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Research Article

A Finite Element Analysis for Investigating the Effects of Moving Loads on Flexible Pavements

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Abstract

To assist researchers in solving challenging structural mechanics engineering problems, finite element modeling (FEM) has grown to be a very popular technique. The several layers of various materials that make up a pavement's complicated structure and affect how it responds to stress have an impact on how it behaves. In this study, finite element analysis is done on a real existing road which is named Nowhata-Chowmasia road, situated in Rajshahi, Bangladesh. FEM is used to study this flexible pavement, which consists of 7 layers (surface, binder, base type-1, base type-2, sub-base, enhanced subgrade, and subgrade). The effect of the depth of the base layer on vertical stresses and displacements is examined using the ABAQUS/CAE 2017 modeling and simulation program. The base layer of the real existing road is 150 mm provided by the Roads and Highways Department (RHD) Rajshahi, Bangladesh. The analysis is done by measuring stress and displacement under wheel load by decreasing the base layer thickness to 100 mm and further increasing it to 200 mm. The modeling approach assumes that all materials function in a linear elastic manner. The Poisson's ratio, layer thickness, and material elastic modulus are the major inputs used in the modeling procedure. In this work, flexible pavement is simulated using a conventional axle load of 100 kN, which corresponds to a single four-wheeled axle. Finally, FEM analysis showed that the maximum stresses are 0.35 MPa, 0.27 MPa, and 0.21 MPa and maximum displacements are 0.52 mm, 0.34 mm, and 0.21 mm for 100 mm, 150 mm, and 200 mm base layer thickness respectively. So, for the increase of base layer thickness the stress and displacement are decreased.

Keywords

Finite Element Modeling (FEM), ABAQUS, Flexible Pavement, Poisson's Ratio, Elastic Modulus

1. Introduction

The intricate network of interconnecting lanes known as roads and highways serves as the foundation of transportation infrastructure in the majority of nations. They are essential to facilitating the flow of people and vehicles and are the backbone of contemporary society. These large networks of paved surfaces, which range from wide urban boulevards to isolated country roads, make it possible to travel quickly and easily, which has a substantial positive impact on social and economic growth. Roads and highways are the conduits that allow us to commute to work, carry things across great distances, or go on cross-country adventures.

Road embankments can be classified as rigid pavement roads, semi-rigid pavement roads, or flexible pavement roads depending on the kind of pavement. Due to its many ad-

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vantages, including low construction costs and the wide availability of building materials (granular material and bituminous binders), flexible pavement is the most widely used type of road pavement worldwide. The layers that make up flexible pavement roads are typically the surface, base, and sub-base layers as well as the subgrade (foundation) soil.

2. Literature Review

Standard flexible pavements with the surface of Asphalt Concrete (AC) are utilized worldwide. The numerous layers of the flexible pavement structure have varying strength and deformation qualities, which make it challenging to assess the system layers [1]. Pavements are impacted by elements such as material qualities, pavement structure geometry, environment, traffic volume, and building methods. Additionally, the load axle and wheel design of the vehicle as well as its features could damage the pavement [2].

In causal methodologies employed in the study of multilayer pavement systems under traffic load, the road embankment layers are assumed as homogenous, linear elastic, and isotropic, and the loading is regarded as static [3]. If the behavior of the pavement subgrade system is linearly elastic, these causal approaches perform superbly [4]. These heterogeneous pavement layers behave substantially differently than they would in an ideal situation in practice due to dynamic loads. When examining the dynamic behavior of pavement layers, researchers altered the focus of their work to the finite element technique, taking into account heterogeneity, nonlinearity, and orthotropy at the same time as the pavement's structure [5].

The most important factor in designin a pavement is the material's elastic modulus. Resilient modulus (MR) testing was used to gauge the elastic properties of various highly stiff materials. The soil's mechanical response to a dynamic load application is known as MR [6]. Another important factor for designing a pavement is Poisson's ratio.

The best method for addressing several essential problems about pavement performance is now thought to be three-dimensional finite element analysis techniques [7]. Finite element methods are becoming more popular as high-speed computers become more accessible because the algorithms used for finite element analysis can easily handle complicated geometry, boundary conditions, and material properties [8]. To analyze flexible pavements, research is being done to model the flexible pavement as a finite element model, with defined boundary conditions, and explore the impacts of static loading with linear properties of pavement materials. Commercial Finite Element (FE) modeling software is called ABAQUS. Worldwide, the engineering analysis software package ABAQUS/CAE 2017 is used to simulate the physical response of structures and solid organisms to loading, contact, temperature, impact, and other environmental factors. The program can control how components are put together, including flexible pavement layers like the surface, binder, base-course, sub-base, and subgrade layer, as well as how these layers interact with one another and the proper boundary conditions. Finally, it can determine the maximum stress and displacement values for each pavement layer.

