PREDICTION MODEL TO DETERMINE NATURAL FREQUENCY FOR INTEGRAL ABUTMENT BRIDGE: A SIMPLIFIED METHOD

Muhammad Khairil Ibrahim [1, a], Azlan Ab Rahman [1, b], Baderul Hisham Ahmad[1, c], and Fairul Zahri Mohamad Abas [2, d]

[1] Department of Structure, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

[2] Jabatan Kerja Raya, 50582 Kuala Lumpur, Malaysia

[a]imkhairil@gmail.com, [b]azlan@utm.my, [c]baderul@utm.my, [d]fairul@jkr.gov.my

Keywords: Integral Bridge, Natural Frequency, ABAQUS software, Dynamic Characteristics.

Abstract. All bridges can be resonated with certain frequencies known as modal frequency. Different bridges will have their own natural frequencies depending on their types, parameters and configurations. In order to overcome this phenomenon, the engineer should ensure that the natural frequencies of the bridge to be within 1.5 Hz to 4.5 Hz which are the normal vibration induced by the vehicle. Therefore, it is necessary to have a reliable model to predict the natural frequency of an integral bridge when this type of bridge is a commonly being used this day. Whilst most of the previous researches have been focusing on predicting the natural frequencies of other types of bridges, less research can be found for integral bridges. The effect of span length with clay soil is discussed in this paper and the final expression is presented and verified.

Introduction

All bridges experience some form of vibration when induced with dynamic loading. One of the emerging ways in damage detection nowadays is using vibration characteristic. Evolution and current development of monitoring equipment such as a portable signal analyzer, wireless transducer, etc. contribute to the knowledge and research in structural health monitoring [1] and thus allowing engineers to predict and assess the dynamic behaviour of the bridge structures. Among the various parameters, the natural frequency is widely used as a reliable indicator of damage occurring in a structure since it can be readily identified from the model test [2,3]..

Since the last few decades, the dynamic characteristic behavior of bridge structures has drawn extensive interest to the researchers around the globe. The necessity arises to accommodate the design limit when the bridge is subjected to the dynamic load. From as early as the 1920s, bridge engineers has resorted the dynamic effect to the bridge by increasing the static load with the empirical value of impact factors [4]. This simplification was mainly due to the complexity of the dynamic behaviour imparted to the bridge structure. Nowadays, with the advancement of the computational facilities as well as the on-site instrumentations, the study of the dynamic behaviour of bridge structures has been well established.

If damage occurs in a structure, stiffness degradation will take place, which accordingly causes the change of resonant frequencies for various modes. The significant reduction in stiffness can be inferred when the measured resonance frequencies are substantially lower than the baseline values (usually defined as frequencies in the undamaged state) [5,6].

Meanwhile, in Malaysia, the data of vibration of a bridge are hardly to obtain due to a lot of procedures and authorities to be met before getting access to the bridge. The initial natural frequencies of the newly built bridge are difficult to assess unless there is a provision under the construction term and before opening to the public the data of natural frequency are being recorded. If there is a tool or theory to predict the natural frequency of a bridge at service, it may favour the researcher or authority to further use the technique to investigate the structural health of an integral bridge.

Existing Prediction Model

Due to predicting natural frequency of a structure can be tedious and time consuming, there are several researchers has developed the empirical equation to predict the natural frequency of bridges. The Union of Railway [7], proposed that the natural frequency of any bridge can be calculated according to the Eq. (4) as follows:

$$f = \frac{208}{L} \qquad \text{Eq. (4)}$$

This mathematical model is based on a testing which had been conducted on site for 200 railway bridges. The equation is based on the experimental test of railway bridges regardless of the types, material and systems.

