Modal Analysis of Barikin Saleh Bridge Deck Using Finite Element Software Simulation Method

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ABSTRACT
The increase in traffic along Barikin Saleh area of Minna Niger State calls for the analysis of the bridge deck due to the increasing and fluctuating traffic volume. In this paper, the modal analysis of the Barikin Saleh bridge deck based on finite element software simulation method was studied. The simulation was carried out to determine natural frequencies and the corresponding mode shapes of the bridge deck using ANSYS workbench software. The parameters of the bridge used in the simulation were Length,16m; Width, 10.75m; Second moment of inertia I, 4.16m4; Area A, .56m2; Young's modulus E, 35300MPa; Density p, 2600 kg/m3, and Concrete Grade G, 50MPa. Based on the simulation output, the bridge exhibited six (6) clear mode shapes and corresponding natural frequencies of 20.299Hz,20.436Hz, 22.875Hz, 25.087Hz, 30.003Hz, and 35.205Hz. The highest natural frequency for the bridge was 35.205Hz, at the bridge deck mid-span. The implication of this is that the lifespan of the bridge might be reduced due to fatigue damage that can occur as a result of repeated loading and unloading of the bridge deck at this frequency. The findings from this study provide valuable insights into the dynamic behavior of Barikin Saleh bridge deck, which can be useful for its maintenance, repair and retrofitting.

Keywords: *Bridge deck, Modal analysis, Natural frequency, Mode shape*

1 INTRODUCTION

The finite element method is a numerical procedure that can be applied to obtain solutions to a variety of problems in engineering. Steady, transient, linear, or nonlinear problems in stress analysis, heat transfer, fluid flow, and electromagnetism problems may be analyzed with finite element methods. The origin of the modern finite element method may be traced back to the early 1900s when some investigators approximated and modeled elastic continua using discrete equivalent elastic bars (Moaveni, 2015).

According to Prakash *et al.,* (2018), Finite element method is a numerical technique generally employed for solving complex engineering problems. It is mostly preferred during design and product development which involves complicated geometries, complex dynamic loadings and the corresponding material property changes that cannot be obtained analytically. In the case of analytical solutions, analysis is typically carried out using dramatic idealization and simplification.

Modal analysis is a process whereby a structure is described in terms of its natural characteristics which are the frequency, damping and mode shapes (Avitabile, 2001.). According to Nikitas & Tsavdaridis (2018), the conception of vibration modes dated back to the eighteenth century and the pioneering studies and debates of Daniel and John Bernoulli, Euler, and d'Alembert who while studying the problem of the vibration of a taut string came up with the notion of the modal shape contributions that build up the total observed oscillations. Vibration monitoring of a bridge is a useful and widespread technique for assessing the current condition of a bridge, in which damages or structural degradation can be detected, for example, by changes in the natural frequencies or in the frequency spectrum of the response due to ambient excitation (Eberle & Oberguggenberger 2023).

ANSYS is an engineering simulation software (computer-aided engineering, or CAE) developer that is headquartered south of Pittsburgh in Canonsburg, Pennsylvania, United States. The ANSYS Workbench interface consists primarily of a Toolbox region, the Project Schematic, the Toolbar, and the Menu bar (Sai, 2021). Moaveni (2015) described ANSYS as a comprehensive general-purpose finite element computer program that contains more than 100,000 lines of code which is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analyses.

Barikin Saleh Bridge is a 16m long span bridge. The bridge is simply supported and of concrete beam and slab construction which forms part of a larger structure. Six longitudinal beams support a slab with a layer of asphalt acting as the road surface. Plate I below shows a pictorial view of the bridge while plate II shows the aerial view of the bridge with coordinate 90 35' 29" N 60 32' 16" E.

There exists limited data or studies that provides the current dynamic behavior of the Barikin Saleh bridge, so, this study tends to investigate the dynamic behavior of the bridge using ANSYS workbench as a simulation tool to determine the bridge natural frequencies and the corresponding mode shapes. The outcome of this study will provide a basis for comparison between ANSYS simulation results and that of physical measurement of the bridge dynamic response.