In this study, ABAQUS is used to investigate vertical displacement and stress under moving conditions on flexible pavement. The pavement data are collected from the Roads and Highways Department, Bangladesh based on an existing road. The primary goal of this investigation is to execute the existing road as a flexible pavement model by ABAQUS software and simulate the flexible pavement model under dynamic load for determining stresses and displacements concerning the horizontal distance of road pavement. Besides, the displacements and stresses of the selected road under moving wheel load concerning depth are simulated, and finally, the results of stresses and displacements in various base layer thicknesses are compared.

Research was conducted on the performance of flexible pavement using a numerical solution based on the Finite Element Method. With various base layer material properties, they investigated the impact of base layer thickness on pavement stress and strain characteristics. They discovered that the cumulative number of standard axles and the horizontal tensile strain decreased with increasing bituminous layer thickness [9].

An attempt to analyze the stress-strain characteristics of asphalt pavement through a thorough understanding of numerous traffic and loading parameters and their interactions with pavement distress and failure initiation. Using the finite element software, they also attempt to construct the ideal tire configuration, including tire contact area and inflation pressure [10].

Research carried out on flexible pavement analysis to account for variations in base layer thickness. They compared the outcomes with different base layer thicknesses (10 cm, 20 cm, and 30 cm) and used ABAQUS to evaluate the stress and vertical displacement on the top of the surface layer in multi-layer flexible pavements under static loading. For each percentage increase in base layer thickness, the change in vertical displacement and the degree of stress at the top of the base layer were represented [11].

An experiment conducted by using the value of FEM for investigating parameter-sensitive analyses was discussed. The important performance parameters were investigated by altering the thickness and material characteristics of various layers of flexible pavement using 2D axisymmetric analysis [9].

Another investigation covered the non-linear finite element analysis of flexible pavements in another article. The goal of the project was to use finite element analysis to analyze flexible pavements while taking into account realistic material properties and changing traffic loads. The ABAQUS/STANDARD computer package was used to conduct the analysis, which took into account the pavement layers' linear and non-linear material properties. The outcomes demonstrated that displacements using non-linear materials under cyclic stress closely matched field-measured deflections. The research emphasized how non-linear materials must be taken into account while designing pavement to avoid early collapse [12].

The research highlighted the effects of materials' linear and non-linear mechanistic behavior on the reaction of layered flexible pavements. The work used cross-anisotropic stress-dependent features for granular layers and focused on dynamic analysis. Using the computer program Abaqus/standard, the researchers carried out a finite element study. The conclusions showed that the displacements under cyclic loading, in the presence of non-linear materials, closely matched the field-measured deflections. To effectively estimate pavement response and avoid premature failure, the paper underlined the significance of taking non-linear behavior into account in pavement analysis and design [13].

The investigation was conducted by looking into how different base layer materials affect the deformation and strength of flexible pavements. The study builds three-dimensional models of the pavement layers using the ABAQUS application and the finite element method. The study emphasizes how base layer materials and their stabilizers are crucial for minimizing deformation and enhancing the strength of flexible pavements. The research advances knowledge of pavement behavior and offers suggestions for creating more resilient and economical road infrastructure [14].

There are limitations when using Abaqus for flexible pavement analysis. The problems include realistic boundary conditions, mesh generation, and accurate representation of pavement material behavior. Viscoelasticity, temperature impacts, and soil-structure interaction must all be carefully modeled. It can be challenging to validate against field measurements. The learning curve and the computing cost of simulating massive structures are additional issues. Even with these drawbacks, Abaqus is nevertheless a useful tool when applied skillfully and in concert with field data.

3. Methodology

3.1. Finite Element Method

In engineering and physics, the Finite Element Method (FEM) is a potent numerical method that is used to tackle difficult problems that have complicated geometries, stresses, and material properties that cannot be handled analytically. It is beneficial for addressing three-dimensional problems, where the sheer complexity of the equations makes manual solutions unfeasible. Through a procedure known as finite element discretization, FEM creates a finite element mesh by dividing the problem domain into smaller, non-intersecting subdomains called finite elements. Unlike the more traditional finite difference method, this approach does not require orthogonal lines in the mesh, making it possible to analyze complex structures accurately. This method is suitable for early and suitable results.

There are two primary types of research methodology used in this study: field-based and simulation-based methodologies. With assistance from the Department of Roads and Highways, field data was gathered from an operational road in Rajshahi, Bangladesh. The study produces graphs using Microsoft Excel and simulates existing road data using ABAQUS software. The Finite Element Method (FEM) is a popular method that is used in both academic and industry contexts to simulate different structural engineering issues. This study uses a linear, multipurpose brick to model and explore the pavement system's behavioral reaction using the ABAQUS/CAE 2017 software.

