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Free Vibration Analysis of Bridge Structures using ANSYS

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Abstract:The phenomenon of bridge vibration is a complex and uncertain occurrence that may be attributed to several factors, such as the dimensions and velocity of the vehicle traversing it, the uniformity of the bridge's surface, and the structural properties of the bridge. The main aim of this study is to use Finite Element Analysis (FEA) to examine the dynamic behavior of a bridge deck with a frame structure when exposed to vibrational loads. The computer-aided design (CAD) model of the bridge included I-shaped girders, using the ANSYS Design Modeler technology. The computer program ANSYS was used in the execution of the Finite Element Analysis (FEA) procedure. The occurrence of cracks inside the bridge deck resulted in a decrease in the inherent frequency of the deck, as well as an augmentation in the level of deformation it displayed.

Key Words: *Bridge, vibration, natural frequency*

1. INTRODUCTION:

The intricate and uncertain nature of bridge vibration arises from a variety of factors, including aspects such as bridge dimensions, traffic velocity, surface uniformity, and architectural configuration. Friction arises as a consequence of the persistent use of a bridge, mostly due to the exertion of physical forces resulting from the motion of vehicles traversing the primary deck. Therefore, friction is to blame for the continuously escalating deterioration and structural damage that the bridge experiences as a consequence of its operation during the course of its existence. The buildup of frictional forces resulting from the acceleration and braking of these vehicles has a significant role in the degradation of the infrastructure. Bridges with piers that are in close proximity to running water and encounter a lot of friction over time will decay. The frequency of vehicle use has little impact on the overall resilience of the deck. In contrast, the rate of degradation will accelerate if the road surface exhibits even minimal imperfections, potentially resulting in damage. When evaluating bridges that use simply supported girders, it is essential to meticulously construct the connections between the supports, paying careful attention to every detail. The significance of these joints lies in their role as pivotal spots within a structure, where alterations in building procedures might potentially lead to abnormalities or uneven surfaces. Fatigue is a physical phenomenon that may potentially impact the structural integrity of bridges, especially in regions experiencing significant stress levels.

Figure 1: Bridge collapsing [10]

The primary cause of this phenomenon may be attributed to the consistent application and removal of loads due to traffic patterns. The continuous flow of vehicles results in degradation and subsequent decline in the mechanical properties of the deck, leading to reduced reliability over an extended period. If the magnitude of stress induced by each cyclic load is equal to or greater than the yield stress of the material, it is very probable that the structural integrity of the material will experience a significant decline. Upon undergoing a substantial number of cycles, there exists a potential for the component to eventually exhibit brittleness and experience failure.

2. LITERATURE REVIEW

In a study conducted by Kim et al. [1], researchers investigated and devised a methodology aimed at using vibrations for the purpose of damage assessment. The purpose of this technique is to promptly notify users about the presence, location, and degree of damage in situations where there may be uncertainty caused by temperature variations. The data collected before and after damage occurred at constant temperature settings provided empirical support for the accuracy of the conclusions pertaining to damage localization and damage sizing. Conversely, a decrease in precision was seen in instances when a larger disparity in temperature existed.

Brownjohn et. al. [2] In order to accomplish this goal, many approaches were used, including the natural excitation methodology/Eigen system realization technique, the poly-Least Squares Frequency Domain approach, and the stochastic subspace identification method. Upon comparing the present results with those of a bridge test conducted in 1985, it becomes readily evident that the modal parameters have shown little changes throughout the prior 23-year period. This consistency facilitates the establishment of credible comparisons. Estimations of parameters exhibit substantial levels of inter- and intra-methodological divergence, with temporal fluctuations. The phenomenon of bridge vibration has been subject to significant investigation and evaluation, resulting in a comprehensive understanding of the subject matter. The progress in technology has enabled the monitoring of the condition of different bridges to become a viable option.

