ASPS Conference Proceedings 1: 1111-1114 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

State of Art for Dynamic interaction of High Speed Bullet Train Load for Cable Stayed Bridge

J.P. Variyavwala [1, *], A.K. Desai [2]

[1] Department of Civil Engineering, Saradar Vallabhbhai National Institute Technology, Surat, 395 007, India,
[2] Department of Civil Engineering, Professor, Saradar Vallabhbhai National Institute Technology, Surat, 395 007, India.

Paper ID - 070375

Abstract

Cable stayed bridge (CSB) is the center of attraction among all bridges due to aesthetic appearance and structural integrity. Earlier CSB used only for pedestrian and vehicular loads but with time passes it uses more intended towards mass transportation. When a bridge is designed to serve such heavy and rapid load; it should be analyzed for such load intensity. The question is how this high-speed rail load should be applied? The trainload is applied to bridge structure by different approaches by different researchers. In this article, a state of art for high-speed train load applications is discussed.

Keywords: cable stayed bridge, bullet train, train load application, dynamic train model

1. Introduction

As time evolved infrastructure facilities are its top and it's a matter of global prestige for any nation. With the development of technologies and economies, the need for a high-speed transport network arises. The high-speed rail network is the most promising way of mass transportation which will reduce traveling time to a certain extent. Over the world, the demand is raised for the development of rail supporting structures. High-speed railway is accepted broadly in many developed nations but by introducing the Mumbai-Ahmedabad high-speed rail corridor developing nations also enter in the same field. As a result of such evolution more complex structure comes in reality. Cable stayed bridge is among them. CSB is the most favourite structure of researchers not only for its aesthetic appearance but its intended use. Currently, Cable Bridge is used to serve both vehicular loading and train loading. Table 1 represents some example of cable stayed bridge which is used as a high-speed rail bridge.

Where, RB, CSB & STG stands for River bridge, Cable stayed bridge and Steel truss girder. In functionality, R represents railway and H represents highway; e.g., 2R, 4R 6H represents a two-line, four-line railway and six-lane highway.

2. Vehicle model

The vehicle used for bridge analysis plays a vital role in bridge behaviour forecasting. The more detailed model, the higher the accuracy of results in terms of passenger comfort criteria. With the development of high-speed rail, different researchers used different rail load application approaches. The most common type of approaches are discussed below.

2.1 The moving axle load model

The moving axle load models are suitable for those bridges where only bridge dynamic response required. This is the simplest train load application approach as presented in figure 1; which completely omits the train wagon mechanism and serviceability criteria of passengers. In this approach, the train load is applied as constant forces moving on the bridge deck with a constant speed. The vehicle inertial effects and wheel-bridge interaction is completely neglected. This approach is highly accepted by researchers because of its simplicity [1-3].

In the same context, some researchers used a series of train axle load which also signifies the deflection criteria of the bridge.

2.2 The moving mass model

This modelling approach comes in reality when vehicle mass ratio cannot be neglected and the vehicle inertial effects are very accentual. The complexity of such a model is higher than the above mention approach. The moving mass model for the train load is presented in figure 2. Many scholars used this modelling strategy by different mathematical functions i.e. newton Rapson function, Fourier series expansion, and Green's function, etc. rail buckling is a highly affected phenomenon after rail wagon passes. So that this model approach can't be used for the rail tracks having irregularities and analytical studies where the train response study is accentual [4].

*Corresponding author. Tel: +919924860200; E-mail address: variyavwalajigar8@gmail.com

Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India| 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.629

