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DYNAMIC ANALYSIS OF LALPARI RAILWAY BRIDGE UNDER THE INCREASING SPEED OF TRAIN

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ABSTRACT: Due to the introduction of high speed train in the world, the interest in Dynamic behavior has increased. According to current scenario, HST (High Speed Train) is under construction more than ten countries including India. The existing bridges in India are designed according to Indian bridge codes in which the dynamic behavior of high speed train is added by including dynamic impact factor. Dynamic impact factor is a function of loaded length only. However dynamics response of bridge involves a number of parameter like frequency characteristics of bridge structure (i.e. the length, mass, rigidity of individual member), the frequency characteristics of vehicle (i.e. the sprung and unsprung masses, the stiffness of spring), the damping in bridges and vehicles, track irregularities, and the velocity of vehicle and so on. This paper represents the analytical study carried out on existing Railway Bridge to know the dynamic behavior of Railway Bridge under the increasing speed of train.

KEYWORDS: Railway Bridges; Train speed; Dynamic behavior.

1 INTRODUCTION

The global **High Speed Train (HST)** network is one of the great feats of modern engineering, and proves to be the best form of transportation ever invented. The global high speed train network is rapidly expanding across continents world wide- delivering fast, efficient mobility to numerous nations every day.

HST is currently in operation in more than 20 countries (including the UK, France, Germany, Belgium, Spain, Italy, Turkey, Japan, China, Korea and Taiwan). HST is under construction in more than 10 countries (including China, Spain, Saudi Arabia, Turkey, France and Italy); and in development in another 14 countries (including Qatar, Morocco, Russia, Poland, Portugal, South Africa, India, Argentina, Mexico, and Brazil). HST has been in operation in Japan for 50 years carrying more than 9 billion passengers without a single fatality.

One of the first proposals to introduce high-speed trains in India was mooted in the mid-1980s by then Railway Minister Madhavrao Scindia. A high-speed rail line between Delhi and Kanpur via Agra was proposed. An internal study found the proposal not to be viable at that time due to the high cost of construction and inability of travelling passengers to bear much higher fares than those for normal trains.

The Indian Ministry of Railways' white-paper "Vision 2020", submitted to Indian Parliament on December 18, 2009, envisages the implementation of regional high-speed rail projects to provide services at 250–350 km/h, and planning for corridors connecting commercial, tourist, and pilgrimage hubs.

2 LITERATURE SURVEY

2.1 Previous researches

Ashish Gupta and Amandeep Singh Ahuja (2014)[1], The author's objective was to investigate the dynamic behavior of an existing railway bridge subjected to high speed trains. The bridge model has been developed using MATLAB software. By dynamic analysis, the relation between speed, acceleration, time step and displacement of bridge was obtained at any instant of loading. In this paper two cases of analysis were used, with damping and without damping. The structural response is inversely proportional to the damping value of structure. Lower damping value gives higher amplitude of response while higher damping value gives lower amplitude of response. At the time of resonance, peak amplitude of response occur which was observed on same bridge at 75 to 85 m/s.

He Xia et al (2003)[3], this paper is about vehicle-bridge dynamic interaction under articulated high speed train. A dynamic interaction model of the bridge-articulated train system is developed, which is composed of an articulated vehicle element model and a finite element bridge model. The vehicle model was created according to the structure and suspending properties of the articulated vehicles. A case study of Antoing Bridge on Paris-Brussels railway line is carried out in this paper. The numerical solution was compared with actual field test results. Calculated deflection, vertical acceleration and lateral acceleration of bridge were well accordance with in situ measured data.

Rvindra Kumar Goel(2009)[2] present the paper on dynamic impact of increasing speed of vehicle on plate girder bridge. The coefficient of dynamic augment which is used in IRS Bridge Rules is function of loaded length only and does not represent the actual dynamic impact of moving train loads at high speed train. This paper presents the results of an analytical study undertaken on standard railway bridge. In this study, two plate girder bridge of different span and two truss bridge of different span were used to analyze. Train models were used as per bridge rules for moving load analysis. The author says that significant work has not been done in India on existing bridge to confirm their adequacy for high speed train.