3.2. Field Survey and Data Collection

The major four-lane by-pass that links Rajshahi and Naogaon is the subject of the study: the Rajshahi-Nowhata-Chowmasia Road. This route was selected because it is important and experiences high traffic, mostly from buses and trucks, which causes more stress and deformation than other roads in Rajshahi. All information was gathered from the Roads and Highways Department (RHD), which oversaw its construction. The data are:

1. Width of the road
2. Thickness of each layer
3. CBR value of each layer of materials

3.3. Pavement Modeling

The Surface, Binder course, Base course-1, Base course-2, Sub-base, Improved Subgrade (ISG), and Subgrade were all modeled using 3D FE and can be considered as closed systems made up of several layers. This study examined the effect of Base course-1 thickness on the performance of flexible pavement layers using a standard pavement section with bituminous layers for the surface, binder, base, sub-base, and subgrade. The Base course-1 thickness was increased by 50 mm and also decreased by 50 mm with the fixed surface, binder course, sub-base, ISG, and subgrade depth thicknesses (50, 125, 200, 300, and 150 mm respectively).

Figure 1 represents the analytical model (3D view) of the road. The dimensions of the pavement are 1125 mm along the y-axis, 7300 mm along the x-axis, and 6000 mm along the z-axis. To save time and effort, one-fourth of the model was constructed using the 3D axis symmetry characteristic. In the model, two lanes are taken into consideration.

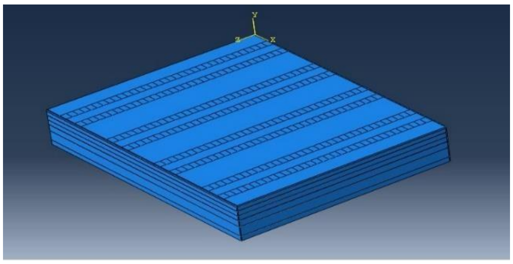

Figure 1. *Whole analytical model (3D View).*

Various pavement layers were designed in ABAQUS/CAE 2017 as Part step. Every component was made using the pavement modeling dimensions. The only difference between the layers' length and width is their depth. The length, width, and depth of different layers are created differently, and named as surface, binder course, base course-1, base course-2, sub-base, ISG, and subgrade.

To observe the change in stress and displacement, Table 1 shows the thickness change of Base type-1 for cases 1, 2, and 3. Subgrade, ISG, sub-base, base type-2, base type-1, binder, and surface are oriented from bottom to top in this step. A tie constraint is used between each contact layer. The ABAQUS interaction module also models how different pavement layers interact with tire contact, including the surface and binder course; binder course and base course-1; base course-1 and base course-2; base course-2 and sub-base; sub-base and ISG; ISG and subgrade. The model is created in such a way that all degrees of freedom are entirely fixed for the lower surfaces. Only the edges can move in the vertical direction movement is considered in the horizontal directions for four sides of the model.

Table 1. *Layer thickness for change in base type-1.*

Layer	Layer Name	Thickness (mm)		
		Case-1 (For 100mm)	Case-2 (Existing Road- 150 mm)	Case-3 (For 200 mm)
1	Surface	50	50	50
2	Binder Course	125	125	125
3	Base Type-1	100	150	200
4	Base Type-2	150	150	150
5	Sub-base	200	200	200
6	ISG	300	300	300
7	Subgrade	150	150	150

3.4. Equations Used

To convert the CBR value into Resilient Modulus, the following equation is used.

Resilient modulus from CBR value [15]:

$$MR = 91.226 + 0.017 \times (CBR)^2 \quad (1)$$

Modulus of Elasticity from Resilient modulus: Equations used are,

For Subgrade [16]:

$$MOE = 0.83 \text{ x } MR \quad (2)$$

For Sub-base [17]:

$$MOE = 1.1 \text{ x } MR \quad (3)$$

For Base [17]:

$$MOE = 1.3 \text{ x } MR \quad (4)$$

Bituminous concrete (BC) [18]:

$$MOE = 26.8 \text{ x } MR^{0.84} \quad (5)$$

Another important factor is Poisson's ratio, which is obtained from the findings [19].

Table 2 is created by compiling all of the field data. The two key characteristics that are utilized to design the pavement model are the modulus of elasticity and poison's ratio. Table 1 below shows the thickness based on field data, calculated modulus of elasticity and resilient modulus, and the poison's ratio of the pavement layers.

Table 2. *Field data of each layer.*

Layer Name	CBR Value	Resilient Modulus (MPa)	Modulus of Elasticity (MPa)	Poisson's Ratio	Thickness (mm)
Subgrade	6.29	91.90	76.28	0.4	150
ISG	10.7	93.18	77.34	0.4	300
Sub-base	29.1	105.6	116.1	0.3	200
Base type- 2	58.6	149.7	194.6	0.3	150
Base type- 1	94.0	241.5	314.0	0.3	150
Binder course	100	261.2	2873.65	0.4	125
Surface	110	296.9	3200	0.4	50

3.5. Loading

In the flexible pavement model, pressure is used as a load on the pavement's surface. Various kinds of vehicles move on the road surface, but to achieve existing road conditions, a standard axle load is applied to the road's surface. It is believed that the shape of the contact between the tire and the pavement is rectangular. It's called the contact area, also known as the Tire imprint area. This rectangular tire impression area distributes the tire stress throughout the pavement's surface.

