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Finite Element Analyses on Dynamic Behavior of Railway Bridge Due To High Speed Train

Mehrdad Bisadi, S.A. Osman and Shahrizan Baharom

Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Selangor, Malaysia

Abstract: This paper presents an investigation of dynamic behavior of an existing railway bridge in Sweden, due to high speed train. In this study, three different finite element (FE) models (single-span, three-span and full bridge) are developed and compared with the corresponding results published by other researchers. The simulation results show good agreement with previous study from G. Kaliyaperumal et al. (2011). Initially, eigenvalue analyses of developed single-span FE models with different skew angles are carried out to obtain the bridge periods and the results are compared to each other. Following eigenvalue analyses, moving load analyses are carried out on the full bridge to obtain the bridge acceleration. Different geometric parameters such as Young's modulus and damping coefficient of the bridge are considered and the effects of them are shown in this analytical study.

Key words: Railway Bridge, Eigenvalue analysis, Skew angle, Frequency, Moving load-analysis, Vertical acceleration.

INTRODUCTION

During the last few decades, the interests in dynamic analysis of railway bridges have increased considerably due to the demand of high speed trains. Under train passage, the bridges are subjected to the vertical and horizontal forces in which would influence on the dynamic behavior of the bridges (L. Frýba, 1996).

In case of bridge design, the dynamic effects which are introduced by dynamic amplification factors are employed. Dynamic amplification factor states that how many times the static effects have to be amplified to cover the dynamic effects and is usually a function of natural frequencies or span length of bridge. As the dynamic behavior of bridges depend on more parameters such as damping, stiffness, axial load and speed of train as well, using this traditional method results an expensive and unsafe design. Thus dynamic analysis which considers all the depended parameters are required (Lena Björklund, 2004).

Skew angle and vertical acceleration of the bridge are two important factors which influence on the dynamic behavior of bridge. Skew angle is defined as the angle between the normal to the centerline of the bridge. Bridges with skew angle less than 20° can be designed as a straight bridge and more than 45° are not recommended (Ibrahim S. I. Harba, 2011; X.H. He et al., 2012; AASHTO, 2003). Acceleration influences on the stability of bridge. In high speed the bridge acceleration can reach unacceptable quantities and decrease the stability of superstructure. In case of unballasted bridge, it is important to ensure that the maximum accelerations of the bridge remain below 0.5g (Ibrahim S. I. Harba, 2011).

This paper focuses on the effect of skew angle and geometric parameters on the dynamic behavior of bridge. A number of FE models of the bridge are developed. Initially, eigenvalue analyses are carried out on the single-span FE models with different skew angles and the results are compared to each other. This is followed by moving load analyses of the full bridge under the passage of train. Different geometric parameters, Young's modulus and damping coefficient, are considered and the effects of them on the bridge acceleration are shown in this study.

Description of Bridge:

The case study of railway bridge is located between the Central Station and the South Station, over the Söderström stream, in Stockholm Sweden and was built in mid-1950s. The Söderström Bridge in which appears to be one of the most important bridge in Sweden is a continuous steel girder skew bridge with six spans. The north and south part of the bridge are 27 and 26.9 meters respectively and the inner spans are 33.7 meters as shown in Fig.1. The superstructure consists of two main girders of 3000 mm deep and 600 mm wide. The cross beams have an orientation with the main girder at a skew angle of 80° and four stringers are provided in between the cross beams. Bracings are provided at two levels, one at the top to connect the rails and other at the bottom to connect the cross beams. Detail information of the bridge can be found in (G. Kaliyaperumal et al., 2011; John Leandera et al., 2010).

