ICCES, vol.13, no.2, pp.43-47

Role of distortional and warping stiffness of end regions at 3D performance of concrete bridges

Z. Bittnar, L. Vrablik, M. Polak, V. Kristek[1]

Summary

Detail structural and dynamic analysis of concrete suspended bridge structure in Prague which was assessed because of severe damages of parapets and expansion joints is presented. Measured and calculated results are compared and approaches to repairing and stiffening are also recommended.

keywords: Suspended bridge, structural and dynamic analysis, stiffening

Introduction

The principal significance of the research for bridge design practice consists in that the results of the appropriate solutions and the developed analytical and design methods will help creating the sufficient theoretical tools for reliable and economic structural design of prestressed concrete box girder bridges, enabling great economy of materials, energy and costs and their better utilisation and offer objective and effective tools increasing in the same time the level of durability and efficiency of concrete box girder bridges. The achieved results enable not only to avoid long-time serviceability problems, but also possibly other serviceability impairments.

Generally, at 3D performance of box shaped bridges, besides the common flexural action, the following characteristics phenomena appear:

- Torsion – characterized by the angle of twist or by the unit angle of twist
- Warping - the cross sections are do not remain plane
- Distortion – deformation of shape of cross sections, depending on transverse flexural (frame) stiffness of cross sections and on location and stiffness of diaphragms

Distortional and warping stiffness relations of end regions play very significant role at the three-dimensional performance of suspended concrete bridges. Traditionally, box girders have been analyzed according to the simplified classical engineering theory of bending in which the cross sections are assumed to remain plane. It is obvious that the three-dimensional analysis, which is much more realistic than the beam analysis, has to be applied to capture the above mentioned effects of box girders accurately.

Intensity of distortional and warping effects depends mainly on overall arrangement of a bridge structure and on manner of application of concentrated loads. To

---

[1] CTU in Prague, Faculty of Civil Engineering

demonstrate their significance, a three-dimensional analysis of an outstanding suspended bridge over railway station in Prague-Vrsovice was performed. The bridge - carrying extremely heavy traffic loads - is in service since 1997 and severe damages at end regions of the bridge were observed in 2008.

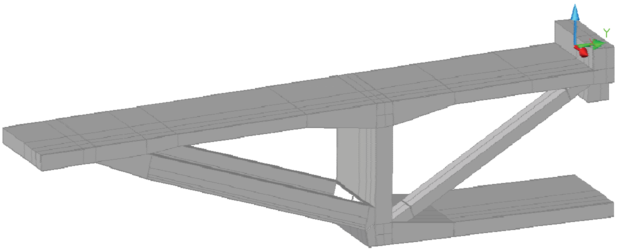

Figure 1: Computational scheme of cross section

The suspended bridge of the total length 400.4 m has structural arrangement formed as a continuous beam having 9 spans. The main part of length 102.2 m is arranged as a suspended bridge with a bulky pylon and 14 pairs of cables. The spine box beam (Fig. 1) has long cantilevers supported by a system of individual independent skew supporting plates which are able to carry the compression forces only, without any capability to transfer shear flows corresponding to torsion and to contribute to the distortional stiffness which is thus produced solely by the relatively small and shallow spine box beam alone.

The structural performance of damaged end regions very significantly depends on provision of sufficient distortional and warping stiffness above supports. Unfortunately, only a thin wall of brickwork was embedded in the box section end cross section (Fig. 2).

Figure 2: “Stiffening” of end cross section by thin masonry wall

Structural and dynamic analysis

The structural performance of the bridge was analyzed by shell finite elements, essential for capturing the three-dimensional character of the bridge arrangement. Such an analysis was carried out with a commercial finite element program - the software SCIA Engineer has been chosen. The plates of the cross section were subdivided into isoparametric elements extending through the whole thickness of the plate (slab of web). Special attention was directed to model end parts of the structure, special function of plates supporting cantilevers and strongly non-linear performance of cable stays. As an adequate approximation under short-time service conditions, concrete and steel can be assumed to follow linear elasticity; the three-dimensional generalization was obtained assuming material isotropy.

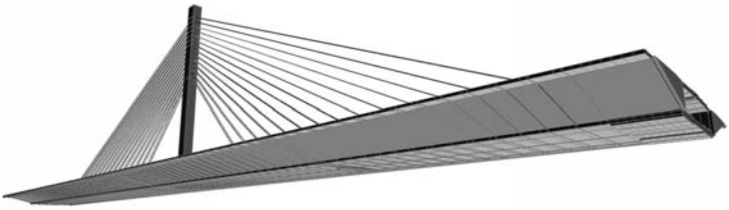

Figure 3: Computational model

Several structural arrangements and loading case were investigated:

- The influence surface of deflection at the corner of the structure in the present state (i.e. with weak end parts without appropriate stiffness). It is seen (Fig. 4) that high values of the influence surface appear also in very distant locations from the corner, thus indicating an extreme flexibility of such a structural arrangement – loads distant from the corner produce significant deformations at the corner.