The load is divided by this area to determine the pressure. Two semicircles and a rectangle can be used to depict the print area of the tire. The contact area is 0.254 meters and 0.175 meters in size. Even a simple model like this one is frequently used in research computing applications as a load that is evenly spread over a circle or rectangle.

3.6. Wheel Load Characterization

The wheel load is a conventional axle loading regarded as a single-axis dual tire in a rectangular uniform surface charge. The axle's total load is 100 kN, and the tire's pressure is 0.75 MPa. The width of each tire's print zone is 175 mm, equal to the width of equally distributed surface loads, and its length is 254 mm according to Bangladesh Road Transport Authority (BRTA).

In our 3D model, the moving load process is depicted in Figure 2. Two lanes are present. The load begins in one lane and travels the entire length of it before beginning again in another lane and completing its journey. This load is the wheel load of a vehicle with single-axle dual tires.

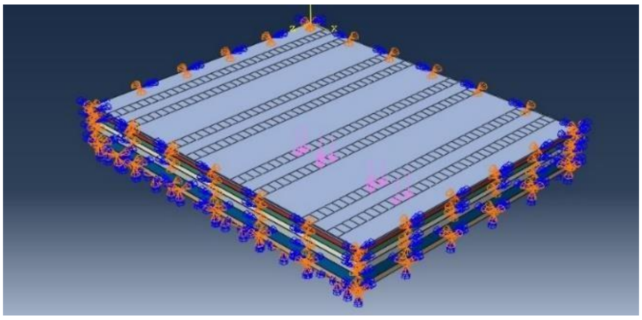

Figure 2. *Moving wheel load on the model.*

3.7. Numerical Analysis

An overall analysis has been shown for different thicknesses (100 mm, 150 mm, 200 mm) for Base type-1. The dynamic condition shows different behavior for changing the base layer thickness. Here, a comparison of displacement and stress for dynamic conditions has been carried out. The load is applied along two lanes for four wheels. Here are the simulations of displacement and stress represented for base type-1 are shown for the following cases:

Case 1: Base Type-1; thickness 100 mm
Case 2: Main Existing Road; thickness 150 mm
Case 3: Base Type-1; thickness 200 mm

3.8. Stress and Displacement Distribution

Figure 3 represents stress distribution and the effects of moving load on the existing road (150 mm). The rainbow spectrum approaches along the path of vehicles moving on pavement. The magnitude of stress is shown on the upper left side. The spectrum varies as the vehicle moves and also for varying thicknesses of base layer-1.

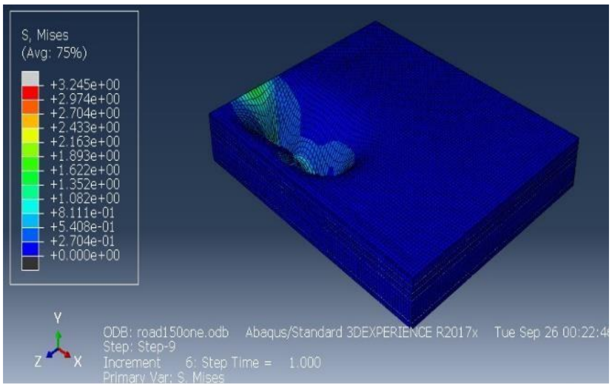

Figure 3. *Stress distribution for the existing road (150 mm).*

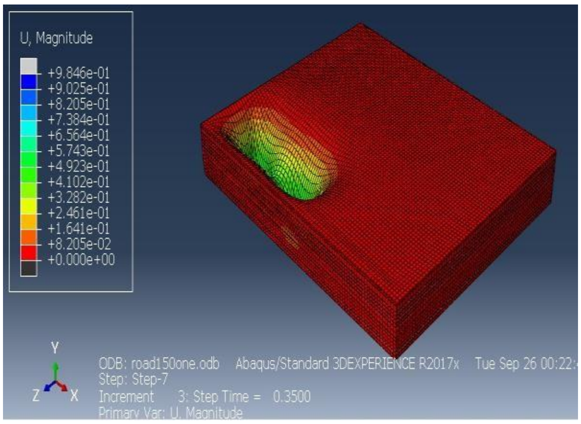

Figure 4. *Displacement distribution for the existing road (150 mm).*

The displacement distribution and moving load impacts on the current road (150 mm) are shown in Figure 4. As vehicles travel on pavement, the rainbow spectrum in reverse begins to approach. On the upper left, the magnitude of the displacement is displayed. The spectrum changes for different base layer 1 thicknesses as well as vehicle motion.

