© APR 2026 | IRE Journals | Volume 9 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I10-1716408

System Identification of Truss Bridge Using Phyphox Mobile Application and Analytical Modeling in CSI Bridge

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Abstract- This study presents an ambient vibration–based dynamic assessment of the Ghatte Khola steel truss bridge using a smartphone accelerometer and advanced vibration-based system identification techniques. Acceleration data were collected through the Phyphox mobile application under natural excitations such as vehicular traffic and wind. The recorded responses were analyzed in both time and frequency domains to extract key modal parameters, including natural frequencies, mode shapes, and damping ratios. To ensure accuracy and reliability, multiple system identification methods—Peak Picking (PP), Enhanced Frequency Domain Decomposition (EFDD), Autoregressive Moving Average (ARMA), and Stochastic Subspace Identification (SSI)—were employed, and their results showed strong consistency. A finite element model of the bridge was developed in CSI Bridge to simulate its dynamic behavior, and the numerical results were compared with experimental findings. The comparison revealed good agreement, with natural frequency discrepancies within 10%, indicating that the model effectively represents the actual structural behavior. The estimated damping ratios were approximately 3%, which is consistent with the typical range for steel truss bridges and reflects realistic energy dissipation characteristics. Overall, the findings demonstrate that smartphone-based vibration monitoring, when combined with robust modal identification techniques, provides a reliable, efficient, and cost-effective approach for structural health monitoring. This method is particularly beneficial for resource-limited regions like Nepal, offering a practical solution for bridge assessment and establishing a foundation for future development of low-cost structural monitoring systems.

Keywords: Smartphone Accelerometer, Fast Fourier Transform, System Identification, Finite Element Method

I. INTRODUCTION

Bridges are essential components of civil infrastructure, enabling safe and continuous transportation across physical obstacles while supporting economic development, regional connectivity, and disaster resilience [1]. Among various bridge types, steel truss bridges have been widely used due to their high strength-to-weight ratio, efficient load transfer mechanism, and suitability for medium to long spans. Their extensive use during the late 19th and early 20th centuries marked a significant advancement in bridge engineering, and many of these structures continue to serve as vital links in modern transportation networks [2]. However, many of these bridges are now aging and are increasingly subjected to challenges such as corrosion, fatigue, and increased traffic loads, which may compromise their structural performance and safety [3]. These conditions highlight the necessity for effective structural health monitoring (SHM) systems.

Conventional methods of structural assessment and dynamic testing typically require sophisticated instruments, controlled excitation, and significant financial resources, limiting their application in developing countries like Nepal [4]. In recent years, vibration-based system identification techniques have emerged as reliable tools for evaluating structural behavior using ambient excitations such as traffic and wind. At the same time, rapid advancements in smartphone technology, particularly the integration of built-in accelerometers, have created new opportunities for low-cost and accessible monitoring solutions. The Phyphox mobile application enables real-time acquisition of acceleration data and has shown potential as an alternative to traditional data acquisition systems.

Despite these advancements, the application of smartphone-based vibration measurements for bridge system identification remains limited, particularly in rural and resource-constrained environments [6]. Therefore, this study focuses on the system identification of a steel truss bridge using the Phyphox mobile application and analytical modeling in CSI Bridge. The research aims to extract key dynamic parameters such as natural frequencies, mode shapes, and damping ratios from ambient vibration data and validate them through finite element analysis, providing a cost-effective and practical approach for bridge monitoring in Nepal and similar contexts.

Steel truss bridges in seismic regions like Nepal demand careful dynamic evaluation to ensure structural safety and long-term performance. However, the widespread application of conventional Structural Health Monitoring systems is often constrained by their high cost, technical complexity, and maintenance requirements, leaving many bridges without proper monitoring and their key dynamic properties—such as natural frequencies and damping ratios—largely unknown. The 2023 Jajarkot earthquake brought this issue into sharp focus, underscoring the urgent need for rapid, reliable, and affordable methods to establish structural baselines and assess vulnerability in existing infrastructure. In this context, the present study explores a practical alternative by using Phyphox to capture ambient vibration responses through smartphone-based sensors, taking advantage of everyday technology for engineering-scale measurements. The obtained field data are then systematically compared with high-fidelity analytical models developed in CSI Bridge to evaluate their consistency and reliability. This research ultimately investigates the capability of smartphone-grade MEMS sensors to capture meaningful dynamic behavior and support system identification and model calibration, offering a promising, low-cost, and scalable solution for bridge monitoring in resource-limited environments like Nepal where traditional SHM approaches are often difficult to implement.