Plate I: Barikin Saleh Beam and Slab Bridge

Plate 1I: Aerial view of the bridge

2 METHODOLOGY

2.1 Bridge Modal Analysis

Modal analysis for the bridge was conducted in ANSYS finite element software to determine the bridge's natural frequencies and their corresponding mode shapes. The flowchart for the modelling and analysis of the bridge is presented in Figure 2.1 while the parameters of the bridge are presented in Table 2.1.

TABLE 2. 1 BRIDGE PARAMETERS

L(m)	16
W(m)	10.75
I(m4)	4.16
A (m2)	5.56
E (MPa)	35300
p(kg/m3)	2600
G(MPa)	50

Where;
L = Bridge deck span
W = Bridge deck width
I = Bridge second moment of inertia
A = Bridge deck cross-sectional area
E = Young modulus of elasticity
P = Density of concrete
G = Grade of concrete

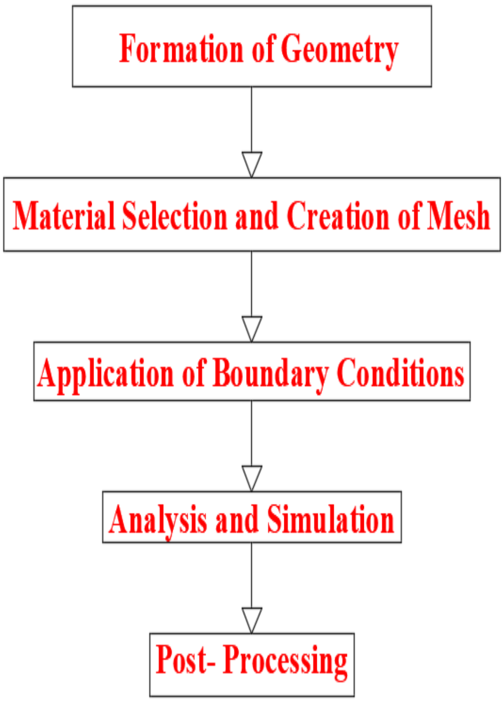

Figure 2.1: Flowchart for Modal Analysis

3 RESULTS AND DISCUSSION

3.1 Bridge Modal Analysis

The modal analysis for the bridge was conducted using the ANSYS workbench finite element software. It was observed from the results that the bridge has six mode shapes and natural frequencies. Figure 3.1 presented the bridge deck model with the slab and six longitudinal beams.

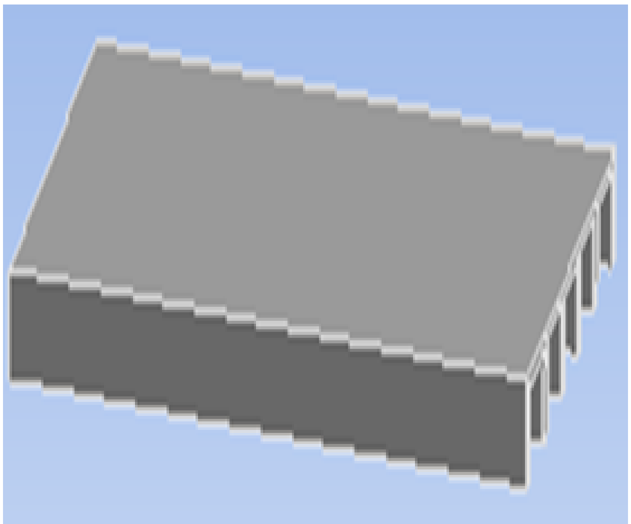

Figure 3.1: Bridge Deck Model

3.1.1 Mode shapes

The six mode shapes for the bridge are presented in Figures 3.2 to 3.7.

