DYNAMIC BEHAVIOUR OF STEEL TRUSSED RAILWAY BRIDGES DUE TO THE PASSAGE OF HIGH SPEED TRAINS

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1 ABSTRACT

During a recent involvement in the design of the Taiwanese High-Speed Railway a series dynamic analyses of three steel truss bridges was performed. The object of this paper is to present:

A brief report on the the dynamic analysis of these steel truss bridges consisting of one single span bridge (65m) and two three span bridges (60m/70m/60m and 150m/120m/140m respectively) with special emphasis on the applied design checks associated with dynamic effects and train-bridge interaction.

- A discussion on the differences between the Taiwanese and the European regulations.
- Various issues related to the computer modelling of these structures.
- An example of structural modification of one of the bridges to ensure that the vertical accelerations remain within the allowable limits.

The evaluation of the dynamic effects in these bridges due to moving loads and masses will be presented. Certain modelling issues will be discussed including possibilities for modelling the train loading on the bridge, choice of valid time steps and a validity check of the dynamic analysis for the single span steel truss bridge. The selected modelling solution is presented.

As a result of the performed analyses modifications to one of the bridges were deemed necessary in order to comply with the design rules. The presented detailed numerical study therefore revealed that certain dynamic characteristics of these particular bridges, namely the vertical acceleration, can have an influence on the design. Design checks were carried out according to the Taiwan High Speed Rail Criteria. A brief comparison to the relevant European rules is given.

2 INTRODUCTION

Currently the new Taiwan High Speed Rail line between Taipei and Kaohsiung is under construction and will be completed in the near future. The civil engineering work is almost completed. In 2005 the first trains will start service as scheduled. Within the total length of 354km there are 242km of Bridges. A dynamic analysis of all bridges along this line had to be performed in accordance with the Taiwanese design specifications [1]. Due to the maximum operating speed of 300km/h a multitude of dynamic effects [5,6] had to be investigated to ensure traffic safety. A number of these investigations were performed by TDV, Austria. This paper presents results stemming from the analyses of three steel truss bridges with different span arrangements. Some modelling issues will be and a case study of a required design modification due to dynamic effects will be presented.

Fig. 1: Launching of a 3-span truss bridge.

3 INVESTIGATED BRIDGES

Table 1 gives some properties of the bridges reported on in this paper. All bridges analysed for this investigation are steel trusses with composite decks with one and three spans. A typical cross-section (Bridge #1) is shown in Fig.2. System sketches for the on-span bridge and one of the tree-span bridges are shown in Fig. 2 and Fig. 3 respectively. Bridge #2 is situated near a railway station and broadening from two to three lanes was necessary. All considered bridges were part of a system of bridges with adjacent structures on each side sharing piers. These bridges were modelled to a high degree of detail taking special care to accommodate requirements of dynamic analysis. Damping was assumed according to the specified design code [1]. The value for damping in Bridge #1 (Table 1) differs from the other structures which will be explained later.

Table 1: Some properties of the investigated bridges.

#	spans [m]	lanes	design Speed [km/h]	damping [%]	width [m]
1	65	2	350	2.25	11.95
2	60/70/60	2 to 3	350	0.80	11.56-18.75
3	150/120/140	2	350	0.80	11.50

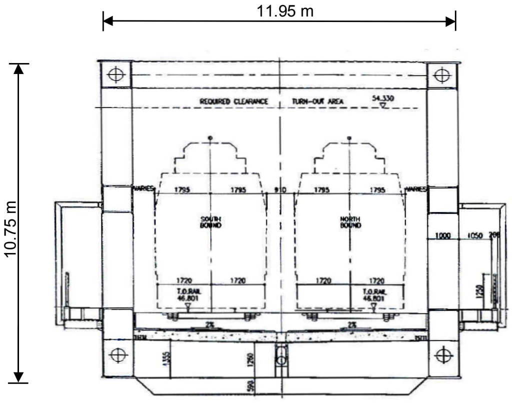

Fig. 2: Typical cross-section.