Traditional dynamic assessment methods rely on sophisticated sensors, controlled excitation techniques, and expensive data acquisition systems to evaluate structural behavior. In recent years, vibration-based system identification techniques such as Peak Picking (PP), Enhanced Frequency Domain Decomposition (EFDD), Autoregressive Moving Average (ARMA), and Stochastic Subspace Identification (SSI) have been widely used to extract modal parameters of structures. Additionally, finite element modeling tools like CSI Bridge are commonly employed to simulate and validate structural responses [2].

smartphone-based vibration measurements using FFT and Peak Picking can estimate natural frequencies of steel truss bridges, but their study had key limitations. It did not evaluate damping ratios, which are essential for assessing structural health, and relied only on basic frequency-domain methods, making higher-mode identification unreliable under low ambient excitation. Advanced system identification techniques such as EFDD, ARMA, and SSI were not applied, and no finite element model validation was performed. These gaps highlight the need for a more comprehensive smartphone-based system identification framework that includes advanced modal analysis methods and FEM validation, especially for cost-effective bridge monitoring in Nepal [7].

The system identification of the steel truss bridge involved collecting tri-axial acceleration data using a wireless sensor network, organizing the data according to functional locations, and applying frequency domain decomposition to extract modal parameters. The accuracy of the results was further enhanced by correcting the orientation of the sensors [8].

A comprehensive review of smartphone-based sensing technologies for structural health monitoring (SHM) analyzed 147 studies published between 2012 and 2023, demonstrating that smartphone sensors—such as accelerometers and cameras—can effectively capture structural responses and estimate modal parameters with reasonable accuracy. The study highlighted the advantages of smartphones as low-cost, portable, and accessible tools for SHM, while also identifying limitations such as low sensor sensitivity, synchronization issues, and data quality concerns. It further emphasized the need for standardized calibration, improved data validation, and integration of artificial intelligence to enhance reliability in practical applications [9].

The study highlights the importance of ambient vibration testing and modal analysis in evaluating bridge dynamics by identifying the modal parameters of a 1960 steel arch highway bridge. High accuracy was achieved through cross-validation using advanced techniques such as Stochastic Subspace Identification (SSI) and Enhanced Frequency Domain Decomposition (EFDD). A total of 11 vibration modes were identified within the 0–20 Hz frequency range, revealing key insights into the bridge's flexible supports and torsional behavior of the deck. Additionally, the integration of video-motion analysis with conventional testing methods enhanced the accuracy and completeness of structural deformation assessment [10].

II. RESEARCH METHODOLOGY

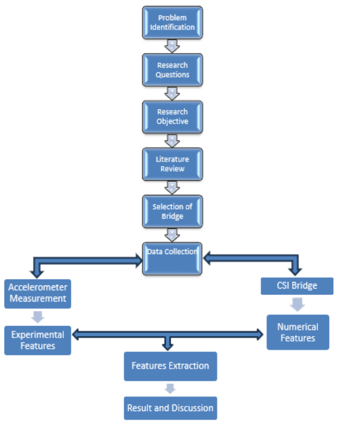

Figure 1 Research Flowchart

2.1 Ambient Vibration Measurements:

Phyphox, developed by the Experimental Physics group at RWTH Aachen University, Germany, is a free iOS and Android application that enables the use of built-in smartphone sensors for scientific and engineering measurements, including acceleration, rotation, and other physical parameters [5]. In this study, Phyphox was used as a low-cost, portable sensing tool for structural health monitoring of a steel truss bridge by utilizing the smartphone's MEMS-based tri-axial accelerometer to capture ambient vibration responses. The application provides real-time data acquisition, customizable sampling settings, and easy export of data in formats such as CSV, making it suitable for field-based structural testing in resource-limited environments. During the experiment, the smartphone was securely placed at different locations on the bridge deck to record dynamic responses, which were then processed using system identification techniques such as Peak Picking, EFDD, and ARMA to extract modal parameters including natural frequencies and damping ratios. These experimental results were subsequently validated against numerical models developed in CSI Bridge, demonstrating that smartphone-based vibration sensing offers a practical, scalable, and cost-effective approach for preliminary structural health assessment and seismic vulnerability evaluation of existing bridges.