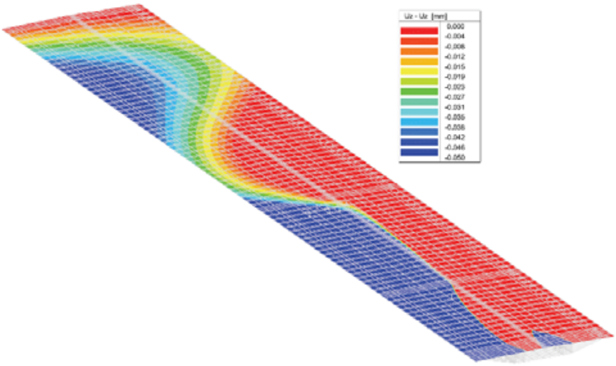

Figure 4: The influence surface of deflection at the end corner

- The structure in the present state loaded by a vehicle (260 kN) located in the position producing the extreme deflection at the corner (assuming material characteristics: Young modulus E = 39 GPa and Poisson ratio $\nu = 0.15$).

Excellent agreement between obtained deflection values as well as the shape of deflection surface was achieved, proving reality of the applied structural idealization of the bridge arrangement.

- The structure in the present state under the load system of according the standard, located to produce the extreme deflection at the corner. The deflection reached the high value of 7.3 mm (Fig. 5).

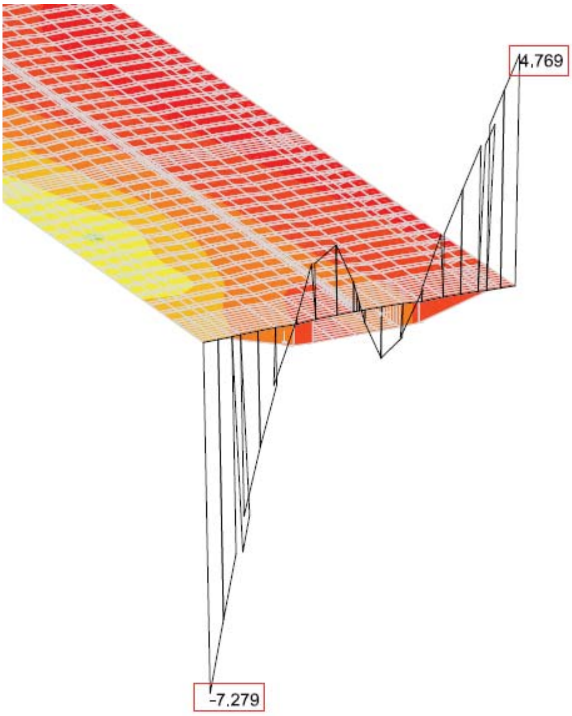

Figure 5: Deflection of the structure

- The structure complemented by an additional stiffening of the end region applying a bulky diaphragm at the end cross section resisting to distortional as well as to warping tendencies, under the load system of according the SI standard, located to produce the extreme deflection at the corner; the deflection was suppressed to value of 1.8 mm only.

It can be concluded from the presented results that the sensitive end region of the bridge is affected by repeated deflections whose only the statical component can reach 7.3 mm; this value will be considerably amplified due to dynamic effects of moving vehicles, being excited by the jump between the quite stiff abutment and the very deformable end region of the bridge. This will necessarily be a cause of harmful impacts on the bridge condition, durability, making many serviceability impairments.

Conclusion

The structural analysis results were compared with measurements (loading test of the structure by lorry crane with total weight 26t). The results confirmed low stiffness of the end part of the bridge.

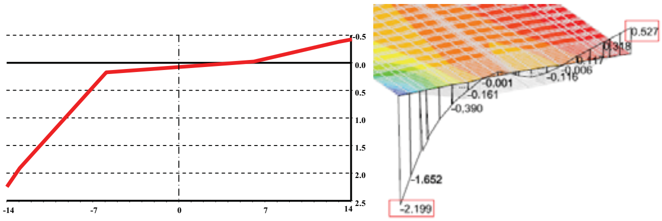

Figure 6: Comparison of analysis results and measurements

It is important to make an additional stiffening of the structure to ensure long term serviceability of the bridge.

Acknowledgement

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No.1M680470001, within activities of the CIDEAS research center. The support of the Grant Agency of the Czech Republic Grant Project 103/08/1677 is also gratefully acknowledged.