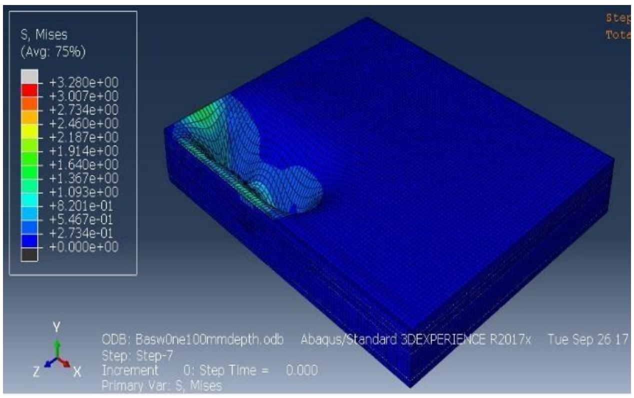

Figure 5. *Stress distribution for base-1 (100 mm).*

The stress distribution and moving load effects are depicted in the following Figure 5. The path taken by moving vehicles on the pavement is where the rainbow spectrum is approaching. On the upper left side, the amount of stress is displayed. As the vehicles move, the spectrum changes. The spectrum, which represents the change in magnitude, spreads over the width and depth of the road. Compared to the current road, the stress is higher.

In Figure 6, the displacement distribution and the effects of a moving load are shown. The route of moving automobiles on the pavement is where the reversed rainbow spectrum approaches. The upper left side displays the displacement's magnitude. The spectrum changes as the vehicles travel. The spectrum stretches out across the width and depth of the road, signifying the difference in magnitude. There is a bigger displacement than the current road.

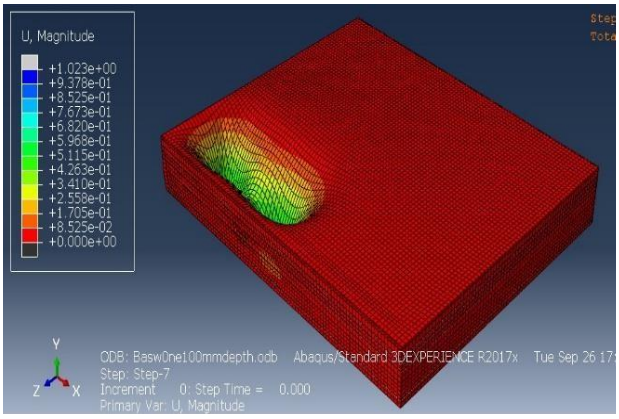

Figure 6. *Displacement distribution for base-1 (100 mm).*

The effects of a moving load and the distribution of stress for case 3 (200 mm) are shown in Figure 7. Vehicles traveling on the pavement are the pathway that the rainbow spectrum follows. On the upper left, the magnitudes of stresses are displayed. Moving with the vehicle causes the spectrum to change. Symbolizing the shift in magnitude, the spectrum extends throughout the width and depth of the road. The road now experiences less stress than it did before.

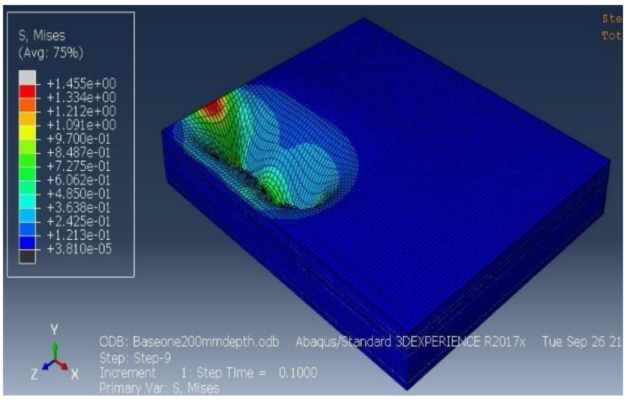

Figure 7. *Stress distribution for base-1 (200 mm)*

The consequences of a moving load and the displacement distribution for case 3 (200 mm) are shown in Figure 8. Along the route of moving vehicles on the pavement is where the reversed rainbow spectrum advances. The left top corner displays the displacement magnitude. Moving with the vehicle causes the spectrum to change. Symbolizing the shift in magnitude, the spectrum extends throughout the width and depth of the road. Compared to the current road, there is less displacement.

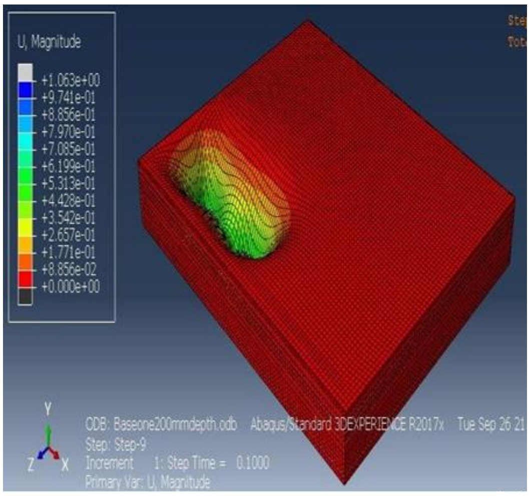

Figure 8. Displacement distribution for base-1 (200 mm)

4. Results and Discussion

Some of the most important factors taken into account when designing flexible pavements are stresses and displacements caused by wheel loads on pavement layers and interfaces. Below is a presentation of the stresses collected results and their vertical displacement from the FE model analysis used in this study.