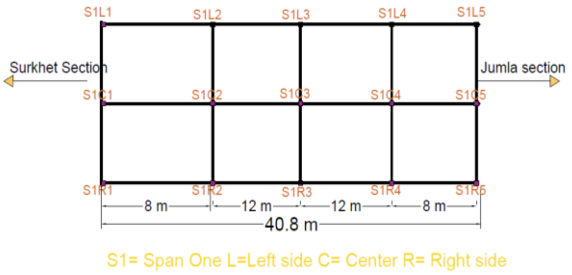

Figure 2 Sensor layout diagram of bridge.

Before field data acquisition, the Phyphox application was installed and configured on a smartphone equipped with a built-in MEMS accelerometer, with sampling parameters set to record continuous acceleration time histories for 10 minutes to ensure sufficient data for reliable modal and frequency-domain analysis. Prior to testing, key geometric properties of the steel truss bridge, including span length and deck configuration, were verified through field measurements to maintain consistency with the analytical model. For ambient vibration monitoring, the smartphone was securely mounted at 15 locations along the bridge spans, selected to capture representative vertical and lateral dynamic responses under normal traffic and environmental loading conditions. A sampling frequency of 200 Hz was adopted to capture even low-amplitude vibrations with adequate resolution, while ensuring the device remained stable throughout the measurement period to maintain data quality and repeatability. After each test, the recorded acceleration data were saved in digital format and transferred via email or messaging applications for further processing and system identification, enabling detailed evaluation of the bridge's dynamic behavior under ambient excitation.

2.2 Finite Element Model of Ghatte Khola Bridge

A three-dimensional finite element model of the steel truss bridge was developed in CSI Bridge 25 to evaluate its dynamic characteristics. The bridge was modeled as a single-span, simply supported structure based on the approved design geometry and member connectivity. Structural steel of Fe345 grade was assigned to all truss elements, with ISMC 400 sections used for the top chord, bottom chord, and end posts, while ISMC 250 sections were used for vertical and diagonal members, all represented as frame elements. The deck slab was modeled as an area element supported by steel cross girders, and appropriate boundary conditions were applied with one end pinned and the other roller support. Mass sources were defined considering self-weight and superimposed dead loads, and eigenvalue modal analysis was performed to determine the natural frequencies and mode shapes, which were later compared with field measurements obtained using the Phyphox application for validation of the bridge's dynamic behavior.