G. Kaliyaperumal et al (2010)[4],this paper presents the advanced technique of modeling for dynamic analysis of steel railway bridge. The author studied the dynamic behavior of skew bridges with the help of FEM based software ABAQUS and also compared software results with actual field experiments. For finding out the fundamental mode shapes and natural frequency of bridge, eigen value analysis of different models were carried out. Single span, three span and full bridge model were created using shell element, beam element and combination of both. For dynamic analysis, time history analysis was carried out with available field experiment results. The result of paper shows that fullbridge modeled with using combination of beam and shell element was efficient to capture dynamic effect of bridge.

2.2 Conclusion of literature

- By referring the research papers, it is found that lots of research is done on high speed train in the world. But there is a lack of research in India on existing bridge to confirm their adequacy for high speed train.[2]
- The Indian codes does not include dynamic effect of high speed train($> 200\text{kmph}$)
- According to bridge rules(RDSO), co efficient of dynamic augment(CDA) is multiplied with live load to add dynamic effect on bridge, CDA=0.15 + $\frac{8}{6+L}$, where L is loaded length of bridge.
- Under current design practice, the impact factor is considered to add the dynamic effect on bridge. This impact factor is a function of loaded length only. But, actual dynamic response depends on a number of parameters, including properties of vehicle, characteristics of bridge, and roughness of track. Although the current design practice with design codes may underestimate greatly the dynamic response of bridge.

3 INDIAN CODE PROVISION FOR DYNAMIC EFFECT OF TRAIN [6]

Current design practice for Railway Bridge in India is done according to guidelines given in steel bridge code and bridge rules. According to steel bridge code, the dynamic effect of moving load is considered by increasing live load by impact factor or coefficient of dynamic coefficient. This factor depends on many factors like the type of loading, speed, type of structure, material of structure, loaded length etc. But for simplicity an impact factor is specified by the Bridge Rules in India involving only one parameter, i.e., the loaded length. All the other parameters are considered as constants in the expression for impact factor. For Broad Gauge and Meter Gauge steel railway bridges carrying a single track, the Coefficient of Dynamic Augment (CDA) is given by the following expression-

$$CDA = 0.15 + \frac{8}{6+L}$$

Where L is defined as given below:

a) L is loaded length of the span in meters for the position of the train giving the maximum stress in the member under consideration. For the design of chord members, it will be the whole span of the truss and for the web members only part of the span is to be loaded.
b) L is taken as 1.5 times the cross-girder spacing for finding stresses in the stringers (rail-bearers).
c) L is taken as 2.5 times the cross-girder spacing for finding moments in the cross-girders (floor-beams).

4 DETAILS OF EXISTING PLATE GIRDER

The bridge chosen for this analytical study is steel plate girder bridge located on Lalpari river, Rajkot, Gujarat. It is constructed under Viramgam-Okha-PBR-conversion Project. The bridge consists of 7 spans each having 11.052m length. The steel girder rested upon the concrete piers. Longitudinal and transverse stiffeners are provided to prevenuckling of web plates.

Photo 1. Plate girder bridge on Lalpari River in Rajkot

5 ANALYSIS OF EXISTING RAILWAY BRIDGE

In order to have realistic and accurate enough results on the bridge, a finite element analysis must be carried out. This model aims to analyze the actual bridge under actual train loads. Real load cases can be simulated with all the actions considered in this project to see their influence on the structure.

