Train-Track-Bridge Interaction: A State of The Art Review

Muhammad Habib[1,2], Zhijun Chen[3,4]

[1,3] School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, China
[2] Civil Engineering Department, Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan
[4] Professor, School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan, China

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Abstract - *Train-track-bridge coupled system have a complex behavior and here is it tried to cover all the developments happened in this field keeping the dynamic response of the coupled system for high-speed railways in mind. The evolution of the vehicle models and track models are discussed considering their complexity and other constraints. Different techniques and models adopted to study the response of the bridge system are discussed. The effect of the selected vehicle and track models on the dynamic response of the system is also discussed. This current review can give an oversight of the important work done in this field and can help the beginners.*

***Key Words*: Dynamics, high-speed railways, railway bridges, vibrations, train models, track models.**

1. INTRODUCTION

With the development of economies and technologies, the requirement for quick and high quality of transportation means increases. High-speed railways is one of the most vital and important way of transportation in many countries in Europe (France, Sweden, Spain and Germany) and Asia (Japan, South Korea and China) [1]. Around the world, the demand of the supporting structures for the high-speed railways is increasing because of the future expansion of the high-speed trains, which demands high speed, high axle loads and greater vibrations [2]. China has expended its high-speed railways network at a staggering rate. Opening its first fast train railway line back in 2007, the Chinese high-speed railway network has gone past 20,000 km till date and it is still expanding. With the increase in the high-speed railways network, the percentage of the railways bridges increases. More than 50 percent of the high-speed railways lines are built up of bridges [3-5]. As it is very difficult to provide dedicated infrastructures for the high-speed railways in developed countries, therefore the percentage of the elevated tracks will increase. Thus the assessment of the existing bridge structures to support the extra loads and efficient design of the new infrastructure needs a better modelling which is only possible by having a deep insight of the dynamic behavior of the coupled train-track and bridge system.

2. VEHICLE MODELS

Vehicle models have very important role in determination of the system response, the time required by the analysis and the computational efforts required. There are different models available in the literature. Different researchers used different vehicle models in their analysis. The most common type of vehicle models used are as:

2.1 Moving Load Model

Moving load vehicle models are suitable to be used where the response of the bridge should be determined only and the vehicle mass is negligible as compared to the bridge mass. This is the simplest type of vehicle model which can be used to study the dynamic response of the bridge and vehicle. In this type of model the wheel or axle forces are simplified as constant forces moving on the bridge surface with a constant speed neglecting the vehicle inertial effects and contact between wheel and bridge [6, 7].

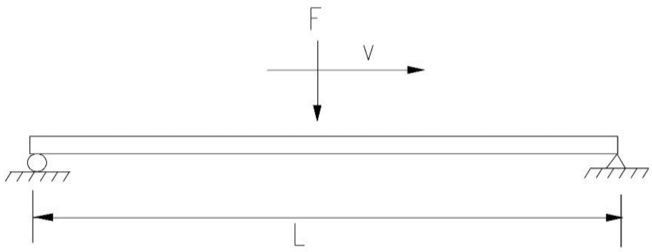

Figure 1: Moving Force Model

A lot of researchers used this model for their design and analysis of bridges, because it is the most simplest vehicle mode and the determination of the important parameters is easy [8-11].

2.2 Moving Mass Models

Moving mass model is used when the mass ratio of the vehicle cannot be neglected and the vehicle inertial effects need to considered. Its complexity level is higher than the moving load model but still it is simple than the real vehicle models. A lot of researchers used moving mass model for the analytical and numerical solutions of the simple beam bridges using different techniques such as Fourier series expansion and Green's function [12, 13]. In moving mass model, wheel and bridge detaching/ bouncing/ relative displacement is not considered. Rail corrugations are one of the most important excitations besides train loads. Therefore, this model cannot be used for the rail tracks with irregularities and the analysis where train response needs to be studied [12, 14-16].