Whelan et al. [3] used a real-time wireless vibration monitoring system to conduct an operational modal analysis on an integrated abutment highway bridge. With the increasing prevalence of remote structural health monitoring systems, it is anticipated that future long-term bridge management programs will heavily rely on sensor-based quantitative evaluations of the structural condition. The study results suggest that stochastic subspace identification (SSI) methods outperform frequency domain decomposition (FDD) strategies in terms of accurately predicting modal parameters using output-only experimental data. The aforementioned conclusion was derived from the discoveries made over the course of the research. Despite accounting for the higher computational expense and the subjective nature of system pole identification, this alternative remains a viable choice.

Wardhana and Hadipriono [4] conducted a detailed analysis of over 500 distinct instances of bridge collapse that occurred from 1989 to 2000. Based on the results of their inquiry, the predominant explanation provided for these failures is the presence of trigger events. The key factors contributing to a significant proportion, namely 73%, of documented failures in controlled, short-duration hydraulic events were identified as overload, collision, and long-term scour. The failure of the hydraulic system was caused by these factors. Approximately 11% of the incidents might potentially be attributed to factors such as the deterioration of structural components, design deficiencies, or challenges encountered during the construction process. The sensor-based monitoring system will provide timely and efficient notifications on the previously mentioned deterioration. By virtue of being alerted in advance, individuals would have sufficient notification, enabling them to undertake essential measures such as repairs or a shutdown prior to the situation escalating into a potentially hazardous state.

According to a comprehensive analysis conducted by Pakzad et al. [5], Paek et al. [6], and Lynch et al. [7], networks often employ local data logging followed by sensor data transmission. Alternatively, they may adopt low sampling rates and/or a limited number of sensors to mitigate the limitations imposed by transceiver bandwidth constraints. This approach is commonly observed in wireless sensor operations for integral bridge health monitoring. The aforementioned analysis was conducted by Pakzad, Paek, and Lynch. The efficacy and use of a structural health monitoring system are significantly impeded by several constraints imposed on sample time, data collection rates, spatial resolution, and the fidelity of the derived mode shapes.

Banerjee et. al. [8] proposed a methodology that offers a simplified approach for studying the dynamic behavior of bridge decks, specifically focusing on free vibration and flutter characteristics. A systematic approach is necessary to develop an analytical strategy for investigating aeroelastic instability and natural oscillation of bridge decks. This involves determining each component element needed for the inquiry before commencing the study. The methodology delineated below is a proficient strategy for mitigating the challenges often faced in the realm of intricate numerical matrix operations. The proposed methodology has been used to provide three examples of flutter velocities and frequencies for integrated bridge decks. The aforementioned instances serve as illustrations of the many manifestations of flutter that may arise. Further research in the specific field of investigating the phenomena of scouring, defining the vibration characteristics of integral bridges, analyzing the influence of traffic dynamics on the substructures of integral bridges, and examining the impact of traffic dynamics on integral bridges is deemed essential.

3. OBJECTIVES

The primary objective of this study is to examine the dynamic response of a bridge deck featuring a frame structure to vibrational stress through the utilization of Finite Element

Analysis (FEA). The CAD model of the bridge included I-shaped girders, which were integrated using the ANSYS Design Modeler tool. The Finite Element Analysis (FEA) analysis was performed using the computer program ANSYS.

4. METHODOLOGY

The bridge beam model is generated by using the sketch and shape tools that are accessible inside the ANSYS Design Modeler software. Beneath the horizontal plane, there exists a structural component in the form of a "I" shape.

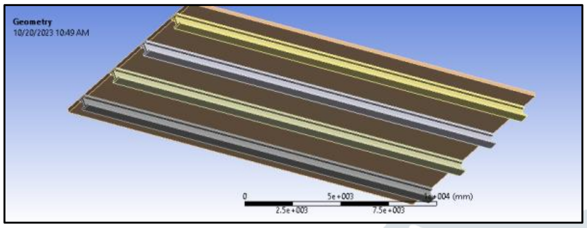

Figure 2: CAD modelling of bridge deck with girder

The geometric model of the bridge deck is then entered into the ANSYS mesher, as seen in Figure 3. A unique model has been developed using hexahedral components. The geometric form has a high degree of spatial uniformity, making it compatible with both brick and hexagonal components. The size function has seen a dynamic transformation, allowing it to efficiently perform at a resolution of four. The functionality of mesh disfeaturing has been activated, and a growth rate of 1.2 has been determined. The discretized model is shown in Figure 4.