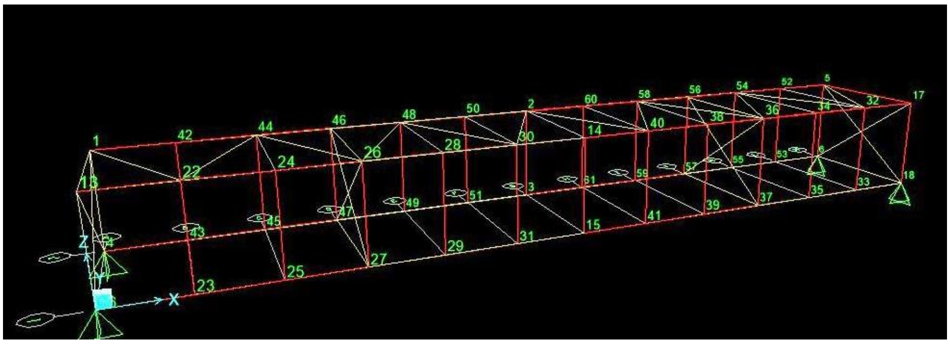


Figure 1. Undeformed shape of bridge

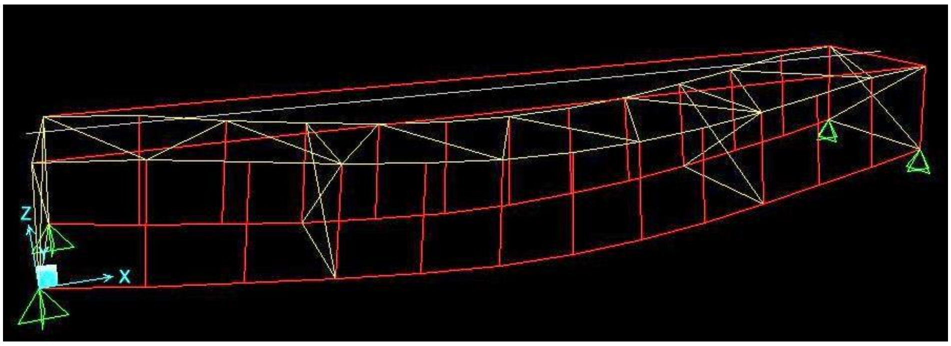


Figure 2. Deformed shape of bridge under dead load

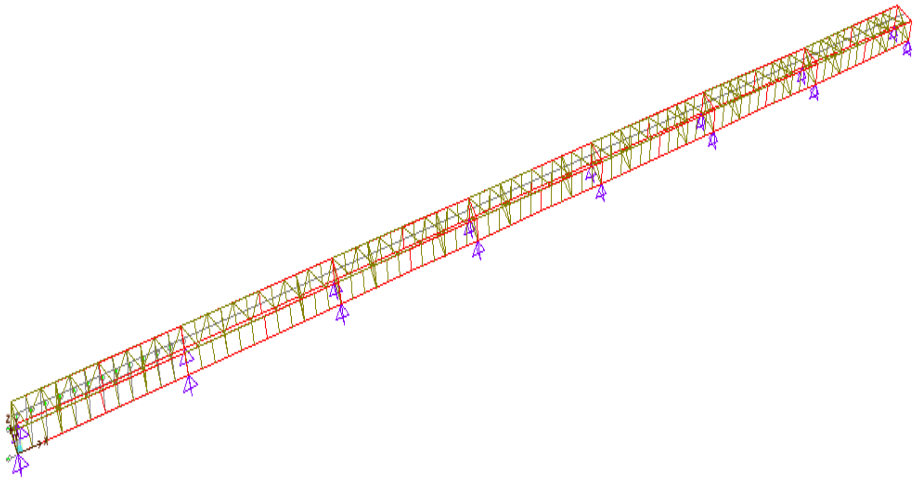
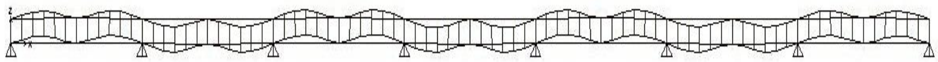


