Frequency Validation of PCI Bridge Loading from Experiment and Modelling

Fikri Alami[1*] and Siti Nurul Khotimah[1]

[1]Department of Environmental Engineering, Faculty of Engineering, Lampung University, Gedong Meneng, Rajabasa, Bandar Lampung, 35141
*fikri.alami@eng.unila.ac.id

Abstract. Since 1949, precast, prestressed concrete become the preferred composite material for bridge design and construction. Today, it remains the solution for bridge designers across the country. Before operated, a bridge needs to be loading test to ensure it can be function properly and safely. The test can be static and dynamic loaded and the quickest and general parameter to assess the bridge performance is the natural frequency of the bridge. The simplest theory is that linking the frequency against the mass or stiffness of the structure is not fully well estimated. The need of computer model using finite elements can be good solution to validate the experiment data. The results showed here that the 3D shell model was similar compared with experiment result. The difference was only 1.6%. Whereas, the grid-line model and theory were far away from the experiment with the difference between 76% to 85%.

Keywords: Natural Frequency, finite element, experiment.

1 Introduction

New bridge needs to be tested before operated [9]. Using frequency measurement, the general performance of the bridge can be evaluated [2]. The natural frequency of the bridge which related to first mode of vibration was interesting standard in evaluating the condition of the bridge. Engineers are usually getting this value by using simple calculation from general formula [5][6]. However, some engineers would be getting this value by using Finite Element Modelling. Simple equations often produce different results from field testing. This is because the shape of the bridge structure is not simple and also the geometry of the main beam can no longer be considered like an ordinary girder beam. The high beam shape which is mostly used in medium length bridge spans has a different behaviour to the square beam which is predominantly considered a flexible beam.

This study showed that a new PCI Bridge tested in field using frequency measurement such as accelerometer to know the fundamental frequency of the bridge system. FEA models using SAP2000 were conducted with grid lines and three-dimensional shell models. The general formula was used to predict and to compare with experiment data from field.

A. Zakaria et al. (eds.), *Proceedings of the 1st International Conference on Industry Science Technology and Sustainability (IConISTS 2023)*, Advances in Engineering Research 235,
https://doi.org/10.2991/978-94-6463-475-4_28

2 Dynamic Behaviour of Bridge

Bridge is subjected to live load. Live load comes from moving vehicular load, that moves across the bridge as well as normal environmental factors such as changes in temperature, precipitation, and winds. Dynamic load refers to environmental factors that go beyond normal weather conditions, factors such as sudden gusts of wind and earthquakes. A vehicle moving over a bridge causes dynamic effects that indicated by different dynamic parameters like – natural frequency, bridge acceleration and dynamic amplification factor (DAF).

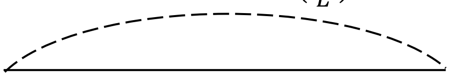
2.1 Bridge Natural Frequency

Natural frequencies are among fundamental properties of bridges in most bridges' unknown [1]. Natural frequency considered to reflect bearing conditions and characterize resonance phenomena under periodic loading are typically identified through acceleration measurement with sensor accelerometer installed on bridges [2][3]. Fundamental frequency, or simply frequency, is sometimes used to refer to the natural frequency or a single frequency with the highest amplitude [4]. The evaluation of natural frequency was used to know the effect of structural damage. The presence of damage or deterioration in a structure causes changes in the natural frequency of the structure. Five percentage damage in structure detection with confidence showed that there is change in natural frequency [4].