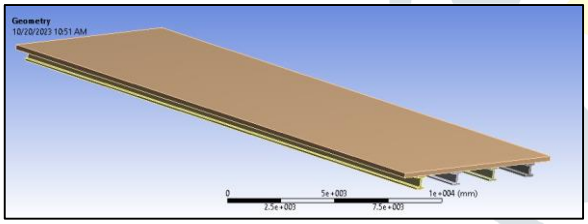

Figure 3: Imported model in mesher

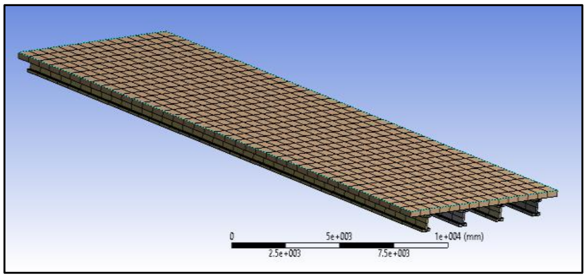

Figure 4: Discretized model in bridge deck with girder

The predetermined design specifications for the bridge have been defined. The research use the sparse matrix technique to develop a solution. The bridge is permanently secured at both ends in a secure manner.

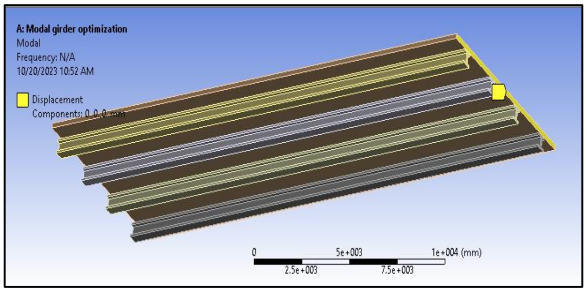

Figure 5: Loads and boundary condition of bridge deck

The primary aim of the simulation is to determine the mode shapes that correlate to different frequencies.

5. RESULTS AND DISCUSSION

The objective of using Finite Element Analysis (FEA) in this study is to ascertain the mode shapes and natural frequencies.

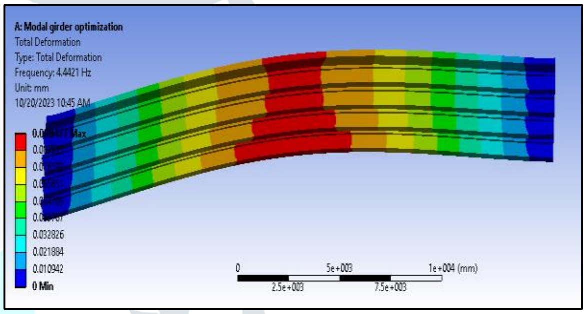

Figure 6: 1^{st} frequency mode shape

The first frequency deformation mode has the most pronounced amount of distortion for positions situated inside the central region. The observed frequency above the previously established threshold. Based on the study results, it has been observed that a distortion above 0.078 mm is present, and the amount of this distortion diminishes with increasing distance from the reference point.

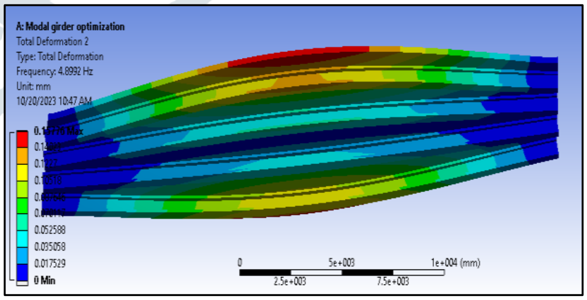

Figure 7: 2^{nd} frequency mode shape

The largest degree of distortion is seen in the areas around the corners, as shown by the contour of the second frequency deformation mode. The visual representation shown in the illustration illustrates this phenomenon. The discernment of distinct frequency types is facilitated by the inclusion of torsional effects. Throughout the duration of the inspection, it was determined that the level of distortion exceeded 0.145 millimeters. The magnitude of this deformation was seen to decrease as one approached the central and supportive portions of the structure. One of the findings that was made pertained to this matter.