Corresponding Author: Mehrdad Bisadi, Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Selangor, Malaysia.
E-mail: me.bisadi@yahoo.com

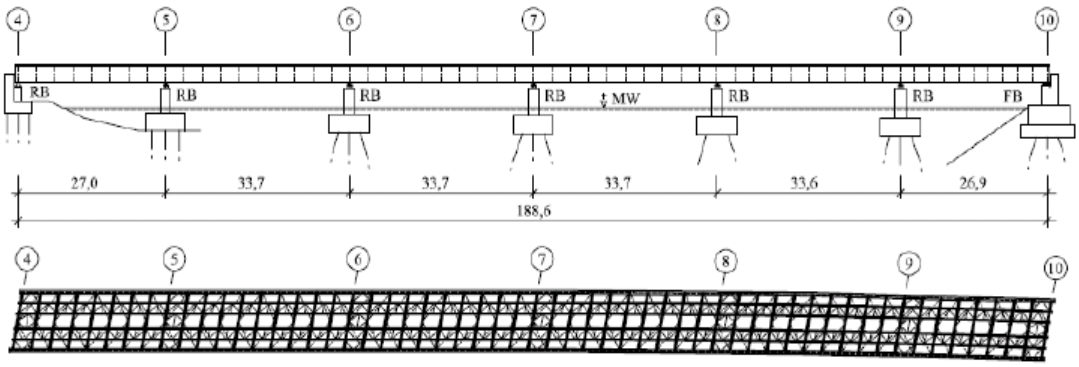

Fig. 1: Elevation and plan view of the bridge (dimensions are in meter).

Finite Element Analysis:

In this paper, a single-span three-span and six-span FE models of bridge were developed using FE software LUSAS (LUSAS- Finite Element Analysis, Version 14). The girders, stringers and cross beams of the bridge were simulated as the shell elements with quadratic mesh (QTS8). Bracings of the bridge were simulated as the bar elements with 3 dimensional mesh (BTS3). The models were simulated with pinned supports and quadratic mesh (QTS8). Mild steel is chosen as the bridge material and pinned supports were used for all the FE models. Fig.2 shows the FE models.

In order to carry out moving load analysis, the full bridge was loaded with high speed load model (HSLM)_A10 under the constant speeds of 50 to 330 km/h and axle loads of the train (210 KN) were applied directly to the top flange of the stringers. Additional details regarding the train can be found in (BS EN 1991–2).

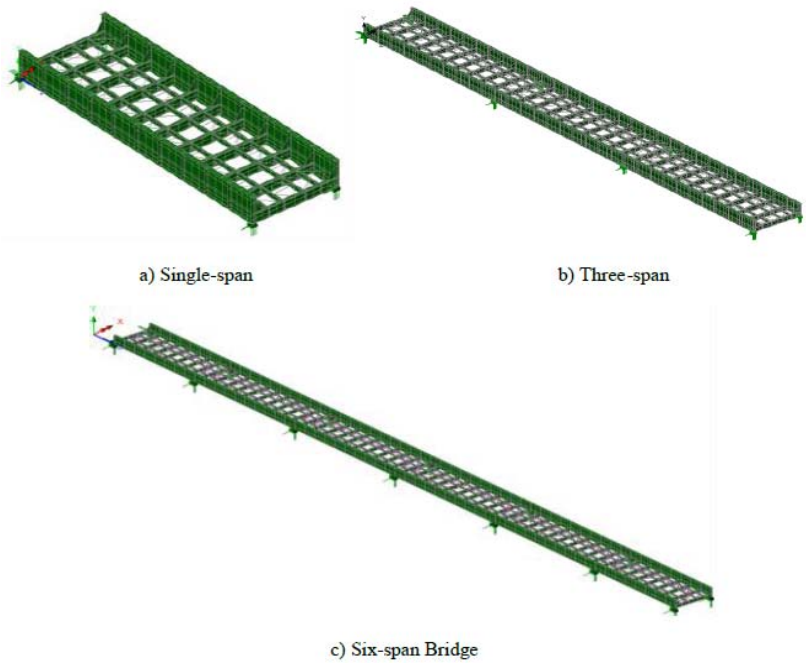

Fig. 2: Finite element models of bridge.

