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# Vehicle-Bridge Interactions (VBI) in High-Speed Rail Corridors

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***Abstract: Moving railway vehicles on the bridges cause excitation in the bridge components and owing to this there is increase in the forces like (bending, shear, torsion, displacement, etc). This increase in the forces in the bridge components are computed using Dynamic impact factor. Dynamic impact factor is applied on to the axles to get the dynamic effect on the bridges. Our Indian Railway codes provide the value DIF (called Coefficient of Dynamic Augment) for speed up to 160 kmph. Most of the railway and metro lines are operating with speed lesser than that, therefore, Coefficient of Dynamic Augment (CDA) can be conveniently taken from codes. For any speed greater than 160 kmph CDA shall need to be computed as per the dynamic analysis as per available international codes. As mentioned earlier that there is imminent need of high-speed rail network in India due to increase in economic activity, increase in travel choices, improvement in mobility, reduction in congestion and to boost productivity.***

***Our objective of this thesis is to study dynamic response of a various types of bridges under high-speed trains currently being used in India for high-speed rail projects like RRTS (Delhi to Meerut and other corridors) and High-speed rail project from Mumbai to Ahmedabad to accurately assess the DIF in bridges under the effect of different governing factors (vehicle speed, vehicle load, bridge superstructure type, etc). This study could be beneficial in upcoming projects of high-speed rail as it is our future need.***

***Keywords: VBI, Rail Bridge, Acceleration, Time History, Truss Bridge***

## I. INTRODUCTION

Vehicles and bridges interact dynamically, and the dynamic response of the bridge during vehicle movement is greater than the static response, as has been known for decades. Through contact forces, the vehicle and bridge—two elastic systems—interact dynamically while the vehicle is moving. The vehicle's velocity, damping, stiffness, and modal frequency are some of the dynamic characteristics of the vehicle and bridge that have a major impact on the bridge's structural response during vehicle movement. By increasing the static effects on the bridge by a factor known as the Dynamic Impact Factor (DIF), the traditional method of designing bridges for dynamic effects is based. The value of DIF is determined by the bridge's length or the first natural frequency of its flexural mode of vibration, according to the majority of design codes of practice. In this approach, various parameters that affect the dynamic response of the bridge such as:

- The Train speed across the bridge.
- The span length of the bridge and its structural configuration.
- The mass of the bridge structure.
- The natural frequency of the entire structure.
- The number of train axles, their loads and distribution.
- The damping of the structure.
- The suspension characteristics of the vehicle.
- The vertical irregularities of the track.
- The wheel defects.

Vehicle-Bridge Interactions (VBI)

Vehicle-Bridge Interaction (VBI), the dynamic relationship between moving vehicles and the bridges they cross, has become a crucial area of research and design as transportation infrastructure changes to satisfy the demands of speed, efficiency, and safety. VBI captures a two-way dynamic exchange rather than a one-way load transfer: the vehicle affects the bridge's motion, and the bridge influences the vehicle's behavior.

This interaction becomes particularly important during extreme events like earthquakes or strong winds, or when heavy freight vehicles or high-speed trains are involved. Static design approaches frequently underestimate the complex vibrational responses, fatigue, resonance, and discomfort that VBI can cause, even under typical operating conditions. Predicting bridge performance and fatigue life, guaranteeing passenger comfort and vehicle stability, and guiding intelligent maintenance and structural health monitoring strategies all depend on an understanding of VBI. More realistic, robust, and economical infrastructure is produced by integrating VBI into design and analysis. This is particularly important as we transition to next-generation mobility systems like autonomous freight convoys, high-speed rail corridors, and smart bridges with sensing and adaptive capabilities.