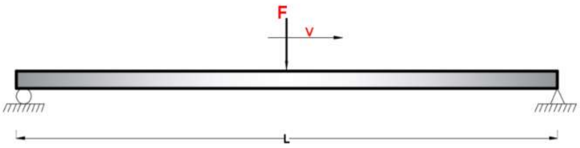

Figure 1 Moving Train Axle Load

Table 1 list of CSB which is used as high-speed Rail Bridge

Name of bridge	Bridge type	Main span (m)	Design speed (km/h)	Function
Tianxingzhou Yangtze RB in Wuhan	STG CSB	504	250	4R, 6H
Zhengxin Yellow RB RB on Beijing Guangzhou HSR	STG CSB	5 * 168	350	2R, 6H
Huanggang Yangtze RB on Wuhan– Huanggang HSR	STG CSB	567	250	2R, 6H
Tongling Yangtze RB on Hefei–Fuzhou HSR	STG CSB	630	250	2R, 4H
Tongling Yangtze RB on Hefei–Fuzhou HSR	STG CSB	630	250	4R, 6H
Anqing Yangtze RB on Nanjing-Anqing HSR	STG CSB	580	250	4R
Hutong Yangtze RB	STG CSB	1092	250	4R, 6H
Wufengshan Yangtze RB	STG CSB	1092	250	4R, 6H
Wuhu Yangtze RB on Shangqiu–Hangzhou HSR	STG CSB	588	250	4R, 6H
Baishatuo Yangtze RB in Chongqing City	STG CSB	432	250	6R
Jiujiang Yangtze RB on Hefei–Jiujiang HSR	STG CSB	672	250	4R
Anji Khad Bridge	Steel arch CSB	290	200	2R

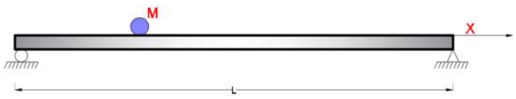

Figure 2 Moving Mass Model

2.3 The moving spring-mass model

The spring-mass model is the Rail vehicle model which consists of the suspension system of the vehicle epitomized by springs and dashpots. This modelling approach is the primitive modelling approach with a single degree freedom system as presented in figure 3. In the same field, some researchers did the detailed study on important parameters and proposed numerical and analytical explanations using moving force model, moving mass model and moving sprung mass models [5, 6, 9]

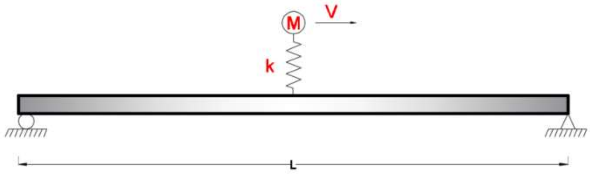

Figure 3 The moving spring-mass model

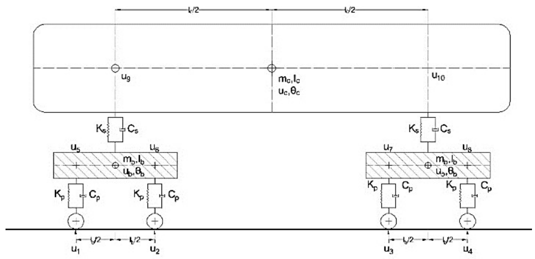

Figure 4 Detailed Rain Wagon with 10 DOF

2.3 Detailed rail wagon model

These are the most realistic and detailed modelling approach used to simulate the vehicle. This model comprised of carriage, bogies, and wheelset modeled as 2 masses and connected by suspension systems (primary and secondary spring and dampers). The difficulty level of the vehicle model used by researchers varies from four degree of freedom (D.O.F.) to twenty-seventh degree of freedom (D.O.F.) according to passenger safety, comfort criteria, and analysis requirements [7-19]. Here in figure 4, rail model is presented by 10 D.O.F. just to understand the basic modelling concept. The values for the suspension system are adopted from the real train wagon. The values for each suspension system vary with the train model. The difficulty level increases with considering the pitching effects, yawing effect, tractive and centrifugal forces, wheel-rail interaction, reviewing the vertical response or lateral response of rail on the bridge due to braking and acceleration effects [12-16]. In the same era, vibration analysis for bridge deck requires high modelling proficiency and advance analysis techniques [29].

3. Rail structure interaction study

After a detailed behavioural study researcher found that rail impact on bridge surface highly influenced by the suspension system. Basic moving axle or moving mass model cannot predict the exact impact on the bridge i.e. smooth surface bridge deck moving axle rail load overestimate the rail impact on the bridge.

More complex rail vehicle used for interaction study will give higher result accuracy. All the primary and secondary spring and dampers assigned to the model are the exact representation of real rail. These models are assigned to respective structures by 2D or 3D manner. Therefore the result obtained by such modelling is very nearer to reality.

