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Evaluation of a steel railway bridge for dynamic and seismic loads

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ABSTRACT

In this study, dynamic and seismic assessment of a railway bridge system with four discrete spans giving service on a double track railway line and located in an earthquake-prone region in Turkey is presented. A three-dimensional computer model of the bridge was generated using a commercial general finite element analysis software. Field measurements such as static and dynamic tests as well as material tests were conducted on the bridge system. Validation of the finite element model was performed based on the results of these tests. The calibrated 3D model of the bridge structure was then used for necessary calculations regarding structural assessment and evaluation according to train loads as well as seismic loads. Additional members were proposed to transmit seismic loads to supports. The fourth span, which had a permanent imperfection due to truck collision was studied in detail. Results have shown that due to excessive amount of capacity loss, the only choice was to write off the fourth span.

1. Introduction

Most existing railway bridges giving service on current railway networks may not be capable of carrying the heavy vehicles of modern traffic, although no apparent signs of structural deficiencies are observed. However, studies demonstrate that there are large differences between the actual load carrying capacities of bridges and those predicted by conventional theory. To get the maximum use out of a bridge, its assessed load carrying capacity should be safely close to its actual resistance. For evaluating the safety of a bridge, safety index and rating factors are used. Actual reduced capacity of deteriorated members and the maximum loading due to the most critical composition and volume of heavy traffic that may be projected for the future affect these two safety parameters.

Assessment of a railway steel truss bridge by using a validated computer model that was developed based on dynamic field measurements and laboratory tests was conducted by Ermopoulos and Spyrakos [1] under heavier train loads as well as seismic and wind loads with regard to current design codes. In another experimental and analytical study of a historic railway bridge by Spyrakos et al. [2], seismic and wind load carrying capacities of the bridge were evaluated based on the analytical model validated with static and dynamic field measurements and laboratory tests. Schlune et al. [3] proposed a methodology for finite element model updating for improved bridge evaluation and this methodology was applied to one of the world's largest single-arch bridges. For numerous existing small and medium single span ballasted railway bridges in Austria, dynamic field measurements were performed by Rebelo et al. [4] and the calibration of the finite element models of these bridges was carried out using the measured modal parameters. Calcada et al. [5] conducted the experimental and numerical dynamic analyses of Luiz I Bridge, an old arch and double-deck iron bridge in Lisbon, to obtain an experimentally calibrated finite element model of the bridge structure. Full-scale ultimate load tests were carried out by Maragakis et al. [6] on a typical ballasted railway bridge, located in Los Angeles, to identify the contribution of bridge components during a seismic event. Chajes et al. [7] presented results of experimental load tests on a three-span, steel girder-and-slab bridge and generated a finite element model of the main span using the measured response of the bridge and using this calibrated model, various load ratings for the bridge were determined. Wang et al. [8] summarised a condition assessment procedure for bridges based on a complete system of field-testing, finite element modelling and load rating. A study was conducted by Akgul and Frangopol [9] on the rating and system reliability-based lifetime evaluation of a number of existing bridges within a bridge network, including pre-stressed concrete, reinforced concrete, hot-rolled steel and steel plate girder bridges. Itani et al. [10] discussed the behaviour of steel plate girder bridges during recent earthquakes and the experimental and analytical investigations that were conducted on steel plate girder bridges and their components. Results of these investigations show the importance of shear connectors in distributing and transferring the lateral forces to the end and intermediate cross frames.

In this study, assessment of a railway steel bridge was conducted for train and seismic loads according to relevant specifications. A three-dimensional computer model of the bridge was generated and validated based on dynamic field measurements and laboratory tests. The calibrated 3D model of the bridge structure was then used for necessary calculations regarding structural assessment and evaluation.

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Fig. 1. A general view of the bridge.