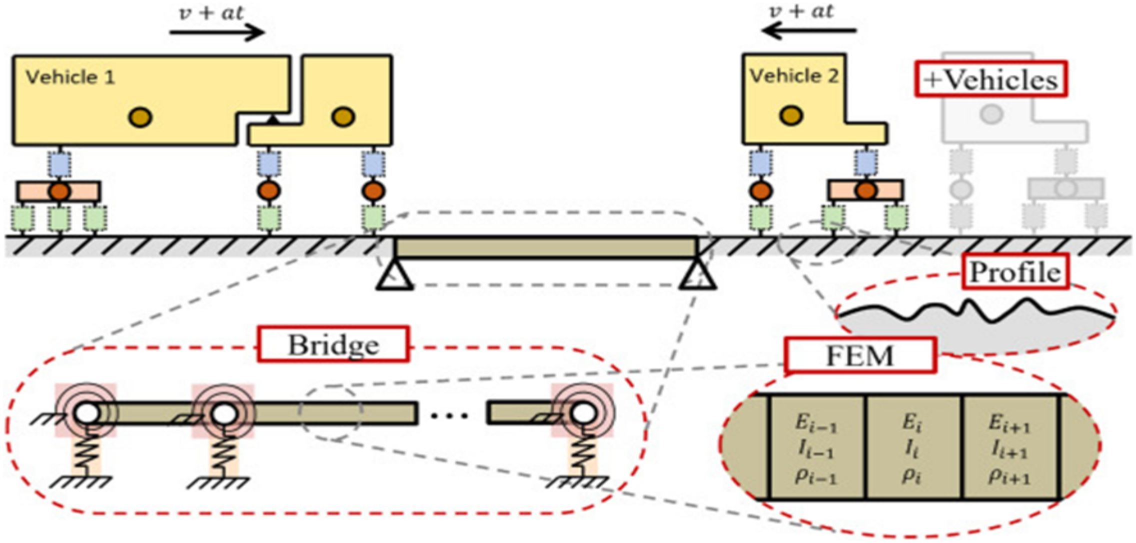



Fig. 1 Graphical description of VBI-2D simulation software

## II. LITERATURE REVIEW

Due to presence of significant number of high-speed rail corridors in Europe, most widely codes are European codes.

Before elaborating the codal provisions of European code, we first need to understand about the need of Dynamic analysis. We know that at lower speeds, structural deformation of the bridge due to moving live load is quite similar to static deformation due to live load. However, as train crosses a bridge at a certain speed, the deck will deform as a result of excitation generated by the moving load. At higher speed, deformation of structure exceeds as compared to static deformation due to regular excitation generated by evenly spaced axial loads.

In 1995 the problem was found in the high-speed lines in EUROPE, in particular high vertical acceleration was observed which cause discomfort to passengers in train. Therefore, dynamic analysis is required to control and assess the following:

- To control excessive high vertical acceleration.
- To avoid matching of structural frequency with natural frequency (Resonance).
- Under the loads of high speed, the bridges are subjected to high dynamic impact and they should be designed accordingly.

In Indian context, our Railway design code i.e. IRS bridge rule does not provide Impact factor for speed more than 160km/h for BG and 100km/h for MG. Therefore, for trains having speed more than that we need to refer international codes to evaluate dynamic effects. As per Euro code, dynamic analysis is required for below conditions:

- As per EURO Code maximum line speed at site > 200km/h
- Frequent operating speed of a real train equal to resonant speed of the structure.

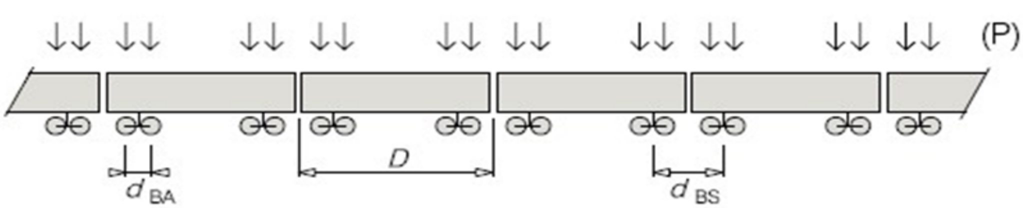



Fig. 2 Axial loads of vehicle

## III. OBJECTIVES

- The objectives of present study are:
- To develop a procedure for study of the Dynamic response of bridge under action of moving vehicular traffic.
- To analyse the various type of superstructure type under the effect of governing parameters like vehicle speed, bridge superstructure type, etc to obtain its dynamic response.
- To compare the DIF with the outcomes of codal provisions after obtaining it through vehicle bridge interaction.
- To examine the mechanisms of dynamic interaction between bridge structures and high-speed trains.