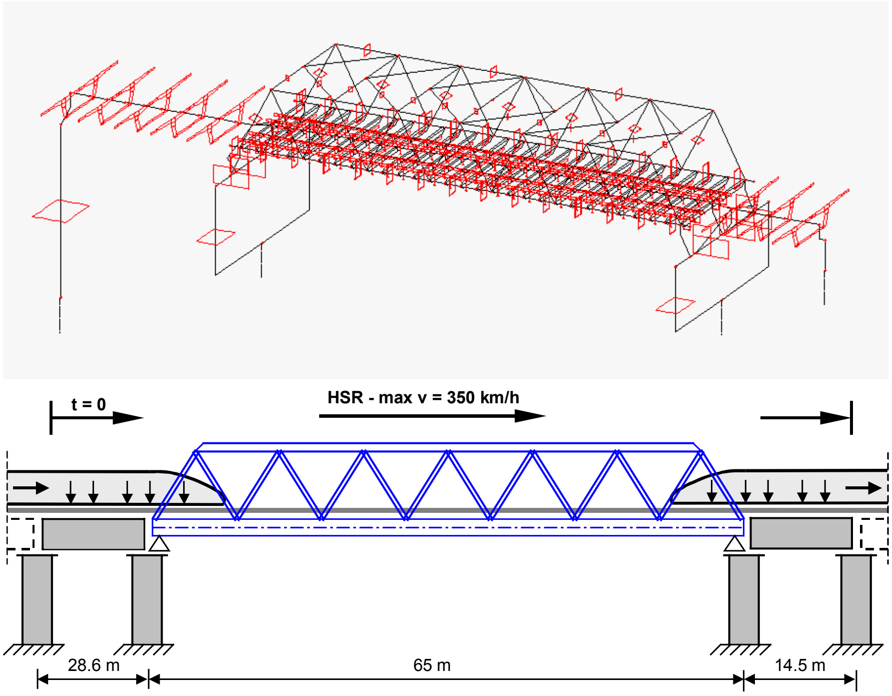

Fig. 3: Computer model and system sketch of Bridge #1.

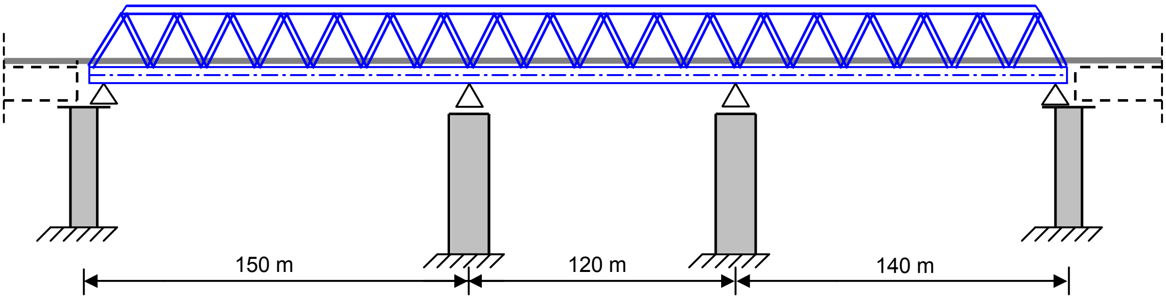

Fig. 4: System sketch of Bridge #3.

4 DESIGN CODES

Dynamic analyses of the structural response of high-speed trains passing over the described bridge structures were performed according to Taiwanese design specifications [1]. The three limiting conditions in this code are:

- Vertical acceleration of the bridge structure < 3.43 m/sec^2.
- The variation of the induced cant < 0.4 mm/m by transverse rotation of the bridge (upon a base of 3m longitudinally).
- End rotations must not exceed certain limits, depending on the connection of the main structure with the adjacent spans and on the type of the rail support (ballast or slab tracks).