On site testing conducted by Cantieni [8] on 213 bridges, suggested that the natural frequency of a bridge can be calculated using the expression as follows:

$$f = 90.6L^{-0.923} \qquad \text{Eq. (5)}$$

This research was extended by Tilly [9] and proposed that the natural frequency of a concrete bridge can be determined from the equation as follows:

$$f = 82L^{-0.9} \qquad \text{Eq. (6)}$$

The above equation is developed from on-site measurement for 874 concrete bridges. Fryba [10] suggested that the natural frequency of a bridge can be calculated based on the equation as follows:

$$f = \frac{133}{L^{0.9}} \qquad \text{Eq. (7)}$$

Preliminary prediction of bridges can be calculated using Eq. (8) as follows [11]:

$$f = \frac{100}{L} \qquad \text{Eq. (8)}$$

Where the fundamental frequency can be varied from shorter span to longer span from 80/L to 120/L. Samaan *et. al* [12] proposed that the natural frequency of a straight composite box girder bridge can be expressed as follows:

$$f = \frac{94}{L} \qquad \text{Eq. (9)}$$

On the other hand, work by Mohseni *et. al* [13] suggested that the value of box girder fundamental frequency should be expressed as follows:

$$f = \frac{70.14}{L} \qquad \text{Eq. (10)}$$

Works by Mohseni was done using computer models of several box girder bridges with different length, number of cells, and skewness. The developed equation has been tabled from the computer generated output.

British Committee through Eurocode [14] suggest that the natural frequency of the bridge should be within the range of:

$$f = \frac{23.58}{L^{0.592}} \qquad \text{Eq. (11)}$$

for bridge span length between 20 m to 100m. While for bridge more than 100 m the natural frequency is:

$$f = \frac{94.76}{L^{0.745}} \qquad \text{Eq. (12)}$$

Integral Bridge

Integral bridge design is an innovation in bridge technology due to its ability to cater for movement and the rotation of the whole structure, compared to the conventional type of bridge where the movement and rotation are being tackled by expansion joint and bearing [15]. Considering the beneficial contribution of integral bridges, most of the design for simple bridges in Malaysia started to embark on this type of construction since 2003. Integral bridge type has been proven to be cost effective in terms of construction as well as its overall lifespan [16].

Integral Abutment Bridges are likely to be adopted as the concept of construction if the bridges are going to use the integral system for single span structures. In Malaysia only, most of the integral bridges are from the integral abutment bridge type [17].

Methodology

This research work was carried out in two phases. The result from the first part of analysis, i.e. verification of the simply supported ABAQUS model as compared to the established model is as follows. The model used for the generation of models is a 15m long simply supported bridge with the a width of 14m , i.e. a common width for Type R5 road in Malaysia.

The generated model from the ABAQUS was then being verified using the above established model to make sure that all the assumptions in the model could be used before it could be further extended to integral bridge.

After the verification has been made, the model is further extended to integral bridge. The factors of length and soil conditions are manipulated to obtain the dynamic characteristics. The soil structure interaction in the model are used published values provided from the of paper by Terzaghi [18] using the equation from Geoguide 1, 1993[19]. This paper provides part of the determining factors to predict the natural frequency of an integral abutment bridge.

Results and Discussion

The results are shown in Figure 1 and the comparison using statistical pair t-test as shown in Table1.

Figure 1: Relationship between Natural Frequency and Length of Simply Supported Bridge

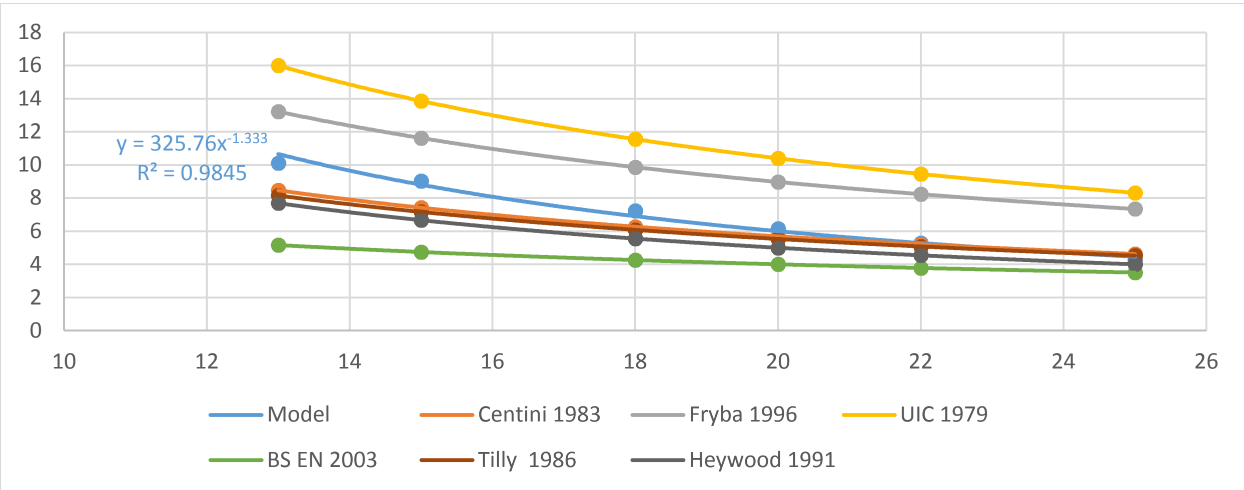
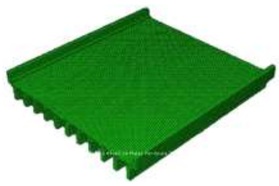