## IV. MODELLING & METHODOLOGY

All developed and developing countries are having high/ semi high-speed train network available to minimise the travelling time of commuters to the increase business activities for improvement of economy. In India neither we have high speed / semi speed railway network nor the codal provisions for high-speed trains. Considering the above, Indian government has started constructing high speed rail corridor (Mumbai-Ahmedabad) and semi high-speed rail corridors (Delhi-Meerut RRTS). Therefore, it is imperative to study the impact on various type of bridge superstructures for the high-speed trains as it may assist in choosing the appropriate type of superstructure. In this thesis, dynamic analysis for various type of superstructure has been carried out for Delhi-Meerut RRTS project which is having design speed of 180 kmph.

Type of Superstructure considered for dynamic analysis

- Steel truss of 73 span (Type 1)
- Steel composite plate girder for 50m span (Type 2)
- Prestressed concrete segmental box girder of 34m standard span (Type 3)

Data considered for modelling of Structures:

Design Basis

The Dynamic Analysis is carried out in accordance with the following documents:

Design Basis Report-Viaduct – (Document: DM12DDC-GEN-GEN-VDC-REP-000005) which summarizes the general assumptions for the whole project.

BS EN 1991-2 (Eurocode 1: Actions on structures – Part 2: Traffic Loads on Bridges)

BS EN 1990-2002+A1(Basis of structural Design)