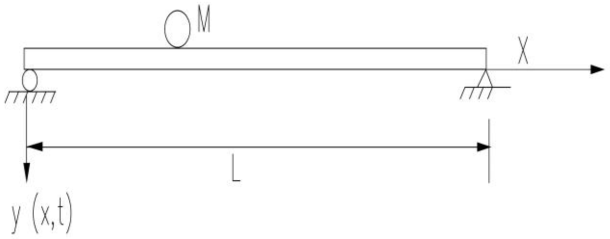

Figure 2: Moving Mass Model

2.3 Moving Sprung Mass Model

Sprung mass model is the vehicle model which considers the effect of suspension system of the vehicle represented by springs and dashpots. The vehicle bridge interaction can be considered in sprung mass model and it was used to solve a simply supported beam [17]. Fryba studied the effects of important parameters and proposed numerical and analytical explanations using moving force model, moving mass model and moving sprung mass models [18, 19].

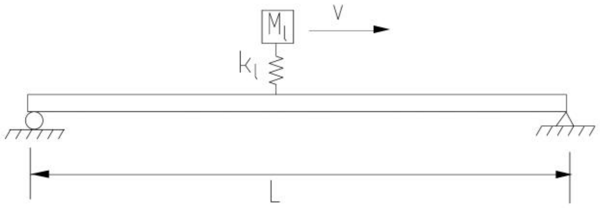

Figure 3: Sprung Mass Model

2.4 Vehicle System Model

More realistic and detailed models used to simulate the vehicle are the vehicle system models. This model consists of car body, bogies and wheels modeled as discrete masses and connected by suspension systems (primary and secondary). The complexity level of the vehicle system model used by a number of researchers varies from 4 degree of freedom to 27 degree of freedom according to the calculation and analysis requirements [6, 20-23]. Both linear and nonlinear springs and dampers systems are used by different authors [6, 22-25]. The complexity increases with considering the wheel rail interaction, pitching effects, braking and acceleration effects, studying vertical response or lateral response [1, 26-28]. Furthermore, if vertical and lateral responses are required to be studied, then the complexity of the system will be high [29].

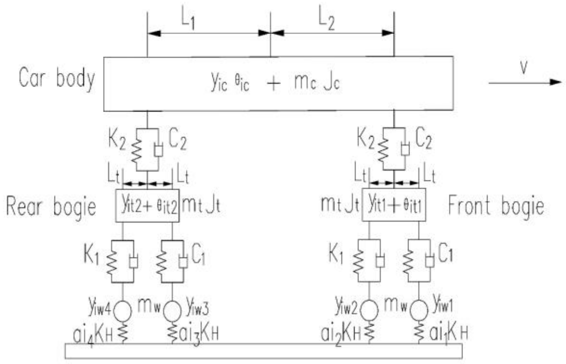

Figure 4: Moving System Model

2.5 Vehicle structure Interaction Studies

For highways bridges, the researchers studied that the initial jump and damping of the vehicle suspension system can affect the response. For smooth surfaces, moving force model response is found to be greater than that of the sprung mass model [30-32].

More complex and detailed train models were used by [8, 33, 34] with considering the rigid masses and connection were provided using linear and nonlinear spring and dampers using multi body dynamics [35, 36]. These models are more detailed than the sprung mass models. Both two dimensional (2D) and three dimensional (3D) models were used with various number of degree of freedoms (DOF's). A typical 2D models considers wheels, bogie (truck), car body masses and only the vertical suspension of the vehicle. Where in 3D model, vehicle lateral properties are considered too which adds to the complexity of the model.

From the study of number of researchers about the moving force, moving mass, and moving sprung models has established that the bridge response will be higher if moving mass model is used. Moving force model and moving sprung models comes after moving mass models. Moving force and moving mass models can only be used to predict the bridge response while the sprung mass and moving system models can be used to study the passenger comfort too [6, 7, 37, 38].

3. EVOLUTION OF TRACK MODELS

Track structure is the system component which helps the trains to move and distribute the loads of the trains to the underlaying bridges or subgrades. So the type of track system used can affect the response of the bridge. There are mainly two types of track systems used; ballasted tracks system and ballastless tracks system.

