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STUDY ON THE IMPACT OF SHORT WAVELENGTH VERTICAL IRREGULARITY TRACK ON A COMPOSITE RAILWAY BRIDGE

Shilpa P.[1] , Dr. Rajesh K. N.[2]

[1]*M. Tech scholar, Dept. of Civil Engg, Govt. College of Engineering Kannur, Kerala, (India)*

[2]*Associate Professor, Dept. of Civil Engg, Govt. College of Engineering Kannur, Kerala, (India)*

ABSTRACT

The modernisation of railway network is progressing day by day by the fast developing economy and technologic evolutions. The interest in dynamic behaviour of railway bridges has increased in recent years, due to the introduction of high speed trains. Under the loads of high speed trains, the bridges are subjected to high impacts. Higher speeds of the trains resulting in larger and more complicated loads than earlier, and produces much higher dynamic effects. Therefore it is very essential to ensure the safety of train movement. The earlier studies on this confirmed that the track irregularities are considered as one of the main factors affecting the dynamic response of the bridge. In this paper the effect of short wavelength track irregularities of track on a composite railway bridge was studied. The finite element model of the bridge and vehicle was created by using the software Abaqus. Free vibration analysis and Time history analysis were carried out for analysing the dynamic response of the bridge.

Keywords*: *Composite Railway Bridge, High speed trains, Track Irregularity, Free Vibration Analysis, Time History Analysis.

I. INTRODUCTION

The steel-solid composite solutions for bridges and viaducts are broadly utilized as a part of European high speed railway systems. Despite the fact that concrete structures are still generally favoured in many countries, composite ones turned out to be increasingly a legitimate option because of the development of materials and innovations. The nearness and typologies of composite bridges in the European nations shifts significantly from nation to nation. Box girders were typically used in the construction of longer span and horizontally curved bridges because of their higher flexural capacity and torsional rigidity. The closed shape of the box girders permitted the reduction of the exposed surface, making them less helpless to corrosion. Box girders additionally gave smooth, aesthetically great structures.

Various analytical and experimental studies have been done to contemplate the vehicle-bridge dynamic interaction. The vibration of the train and bridges is the main concern in these studies [1, 6]. Safety and comfort standards of the bridge and train were taken into consideration. A new model for the analysis of the ballast vibration also established [2]. Different methods have been developed for modelling the train and bridge and for the dynamic analysis of the vehicle/bridge system. It was found that three dimensional FE model is able to simulate the overall flexural behaviour of simply supported composite beams subjected to either concentrated or uniformly distributed loads. Studies were also conducted to study about the impact forces on the bridge due to the moving vehicle load. Numerical analysis were conducted to study the weak coupling between the adjacent spans of the composite bridge. It was proved that symmetrical modes are more excited during the train passage than the anti-symmetrical modes [9].

In any case, just few investigates have been directed on examination utilizing commercial FEM packages like MATLAB, ANSYS and ABAQUS to learn about the parameters impacting the bridge-vehicle interaction. Especially those parameters, identified with track irregularities. The prior directed studies affirmed that the track irregularities are considered as one of the principle variables influencing the dynamic response of the extension [7]. In this way it is key that the bridges loaded quick moving trains must be intended to guarantee the security of train movement.

II. FINITE ELEMENT MODELLING

2.1 Geometry of Sesia Viaduct

The Sesia viaduct which is located on the new Italian high-speed line between Torino and Milano was chosen for the study. It is a simply supported composite railway bridge. This bridge has seven spans of 46 m and has a total length of 322 m. Each simply supported span of the bridge consists of a girder of the same double box cross section. On the top of the double box girder there is a concrete slab which has a thickness of 0.4 m and width of 13.6 m. The slab is connected to the steel girder by studs. Above the concrete slab ballast is placed. The thickness of ballast is 0.84m. Fig. 1 shows the geometric specifications of the cross section of the Sesia Viaduct.

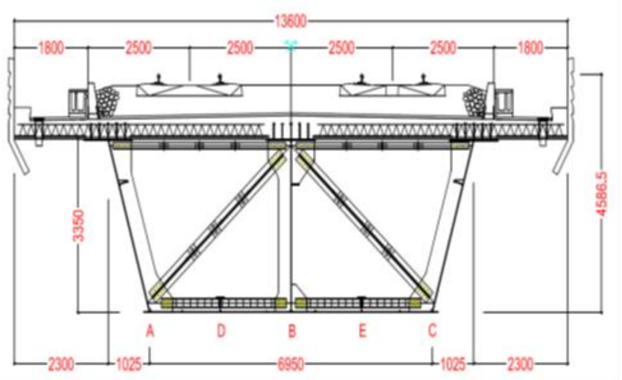

Fig. 1 Cross section of the Sesia Viaduct

2.2Boundary Conditions

The Sesia Viaduct is a simply supported bridge and symmetrical boundary conditions are adopted. The continuity between adjacent spans is represented by restricting both the rotation and longitudinal displacements of the ballast and the rails. The Fig. 2 shows this.