4.1. Effect of Changing Base Layer Thickness for Stress with Respect to Depth

In Figure 9, variation of Stress along depth under wheel load for changing base layer thickness for 100 mm, 150 mm, and 200 mm is shown. The figure describes that the stress decreases with the increase of depth. For case-1, the maximum stress is 0.35 MPa; for case-2, the maximum stress is 0.27 MPa and for case-3, the maximum stress is 0.21 MPa. Stress increased by 29.63% for decreasing thickness from 150 mm to 100 mm. For increasing every 50 mm thickness the stresses decrease 22.86% to 22.22%. The compared results are shown in the Figure. This graph displays the variations among the examples. This is apparent since the pavement surface is supported by the foundation layer, which also helps to distribute the weight across a larger area. Thick layers will result in less stress on the pavement surface since the load will be distributed more effectively by a thicker foundation layer.

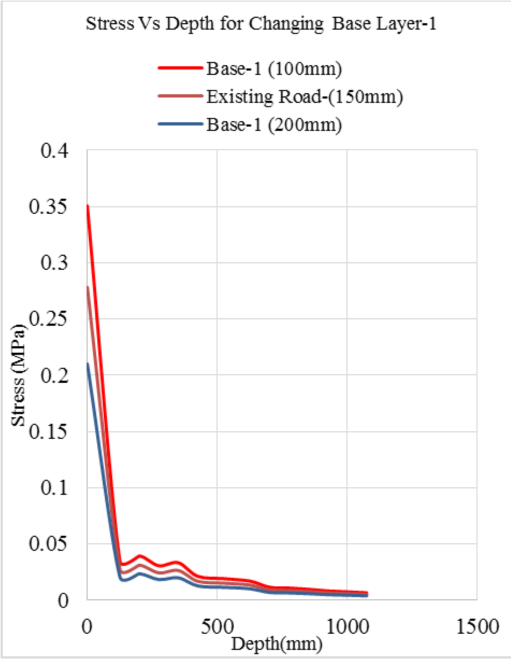

Figure 9. Variation of stress with depth for changing base layer-1 thickness.

4.2. Effect of Changing Base Layer Thickness for Displacement with Respect to Depth

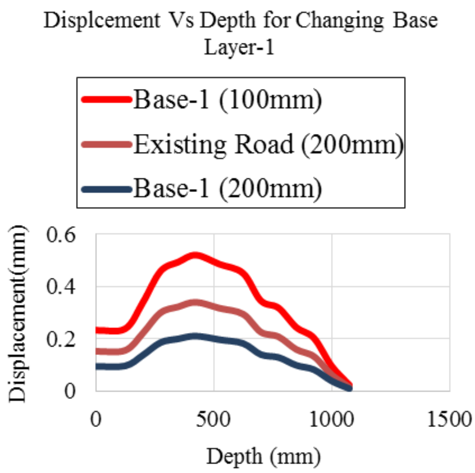

Figure 10. Variation of displacement with depth for changing base ayer-1 thickness.

In Figure 10, the variation of displacement for depth is measured for case-1, 2, and 3. For case-1, the maximum displacement is measured at 0.52 mm; for case-2 maximum displacement is 0.34 mm. Finally, for case 3, the maximum displacement is 0.21 mm. Increasing layer thickness from 100 mm to 150 mm, displacement decreases by 34.62%. On the other hand, increasing layer thickness from 150 mm to 200 mm displacement decreases 38.24%. This graph shows the difference between the cases. This is noticed because the foundation layer serves to disperse the weight across a greater area and supports the pavement surface. There will be less displacement on the pavement surface with thick layers since a thicker foundation layer will be more efficient at dispersing the load.

4.3. Effect of Changing Base Layer Thickness for Stress with Respect to Horizontal Distance

In Figure 11, variations of stress with horizontal distance are shown. Here, the maximum stress is developed in case-1 (100 mm) then Case-2 (150 mm), and the minimum stress is developed in case-3 (200 mm). Figure 11 shows how stress changes with horizontal distance and how stress decreases with increasing layer thickness. If the base layer-2's thickness is reduced from 150 mm to 100 mm, the stress will rise by 24.88%. However, the stress drops by 38.22% if the thickness is increased from 150 mm to 200 mm. Changing the thickness of a base layer in engineering and geotechnical applications impacts stress distribution concerning horizontal distance. Thicker base layers tend to spread loads over a larger area, reducing stress concentrations near the surface. This can increase load-bearing capacity, minimize settlement, and influence shear stress and stability. The decision on the optimal base layer thickness should be made after considering a range of factors, including load requirements, soil characteristics, settlement considerations, stability, and cost-effectiveness.

