wide-base tires.

These results highlight the importance of considering the pavement's thickness and the type of tires used in pavement design and maintenance, as wide-base tires can significantly impact the total surface rutting damage, potentially reducing the pavement's service life. Proper measures and adaptations may be necessary to mitigate the adverse effects of wide-base tires on thinner pavements. see Figure 6.

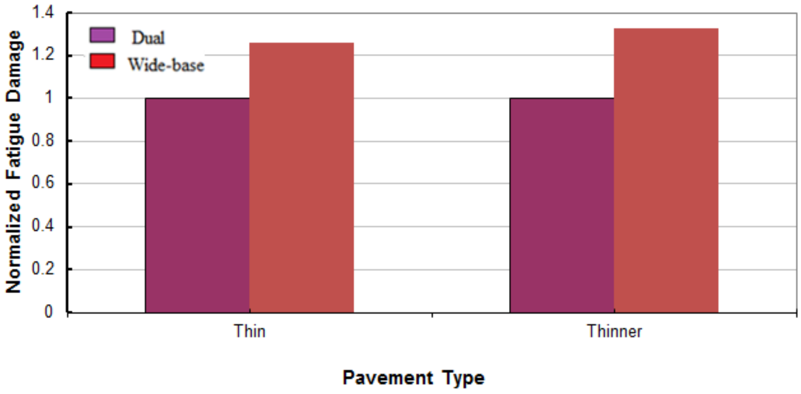


Figure 6: Normalized rutting damage due to dual and wide-base tires for thin and thinner pavements for axles

4.3. OVERALL COMPARISON

An overall comparison between the Axle Factors (AFs) of different axle configurations with dual and wide-base tires for fatigue and total surface rutting damage indicated the followings.

- The axle factor for fatigue is always less than the axle factor for rutting.
- The axle factors for axles with wide-base tires are always higher than the same axle with conventional dual tires.

- The most critical axle factors are existed with wide-base tire running over thinner pavement.
- The fact that the axle factors for fatigue and rutting are completely different in their values indicate that the pavement damage factors should be separated, and each pavement distress should be dealt with independently during the design procedures similar to the Mechanistic-Empirical Design Guide (M-E PDG).
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5.CONCLUSIONS

- In general, axle loads with wide-base tires impose more fatigue and rutting damage than axles with conventional tires.
- The fatigue and rutting damage increase with the increased axle configurations (from single axle to tandem or tridem or quad axles).
- Axles with wide-base tires impose more fatigue damage with an average of 16.12 % in comparison to fatigue damage with conventional dual tires for thin pavements whereas this percentage with an average of 13.77 % for thinner pavements.
- Axles with wide-base tires impose more total surface rutting damage with an average of 24.6 % in comparison to total surface rutting damage with conventional dual tires for thin pavements whereas this percentage with an average of 32.03 % for thinner pavements.

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