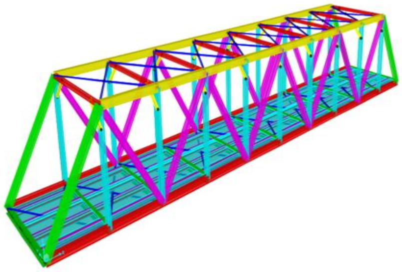

Figure 3 3D Modeling of Ghatte-Khola Truss-Bridge in CSI Bridge

III. FINDINGS

A. Deformed Shape

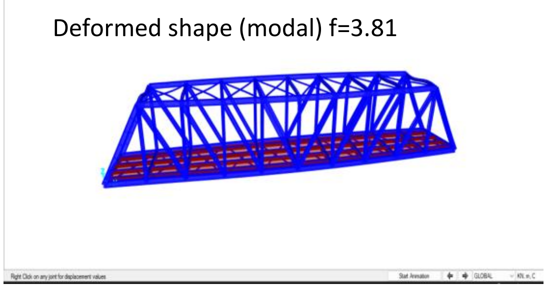

Figure 4 mode 1 deformed shape f=3.81

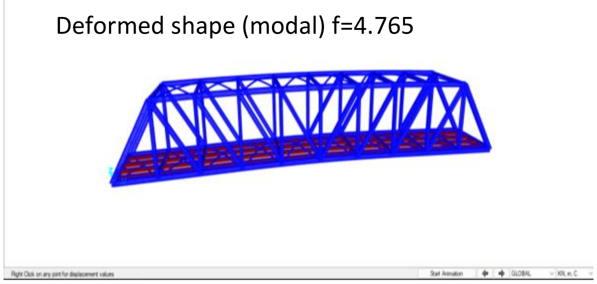

Figure 5 mode 2 deformed shape f=4.765 Hz

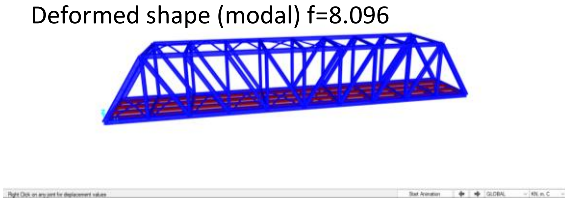

Figure 6 mode 3 deformed shape f=8.096 Hz

B. Plotting of Raw Acceleration Data

The Phyphox application was used to collect ambient vibration data for evaluating the dynamic behavior of the steel truss bridge superstructure, with the span length first verified through field measurements to ensure consistency with design specifications and accurate sensor placement. A smartphone was then configured as a portable sensing device to record acceleration data for 10 minutes at a sampling frequency of 200 Hz, and it was securely mounted at different locations on the bridge deck to capture peak modal responses under normal traffic-induced excitations. After completing the measurements, the recorded acceleration time-history data were saved in digital format and transferred via Gmail or WhatsApp for further processing and analysis.

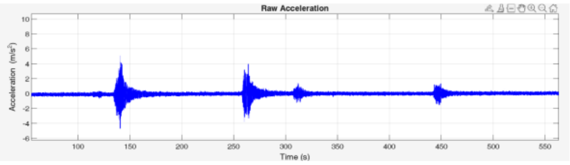

Figure 7 Raw Acceleration vs Time at S1C1

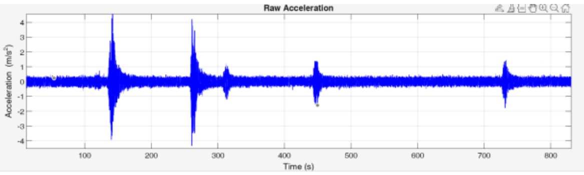

Figure 8 Raw Acceleration vs Time at S1C2

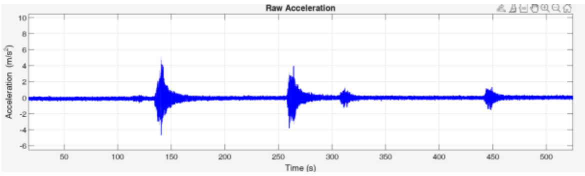

Figure 9 Raw Acceleration vs Time at S1C3

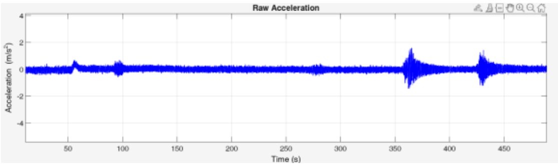

Figure 10 Raw Acceleration vs Time at S1C4

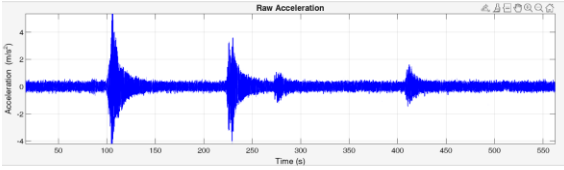

Figure 11 Raw Acceleration vs Time at S1R3

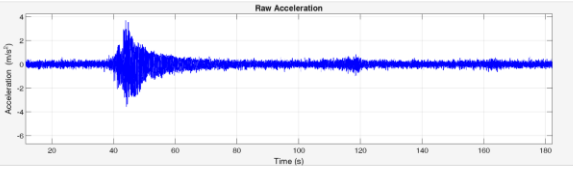

Figure 12 Raw Acceleration vs Time at S1R2

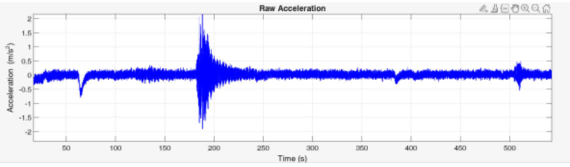

Figure 13 Raw Acceleration vs Time at S1L2

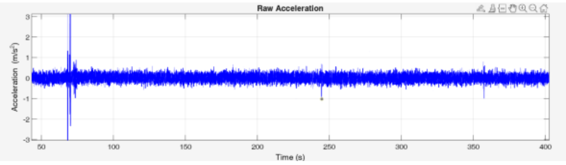

Figure 14 Raw Acceleration vs Time at S1L3

C. Power Spectral Density

The dynamic characteristics of the ghatte khola steel truss bridge were identified using the Peak Picking including EFDD, and ARMA method applied to ambient vibration data. The recorded acceleration signals in the time domain were processed in MATLAB, where they were transformed into the frequency domain using the Fast Fourier Transform (FFT). The corresponding Power Spectral Density (PSD) plots were then analyzed to identify distinct spectral peaks representing the natural frequencies of the structure. Through this analysis, the fundamental frequency along with several higher-order vibration modes was successfully extracted. These identified frequencies reflect key structural properties such as stiffness, mass distribution, and boundary conditions. The resulting modal parameters provide a clear understanding of the bridge's dynamic behavior under ambient loading conditions.