The analytical result proves that bridge response will be more if the moving mass model is used. Moving rail axle model and moving spring models are superior to moving mass models. Moving axle and moving mass models can only be used to predict the bridge response while the spring-mass and detailed rail models can be used to study passenger safety and comfort. [6, 8, 9, 14].

4. Advancement of track models

The track assembly is a key component in rail bridge interaction study. Ultimately rail load will be transferred by this assembly. Till date there are three track modelling approach is observed which is vibrating ballasted track, non-vibrating ballasted track, and ballast-less track.

4.1 Ballasted Tracks

Ballasted tracks are comprised of rail, rail pads, sleeper, and ballast layer in descending order of their placement. The rail-pads are connected by fasteners. Ballasts also available between two sleepers. In the bridge analysis tack assignment is neglected in the case of only long-span bridges because long spans of bridge support higher flexibility. So, track stiffness may not affect much in bridge behavior. But in case of a short span, track assembly should be assigned to know exact bridge behavior. The track influence in bridge dynamics has been avoided by many researchers [19-21]. Although Supplementary mass should be assigned during the analysis procedure for the rail, ballast, and sleepers in case of omission of track modelling.

The ballasted track can further differentiate by two methods, i.e. vibrating ballasted track and non-vibrating ballasted track. The non-vibrating ballasted track act as a stiff layer of the slab as they are closely spaced and compacted. The interface of such a ballast is closely connected.

4.2 Non- Ballasted or ballast-less Tracks

In the Ballast-less track system rail is directly connected to the slab by fasteners. This is the most advanced track approach; recently Rheda 2000 ballast-less track is highly used. The concrete slab is assigned as a floating slab because elastic mats or bearings are used to separate bridge and track.

4.3 Comparison Studies of the Track Models Effects on the Bridge Response

For the long span bridges, the track modelling doesn't have a significant role but it plays a significant role in the wheel-rail interaction analysis. The response of the bridge is observed intense in the case of vibrating ballasted track; whereas not much variation is observed for non-vibrating ballasted track and ballast-less track [22].

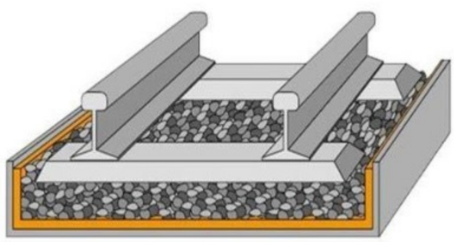

Figure 5 Ballasted Track assembly

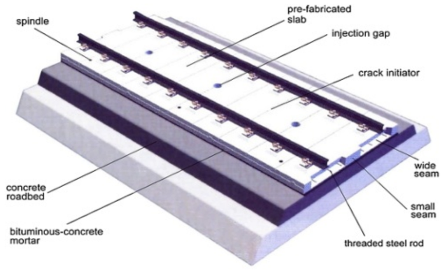

Figure 6 ballast-less track assembly

5. Conclusion

After reviewing the literature for rail modelling, rail bridge interaction, and different track approach, it is observed that sophisticated rail model adoption will lead to more accurate results for passenger's serviceability criteria. Train bridge interaction analysis plays a vital role in the case of an intermediate span bridge. Interaction analysis does not affect much for a longer and shorter span. Rail load can be introduced to bridge structure analysis by a simple moving axle for long-span bridges. Ballast-less track assembly proves more economical and maintenance-free over the conventional ballasted track.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. Au, F. T. K., Wang, J. J., & Cheung, Y. K. (2002). Impact study of cable-stayed railway bridges with random rail irregularities. Engineering Structures, 24(5), 529–541. https://doi.org/10.1016/S0141-0296(01)00119-5
2. Banning, Q. (1998). Dynamic Response of Cable-Stayed Bridges under Moving Loads by Fuheng Yang and Ghislain A. Fonder, 124(July), 741–747.
3. Cheng, Y. C., Lee, S. Y., & Chen, H. H. (2009). Modeling and nonlinear hunting stability analysis of high-speed railway vehicle moving on curved tracks. Journal of Sound and Vibration, 324(1–2), 139–160. https://doi.org/10.1016/j.jsv.2009.01.053
4. Nguyen Trong Phuoc, D. N. V. V. (2015). Dynamic Response of Cable Stayed Bridges under Vehicles considering the moving mass.
5. D. Y. Zheng, Y. K. Cheung, F. T. K. A. and Y. S. C. (1999). Vibration of Multi-Span Non-Uniform Bridges Under Moving Vehicles and Trains By Using Modified Beam Vibration Functions, 228, 611–628.
6. Fesharaki, M., & Wang, T.-L. (2016). The Effect of Rail Defects on Track Impact Factors. Civil Engineering Journal, 2(9), 458–473. https://doi.org/10.28991/cej-2016-00000049
7. Gupta, A., & Singh Ahuja, A. (2014). Dynamic Analysis of Railway Bridges under High Speed Trains. Universal Journal of Mechanical Engineering, 2(6), 199–204. https://doi.org/10.13189/ujme.2014.020604
8. Li, Y., Dong, S., Bao, Y., Chen, K., & Qiang, S. (2015). Impact coefficient analysis of long-span railway cable-stayed