Eigenvalue Analysis:

In order to determine the fundamental dynamic properties of the railway bridge with moving load, therefore eigenvalue analyses were carried out. The obtained results of bridge periods were compared with Eurocode and the previous study (G. Kaliyaperumal et al., 2011) to ensure the capability of the modeling procedure. The Equation of motion for a multiple degree of freedom undamped structural system is represented as follows:

$$[M]\{\ddot{u}\}+[K]\{u\}=\{F(t)\} \tag{1}$$

Where [M] is mass matrix, [K] is stiffness matrix, $\{\ddot{u}\}$ is acceleration vector, $\{u\}$ displacement vector and {F (t)} is the external force vector (Ray W. Clough; Joseph Penzien, 1993). Under free vibration analyses, the natural frequencies and the mode shapes of a multiple degree of freedom system are the solutions of the eigenvalue problem.

$$\left[[K]-w^2[M]\right]\{\Phi\}=0 \tag{2}$$

Where w is the angular natural frequency and $\{\Phi\}$ is the mode shape of the structure for the corresponding natural frequency. From Eq. (2), the eigenvalues can be found by making the determinant equal to zero (G. Kaliyaperumal et al., 2011; Chopra, A.k, 2006).

It has been suggested that first natural frequency of railway bridges of all type and materials should lie between the upper and lower limit which is given by equation 3 and 4 suggested by design codes (Eurocode 2003; UIC 776–1, 1979).

Lower limit (for span 20 < L ≤ 100 m)

$$f_1 = 23.58 \times l^{-0.592} \tag{3}$$

Upper limit

$$f_1 = 94.76 \times l^{-0.74} \tag{4}$$

Accuracy of the Finite Element Modeling:

It is important to establish the accuracy of the finite element modeling of the railway bridge before further analyses can be carried out. The eigenvalue analyses were carried out based on the convergence study. The results were compared with previous study which was carried out with FE software ABAQUS by (G. Kaliyaperumal et al., 2011). Table 1 presents the comparison of the periods of FE models in the first three modes. As shown in Table 1, it can be seen that there is a good agreement of the results although in the previous study the eigenvalue analyses were carried out by different software.

Table 1: Comparison of periods.

Software	LUSAS			ABAQUS		
No of span	Single-span	Three-span	Full bridge	Single-span	Three-span	Full bridge
T_1(s)	0.180	0.176	0.201	0.182	0.181	0.208
T_2(s)	0.134	0.174	0.188	0.156	0.161	0.164
T_3(s)	0.106	0.170	0.16	0.110	0.146	0.145

Table 2 shows the comparison of periods in the first mode which is obtained from the FE eigenvalue analyses with the Equation 3 and 4 as presented in Section 4. It can be seen that the first natural frequencies obtained from the FE models lies within upper and lower limits suggested by Equation 3 and 4. It demonstrates a good prediction of the moving load analysis for the full bridge.

Table 2: Comparison of the first period of FE models with available empirical formulae.

No. of span	Single-span	Three-span	Full bridge	Equation (3)	Equation (4)
T_1(s)	0.180	0.176	0.201	0.340	0.147

RESULTS AND DISCUSSIONS

Effect of Different Skew Angle:

In order to study the true effect of skew angle on the natural frequencies, four different skew angles of single span of the railway bridge with same material properties and simply support boundary condition have

been considered. The considered skew angles are 0°, 10°, 30°, and 40° respectively, as shown in Fig.3. Eigenvalue analyses were carried out on the developed FE models and the results were tabulated in Table 3.