2.2 Free Vibration

Free vibration of A structure when a structure is disturbed from its static equilibrium position and allowed to vibrate without any external dynamic excitation [5][6]. Natural frequency refers to the number of vibrations a freely vibrating body produces per second. For simply supported uniform beam, the first vibration modes and frequency are depicted as follows:

$$\emptyset_1(\mathrm{x}) = sin\left(\frac{\pi x}{L}\right)$$



$$\omega_1 = \frac{\pi^2}{L^2}\sqrt{\frac{EI}{m}} \text{ or } f = \frac{\pi}{2.L^2}\sqrt{\frac{EI}{m}} \quad (1)$$

Fig. 1. First vibration modes and frequency of simply supported beam.

where:
f: Natural frequency (for first mode) in Hz
L: length of bridge span (m)
EI: flexural dynamic stiffness (kN.m^2)
m: mass of structure in Kg

Equation (1) shows the first frequency of simply supported beam. In simple bridge system, this equation is theoretically used for predicting natural frequency of simply supported bridge. In some cases, this equation is accurate enough to compare with frequency obtained from test in field. However, with varies shape of cross section beams and type of high beam mostly used in concrete bridge, the natural frequency results obtained from field tests gives large different compared with the equation (1). Therefore, Finite Element Analysis (FEA) model was used to get the mode shape of bridge structure system and their related frequencies. Advanced FEA software's available in design and constructions gives engineers better understanding the whole behaviour of the bridges design.

3 FEA Modelling

Finite Element Analysis (FEA) modelling by using SAP2000 was carried out to implement the bridge model [7]. Two main types element were used for 3D model which are beam and shell. The first model beam was selected as grid line model and shell-element as the second model.

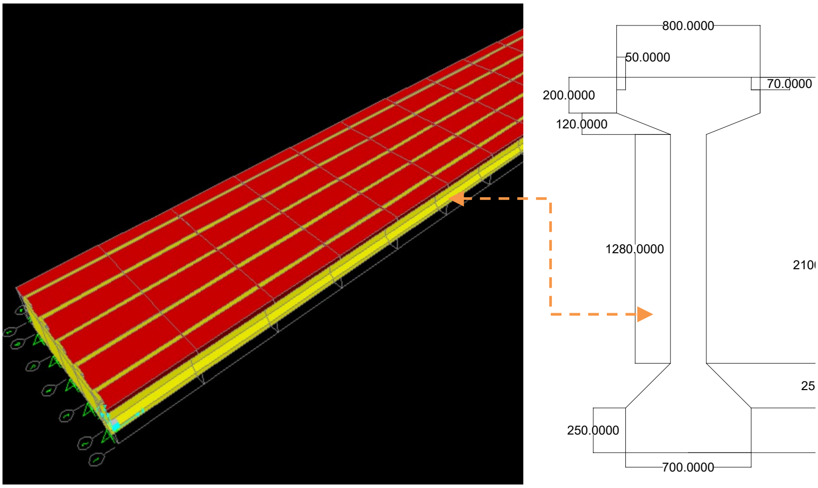


Fig. 2. Left picture is the grid line FEA model and the right picture is PCI Beam cross section.