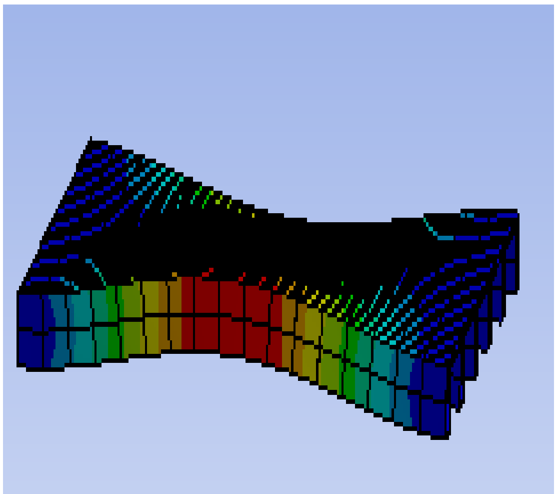

Figure 3.2: Mode Shape 1

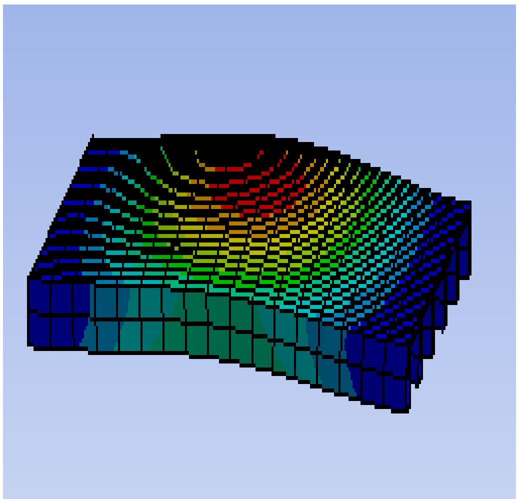
Figure 3.3: Mode Shape 2

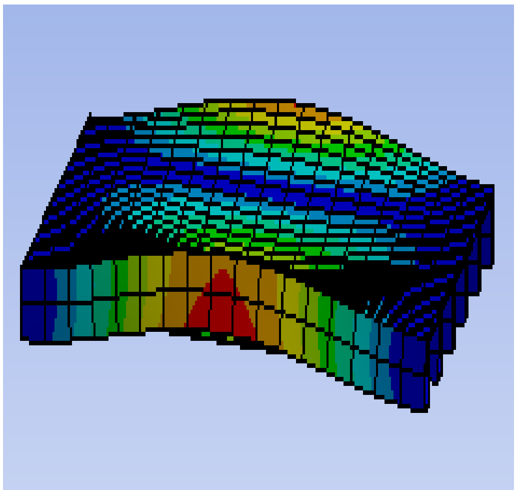
Figure 3.4: Mode Shape 3

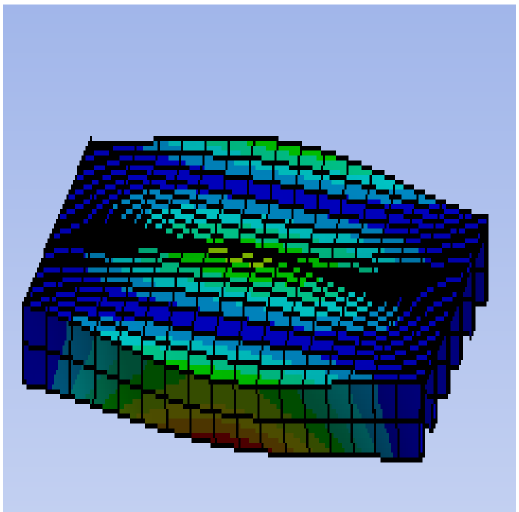
Figure 3.5: Mode shape 4

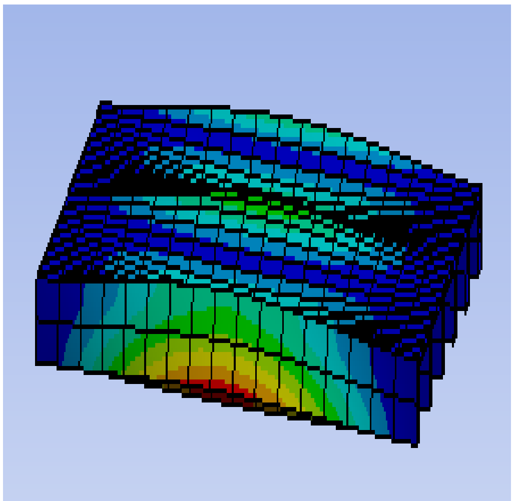
Figure 3.6: Mode Shape 5

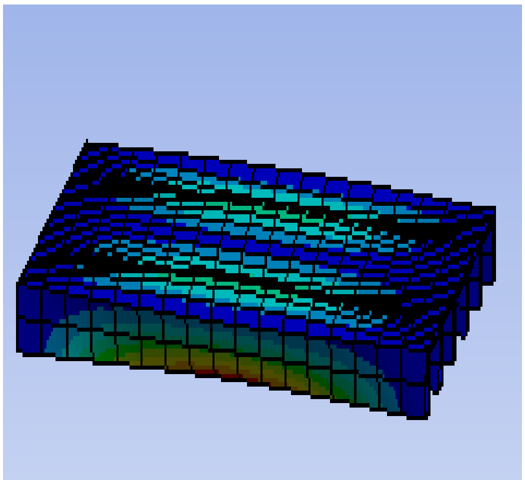
Figure 3.7: Mode Shape 6

The results from the modal analysis showed that the bridge deck can deflect in six different ways. The maximum deformation for each mode shape from mode shape one to six were 0.0051935m, 0.0042058m, 0.0059059m, 0.0067845m, 0.0079419m, 0.0078377m respectively. All the mode shapes have their maximum deformation at the mid- span of the bridge, this showed that the most critical section of the bridge is the mid-span. It was observed that mode shape five has the highest deformation of 0.0079419m which consequently is the most critical

3.2 NATURAL FREQUENCY