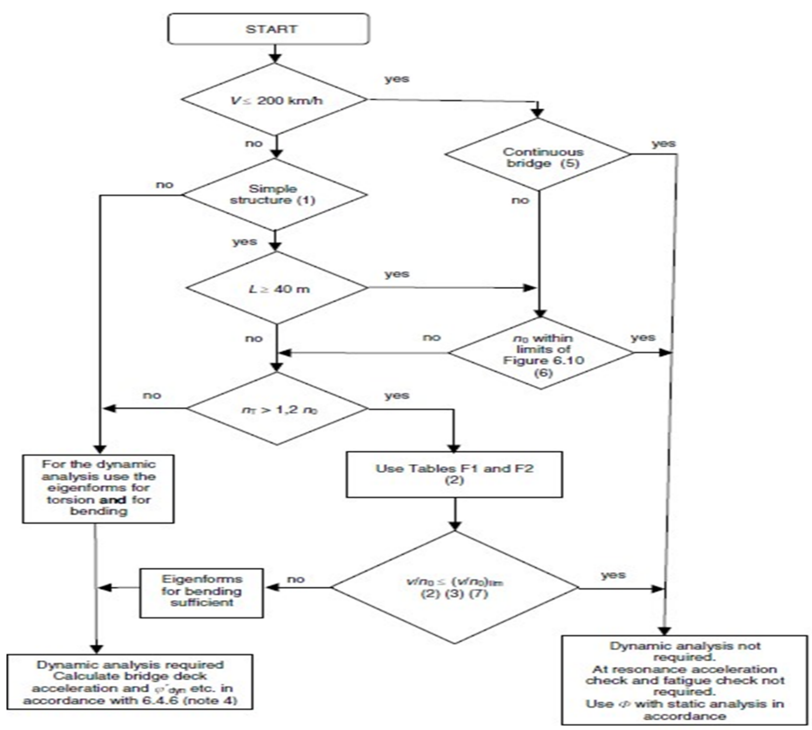



Figure 3. Flowchart for Dynamic analysis

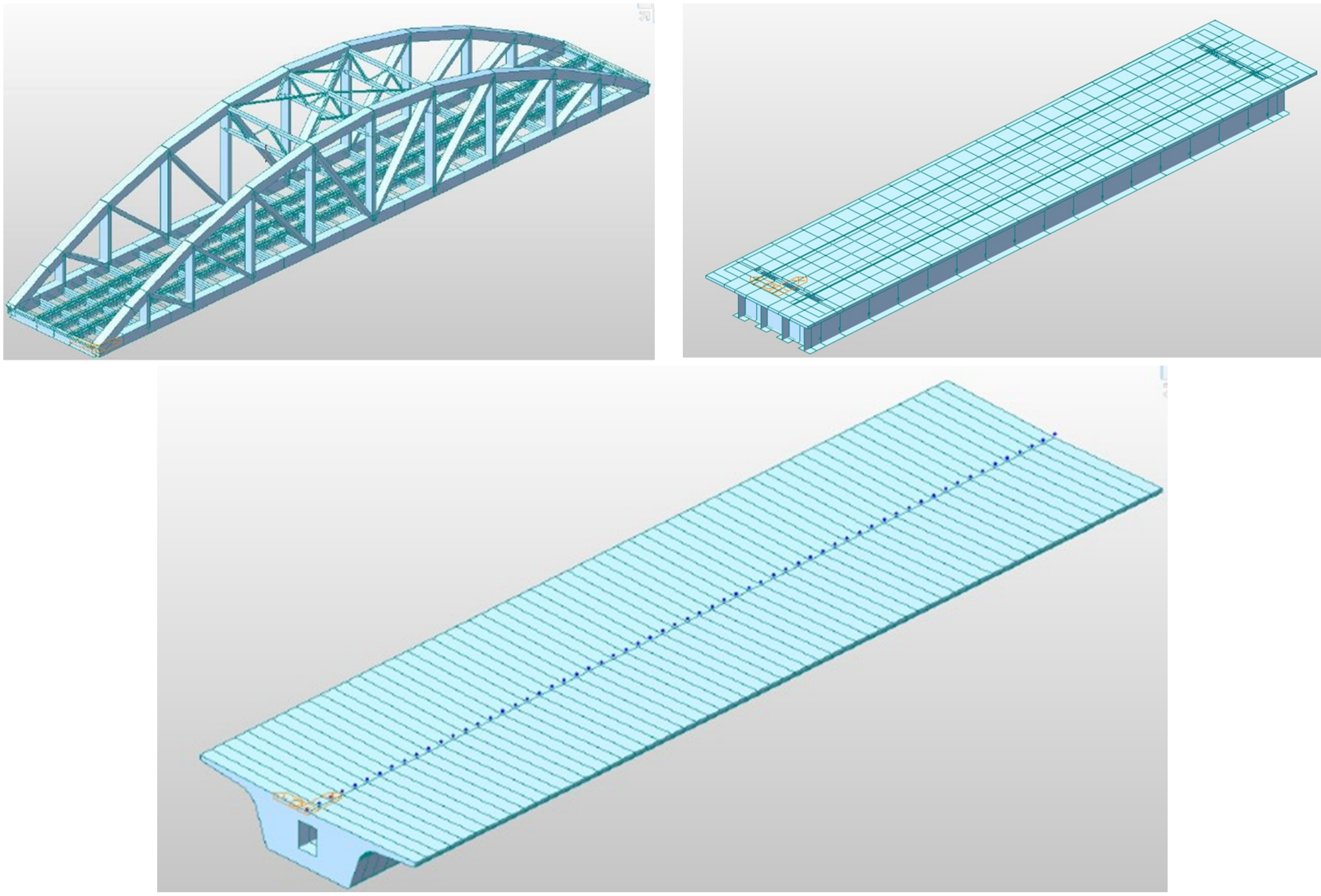


Fig. 4 Models considered for the study

## V. METHODOLOGY

In order to conduct the current study, various model configurations must be examined in order to obtain seismic responses. Finite element package I is used to obtain results numerically. e. ETABS is used in this study. Following analysis, base shear, drift, and lateral displacement are the results. Finally, the results are compared, interpreted, and validated. Responses for regular configuration models are compared with results found in the literature in order to validate the results. ETABs is a versatile structural analysis tool that can be used for both static and dynamic analysis. A three-dimensional (40-story) model of the structures is used to perform nonlinear dynamic analysis.