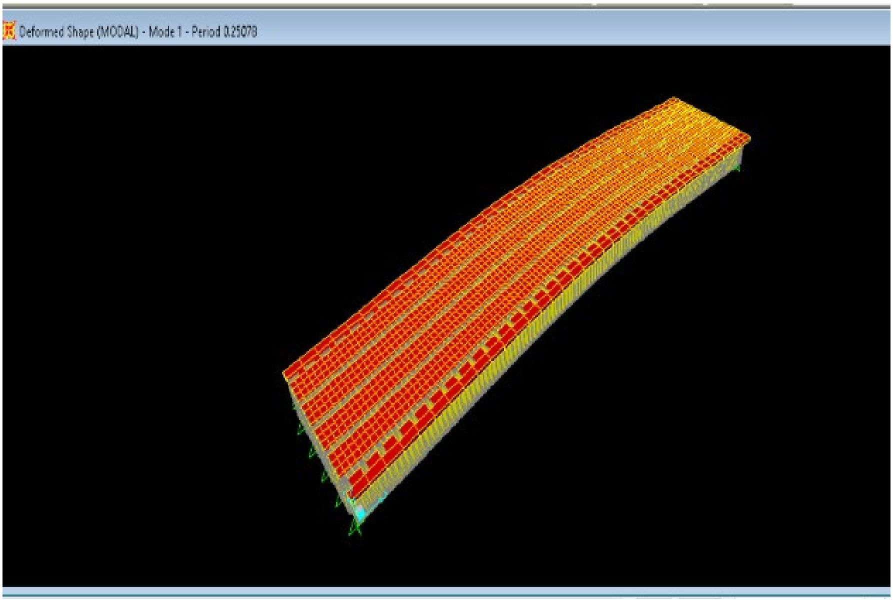


Fig. 3. Vibration first mode of Grid Line Model, T = 0.2507 second, $f_0 = 3.988\ Hz$.

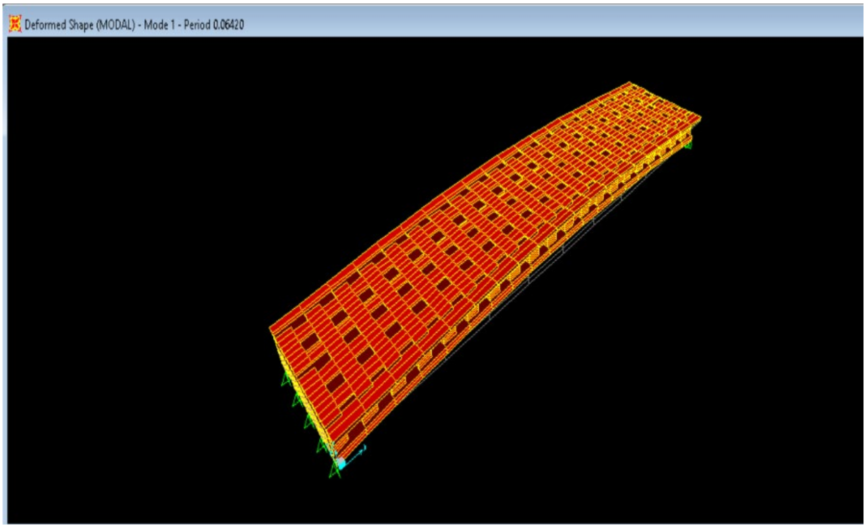


Fig. 4. Vibration first mode of 3D-shell Model, T = 0.064 s, $f_0 = 15.58\ Hz$ (moving load).

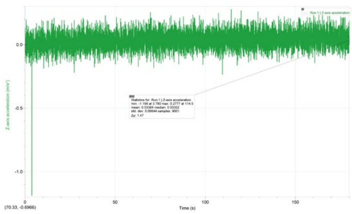
4 Experimental Study

Research location was located at Central Lampung Regency as shown in Fig. 5. The Way Lempuyang Bridge has span of 40m and width of 9m. Five Main support beams used were Pre-stressed Concrete Beam (PCI) with height of 2.1m. Fig. 6 showed that three-axis accelerometer attached to the bottom of the PCI beam at beam number three from the left to measure the vibration of the bridge system. Natural frequency of the Way Lempuyang Bridge was found when the bridge vibrated naturally. In addition, the moving vehicle load by single truck with speed of 20 km/h ran from one support to another support. At the bottom of the PCI girder beam, the 3-axis accelerometer attached and connected to the Labquest 2 data logger. Three accelerations in X,Y and Z directions were recorded against the time. Only acceleration in Z-direction was interesting and evaluated in the study.

Fig. 5. Way Lempuyang Bridge at Central Lampung Regency.

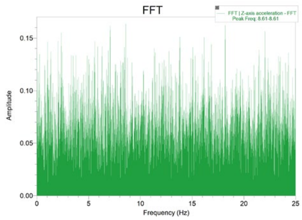
Fig. 6. Vibration data recorded using 3-Axis accelerometer sensor and transferred to LabQuest 2 data logger.