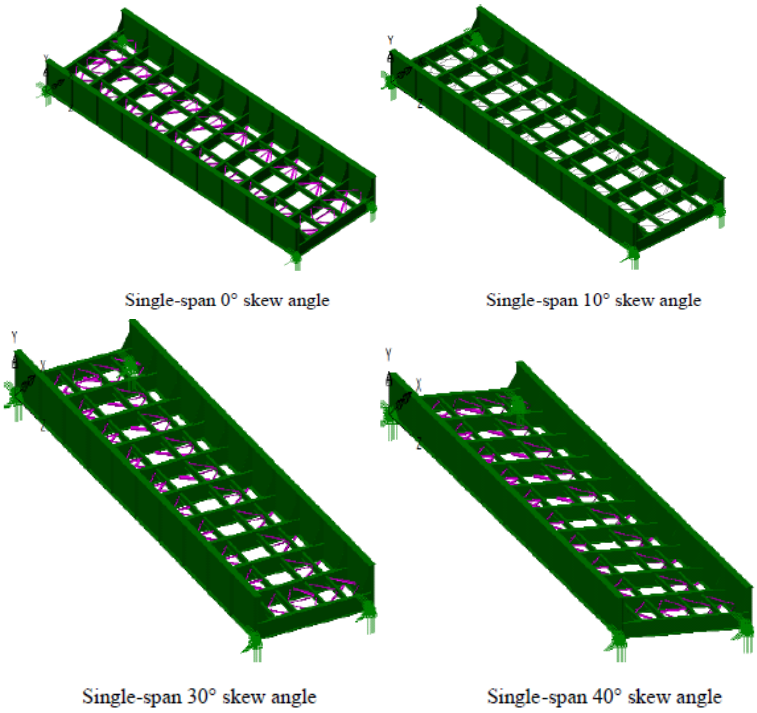

Fig. 3: Single-span skewed FE models.

Table 3 shows the first two modes of frequencies for different skew angles of the single span bridges. It can be seen that, the first natural frequency decreased by 60% when the skew angle changed from 0° to 40°. The results of Table 3 are shown by graph as well, as in Fig 4. The obtained results have been compared with the previous study (Wong et al. 2010). Both studies show the same results of decreasing natural frequencies due to the rising skew angles of the bridge.

Table 3: Natural frequencies for different skew angles of the bridge.

No. of span	Single Span			
Skew angle	0°	10°	30°	40°
f_1	6.87	5.53	4.88	4.287
f_2	7.74	7.45	7.45	6.204

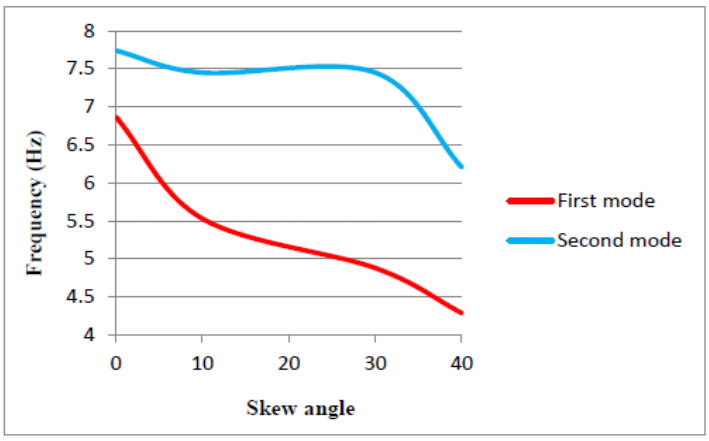

Fig. 4: Natural frequencies for different skew angles of the bridge.

Figure 5 shows the first modes shapes obtained from eigenvalue analyses for the skewed FE models. It can be seen that the first mode shape for straight simulated model is lateral bending and for the FE model with 10° skew angle is vertical bending. As shown in the Figure, the first mode shape for both 30° and 40° skewed bridge is vertical bending which is similar to each other.

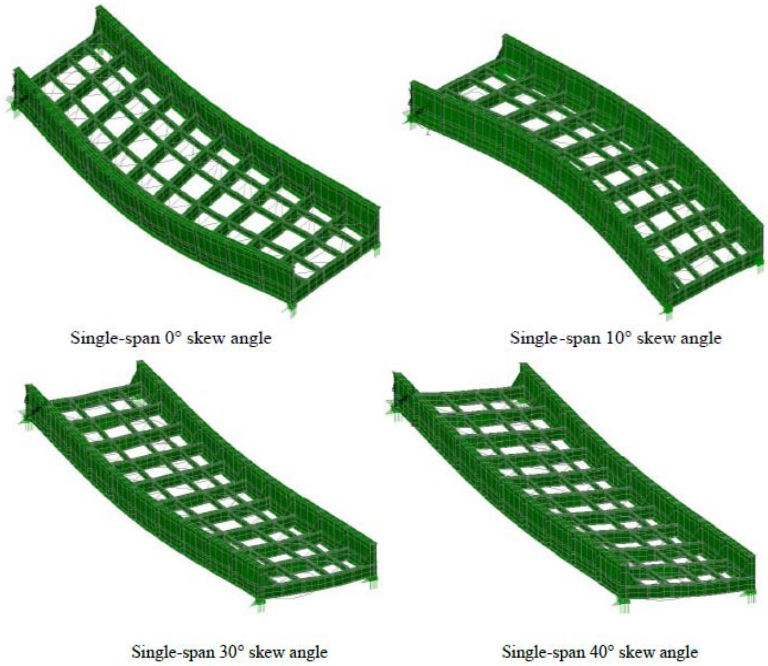

Fig. 5: First mode shape of single-span skewed FE models

Moving Load Analysis:

In this part, the full span bridge FE model was carried out for moving load analysis in order to obtain the vertical acceleration of bridge. Total of 30 modes were used in the analysis and the effect of coefficient of damping and Young's modulus on the vertical bridge acceleration has been investigated. The full-span bridge FE model was subjected to HSLM-A10 train with constant speeds from 50 km/h to 330 km/h. Loading was initiated from the beginning of span 5–6 and the train cross the whole bridge. The effect of train passage was investigated at point S1 at location C of span 7-8, as shown in Fig.6.

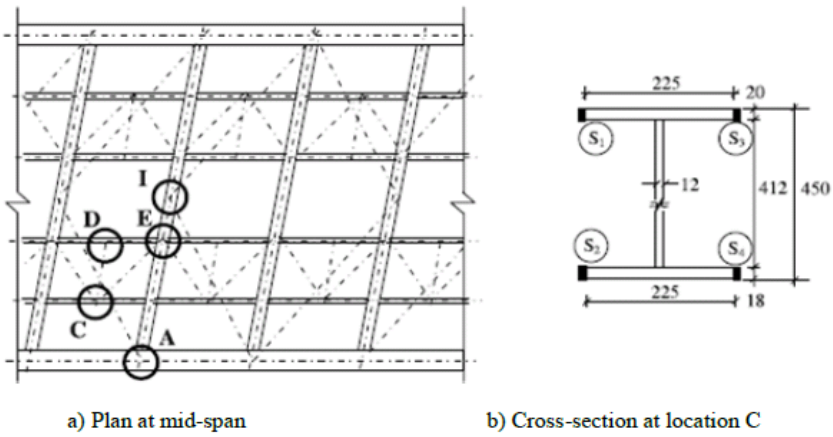

Fig. 6: Details of investigated locations at bridge span 7–8.

Effect of Different Young's Modulus:

Figure 7 shows the comparison of vertical acceleration of the bridge obtained from moving load analysis at point S1 of location C, under constant velocities of HSLAM-A10 train. The analyses were carried out by considering the different Young's modulus of 200 MPa, 250 MPa and 300 MPa respectively. As the Young

modulus is a material property that describes its stiffness, it can be seen that the higher stiffness of the bridge gives the peak resonance value at higher speed than a lower stiffness.

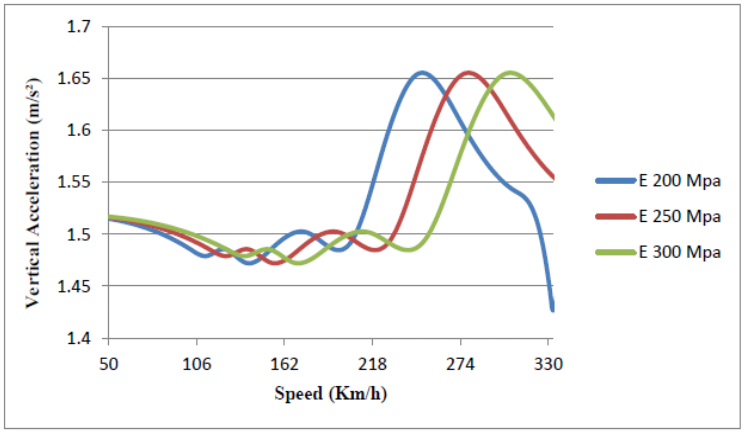

Fig. 7: Absolute Vertical Acceleration of the bridge at point S1 location C, with different Young's modulus.

Effect of Different Damping:

In order to obtain the influence of damping on vertical acceleration of the bridge, the moving load analyses were carried out on the FE model at point S1 of location C. Different values of damping of 0 %, 1 %, 2.5%, 5 %, 10%, 15% and 20% of the bridge have been considered and the results are shown in the Figure 8. It can be clearly seen that the quantities of vertical acceleration decreased due to increasing the coefficient of damping. With regard to having same curves for damping ratio of 15% and 20%, it is shown that the damping with 15% and above do not influence the vertical acceleration of the bridge.