Table 1: Statistical Result for Paired Sample t-test

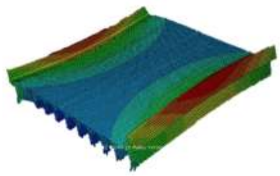
	ABAQUS Model	*UIC 1979*	*Centini 1983*	*Tilly 1986*	*Fryba 1996*	*BS EN 2003*	Heywood 1991
Mean	7.0150	11.5995	6.2821	6.0894	9.8766	4.2440	5.5767
Variance	5.0166	8.2602	2.0601	1.8392	4.8385	0.3829	1.9093
Observations	6	6	6	6	6	6	6
Pearson Correlation		0.9943	0.9950	0.9952	0.9952	0.9974	0.9943
Hypothesized Mean Difference		0	0	0	0	0	0
df		5	5	5	5	5	5
t Stat		-16.2899	2.1782	2.5195	-31.7261	4.1814	4.0118
P(T<=t) two-tail		1.6E-05	0.0813	0.0532	5.8E-07	0.0086	0.0102
t Critical two-tail		2.5706	2.5706	2.5706	2.5706	2.5706	2.5706

From the statistical analysis result in Table 1, there is a significant difference between all established theories if compared to the ABAQUS Model except that of Tilly (1986) at the 95 % confidence level where the value of t for Tilly [8] (DF = 5, p>0.05) is 2.5195. The statistical analysis also shows that all the assumptions during development of model in computer application can be used and represent the actual conditions at site for a simply supported bridge. Furthermore, theory developed by Tilly [8] has been tested for at least 800 concrete bridges.

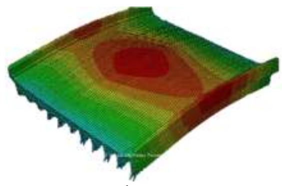
Figure 2(a-f): Natural Frequencies and Mode Shapes of Simply Supported Bridge