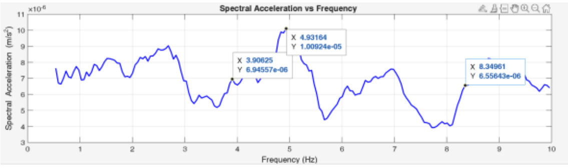

Figure 15 Spectral Acceleration Vs Frequency at S1L1

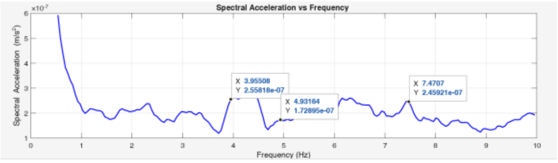

Figure 16 Spectral Acceleration Vs Frequency at S1L2

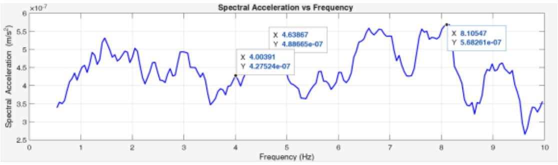

Figure 17 Spectral Acceleration Vs Frequency at S1L3

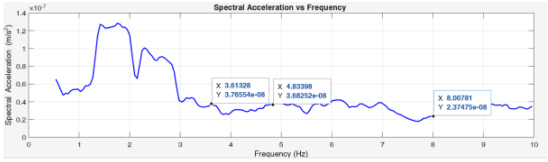

Figure 18 Spectral Acceleration Vs Frequency at S1L4

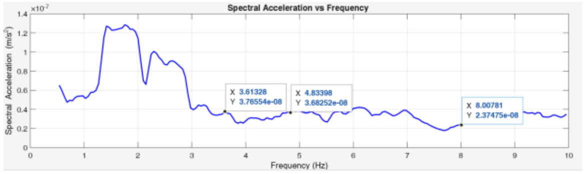

Figure 19 Spectral Acceleration Vs Frequency at S1L5

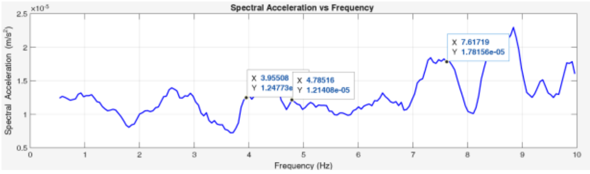

Figure 20 Spectral Acceleration Vs Frequency at S1C1

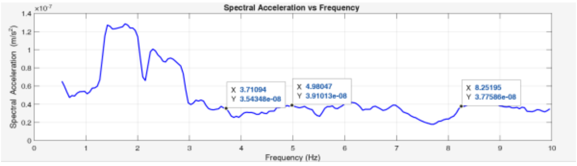

Figure 21 Spectral Acceleration Vs Frequency at S1C2

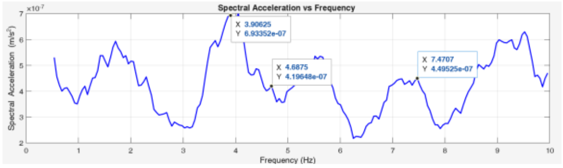

Figure 22 Spectral Acceleration Vs Frequency at S1C3

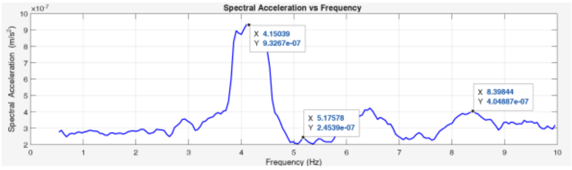

Figure 23 Spectral Acceleration Vs Frequency at 2nd chor S1C4

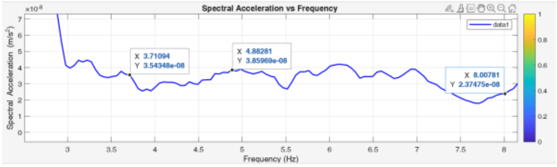

Figure 24 Spectral Acceleration Vs Frequency at S1C5

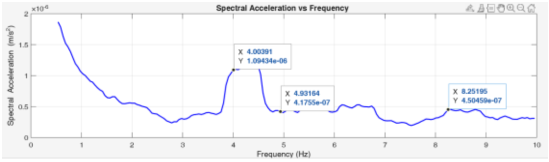

Figure 25 Spectral Acceleration Vs Frequency at S1R1

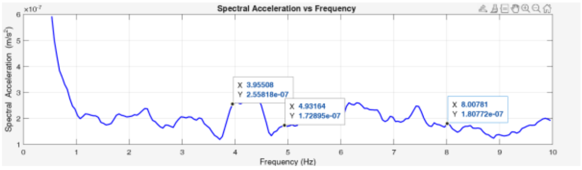

Figure 26 Spectral Acceleration Vs Frequency at S1R2

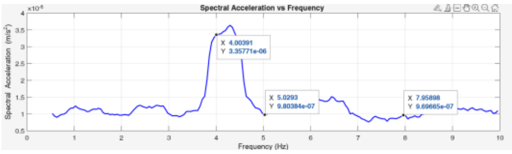

Figure 27 Spectral Acceleration Vs Frequency at S1R3

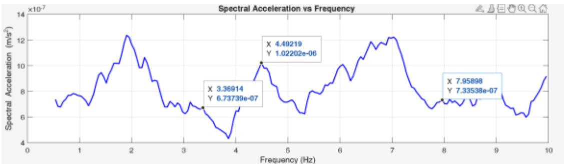

Figure 28 Spectral Acceleration Vs Frequency at S1R4

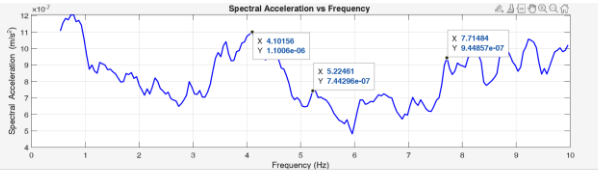

Figure 29 Spectral Acceleration Vs Frequency at S1R5

Table 1 Modal Properties from CSI Bridge

S.N	Modal Frequencies Hz from FEM	Modal No	Response