## VI. ANALYSIS AND DESIGN RESULTS

Train Model - Time History Function

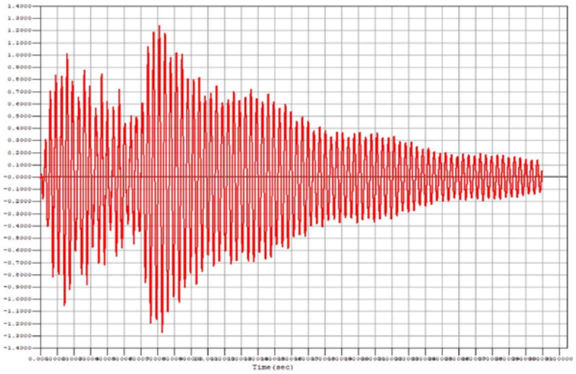
The dynamic analysis is undertaken using characteristic values of the loading from real trains specified. The selection of rail trains is taking into account each train formation for highest speed train permitted or envisaged to use the structure at speeds upto 180 kmph.

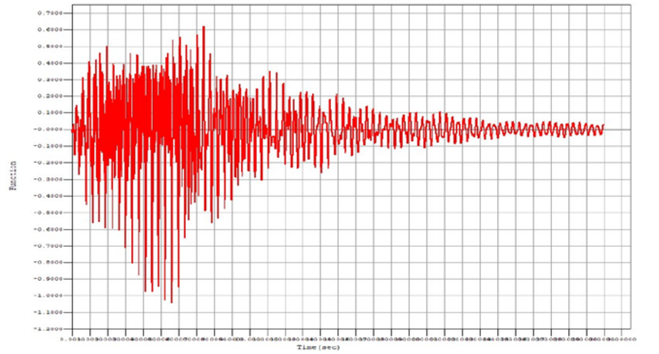
Speeds to be considered

For each train load model of specified bogie, maximum design speed is considered. The maximum design speed is 180 kmph, so:

Maximum Design Speed for RRTS = 180 [kmph] = 50 [m/s]

However, the dynamic analysis shall be done with vehicle speed 216kmph, 210kmph, 200kmph, 192kmph, 180kmph, 175kmph, 165kmph, 155kmph & 144kmph.