bridge based on coupled vehicle-bridge vibration. Shock and Vibration, 2015. https://doi.org/10.1155/2015/641731

9. Liu, K., Zhang, N., Xia, H., & De Roeck, G. (2014). A comparison of different solution algorithms for the numerical analysis of vehicle-bridge interaction. International Journal of Structural Stability and Dynamics, 14(2), 1–17. https://doi.org/10.1142/S021945541350065X

10. Mu, D., Gwon, S. G., & Choi, D. H. (2016). Dynamic responses of a cable-stayed bridge under a high speed train with random track irregularities and a vertical seismic load. International Journal of Steel Structures, 16(4), 1339–1354. https://doi.org/10.1007/s13296-016-0104-x

11. Wang, T.-L., & Huang, D. (1992). Cable-Stayed Bridge Vibration Due to Road Surface Roughness. Journal of Structural Engineering, ASCE, 118(5), 1354. https://doi.org/10.1061/(ASCE)0733-9445(1992)118:5(1354)

12. Xia, H., & Zhang, N. (2005). Dynamic analysis of Railway Bridge under articulated trains. Computers and Structures, 83(23–24), 1891–1901. https://doi.org/10.1016/j.compstruc.2005.02.014

13. Yang, X., Wang, H., & Jin, X. (2016). Numerical Analysis of a Train-Bridge System Subjected to Earthquake and Running Safety Evaluation of Moving Train. Shock and Vibration, 2016. https://doi.org/10.1155/2016/9027054

14. Yang, Y. B., & Wu, Y. S. (2002). Dynamic stability of trains moving over bridges shaken by earthquakes. Journal of Sound and Vibration, 258(1), 65–94. https://doi.org/10.1006/jsvi.2002.5089

15. Yuksel, T., & Unlusoy, Y. S. (2016). Modeling and Simulation of High Speed Railway Vehicle Dynamics International Congress on, (August).

16. Zbiciak, A., Oleszek, R., & Michalczyk, R. (2016). Dynamics of an orthotropic railway bridge in the light of European standards. Archives of civil engineering, Vol. DOI: J0.1515/Ace-2015-00782016, LXII(ISSUE 2).

17. Zhang, H., & Xie, X. (2011). Dynamic responses of cable-stayed bridges to vehicular loading including the effects of the local vibration of cables. Journal of Zhejiang University-SCIENCE A, 12(8), 593–604. https://doi.org/10.1631/jzus.A1000351

18. Zhang, N., Xia, H., & de Roeck, G. (2010). Dynamic analysis of a train-bridge system under multi-support seismic excitations. Journal of Mechanical Science and Technology, 24(11), 2181–2188. https://doi.org/10.1007/s12206-010-0812-7

19. J. F. d. C. S. Henriques, Dynamic Behavior and Vibration Control of High-Speed Railway Bridges through Tuned Mass Dampers , Master thesis, department of Civil engineering, 2007.

20. J. M. Proença, H. Casal, and M. Neves, effect of the type of track on the dynamic Behavior of high speed railway bridges, compdyn 2011, 3rd ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Greece, 25–28 May 2011.

21. W. M. Zhai, K. Y. Wang, and J. H. Lin, "Modelling and experiment of railway ballast vibrations," no. 270, PP. 673-683, 2004

22. L. Frýba, Dynamics of railway bridges. London: Thomas Telford, 1996.