3.1 Ballasted Tracks

Ballastless tracks are mainly made up of rails at the top followed by rail-pads and connected by fasteners supported by sleepers and ballast is present between two sleepers. If the track is placed on the ground i.e. earth, then subgrade and sub-ballasts are also the provided. Figure 5 shows the ballasted track model.

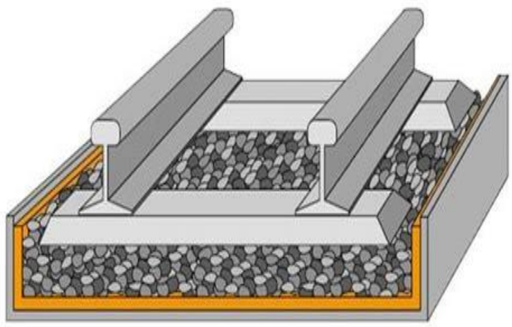

Figure 5: Ballasted Track Model

Ballasted tracks models on the ground/ earthwork are researched extensively and even confirmed the results of the field measurements by many authors [36, 39, 40] . The effect of the track structure is neglected by many researchers in their studies of the dynamic behavior of the bridges for both moving force analyses and train-bridge interaction analysis [18, 28, 41-43]. For long span bridges, the track structure can be neglected as the long span bridges are elastic enough, but for the bridges of short spans, the track stiffness can affect the overall dynamic behavior of the system. As the tracks are continuous structures even at the supports too, therefore, the bridge stiffness is increased and bridge response is reduced. [44]. Supplementary mass for the rail, ballast and sleepers weight is added when the track structure is omitted in the analysis.

3.2 Ballastless Slab Tracks

Ballastless slab tracks are the track system where the rail is directly placed on the concrete slabs (cast-in-situ or precast) with a single or double block sleepers and fasteners are used to connect rail and concrete slabs as shown in Figure 6. The concrete slab is mostly referred to as floating slab because elastic mats or bearings are used to separate bridge and track.

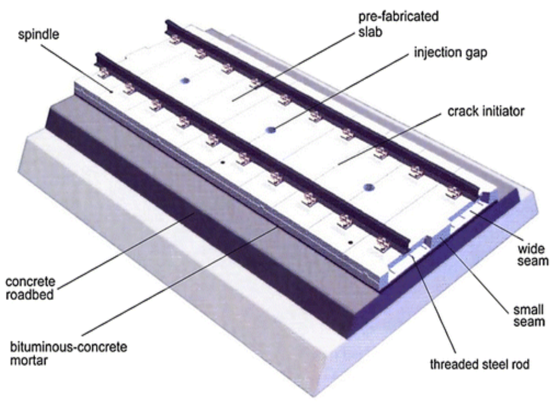

Figure 6: Ballast-less Slab Track Model

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

After studying short span bridges of 20m~30m with track models consists of single layer, they come to the conclusions that the models of the track doesn't have a very significant impact on the response of the beam bridges. However, it can affect the wheel rail contact forces and response of the vehicle significantly[45-48]. The response of the structure have shown no significant changes for ballast layer continuous and intermittent distribution. The response of the bridge structure is found to be almost the same for a three layer track model and a model without considering the track structure for a frequency range of 0-15 Hz [49].

4. CONCLUSIONS

By studying the literature related to the vehicle models, track models and their effects on the dynamic response of the train-rail-bridge system, some important conclusions can be drawn.

1. Train-bridge interaction model can effectively decrease the dynamic response of the bridges with intermediate span and not very significant in the case of long and short span bridges. However, this response reduction can only be relevant when resonance occurs and it depend on many system parameters.

2. To study the vertical response of the bridge system, a simple vehicle model can serve the purpose.

3. The models of the track models doesn't have a very significant impact on the response of the beam bridges with the span ranging between 20m to 30m. However, it can affect the wheel rail contact forces and response of the vehicle significantly. The response of the structure have shown no significant changes for ballast layer continuous and intermittent distribution. The response of the bridge structure is found to be almost the same for a three layer track model and a model without considering the track structure for a frequency range of 0-15 Hz.

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