Unless otherwise justified, structural damping of 2% for steel structures, 2.5% for pre-stressed concrete structures and 4% for reinforced concrete structures shall be used in conducting the dynamic analyses according to [1]. Loading is simulated by one standard loading train with given axle loads and distances as shown in Fig.5.

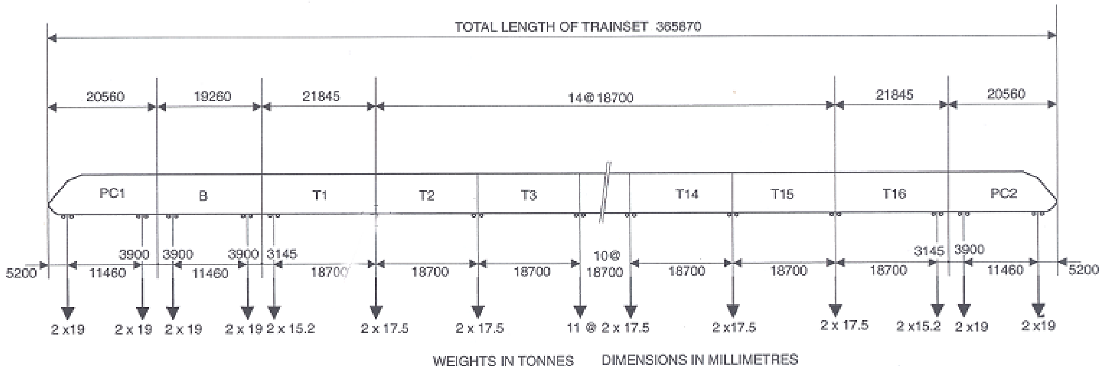

Fig. 5: Taiwanese high-speed train loading specification.

The existing Eurocode [2,3] goes into more detail than the Taiwanese specifications. In addition to the above-listed criteria the following topics are regulated in the Eurocode:

- Checklist whether dynamic analysis is required for a given structure.
- The loading and load combinations are based on a range of different loading train definitions and depend on the actual structure.
- The range of train velocities to be considered in a dynamic analysis.
- The variation of structural bridge parameters (eg. damping, mass, stiffness).
- Guidance on the modeling of the excitation and the dynamic behavior.
- Verification of the limit states.
- Additional checks against fatigue failure and horizontal displacement.
- Limit of maximum vertical deck acceleration 3.5m/s^2; limit of variation of cant depends on train velocity, limit of allowable end rotation depends on train velocity and number of lanes.

In cases where the Taiwanese specifications did not provide guidance Eurocode regulations were used for the described analyses.

5 MODELLING

The structural systems for all bridges reported on in this paper and the adjacent spans were modelled as space frames with the composite deck represented by a grillage. A proprietary software system for the design and analysis of bridge structures called RM2000 [4, 7, 8] was used for all analyses described in this paper. Some typical cross-sections used in the numerical models of the three bridges are shown in Fig. 6. The mass definitions of the superstructure were modelled with lumped masses with three degrees of freedom associated with the bridge girder nodes. Adjacent spans were included in the model in order to account for vibrations transmitted via the common piers on both ends of the structures and also to provide data for the end rotation check. The moving load model defined in the Taiwanese specifications (Fig. 5) was adopted for the presented analyses. No moving masses had to be considered. For the present study a range of train velocities between 150km/h and 350km/h was considered. Rayleigh damping was adopted and was calibrated to the damping values for steel bridges according to [1] for the first two eigenfrequencies (eg. Fig.8) [5].

