



MOVING LOAD ANALYSIS ON SKEWED RAILWAY BRIDGE

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ABSTRACT

Recent developments in the field of high speed rail have heightened the need for improving of railway bridges under the passage of high speed trains. However, little attention has been paid to influence of significant parameters playing a key role in dynamic behavior of such bridges. This paper seeks to fill such a gap by carrying out finite element (FE) analysis on an existing railway bridge. For this purpose, the railway bridge is simulated by finite element software, LUSAS. Eigen value and moving load analyses are carried out to obtain the natural frequencies as well as the displacement of the simulated model, respectively, under the axial load of train passage. Different values of damping ratios and Young's modulus are employed in these analyses and the effects of them are demonstrated in this study.

Keywords: Moving load analysis, Free vibration, Skew angle, Natural frequency.

INTRODUCTION

The past decades have seen the rapid development of high speed railways in many developed and developing countries. France was the first country achieved operations at 300 km/h in 1989 and this has been followed by a long interval until 2013 when the speed has reached over 380 km/h in China (Ryo, 2005). However, the major problem with these rapid changes is the dynamic behavior of the railway bridges under the axial loads of such train passages.

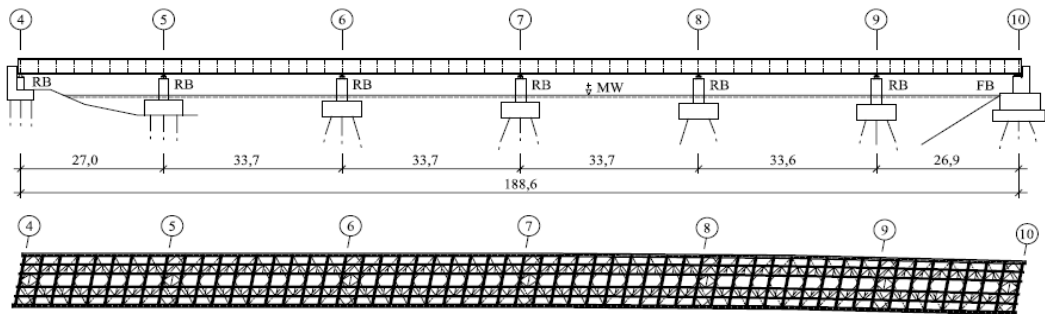
In order to tackle such an issue, engineers need to pay attention to the effect of parameters influencing on the dynamic behavior of the bridge. Skew angle, as the angle between the normal to the centerline of the bridge, as well as Young's modulus are two significant parameters playing an important role in the dynamic behavior of the railway bridges (AASHTO, 2003; Ibrahim and

Harba, 2011; He *et al.*, 2012). This paper focuses on such parameters. For this purpose, the steel structure of an existing bridge, Söderström Bridge, was simulated by FE program and the Eigen value analysis are carried out aimed at obtaining the natural frequencies. This is followed by carrying out the moving load analysis to obtain the displacement of the unballasted bridge. Different values of Young's modulus are employed in both analyses to illustrate the significant effect of such a parameter. Finally, the obtained results are compared to each other.

The Bridge

The railway bridge, considered as a case study, is located in Stockholm and connects northern and southern Sweden. This railway bridge is of six spans with the average length of 33 meters (see Fig.1). The superstructure consists of two continues steel girders and the cross beams with an orientation on the main girder at a skew angle of 80° with stringers provided between them. Two level of bracings, at the top and bottom, are provided to connect the cross beams and the girders respectively. Specific details of the bridge can be found in (John *et al.*, 2010; Kaliyaperumal *et al.*, 2011; MehrdadBisadi *et al.*, 2012).

Figure-1.Elevation and plan view of the bridge (dimensions are in meter)



Finite Element Modelling of Steel Bridge

In this study, the FE model of the railway bridge was developed using the finite element program LUSAS. The selected bridge was modeled as an unballasted bridge and the quadratic mesh (QTS8) was used for the all the components, except the bracings simulated as a bar element. In addition, the mild steel was considered as the material and the simply support was assumed as a boundary condition for the simulated model (Fig. 2)

Figure-2. Simulated model of bridge



Free Vibration

Natural frequencies of an undamped mechanical system which vibrates freely without further force interaction can be calculated based on the equation of motion which 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 and Joseph, 1993; Chopra, 2006). The natural frequency in radian per second is obtained by the given equation:

$$w = \sqrt{\frac{k}{m}} \tag{2}$$

Where w is the natural frequency, m is mass and k is stiffness (Boris and Gergely, 2012). The natural frequency in cycle per second is given by:

$$f = w/2\pi \tag{3}$$

Consequently, the natural frequency can be expressed into more familiar units:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \tag{4}$$

Verification of the Finite Element Modeling

Eigen value analysis was carried on the FE model to obtain the natural frequencies of bridge. This was followed by comparing the obtained results with previous study, carried out by FE program ABAQUS by other researcher (Kaliyaperumal *et al.*, 2011) in order to establish the accuracy of simulated mode. Table 1 shows a comparison of the bridge period in the first three modes of such analyses.