The natural frequencies for each mode shape from mode shape one to six were, 20.293Hz, 20.438Hz, 22.862Hz, 25.118Hz, 30.092Hz, and 35.308Hz respectively. The highest natural frequency for the bridge was recorded at mode shape 6 as 35.308Hz.

The plot of natural frequency against mode is shown in Figure 3.2. It was observed that mode shape 6 has the highest natural frequency of 35.205Hz, this implies that the most critical of all the mode shapes were mode shapes five and six due to their values of deformation and frequency.

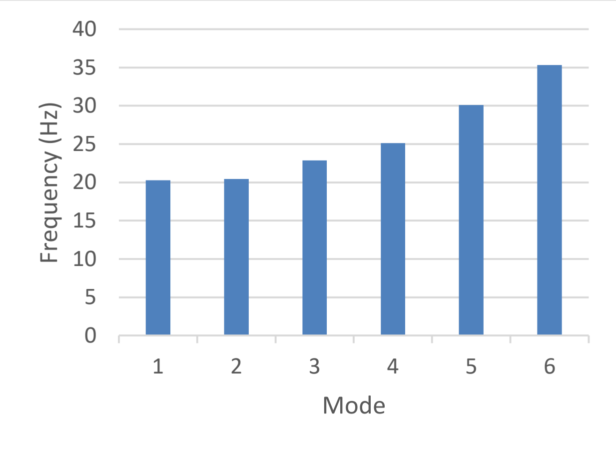

Figure 8: Plot of Frequency against mode

4 CONCLUSION

Modal analysis was carried out on Barikin Saleh bridge deck based on finite element software simulation method. The bridge deck recorded six modes shapes and natural frequencies of 20.299Hz, 20.436Hz, 22.875Hz, 25.087Hz, 30.003Hz 35.205Hz respectively. The highest natural frequency for the bridge was 35.205Hz at the bridge mid-span. The implication of this is that the lifespan of the bridge might be reduced due to fatigue damage that can occur as a result of repeated loading and unloading of the bridge deck at this frequency.