1	3.81081	1	Horizontal Bending
2	4.76466	2	Verical Bending
3	8.09648	3	Torsion

Table 2 Modal Properties Summary of Experimental result from Smart Phone and Csi Finite Bridge Modeling at L1-L5

S. N	Experimental Results of frequency (Hz) from Smartphone	Modal	Mode

S.N.	Setup of the Smartphone along the span					Frequencies (Hz) from FEM	no.
	S1L1	S1L2	S1L3	S1L4	S1L5		
1	3.90625	3.95508	4.00391	3.61328	3.61328	3.81081	1
2	4.93164	4.93164	4.63867	4.83398	4.83398	4.76466	2
3	8.34961	7.4707	8.10547	8.00781	8.00781	8.09648	3

Table 3 Modal Properties Summary of Experimental result from Smart Phone and Csi Finite Bridge Modeling at C1-C5

S.N	Experimental Results of frequency (Hz) from Smartphone					Modal Frequencies (Hz) from FEM	Mode no.
	Setup of the Smartphone along the span						
	S1C1	S1C2	S1C3	S1C4	S1C5		
1	3.95508	3.71094	3.90625	4.15039	3.71094	3.81081	1
2	4.78516	4.98047	4.6875	5.17578	4.88281	4.76466	2
3	7.61719	8.25195	7.4707	8.39844	8.00781	8.09648	3

Table 4 Modal Properties Summary of Experimental result from Smart Phone and Csi Finite Bridge Modeling at R1-R5

S.N	Experimental Results of frequency (Hz) from Smartphone					Modal Frequencies (Hz) from FEM	Mode no.
	Setup of the Smartphone along the span						
	S1R1	S1R2	S1R3	S1R4	S1R5		
1	4.00391	3.95508	4.00391	3.36914	4.10156	3.81081	1
2	4.93164	4.93164	5.0293	4.49219	5.22461	4.76466	2
3	8.25195	8.00781	7.95898	7.95895	7.71484	8.09648	3

Table 5 Percentage Difference of Experimental and Numerical modeling Frequencies L1-L5