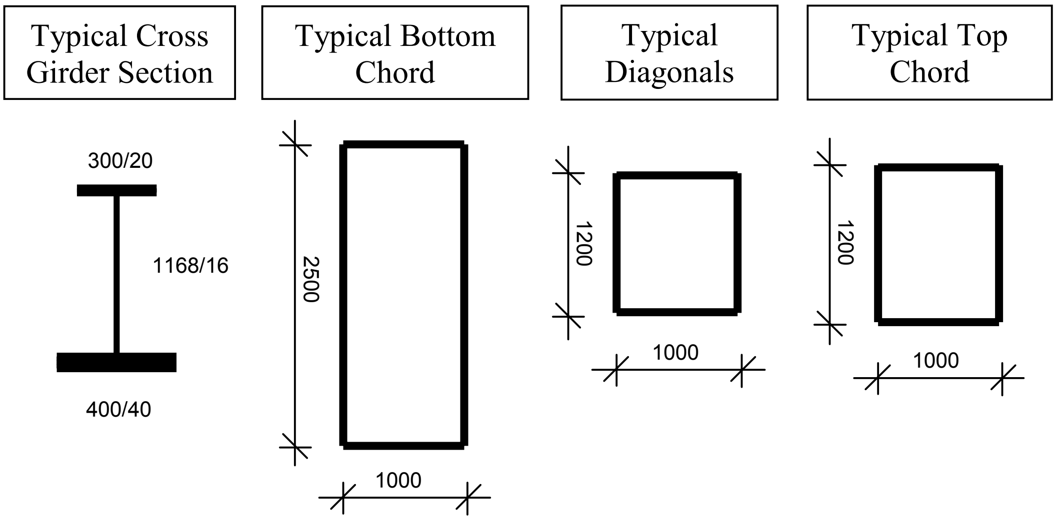

Fig. 6: Typical cross-sections of bridge model.

Features for modal analysis as well as a Newmark time integration scheme [9] are implemented in RM2000 and have been used for the described analyses. The investigation focused on four governing factors for each bridge: (1) maximum vertical acceleration of any point on the bridge; (2) maximum variation of cant along the railway along the bridge; (3) maximum end rotation at the supports; (4) horizontal displacements of the bridge. The time-dependent response of discrete points on the structures were computed and the maximum values were filtered out of the resulting time histories.

Various checks were performed in order to validate the results of the dynamic analysis. The comparison between static and dynamic analyses runs is shown in Fig. 7 as an example. On the right in Fig. 7 the time history for the vertical displacement of a structural node at mid-span for the passage of a train with a given velocity is given. For various loading positions of the axle loads during this passage a separate static analysis was performed. The vertical displacements of the same node calculated in these static analyses is shown as dots in the same figure. The two circled dots correspond to the two load positions shown to the right. It can be seen that in this particular case the vertical displacement increases by up to 30% due to dynamic effects.

Furthermore, a simple moving mass model was developed for the analysis of Bridge #2. Extra care had to be taken in the modelling of these structure to accommodate the effects caused by this extra feature. In this particular case the differences in the results from this moving mass model differed only slightly from the results generated by the moving load model and this modelling approach was not pursued any further.

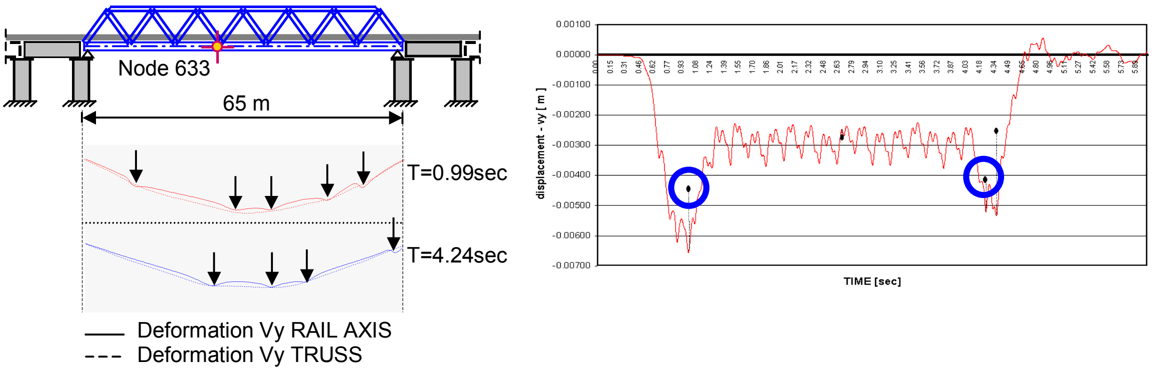

Fig. 7: Comparison dynamic-static results.

