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Dynamic Responses of 87-Type Railway Steel Beam for Rush-repair under Heavy Load Trains

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Abstract. 87-type railway steel beam for rush-repair were established by the finite element analysis software ANSYS and five different spans of beams were taken into consideration in the research of dynamic responses. DF4 locomotive hauling C70 freight heavy load marshalling trains model was established by dynamics software UM, in which specific wheel and rail relationship was used to found a combined simulation vibration system. After modeling, process of train running through the bridge was simulated to study several indexes including mid-span vertical deflection, mid-span lateral amplitude, derailment coefficient, rate of wheel load reduction and lateral force of wheel. These indexes made it possible to find out the changing pattern and the conclusion of maximum recommended speed.

1. Introduction

The railway bridge occupies an important part of railway lines in our country, which makes the design and application of rush-repair beam a great significance in ensuring the running of railway transport, during war and natural disasters[1]. The fundamental task of 87-type beam, military using beam with large in span and used in rush-repair, is to resume traffic in emergency as soon as possible. According to correlative design specifications, speed range of 87-type beam is 15-40km/h owing to differences between types and spans[2]. Dynamic interactions between vehicle and structure, emerge as the train runs on bridge. American researchers first studied the main factors that cause vibration of steel bridges when they ordered motor running through 24 steel truss bridges in the early 20th century. Academician Li GuoHao from Tongji University published the research result of stability and vibration of bridge structures[3]. Professor Cao XueQin from Tongji University worked out the lateral vibration of steel truss bridge by studying plenty of survey data and theoretical analysis[4]. Professor Xia He etc. from Beijing Jiaotong University established dynamic analysis of vehicle-track-bridge system and analyzed the dynamic responses[5]. The structural particularity of 87-type beam makes it great significance to study the responses of the beam under action of heavy loaded train and to analyze the structural performance of beam and the safety of running a train.

2. Dynamic Analysis Model of Vehicle-Bridge Interaction

The method of research is based on the previous vehicle-bridge interaction dynamic analyses. Bridge and vehicle model are established by ANSYS software and multi-body dynamics simulation software Universal Mechanism individually, on the basis of bridge and vehicle dynamics theories. The interaction relation between bridge and vehicle is established by using the multi-point contact theory between wheel and rail. FRA-5 track spectrum is applied as the system excitation, establishing dynamic analysis model of rail vehicle-bridge interactions.

2.1 87-Type Beam Model

2.1.1 Analysis of Natural Vibration Characteristics
The main parameters that reflect vibration characteristics of the bridge include natural frequencies and vibration modes, the level of frequency and vibration mode correspond to the magnitude of bridge stiffness to a great extent, as well as a premise of dynamic analysis of vehicle-bridge interactions. Mode synthesis method was taken into analysis in order to reduce the amount of computational freedom, and the finite element models were carried out in different spans (64m, 72m, 80m, 88m, 96m) of 87-type beams[6].

2.1.2 Finite Element Model
In this section, the finite element model of five different spans 87-type beams is carried out using the element BEAM188 in ANSYS. While the geometric dimensions of five spans 87-type beams are almost the same in both lateral and vertical directions, there are variations in the longitudinal directions. The 64 meters 87-type beam finite element model is in Figure 1.

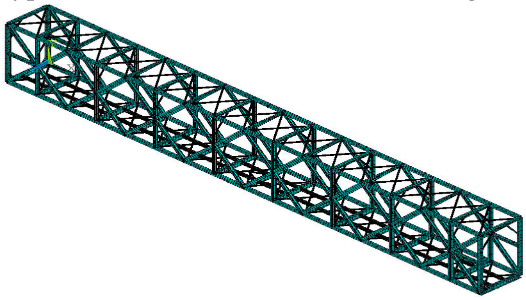

Figure 1 Finite Element Model of 87-Type Beam (64m, Through Type)

2.1.3 Modality Calculation Analysis
As the basis of modal analysis, the vibration theory helps to find out vibration characteristics, which reflect the stiffness and dynamic characteristics, primarily evaluates the dynamic characteristics of bridge[7]. First 10 natural frequencies of five spans 87-type beams were calculated by the Block Lanczos method[8].