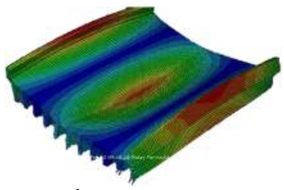
a. Original State



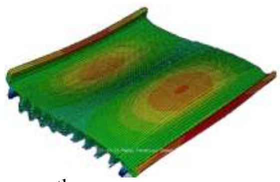
b. 1st Mode : 9.025 Hz



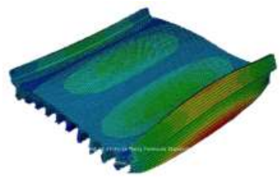
c. 2nd Mode : 9.343 Hz



d. 3rd Mode : 10.197 Hz



e. 4th Mode : 10.955 Hz

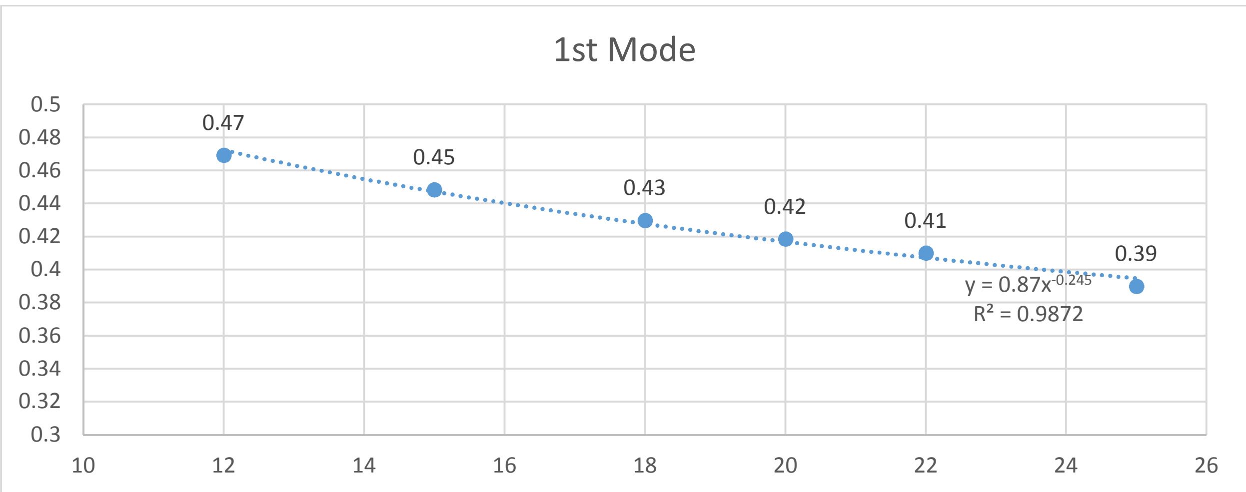


f. 5th Mode : 12.835 Hz

From the Figures 2(a-f), we can see that the bridge does exhibit the basic mode shapes either bending in longitudinal and tranverse, torsion or a combination of both bending and torsion.

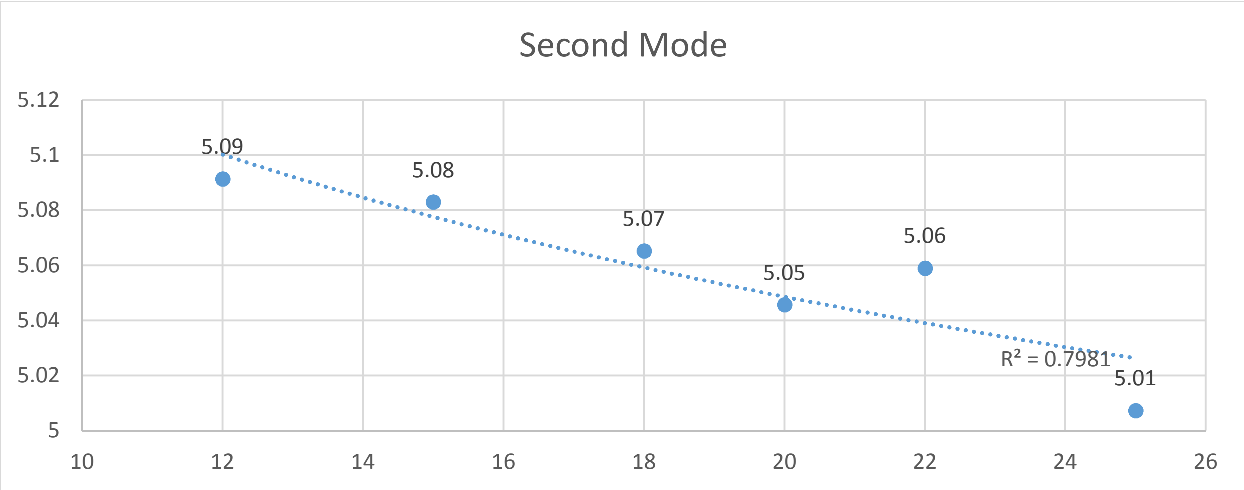
The model is then extended to integral abutment type of bridge with different lengths from 12 meters to 25 meters. This length is chosen due to the uniformity of beam, i.e. JKR T-Beam and it I also the most common length for pre-tensioned beam. The natural frequency of these bridges as recorded. The results from the model as shown in Figure 3 for the first mode and Figure 4 for the second mode.

Figure 3: First Mode of Natural Frequency for Integral Abutment Bridge



From the figure we can see that, the natural frequency of the bridge is decreases, as the span of the bridge gets longer. The value of the natural frequency for the first mode of this type of bridge between 0.39 Hz to 0.47 Hz, which is relatively small compared to other types of bridge between 3.51 Hz to 16.00 Hz.