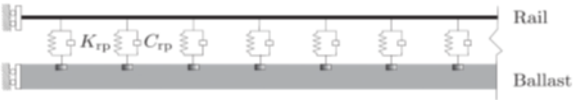

Fig. 2 Boundary conditions for the single span model

2.3Material Characteristics

Table 1. Presents the element types and the material properties of the different components in the FE model.

TABLE1 Material Characteristics of Model

Bridge components	E($x10^6$ N/m^2)	ρ (kg/m^3)	υ	Mass (kg)	Stiffness ($x10^6$ N/m)	Damping ($x10^3$ Ns/m)
Steel box	205600	7850	0.3	-	-	-
Ballast	280	1700	0.28	-	-	-
Concrete slab	31000	2500	0.17	-	-	-
Stud	-	-	-	-	450	-
Rail	205600	7850	0.3	-	-	-
Sleepers	-	-	-	290	-	-
K_{rs}	-	-	-	-	500	-
C_{rs}	-	-	-	-	-	200

2.4Finite Element Types

The steel girder is modelled by shell elements with four nodes, each having six degrees of freedom, whereas the concrete slab is represented by solid elements with eight nodes having three degrees of freedom. The ballast is modelled by solid elements. The headed shear studs are represented by linear spring elements and connect the corresponding nodes in the longitudinal direction. The track is modelled as a longitudinally invariant track, where the rail pads and the sleeper masses are distributed along the track. The track model consists of two solid elements, which representing the rails, and the mass elements representing the sleepers. The rail pads are represented by springs (Krs) and dampers (Crs) between the beams and mass elements. The developed finite element model of single span of Sesia Viaduct is shown in Fig. 3.

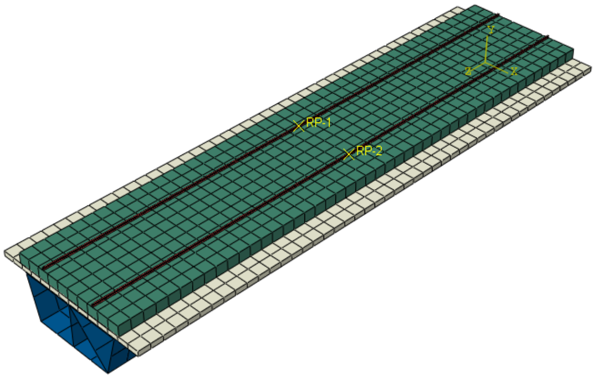

Fig. 3 FE model of the Sesia Viaduct

2.5 Vehicle Model

The characteristics of the ETR500Y train running from Torino to Milano was used to model the vehicle. The weight of the vehicle was taken as 398 tone and speed as 288 km/h.

III. FREE VIBRATION ANALYSIS

In order to validating the model in finite element package ABAQUS, free vibration analysis of Sesia Viaduct was carried out. The results obtained from FE analysis are discussed. The four mode shapes of the Sesia Viaduct are obtained by conducting modal analysis. The corresponding frequencies obtained from the FE analysis are plotted against mode numbers as shown in Fig. 4. The comparison of natural frequencies from journal and Abaqus are given in Table 2.

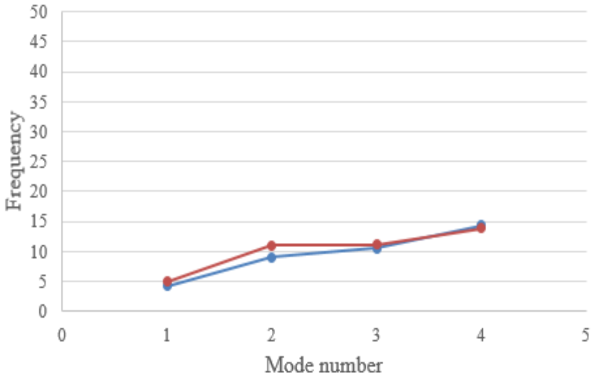

Fig. 4 Frequency-mode number graph

TABLE 2 Comparison of Natural Frequencies

Modes	From Journal	From Abaqus
First vertical bending mode	4.14	4.52
First torsional mode	9	9.17
Second vertical bending mode	10.44	11.13
Second torsional mode	14.28	13.8

IV. RANDOM TRACK IRREGULARITIES

Track irregularities are due to wear and tear, subsidence, clearances, track formation technology, contemporary mechanical maintenance, soil settlement and other factors. These are one of the essential vibration sources in bridge/track/train systems. Only the mean vertical elevation of two rails, is taken into consideration. Long wavelength corrugation irregularities in rail and design geometry irregularities in track formation are neglected.A stationary and ergodic Gaussian process in space, describing vertical irregularities, is characterised by a one-sided power spectral density (PSD) function Srr (Ω). Where Ω=2π/Lr [rad/m] as the spatial frequency, and Lr as wavelength. The most common definition of Srr (Ω) is in the form:

$$S_{rr}(\Omega) = kA\frac{\Omega_c^2}{(\Omega^2+\Omega_c^2)\Omega^2}\left[\frac{mm^2 m}{rad}\right] \quad (1)$$