6 RESULTS

The lowest 20 eigenvalues were computed and the critical vertical and torsional eigenmodes were determined (Fig. 8). The time dependent response of discreet points on the bridge structure was computed and the extreme values were recorded. The computed values for the maximum variation in cant and the maximum end rotations never reached critical levels during the analyses. However, results for maximum vertical acceleration during a train passage exceeded the limits given in the Taiwan HSR regulations [1] in the case of bridge #1. Upon closer inspection it was apparent that the steel cross girder elements significantly affected the dynamic properties of Bridge #1. As a remedy the cross-section of the cross-girders was modified until the design criteria could be (just) fulfilled as illustrated in Fig. 9. It was also argued, that the bridge is a combination of a steel structure and a composite structure and therefore a less conservative value for damping could be adopted.

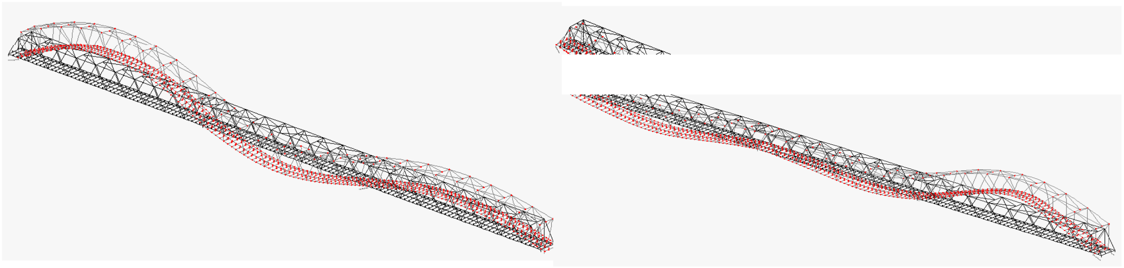

Fig. 8: First two vertical eigenmodes of Bridge #3: 1.05Hz and 1.29Hz.

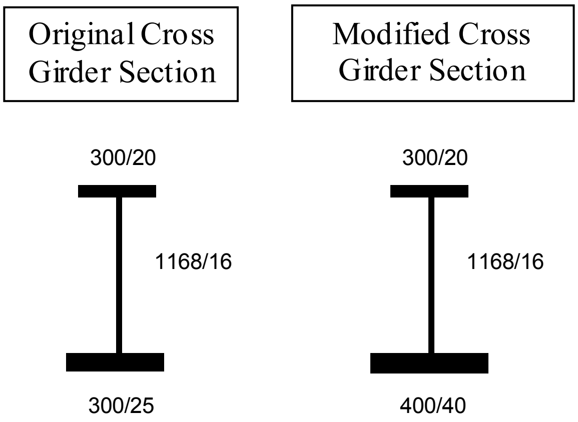

Fig. 9: Modified cross-section of cross-girder.

Table 2 gives a summary of the extreme results for the three bridges reported on in this paper after the modifications for bridge #1 were adopted.

Table 2: Results for the investigated bridges after design modifications.

#	maximum acceleration $[m/s^2]$	allowable acceleration $[m/s^2]$	end rotation v<350km/h [radian]	variation of cant v<350km/h
1	3.431	3.433	ok	ok
2	3.004	3.433	ok	ok
3	2.574	3.433	ok	ok

7 CONCLUSION

Three high-speed railway bridges to be built in Taiwan were analysed with regards to their dynamic behaviour during train passage. Taiwanese specifications were used for these analyses. All bridges in this investigation were steel trusses with composite decks. It was found for one bridge, a simply supported structure, the dynamic effects made a change of the initial design necessary. These design modifications are documented. A brief comparison of the Taiwanese regulations and the existing Eurocode concludes the material presented in this paper.

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KEYWORDS
high-speed railway, steel truss bridge, dynamic analysis, moving load, rolling stock