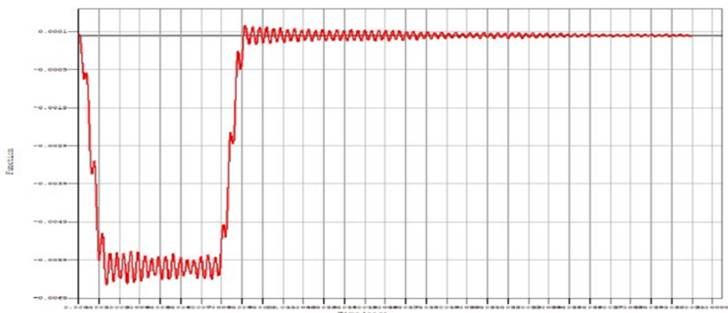



Max. Acceleration at Node no 690: 1.272m/s2

Max. Acceleration at Node No 16: 1.044m/s2

Fig. 5 Peak acceleration at 180Kmph Speed



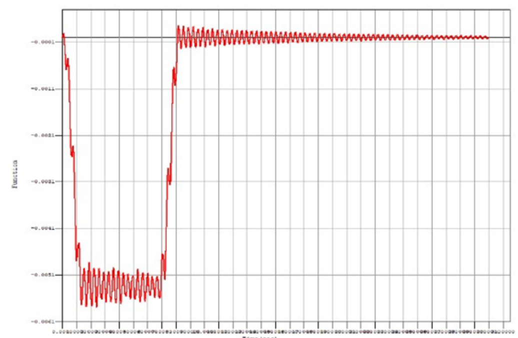
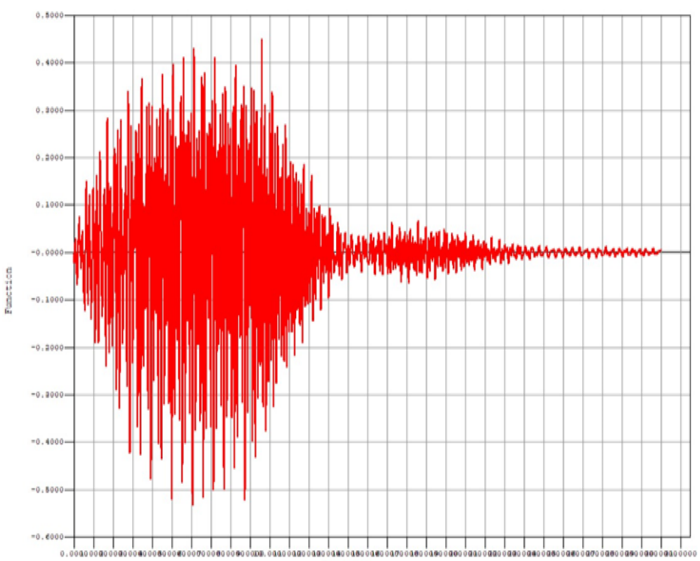
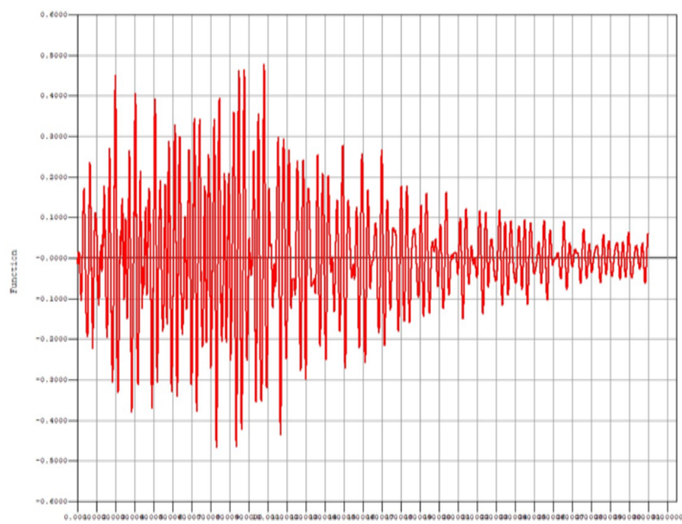




Fig. 27 Summary of the Highest Peak Displacements for Cross Beam

Fig. 4 Peak displacement at 180Kmph Speed




Max. Acceleration at node no 1347 : 0.430m/s2

Max. Acceleration at node no 691 : 0.478 m/s$^2$

Fig. 4 Summary of the Highest Peak Acceleration for Velocity 144 kmph (for Bogie length 22.34m)

Table 4 Vertical acceleration and dynamic deflection

| PSC box girder 34m span | 144 kmph | 144 kmph | 180 kmph | 180 kmph |
|---|---|---|---|---|
| | (21.34 Boggie) m | (22.34 Boggie) m | (21.34 Boggie) m | (22.34 Boggie) m |
| Vertical acceleration (m/s2) | 0.528 | 0.994 | 1.051 | 1.079 |
| Dynamic deflection (mm) | 3.916 | 4.041 | 3.736 | 3.731 |

## VII. CONCLUSIONS

This study is based on the current semi-high-speed rail network i.e. Delhi Meerut Rapid Rail Transit System (RRTS) being constructed and other corridors are to be implemented. Design speed of this project is 180 kmph hence existing IRS codal provision for DIF in cannot be used, therefore, dynamic analysis is needed to establish the DIF. Dynamic analysis has been carried out with two types of boggie length i.e. 21.34m and 22.34m.

In this project, we have started with the understanding of dynamic analysis by mentioning various codal provisions and parameters influencing the DIF. Subsequently, procedures for computation of dynamic analysis for given superstructure, loading, train type, span, etc have been explained including the modelling part. Last part of this study covers the dynamic analysis of various types of superstructures for given data.

- It has been observed that dynamic deflection and vertical acceleration is dependent upon the distance between the axles and the span length for given speed, superstructure type
- Dynamic impact factor for 180 kmph design speed with 17t axle load is majority of the times lesser than that mentioned in the IRS bridge rules as seen is all superstructure type considered in this study.
- It has also been studied that if span length is in multiples of axles spacing, then chances of resonance or increased vertical deflection is possible. Therefore, spans in multiple of axles spacing should be avoided in the initial exercise.
- Above conclusion is drawn for project having similar speed that of RRTS i.e. 180 kmph. However detailed study for speed higher than that of RRTS is to be done as future study.

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