S..No	Percentage difference of closet corresponding values between experimental frequency and modeling frequency (%)					Mode no
	Setup of the Smartphone along the span					
	S1L1	S1L2	S1L3	S1L4	S1L5	
1	2.50 %	3.79 %	5.07 %	-5.18 %	-5.18 %	1
2	3.50 %	3.50 %	-2.64 %	3.47 %	1.45 %	2
3	3.13 %	-7.73 %	0.11 %	-1.10 %	-1.10 %	3

Table 6 Percentage Difference of Experimental and Numerical modeling Frequencies C1-C5

S.N	Percentage difference of closet corresponding values between experimental frequency and modeling frequency (%)					Mode no
	Setup of the Smartphone along the span					
	S1C1	S1C2	S1C3	S1C4	S1C5	
1	3.79%	-2.62%	2.50%	8.91%	-2.62%	1
2	0.43%	4.53%	-1.62%	8.63%	2.48%	2
3	-5.92%	1.92%	-7.73%	3.73%	-1.10%	3

Table 8 Frequency and Damping ratio by PP, EFDD, ARMA, SSI

S. No.	PP	EFDD Freq.	EFDD Damping Ratio (%)	ARMA Freq.	ARMA Damping Ratio (%)	SSI Freq.	SSI Damping Ratio (%)	CSI Bridge (Hz)
1	4.00391	4.1374	1.743	3.8742	1.458	3.9285	2.897	3.81081
2	4.78516	4.8132	1.532	4.7574	1.265	4.8214	2.476	4.76466
3	7.71484	7.7813	1.245	7.4561	0.894	8.457	1.753	8.09648

Table 7 Percentage Difference of Experimental and Numerical modeling Frequencies R1-R5

S.N	Percentage difference of closet corresponding values between experimental frequency and modeling frequency (%)					Mode no
	Setup of the Smartphone along the span					
	S1R1	S1R2	S1R3	S1R4	S1R5	
1	2.50%	3.79%	5.07%	-5.18%	-5.18%	1
2	3.50%	3.50%	-2.64%	3.47%	1.45%	2
3	3.13%	-7.73%	0.11%	-1.10%	-1.10%	3

IV. DISCUSSION

This study evaluates the dynamic behavior of single-span steel truss bridges using ambient vibration measurements and finite element modeling. Vibration data were collected using the Phyphox application at multiple points along the bridge deck under normal operating conditions, ensuring realistic responses from traffic and environmental excitations. The recorded acceleration signals were processed in MATLAB using FFT, and modal parameters were extracted through Peak Picking, EFDD, and ARMA methods. While Peak Picking helped identify dominant frequencies, EFDD and ARMA provided more reliable results, especially for weak or closely spaced modes. The first three modes were consistently identified, representing horizontal bending, vertical bending, and torsional behavior of the bridge. The experimentally obtained natural frequencies were compared with results from CSI Bridge models, showing good agreement with differences within 10%, indicating that the analytical model reasonably captures the structural behavior. The damping ratios obtained from EFDD, ARMA, and SSI were around 3%, reflecting typical energy dissipation in steel truss bridges. Overall, the study demonstrates that combining smartphone-based measurements with advanced signal processing and numerical modeling provides a reliable, cost-effective approach for identifying dynamic characteristics and supports further applications such as seismic assessment and structural performance evaluation.

V. CONCLUSION

This study carried out ambient vibration testing of the Ghatte Khola steel truss bridge using a smartphone accelerometer through the Phyphox application. The bridge response was recorded under normal traffic and wind conditions, and the collected acceleration data were analyzed using Peak Picking, EFDD, ARMA, and SSI methods to extract key modal parameters such as natural frequencies and damping ratios. The identified frequencies from field measurements showed good agreement with results obtained from the analytical model developed in CSI Bridge, with differences within 10%, indicating that the model represents the actual structural behavior reasonably well. The damping ratios were found to be around 3%, which is typical for steel truss bridges and reflects realistic energy dissipation. Overall, the study shows that smartphone-based system identification is a practical, low-cost, and effective approach for bridge monitoring, especially in resource-limited areas like rural Nepal, and it provides a useful base for future work in structural health monitoring.

VI. RECOMMENDATION

Future studies should focus on long-term monitoring with repeated measurements to track changes in dynamic properties over time and detect potential structural deterioration.

ACKNOWLEDGMENT

I wish to express my sincere gratitude to the Graduate School of Engineering at Midwest University for its continuous guidance and unwavering support.

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