Table-1. Bridge periods	
Software	LUSAS ABAQUS
T_1 (s)	0.2010.208
T_2 (s)	0.1880.164
T_3 (s)	0.160.145

RESULTS AND DISCUSSION

Moving Load Analysis

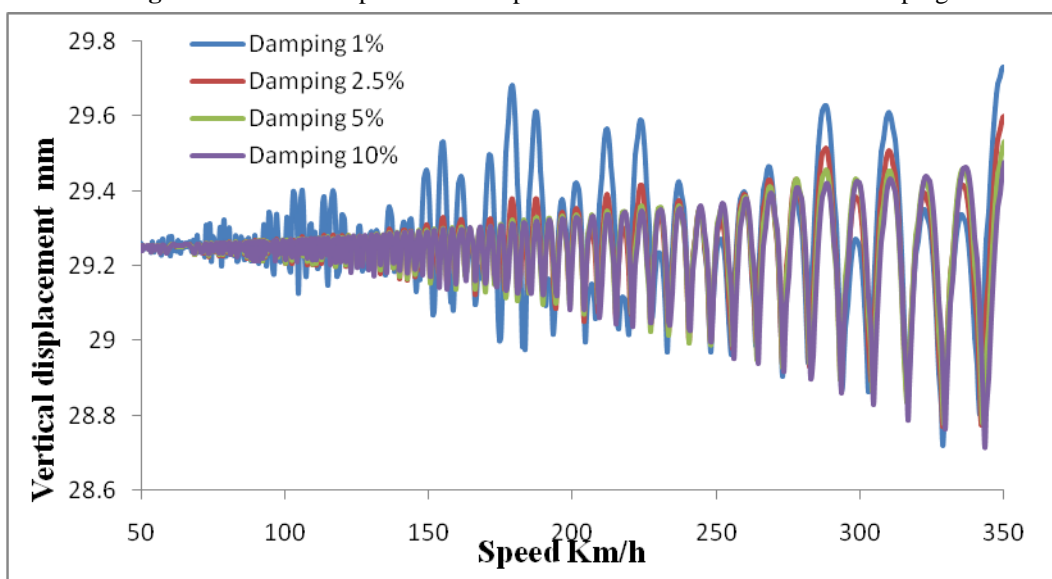
Having found a good agreement in case of FE model verification, the moving load analysis was carried out on the six-span unballasted railway bridge under train passage aimed at obtaining the bridge displacement. The high speed train HSLM-A10 with the constant speed from 50 Km/h to 350 Km/h was assumed and initiated to move from the beginning of span 5–6, crossing the whole

bridge (see Fig 1). The effect of the train passage was investigated at point S1 location C of span 7-8 (detail of the train and the location point can be found in [MehrdadBisadi et al. \(2012\)](#); [Fry`ba \(1996\)](#); [BS EN \(1991–2\) \(2003\)](#)). In addition, the different values of Young's modulus and damping ratio were employed and the influences of them are illustrated in this study.

Effect of Damping Ratio

In an attempt to demonstrate the effect of damping ratio on the bridge displacement, different values damping coefficients, 1%, 2.5%, 5% and 10% were used in such an analysis. As illustrated on Fig. 3 the vertical displacement witnessed a plunge due to increasing the values of damping ratios. In other words, as seen, larger damping values significantly reduced the displacement. Likewise, the results showed that the vertical displacements of the simulated model in damping ratios of 5% and 10% respectively were of similarity with a marginal difference.

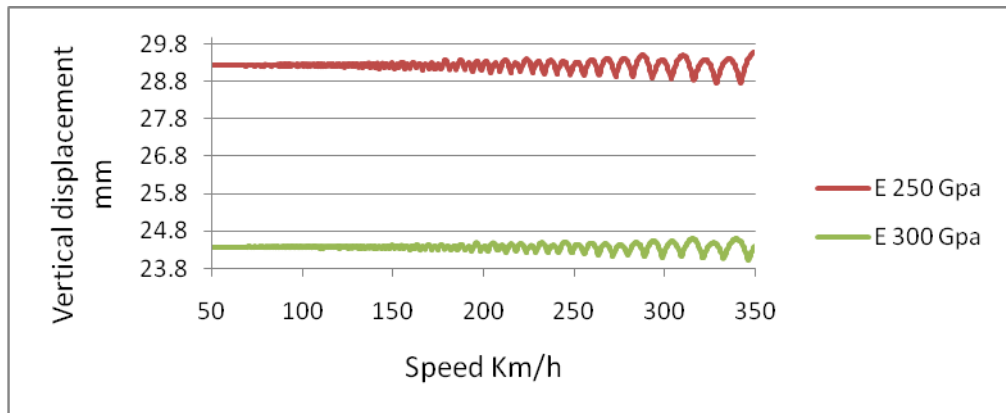
Figure-3. Vertical displacement in speed for different coefficient of damping



Effect of Young's Modulus

In terms of the effect of Young's modulus which is a material property describing its stiffness, two different values of Young's modulus, 250 and 300 Gpa, were considered in such an analytical study. As can be seen from figure 4, the displacement of bridge with Young's modulus of 250 Gpa was considerably high when compared to that with larger Young's modulus, 300 Gpa. Put differently, larger values of Young's modulus significantly reduced the displacement of bridge. Figure 4 presents the vertical displacement of the bridge under the different constant speed of the train passagewith respect to different values of Young's modulus.

Figure-4. Vertical displacement in speed for different Young's modulus



CONCLUSION

This paper has given a good account of the dynamic behavior of a steel unballasted railway bridge subjected to the high speed train. Initially, the existing railway bridge was simulated and the Eigen value analysis was carried out to obtain the natural frequencies. Having shown the accuracy of FE model, moving load analysis was carried out under the train passage.

This study has obtained the displacement of an unballasted bridge due to the passage of the high speed train. Meanwhile, different values of damping ratios and Young's modulus were employed and the effects of them have shown in such an analytical study. It has shown that these two parameters, damping ratio and Young's modulus, played a key role in the dynamic behavior of the bridge

These findings enhance our understanding of a dynamic behavior of the unballasted railway bridges and aid researchers to improve such a dynamic behavior through a simple finite element modeling.

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