Recommendations

1. The findings from this study provide valuable insights into the dynamic behavior of Barikin Saleh bridge deck, which can be useful for its maintenance, repair and retrofitting.
2. Physical measurements should be carried out in the future to determine the natural frequencies and mode shapes of the bridge deck.

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DEVELOPMENT OF MODELS FOR PREDICTION OF SOIL COHESION USING MACHINE LEARNING ALGORITHMS

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ABSTRACT

Accurate prediction of soil cohesion is crucial for the safe and economical design of geotechnical structures. This study employed five machine learning models—Artificial Neural Network (ANN), Random Forest (RF), Support Vector Regression (SVR), Gradient Boosting (GB), and Decision Tree (DT)—to predict cohesion (c) using a laboratory dataset of 233 samples. The dataset, augmented to 5000 samples using Getel, was split into 70% training and 30% testing sets. Model performance was evaluated using R-squared and Mean Squared Error (MSE). Results showed that Random Forest outperformed other models, achieving the highest R-squared score of 0.622 and the lowest MSE of 56.74, indicating excellent model fit and high predictive accuracy. Feature importance analysis revealed that plasticity, primarily influenced by Liquid Limit (LL) with an importance score of 0.879606, and Plasticity Index (PI) with an importance score of 1.441646, significantly impacts cohesion. Natural Moisture Content (NMC) also showed significant influence with a score of 0.670434. Particle Size Distribution and Specific Gravity (Gs) also contributed to the predictions. This study demonstrates the potential of machine learning models to enhance the accuracy and efficiency of soil characterization and geotechnical engineering design in predicting soil cohesion.

Keywords: Machine learning Algorithms, Soil Cohesion, Prediction, Index Properties

1 INTRODUCTION

Soil shear strength is a fundamental parameter in geotechnical engineering, crucial for the stability and performance of various civil infrastructure projects, including foundations, slopes, embankments, and tunnels (Sharma *et al.*, 2021; Ly, *et al.*, 2020; Fondjo *et al.*, 2023). Accurate prediction of shear strength parameters, such as cohesion and the angle of internal friction, is essential for safe and economical design, risk assessment and mitigation, selection of suitable ground improvement techniques, and environmental impact assessment (Chen *et al.*, 2019; Habte *et al.*, 2024)

Traditional methods for determining soil shear strength, such as laboratory testing and empirical correlations, have limitations. Laboratory testing is invasive, time-consuming, and costly (Ly *et al.*, 2020; Irfan and Osman, 2012; Ozelim *et al.*, 2022). while empirical correlations may not be universally applicable and may not adequately capture and address these limitations, there is a growing demand for robust and accurate predictive models that can effectively and efficiently estimate soil shear strength parameters using readily available data, such as geophysical data, geotechnical data, and remote sensing data complex interactions between soil properties. (Awais *et al.*, 2023). These models aim to improve the efficiency and cost-effectiveness of geotechnical investigations and enhance our understanding of soil behavior.

Machine learning (ML) algorithms offer a promising approach for developing predictive models in geotechnical engineering (Awais *et al.*, 2023). ML algorithms excel at analyzing large and complex datasets, identifying intricate patterns and relationships, and demonstrating high predictive accuracy in various engineering domains. Furthermore, their flexibility and adaptability allow for customization to different soil types and site conditions.

This study aims to develop and evaluate various machine learning models for predicting soil shear strength parameters, including cohesion and the angle of internal friction. A comparative analysis of the performance of different ML algorithms, such as Support Vector Machines (SVM), Artificial Neural Networks (ANN), and Random Forest, will be conducted. The accuracy and reliability of the developed ML models will be assessed in comparison to traditional methods, quantifying potential improvements in prediction accuracy and efficiency. The sensitivity of model predictions to