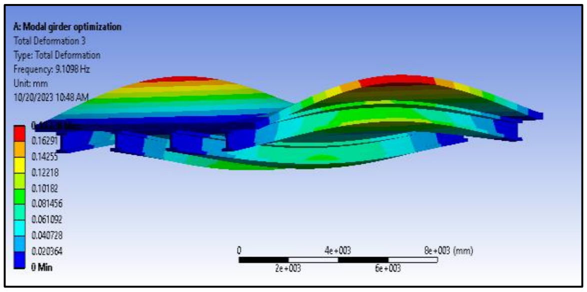

Figure 8: 3rd frequency mode shape

Based on the analysis of the third frequency deformation mode contour, it can be seen that the areas in closest proximity to the corners exhibit the highest degree of distortion. This specific frequency surpasses the predetermined thresholds, which may be seen in the provided documentation. The results of the study revealed a distortion above 0.162 millimeters, accompanied by a consistent decrease in the central and supportive regions.

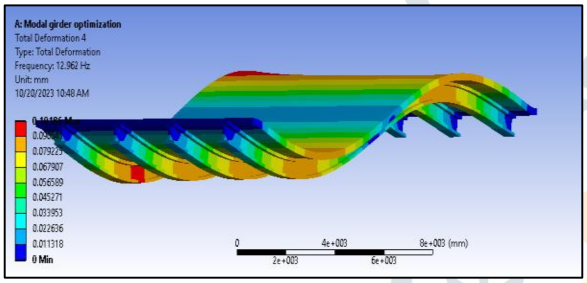

Figure 9: 4th frequency mode shape

The areas near the corners display the highest degree of distortion, as evidenced by the contour of the fourth mode of deformation at a specific frequency. The frequency that has been observed surpasses the predetermined thresholds. The regions that display the most significant deformation, surpassing a threshold of 0.0908mm, are visually indicated by a red hue. As an individual moves closer to the central and sustaining regions, the level of distortion progressively diminishes.

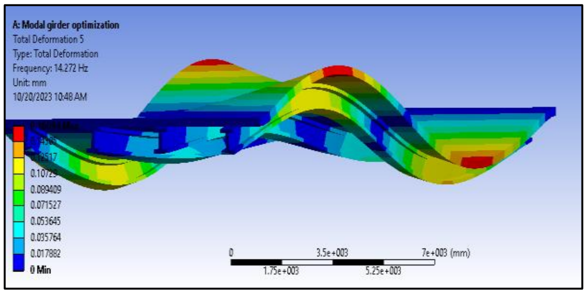

Figure 10: 5th frequency mode shape

Torsional properties manifest in the fifth frequency mode at two discrete locations. The maximum measured deformation was determined to be 0.14mm. The process of creating a graph that enables broad audience engagement entails the utilization of structural elements, such as girders, in conjunction with a platform referred to as a bridge deck. The research findings suggest that the sixth mode form has the highest frequency. The z-axis is a representation of the highest level of interaction. Resonance tends to occur more frequently along the z-axis when subjected to excitation.

5. CONCLUSION

Finite Element Analysis (FEA) may be used to evaluate the vibration characteristics of a bridge deck. The presence of cracks led to the deformation of the bridge deck and a reduction in its natural frequency. The study has shown a mode shape characterized by simultaneous torsional and transverse vibrations. The analysis revealed that, irrespective of the existence of fractures, both designs exhibited the highest mass participation factor along the z-axis.

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