Figure 4: Second Mode of Natural Frequency for Integral Abutment Bridge



For second mode, the natural frequency of this bridge decreases exponentially with respect to the span length where the value is between 5.09 Hz for 12m-bridge and 5.01 Hz for 25m-bridge.

Conclusion

From the first stage analysis of the model, we can conclude that all the parameters being used in the model can be adopted. Therefore the model can be further extended to integral bridge and analysed using Lanczos Eigen Solver with the minimum number of eigenvalues of 5. The natural frequency can be expressed as:

$$f = \frac{0.87}{L^{0.245}} \quad \text{Eq. (13)}$$

Where:

f = Natural Frequency
L = Span Length

This model is applicable for determining the natural frequency of integral abutment type of bridges with bored pile foundation. Previous studies showed that the integral abutment bridge with H-piles foundation does exhibit higher natural frequency.

Acknowledgement

The authors would like to express deep gratitude and thanks to the Ministry of Education via Universiti Teknologi Malaysia for providing financial grant (R.J130000.7817.4F5340) and opportunity to carry out this research.

References

[1] J.M. Ko, Y.Q. Ni, Technology developments in structural health monitoring of large-scale bridges, Engineering structures 27.12, 2005 1715-1725.

[2] Ewins, D. J., and Gleeson, P.T. A Method for modal indentification of lightly damped strcutures. Journal of Sound and Vibration, 84(1) 1982 57-79

[3] Salawu, O. S., and Williams, C. Bridge assessment using forced-vibration testing. Journal of structural engineering. 1995

[4] Memory, T. J., D. P. Thambiratnam, and G. H. Brameld. "Free vibration analysis of bridges." Engineering Structures 17(10) 1995 705-713

[5] Sanders, D. R., Kim, Y. I., and Stubbs, N. Nondestructive evaluation of damage in composite structures using modal parameters. Experimental Mechanics, 32(3), 1992 240-251.

[6] Schulz, M. J., Pai, P. F., and Abdelnaser, A. S. Frequency response function assignment technique for structural damage identification. In Proceedings-SPIE The International Society For Optical Engineering. SPIE International Society For Optical. 1996. 105-111.

[7] International Union of Railways. Loads to be considered in the design of railway bridges, UIC 1979 776-1.

[8] Cantieni, R. Dynamic load tests on highway bridges in Switzerland-60 years experience of EMPA. 1983.

[9] Tilly, G. P. Dynamic behaviour of concrete structures Report of the RILEM 65-MDB Committee, Materials and Structures. 19.6 1996 460-460.

[10] Frýba, Ladislav, and Ladislav, F. Vibration of solids and structures under moving loads, Thomas Telford. 1972.

[11] Heywood, R., Roberts, W., and Boully, G. Dynamic loading of bridges. Transportation Research Record: Journal of the Transportation Research Board, 1770, 2001 58-66.

[12] Samaan, M., Kennedy, J. B., and Sennah, K. Impact factors for curved continuous composite multiple-box girder bridges. *Journal of Bridge Engineering*, *12*(1), 2007 80-88.

[13] Mohseni, I., Rashid, A. K. A., and Kang, J. A simplified method to estimate the fundamental frequency of skew continuous multicell box-girder bridges. Latin American Journal of Solids and Structures, 11(4), 2014 649-658.

[14] British Standards Institution. Eurocode 1: Actions on structures. Part 2: Traffic loads on bridges: British standard. London: BSi. 2003.

[15] Ahn, J. H., Yoon, J. H., Kim, J. H., and Kim, S. H. Evaluation on the behavior of abutment–pile connection in integral abutment bridge. Journal of Constructional Steel Research, 67(7), 2011 1134-1148.

[16] Dicleli, Murat. A rational design approach for prestressed-concrete-girder integral bridges, Engineering Structures 22.3 2000 230-245.

[17] Bridge Management System. Jabatan Kerja Raya, Malaysia. 2012

[18] Terzaghi, and SISK, G. Integral bridge design: derivation of the spring constant for modelling the soil-structure interaction. In Austroads Bridge Conference, 7th, 2009, Auckland, New Zealand. 2009.

[19] Engineering Development Dept. Guide To Retaining Wall Design. 1993