Where k=0.25, Ωc=0.8245 [rad/m] and coefficient A [mm2rad/m] is specified for line grades 1 – 6. Only the better railway lines of grades, i.e. 4(A=53.76), 5(A=20.95), and 6(A=3.39), are considered in this study. Random samples of the track irregularity vertical profile are generated with the Monte-Carlo method which results in the following formula:

$$r(x) = 2\sum_{i=1}^{N_r}\sqrt{S_{rr}(\Omega_i)\Delta\Omega}\cos(\Omega_i x+\varphi_i)\left[mm\right] \quad (2)$$

Where: Ωi=Ωmin+(i-0.5)ΔΩ – discrete frequency, φi – random phase angle uniformly distributed over [0,2π] [rad] interval and independent for i=1,2, … ,Nr, ΔΩ=(Ωmax-Ωmin)/Nr –frequency increment, Nr – total number of frequency increments in [Ωmin, Ωmax] interval, Ωmin=2π/Lrmax, Ωmax=2π/ Lrmin– lower and upper limits of spatial frequency, Lrmin , Lrmax – lower and upper limits of wavelength.The classification of track irregularities is given in Table 3.

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TABLE 3 The Classification of Track Irregularities

Wavelength L_r [m]	Type of irregularities in rail
0.03 – 0.10	short wavelength corrugation
0.10 – 1.00	long wavelength corrugation
1.00 – 3.00	long waves and rolling defects
Wavelength L_r [m]	Type of irregularities in formation
3.00 – 25.00.	alignment, cant, twist, gauge etc.
25.00 – 70.00	Alignment
> 70.00	design geometry

V. TIME HISTORY ANALYSIS

Time-history analysis is a technique used to determine the dynamic response of a structure under the action of any general set of time-dependent loads. The random track irregularities were obtained by using the equations (1) and (2).

The validated model of the bridge was modified by incorporating the vertical track irregularities. Time history analysis was carried out for non-track irregularity (NTI) model and other three types of models having track irregularities, created on the basis of grades of railway lines. The Traffic Safety Condition and Serviceability Conditions were checked.The traffic safety condition (TSC) can be checked by using the following formula:

$$a_p\left(0.5L\right) = \max_t \left|\ddot{w}\left(0.5L,t\right)\right| \leq a_{p,\max} \tag{3}$$

Where, $\max_t \left|\ddot{w}\left(0.5L,t\right)\right|$ -maximum vertical acceleration of the bridge deck at the middle of span.

$a_{p,\max} = 3.5m/s^2$ -Admissible vertical acceleration of the bridge deck at the middle of span.

The serviceability condition (SC) is expressed by the limit vertical deflection of the bridge span under a real train:

$$w_{\lim} = L/1700 \tag{4}$$

Where L is the bridge span.

The time history analysis of the bridge-vehicle model without considering the track irregularity was done in Abaqus. From the analysis results it is found that the maximum vertical acceleration of the bridge deck at the middle of the span as 0.16 m/s^2. The other observations from the time history analysis are given in the Table 4.

TABLE 4 Results

Model code	Maximum vertical acceleration
NTI	0.16 m/s^2
TI4	4.7 m/s^2
TI5	4.2 m/s^2
TI6	3.7 m/s^2
Model code	Maximum vertical deflection
NTI	0.08 m
TI4	0.48 m
TI5	0.32 m
TI6	0.25 m

The model codes used above are NTI- Non track irregularities, TI4, TI5, TI6- Track irregularities corresponding degrees of railway lines 4, 5 and 6. For the non-track irregularities model the maximum vertical acceleration of the bridge deck at the middle of the span is within the limits of traffic safety condition. But for the track irregularities model maximum vertical acceleration is not within the limits of TSC. In the case of maximum vertical deflection observed values for both NTI and TI are not within the limits of serviceability condition.

VI. CONCLUSION

The random track irregularity has great effect on the bridge/track dynamic interaction, especially in the case of high speed trains. Therefore it is essential to ensure the safety of the train movement when the bridges are loaded with high speed trains.

Modelling of Sesia Viaduct and vehicle was done using the finite element program Abaqus. Free vibration analysis of the created model was done and natural frequencies were compared with the experimental values. In order to study the effect of random track irregularities of the track on the behaviour of bridge time history analysis was done using the validated model. For modelling the random track irregularities only the vertical profile was considered. Long wavelength corrugation irregularities in rail and design geometry irregularities in track formation are neglected. A stationary and ergodic Gaussian process in space, describing vertical irregularities, was used for modelling. One model without track irregularities and three others with track irregularities were created.

It was found that the traffic safety condition is significantly exceeded in the case of TI4 and TI5. But in the case of NTI traffic safety condition was within the limit. In the case of TI4 and TI5 there is a possibility of risk. There will be ballast destabilization on the bridge. The serviceability condition was not satisfied for all the models for an operating speed of 288 km/h. Both TSC and SC conditions showed that higher grades of railway lines are better.

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