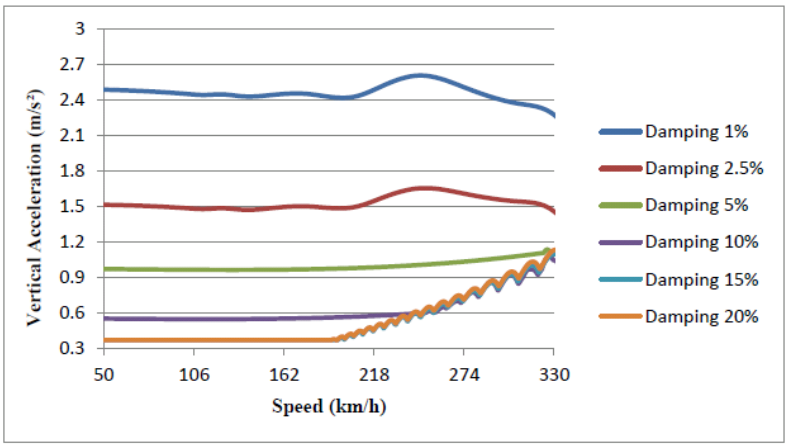

Fig. 8: Absolute Vertical Acceleration of the bridge at point S1 location C, with different coefficient of damping.

Conclusion:

Eigenvalue analyses were carried out on a number of different FE models by LUSAS software and the results were compared with the previous study which was carried out by ABAQUS software. It was found that the proposed two dimensional finite elements modeling using the LUSAS software is sufficiently accurate in predicting the behavior of the case study.

Single-span FE models with different skew angles were carried out for eigenvalue analysis and the results were compared with straight bridges to clearly understand the effect of skew angle on the bridge frequencies. It was shown that natural frequencies dropped due to increasing the skew angles of railway bridges.

In order to obtain the bridge acceleration, moving load analyses were carried out on the full bridge subjected to moving train. Various quantities of damping and Young's modulus were used in the analyses. It was found that damping and Young's modulus play an important role in the dynamic behavior of bridge.

REFERENCES

AASHTO, 2003. Standard specifications for highway bridges, Washington, D.C.

BS EN 1991–2. Eurocode 1: actions on structures-part 2: traffic loads on bridges. UK (London): British Standard Institution, 2003.

Chopra, A.K., 2006. Dynamic of structures, Third Edition, New Jersey: Prentice Hall.

Fry`ba, L., 1996. Dynamics of Railway Bridges, London: Thomas Telford, ISBN 0-7277 2044-9.

He, X.H., X.W. Sheng, A. Scanlon, D.G. Linzell, X.D. Yu, 2012. "Skewed concrete box girder bridge static and dynamic testing and analysis", Journal of Engineering Structures, 39: 38-49.

Ibrahim, S.I. Harba, 2011. "Effect of skew angle on behavior of simply supported R.C.T-beam bridge decks", Journal of Engineering and Applied Science, 6(8): 1819-6608.

John Leandera, Andreas Andersson a,b, Raid Karoumia, 2010. "Monitoring and enhanced fatigue evaluation of a steel railway bridge", Journal of Engineering Structures, 32(3): 854-863.

Kaliyaperumal, G., B. Imam, T. Righiniotis, 2011. "Advanced dynamic finite element analysis of a skew steel railway bridge", Journal of Engineering Structures, 33(1): 181-190.

Lena Björklund, 2004. Dynamic analysis of a railway bridge subjected to high speed trains, M.S. Thesis, Royal Institute of Technology, Stockholm.

LUSAS-Finite Element Analysis, User Manual, Version 14.

Ray W. Clough, Joseph Penzien, 1993. Dynamic of structures, Second Edition, Singapore: McGraw Hill.

UIC 776–1, 1979. R. Loads to be considered in the design of railway bridges, International Union of Railways.

Wong, M.Y., 2010. "Free vibration characteristics of horizontal composite plate girder bridge", Journal of Steel and Composite Structures, 10(4): 297-315.