Table 1 First 10 Natural Frequencies of Five Spans of 87-Type Beams

Number	Natural frequencies (Hz)				
	64m	72m	80m	88m	96m
1	2.568	2.138	1.937	1.705	1.486
2	4.096	3.476	3.029	2.593	2.210
3	5.121	4.554	4.229	3.908	3.634
4	5.664	4.842	4.636	4.255	3.877
5	8.458	7.693	6.911	6.518	5.951
6	9.978	8.708	8.201	7.512	6.858
7	10.162	9.189	8.371	7.682	7.008
8	11.118	10.575	9.697	8.837	7.902
9	11.446	11.372	10.930	10.548	9.807
10	11.547	11.380	11.085	10.883	10.131

Results in Table 1 indicates that:

(1) First vibration mode of five spans of 87-type beams are lateral vibration, which means that the lateral stiffness is weak and it is necessary to pay more attention to lateral deformation of beam during the analysis of vehicle bridge interactions.

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(2) First mode lateral natural frequency of five spans 87-type beams (2.568HZ, 2.138HZ, 1.937HZ, 1.705HZ, 1.486HZ) meet the normative requirements of specification. First mode natural frequency and structural stiffness gradually decreases as the increase of span.

2.2 Vehicle Model

Vehicle model was carried out with 1 locomotive hauling 16 freight heavy load marshalling trains. The motor car adopts the type of DF4-type 6 axles locomotive, hanging 70kN/m uniform live load, the trailers adopts C70-type 4 axles freight cars. Dynamic response calculation of bridge under dynamic load is the main work of this research, therefore, it is reasonable to simplify and assume the model. For instance, the car's body, bogie and wheel-set were considered as rigid bodies, regardless their elastic deformations and six degrees of freedom were taken into consideration (contains nod, sway, shake head, rise and fall, side roll and expansion, etc). There are 33 degrees of freedom in motor car model and 17 in the trailer model[9].

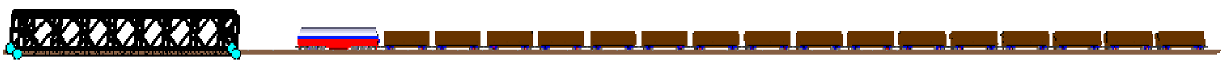

Fig.2 Vehicle-Bridge Interaction Model of 87-Type Beam (64m) with Heavy Load Marshalling Trains

3. Influencing Factors on Vehicle-Bridge Interaction

3.1 Influence of Operating Speed

After calculation of dynamic responses caused by the operating Heavy-haul trains on 87-type beam with a span of 64m the dynamic responses have been plotted in Figure 3-7.

Conclusions in Figure 3-7 show that:

(1) The mid-span lateral amplitude peaks of different speeds were not in the range of code value, defined by Code for Verification Regulation of Railway Bridge, which indicates it was not reasonable to evaluate the rush-repair beam by the code[10]. The results also proved the conclusion that the lateral rigidity of 87-type beam was weak and it was important to mind the lateral deformation of the girder. The lateral amplitude generally increases as the speed increases from 10km/h to 40km/h, then decreases as the speed increases from 40km/h to 60km/h.

(2) Mid-span vertical amplitude is in the range of code value although it increases as the speed grows.

(3) Derailment coefficient, rate of wheel load reduction and lateral force of wheel are the main three factors which influence the safety of train operation on the rush-repair beam. Rate of wheel load reduction reaches the top of the code value when the speed is 45km/h which can be regarded as the highest recommended speed on 87-type beam with a span of 64m.