2. Description of the bridge

The bridge is located approximately 10 km from historical Sirkeci railway station which is the starting point of Europe-directed railway track in Istanbul. It was designed and built in late 1960s by TCDD (Turkish Railways Administration) which is the governmental authority of the country. The bridge is situated in metropolitan area of the city and is subject to heavy traffic of passenger transportation, mainly suburban commuter trains. As shown in Fig. 1, the bridge is composed of four simply supported spans, each with riveted steel plate girders, an open deck, stringers and cross beams. The layout of the bridge is given in Fig. 2. Each span has a length of 13.5 m.

The railway bridge passing over the divided two-way street has been damaged due to truck collisions caused by overloaded trucks passing underneath. Most of the damage has occurred on the lateral cross bracing system of almost all four simple spans (see Fig. 3), the fourth span also has damage at the upper and lower flange of its main girder. However, there is almost no damage on the main girders at other spans. This damage in the fourth span main girder has resulted in a permanent imperfection of maximum 12 cm of lateral deformation at the midspan, as shown in Fig. 4.

3. Material tests for steel

Tension and Charpy-V-notch impact tests were conducted on specimens extracted from damaged horizontal braces.

Table 1
Results of tension test.

Specimen no.	Yield strength (MPa)	Tensile strength (MPa)
1	212.6	367.2
2	239.9	389.7
3	239.7	389.2
4	264.2	405.9
Mean value	238.1	388.0
Standard deviation	21.1	15.9
Nominal value	217.0	372.1

Table 2
Charpy-V-notch test results.

Specimen no.	Charpy-V-notch energy (J)
1	40
2	40
3	43
Standard deviation	1.73

3.1. Tension test

Four specimens were used during tension tests. After having prepared the specimen according to ASTM standards [11], tension tests were conducted to identify the material quality used in construction. Results are presented in Table 1. As is seen from the evaluation of the data from Table 1, bridge material can be classified as S235 quality structural steel.

3.2. Charpy-V-notch test

Charpy-V-notch tests have been conducted for the three specimens taken from the bridge members at room temperature. Test results are given in Table 2. It is clearly seen that obtained results are quite satisfactory.

4. Field tests

Free vibration and quasi-static tests were conducted on bridge spans to understand the actual behaviour of the bridge superstructure. Member sizes were also checked and verified according to constructional drawings.

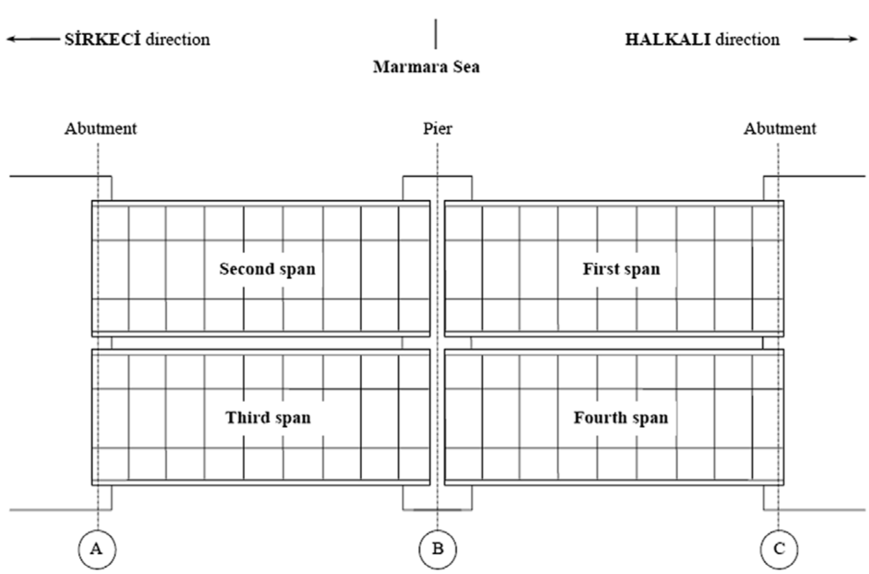

Fig. 2. Layout of the bridge.