Figure 3. Full Bridge model

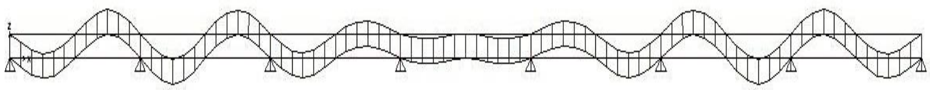
5.1 Modal analysis

Modal analysis is an alternative to solving the complete set of all equations for all unknown displacements. The method is based on mode superposition approach, used in order to calculate the response of a system to an applied load. The modal analysis uses a reduced number of unknowns to represent the global behavior of the structure. Modal analysis requires that the system is linear (small displacements), and type of analyzed problem and whether it is dominated by local or global displacements are governing factors for the success of the method. Comparison to time integration method, the modal analysis method only needs a few modal contributions to be solved. In SAP2000 2 different types of modes are implemented, (1) Eigen vectors (2) Ritz vectors. Eigen vector is used for this study.

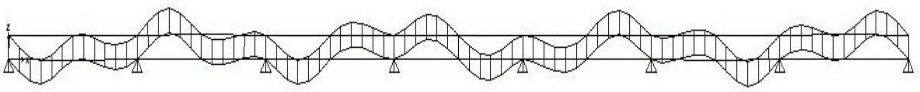
- **First Horizontal mode:** **Mode 1, f_1 = 7.58966 Hz**



- **First vertical mode:** **Mode 8, f_8 = 12.77649Hz**



- **First Transverse Mode:** **Mode 14, f_{14} = 15.28684Hz**



5.2 Multi-step static analysis:

Multi step static analysis is load case used when one or more vehicles moving across the bridge at specified speed.

Mainly two parameters is important in this load case, (a) duration of loading i.e. time required by train to pass over bridge. (b) Time step for discretization of load. For this study, duration of loading is considered as 20 secs for all cases and time step is considered as 0.05 sec. Minimum spacing between two wheels is consider 1.7m for all types of train models.

5.3 Dynamic analysis:

Dynamic analysis is performed by *linear direct-integration time-history analysis* for different velocities of train considering zero percentage (0 %) and two percentage (2 %) damping ratio. From *modal analysis* time periods of two vertical modes are taken for defining mass and stiffness proportional damping.

6 RESULTS AND DISCUSSION

In order to find cut off velocity of train, multi-step static analysis is performed. In multi-step static analysis, two parameters are important (A) duration of loading i.e. the time required by train to pass over bridge. (B) Time step for discretization of the load. Duration of loading is considered as 20 sec. and time step is considered as 0.05 sec

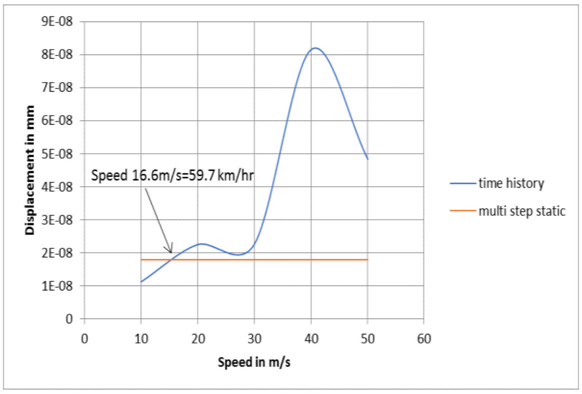


Figure 4. Variation of midspan displacement due to passage of MBGT on Bridge with respect to velocity

Figure 4 shows midspan displacement with respect increase in velocity of MBGT(medium Broad gauge train) when the response of static analysis crosses the response of dynamic analysis, the corresponding velocity is called cut off velocity. For MGGT train model, the cut off velocity is 59.76 km/hr.