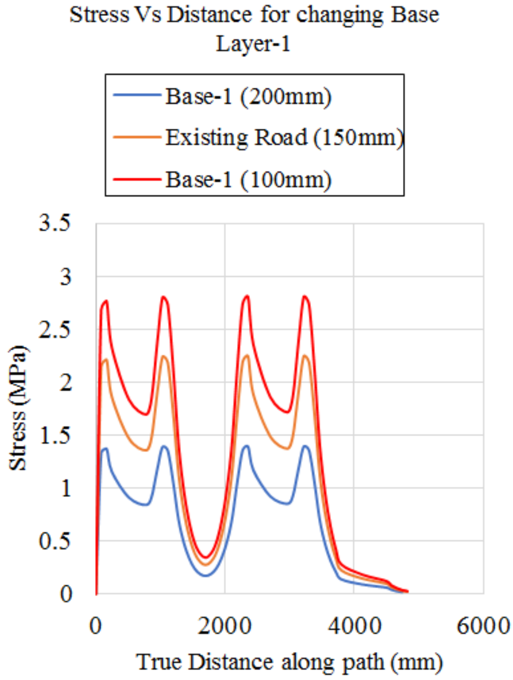

Figure 11. *Variation of stress with horizontal distance for changing base layer-1 thickness.*

4.4. Effect of Changing Base Layer Thickness for Displacement with Respect to Horizontal Distance

Figure 12 illustrates how displacement varies with horizontal distance. In this instance, case-1 (100 mm) develops the most stress, followed by case-2 (150 mm), while case-3 (200 mm) develops the smallest stress. Displacement gradually increases with the increase of distance and near the center it reaches its pick point. Under the surface of the wheel, there is the most displacement. Decreasing base layer-1 thickness from 150 mm to 100 mm, the displacement concerning horizontal distance increases by 25.5%. Moreover, if the thickness increases from 150 mm to 200 mm the displacement with respect to horizontal distance decreases 35.08%. These effects are mandatory in designing the pavement. This is because the base layer provides support for the pavement surface and helps to distribute the load over a larger area. A thicker base layer will be more effective at distributing the load, which will reduce the stress on the pavement surface and reduce the amount of displacement.

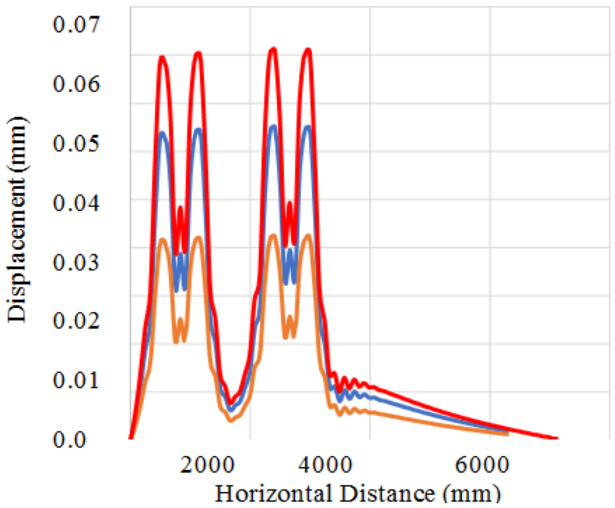

Figure 12. *Variation of displacement with horizontal distance for changing base layer-1 thickness.*

The outcomes displayed by the software correspond with the actual outcomes. Among the prior researches are

1. Early Methodological Foundations: This groundbreaking work highlighted the significance of precise material properties and boundary conditions while modeling the dynamic response of pavements to moving loads using Finite Element Analysis. This demonstrated the need for exact modeling methodologies, laying the foundation for further research.

2. Impact of Magnitude and Speed of Load: The effect of load speed is demonstrated using 3D FEA models, which indicate that increased speeds decrease deformation but raise

tensile stresses, which may result in fatigue cracking. More research on huge vehicle loads, highlighting the significance of taking load distribution and size into account.

5. Conclusions

The following are the key conclusions drawn from the study's findings:

1. For base type -1, stress increases by 29.63% with a drop in thickness along depth and lowers by 22.86% with an increase in thickness along depth.

2. When thickness increases along the depth, displacement for base type-1 falls by 38.24%, and when thickness declines along the depth, displacement increases by 52.94%.

3. With an increase in thickness along the horizontal direction, stress for base type-1 drops by 38.22%, while with a decrease in thickness along the same direction, stress increases by 24.88%.

4. When thickness increases in the horizontal direction, displacement falls by 35.08%; conversely, when thickness decreases in the horizontal direction, displacement increases by 25.5%.

5. The primary factor in lowering displacement and stress in pavement construction is increasing base layer thickness.

6. The entire structure of the pavement may collapse before the intended lifespan if the flexible paving layers are too thin.