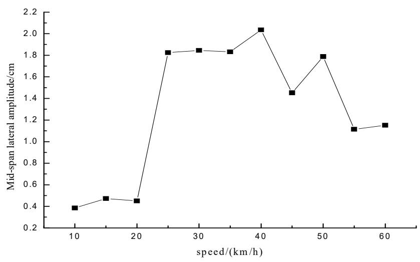

Fig.3 Mid-span Lateral Amplitude of Different Speeds

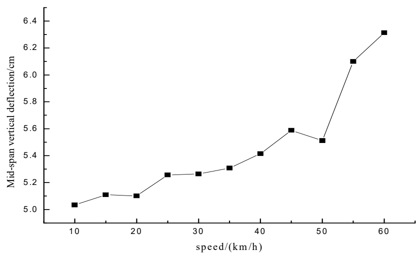

Fig.4 Mid-span Vertical Deflection of Different Speeds

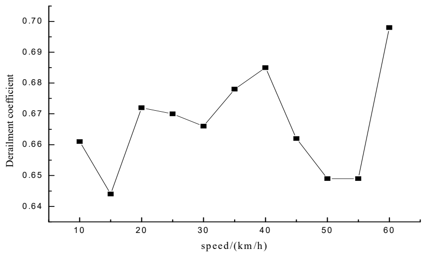

Fig.5 Derailment Coefficient of Different Speeds

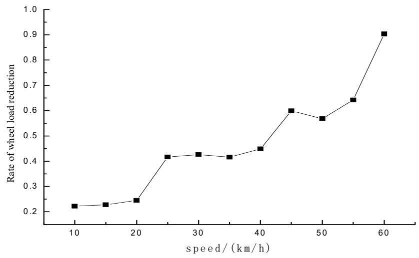

Fig. 6 Rate of Wheel Load Reduction of Different Speeds

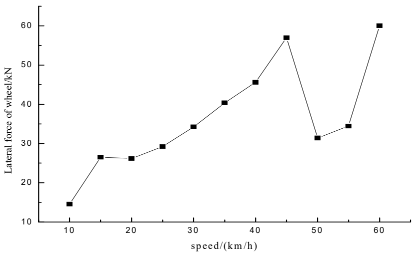

Fig.7 Lateral Force of Wheel of Different Speeds

3.2 Influence of Bridge Span

After calculation of dynamic responses caused by the 5 different spans of 87-type beams, the dynamic responses have been plotted in Figure 8-11, when the operating speed is 15km/h.

Conclusions in Figure 8-13 indicate that

(1) The flexibility of the bridge increases with the growth of span which causes the increase of lateral and vertical dynamic responses at the specific speed.

(2) The rate of wheel load reduction increases with the growth of span and reaches peak at a span of 96m. In order to insure the safety of the train, speed reduce is necessary.

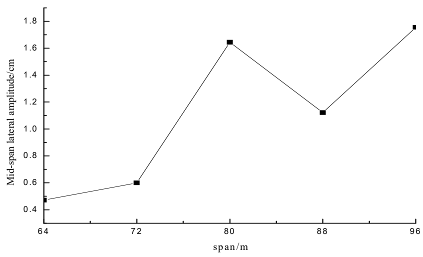

Fig.8 Mid-span Lateral Amplitude of Different Spans

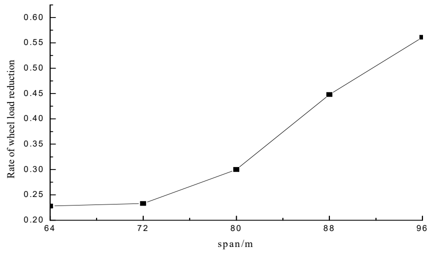

Fig.9 Mid-span Vertical Deflection of Different Spans

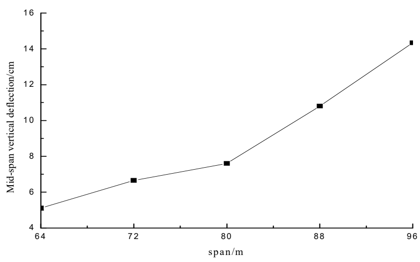

Fig.10 Rate of Wheel Load Reduction of Different Spans

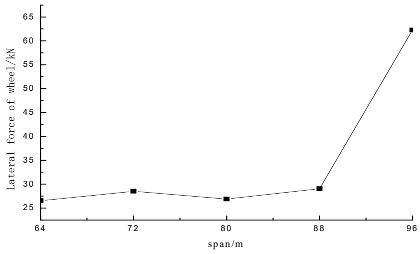

Fig.11 Lateral Force of Wheel of Different Spans

3.3 The Safe Speed Simulation Results of Different Spans

Table.2 Five Different Spans 87-Type Beams Recommended Speed

Span	Limit speed/(km/h)	Operating speed/(km/h)	Analysis index	Result	Recommend ed speed/(km/h)
64	40	45	Rate of wheel load reduction	0.599	40-45
72	40	35		0.629	30-35
80	40	30		1.000	25-30
88	15	18		0.824	15-18
96	15	12		0.915	9-12

4. Conclusion

(1) Lateral and vertical dynamic responses mostly reach peaks at the mid-span.

(2) Vertical dynamic response of the specific span grows as the speed accelerates， so as the rate of wheel load reduction and the lateral force of wheel, while the peak of lateral dynamic response appears in some parts.

(3) The vertical dynamic response increases overall as the span increases with a same operation speed.

(4) The recommended speeds are showed after the simulation. The speeds are in the range of code value mostly and decrease as the span grows.

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