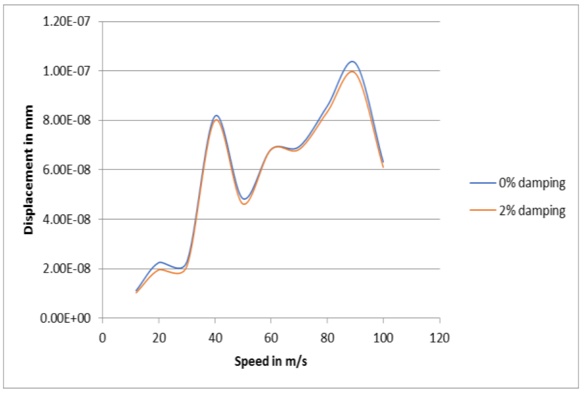


Figure 5. Mid span displacement with different damping values

Figure 5 shows Mid span displacement of bridge with respect to train speed including different damping values. By adding 2% damping the dynamic response of bridge can be reduced.

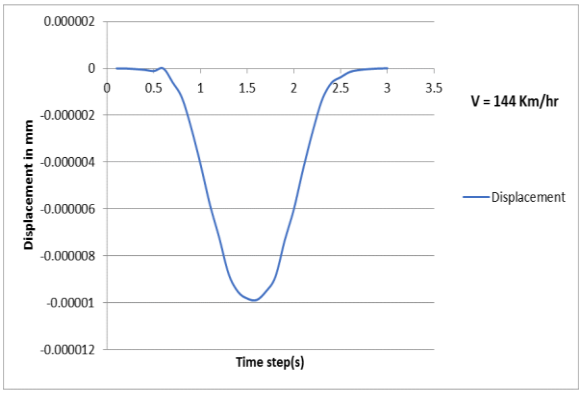


Figure 6. Mid span displacement with respect to time step (MBGT)

Figure 6 shows the middle span displacement history with respect to passage of time, when the train runs on bridge at speed of 144 Km/h. After 1.5s the train is on center of bridge and maximum displacement occurs at that time.

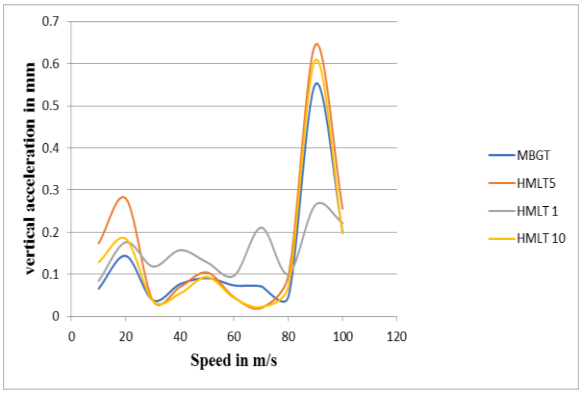


Figure 7. Vertical acceleration versus speed of train

Figure 7 shows vertical acceleration of midspan node with respect to speed of train in comparison with different model. The maximum vertical acceleration occurs when the speed of train is 90 m/s. The maximum acceleration is occurred due to resonance effect at that speed. In HMLT5 model the maximum dynamic response is occurred.

7 CONCLUSION

1) From modal analysis It was found that the fundamental natural frequency of Lalpari Railway Bridge in first mode is 7.58966Hz and corresponding time period is 0.13176s.
2) Cut off velocity is different for different train models. The average cut off velocity for Lalpari Bridge from all load cases is about 50-60 km/h.
3) The static analysis is adequate upto a cut off velocity which is about 60 kmph. Dynamic analysis is required for different types of bridge for permitting higher speeds.
4) In this study, the attempt was made to analyze the bridge at speed 10 to 100 m/s. the maximum dynamic response was shown at train speed 90 m/s. it might be due to resonance effect.
5) For particular Lalpari Bridge, the mid displacement increasing as speed of train increases. However the change is in micro level. The reason behind this might be the sections used in bridge are oversized. From manual design calculation, it is found that the depth of girder required to carry the moment produced by vehicle is only 0.9 m. However the depth in actual bridge is 1.25m. The thickness of side plate required is 5 mm, but the actual thickness is bridge is 20mm. so, from this calculation, the conclusion is that the super structure of bridge is very stiff. So it gives lower response to high speed train.

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