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
FEM	Finite Element Modeling
FEA	Finite Element Analysis
RHD	Roads and Highways Department
BRTA	Bangladesh Road Transport Authority
MOE	Modulus of Elasticity
MR	Resilient Modulus

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Author Contributions

Md. Akhtar Hossain: Conceptualization, Project administration, Supervision

Swapnil Saha: Software, Formal Analysis, Writing – original draft

Shekh Nazmul Hussain Nibir: Investigation, Visualization, Resources

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Data Availability Statement

1. The data available from the corresponding author can be provided for verification purposes.
2. The data supporting the outcome of this research has also been mentioned in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] T. Kumela, “Evaluation of Flexible Pavement Deflections with Respect to Pavement Depths Using Software (A Case Study Jimma to Seka Road),” Am. J. Civ. Eng., vol. 6, no. 5, p. 141, 2018, https://doi.org/10.11648/j.ajce.20180605.11

[2] A. A. E. M., “The Rational Use of Finite Element Method in the Analysis of Flexible Pavements,” JES. J. Eng. Sci., vol. 34, no. 4, pp. 1185–1211, 2006, https://doi.org/10.21608/jesaun.2006.110780

[3] C. V. G. Vallaabhan, “Dynamic analysis of infinite beam on modified Vlasov subgrade,” J. Transp. Eng., vol. 123, no. 3, pp. 247–248, 1997, https://doi.org/10.1061/(ASCE)0733-947X(1997)123:3(247)

[4] W. Uddin, D. Zhang, and F. Fernandez, “Finite element simulation of pavement discontinuities and dynamic load response,” Transp. Res. Rec., no. 1448, pp. 100–106, 1994.

[5] W. Uddin, R. M. Hackett, A. Joseph, Z. Pan, and A. B. Crawley, “Three-dimensional finite-element analysis of jointed concrete pavement with discontinuities,” Transp. Res. Rec., no. 1482, pp. 26–32, 1995.

[6] A. J. L. M. Siang, D. C. Wijeyesekera, L. S. Mei, and A. Zainorabidin, “Innovative laboratory assessment of the resilient behavior of materials (Rigid, Elastic and Particulates),” Procedia Eng., vol. 53, pp. 156–166, 2013, https://doi.org/10.1016/j.proeng.2013.02.021

[7] D. H. Chen, M. Zaman, J. Laguros, and A. Soltani, “Assessment of computer programs for analysis of flexible pavement structure,” Transp. Res. Rec., no. 1482, pp. 123–133, 1995.

[8] B. T. S. Vepa, K. P. George, and Z. Member, “DEFLECTION RESPONSE MODELS FOR CRACKED RIGID PAVEMENTS By T. S. Vepa 1 and K. P. George, Z Member, ASCE,” no. October, pp. 377–384, 1997.

[9] A. B. Tapase and M. S. Ranadive, “Performance Evaluation of Flexible Pavement Using the Finite Element Method,” no. July, pp. 9–17, 2016, https://doi.org/10.1061/9780784480090.002

[10] M. T. Rahman, K. Mahmud, and S. Ahsan, “Stress-Strain Characteristics of Flexible Pavement by Finite Element Method,” Int. J. Civ. Struct. Eng., vol. 2, no. September 2011, pp. 233–240, 2011.

[11] M. A. S. Hadi and M. H. Al-Sherrawi, “The Influence of Base Layer Thickness in Flexible Pavements,” Eng. Technol. Appl. Sci. Res., vol. 11, no. 6, pp. 7904–7909, 2021, https://doi.org/10.48084/etasr.4573

[12] M. N. S. Hadi and B. C. Bodhinayake, “Non-linear finite element analysis of flexible pavements,” Adv. Eng. Softw., vol. 34, no. 11–12, pp. 657–662, 2003, https://doi.org/10.1016/S0965-9978(03)00109-1

[13] Y. Zhuge, W. Duan, and Y. Liu, “Utilization of wood waste ash in green concrete production,” in Sustainable Concrete Made with Ashes and Dust from Different Sources: Materials, Properties and Applications, Elsevier, 2021, pp. 419–450. https://doi.org/10.1016/B978-0-12-824050-2.00007-3

[14] Ad, “Surface Deformation of Flexible Pavement With Different Base Surface Deformation of Flexible Pavement With Different Base Layers Using Finite Element,” no. January, 2014.

[15] A. Dione, M. Fall, Y. Berthaud, and..., “Implementation of Resilient Modulus–CBR relationship in Mechanistic Pavement Design,” Appliquées l’, no. November, 2014, [Online. Available: http://publication.lecames.org/index.php/ing/article/view/358

[16] V. P. Drnevich, M. M. Hossain, J. Wang, and R. C. Graves, “Determination of {Layer} {Moduli} in {Pavement} {Systems} by {Nondestructive} {Testing},” pp. 18–26, 1990, [Online. Available: http://onlinepubs.trb.org/Onlinepubs/trr/1990/1278/1278-003.pdf

[17] AASHTO, “Interim Guide for Design of Pavement Structures,” American Association of State Highway and Transportation Officials. 1993.

[18] Laboratory Determination of Resilient Modulus for Flexible Pavement Design, no. July. 2004. https://doi.org/10.17226/21960

[19] S. F. Brown, “Determination of Young’s Modulus for Bituminous Materials in Pavement Design.,” Highw Res Rec, no. 431, pp. 38–49, 1973.

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