By using Logger Pro software, the accelerometer function and time was transformed to frequency domain using Fast Fourier Transform (FFT) method. FFT is an algorithm to speed up calculations on DFT (Discrete Fourier Transform) to get the magnitude of many frequencies in a signal so that it is faster and more efficient [8][9].



using Method of Fast Fourier Transform (FFT)

Transformed to



TIME DOMAIN DATA:
acceleration function vs time

FREQUENCY DOMAIN:
Frequency of bridge, in (Hz) and amplitude (D) in mm

Fig. 7. Post Processing data obtained from experiment using Logger Pro software.

5 Results and Discussions

Table 1 showed the summary results of the study. Theory and FEA using grid line model showed the lower natural frequency compared with FEA using 3D-Shell model and field experiments. Compared with the field experiments, the Equation (1) and FEA grid line model were different for 85.7% and 76.1% respectively. The FEA 3D-shell model and fields experiments were almost identical. The difference was only 1.6%. The difference mid span deflection between grid line and 3D-shell model was 18.5%. However, these deflections were lower than allowable deflection which was 50mm (=span/800)[10]. Frequency of moving truck with speed of 20 km/h decreased the natural frequency to 15.58Hz or 6.56%. This result showed that the bridge is still in good condition.

Table 1. Summary of Frequency from theory, FEA and experiments

Solution by	Natural Frequency (Hz)	Mid span deflection, mm	Comparison frequency (%)
Equation (1)	2.39		85.7
Grid Line Model	3.98	22	76.1
3D-Shell Model	16.405	27	1.6
Field Experiment	16.67		As baseline
Field Experiment (Moving load)	15.58		6.56

6 Conclusions

Based on theory, numerical and experimental results, It can be concluded as follows:

a) Simple and general equation for determining natural frequency of a bridge must be considered carefully because the beam elements for carrying loads have different shape, dimensions, and span to height ratio varies.

b) The FEA 3D-shell model that represented very close to the real structure to be selected model compared with the simple grid line model. Although the simple model was less time-consuming compared with the 3D-shell model or solid model.

References

1. T. Nagayama, A.P. Reksowardojo, D.Su, T. Mizutani, C.Zhang: Bridge Natural Frequency Estimation by Extracting the Common Vibration Component from the Responses of Two Vehicles. 6th International Conference on Advances in Experimental Structural Engineering, August 1-2, 2015, University of Illinois, Urbana-Champaign, United State (2015)
2. Salawu, O. S.: Detection of structural damage through changes in frequency: a review. Engineering structures, vol. 19 (9), 718-723 (1997)
3. Iman Mohseni, Abdul Khalim Abdul Rashid, Junsunk Kang: A simplified method to estimate the fundamental frequency of skew continuous multicell box-girder bridges. Latin America Journal Solid Structure, https://doi.org/10.1590/S1679-78252014000400006 (2014)
4. J.G.S. da Silva, P.C.G. da S. Vellasco, S.A.L. de Andrade, L.R.O. de Lima, F.P. Figueiredo: Vibration analysis of footbridges due to vertical human loads. Computers and Structures, vol. 85, 1693-1703 (2007)
5. Chopra, Anil K.: Dynamic of Structures: Theory and Applications to Earthquake Engineering, Prentice Hall, ISBN 0-13-855214-2, United State of America (1995)
6. Biggs, J. M.: Introduction to structural dynamics. McGraw-Hill College (1963)
7. CSI Inc.: Getting Started with SAP2000 Linear and Nonlinear Static and Dynamic Analysis of Three-Dimensional Structures. United State of America (2022)
8. Taylor J. L.: The Vibration Analysis Handbook. 2nd Edition. Vibration consultants. ISBN-13: 978-0964051720 (2003)
9. Siringoringo, D. M. and Fujino, Y.: Estimating bridge fundamental frequency from vibration response of instrumented passing vehicle: Analytical and experimental study. Advances in Structural Engineering. 15(3):417434 (2012)
10. AASHTO: AASHTO LRFD Bridge Design Specifications: Customary US Units, 5th Edition, American Association of State Highway and Transportation Officials, Washington DC (2008)