DYNAMIC PROPERTIES OF INCLINED ARCH FOOTBRIDGE WITH FRP DECK

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Summary

This paper summarizes MSc thesis presented on 23.06.2004 at Institute of Roads and Bridges, Warsaw University of Technology under supervision of prof. H. Zobel. Paper covers dynamic design and optimization of the steel arch pedestrian bridge with composite polymer deck. Presented work is effect of additional studies which were aimed in enhancing the comfort of pedestrians due to dynamic properties of the structure.
A new footbridge over national road S-11 was designed by an architect to constitute a landmark for drivers. The proposed structure consists of inclined arch main span and several access ramps. The arch girder is designed as a bent steel pipe with diameter 1200 mm. The span of the arch is 40.0 m and inclination is 17°. Visualizations of footbridge are presented in Fig.1. The investor requested also a FRP deck on the main span which yielded several design problems. Some aspects of the design studies are presented with description of respective analyses. A special attention was paid to the dynamics, particularly actions induced by pedestrians and impact loading from air flow of trucks passing underneath. Description of used analysis procedures is content of next two parts of this paper
The paper is divided into two major parts related to two classes of dynamic actions on the footbridge. First one is related to pedestrian induced vibrations while the second covers related to dynamic actions due to air impact from trucks traveling underneath.

Fig. 1 Visualizations of the complete footbridge and FEM model

The pedestrian loading was assumed to be situated at frequency window of 1.6-2.4Hz. However, the first version of the footbridge had first natural vibration frequency of 2.01Hz. Rayleigh formulation of vibration problem (energy based) was used to develop a method of adjusting mass and stiffness distribution within the structure. Kinetic and strain energy localizations were obtained for strategic mode shapes, what allowed for precise selection of modified elements. The modifications included filling steel arch tube with concrete up to a certain level and managing main elements cross-sections in order to obtain requested stiffness while meeting structural static design criteria. The developed method of mass and stiffness adjustment may be used for arbitrary structure if a proper FEM model is available. The FEM model of footbridge structure was made with SOFiSTiK software (Fig. 2)

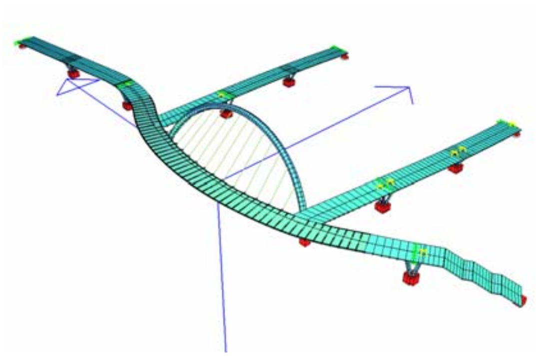

Fig.2 Structural FEM model

The dynamic effect associated with loading from compression wave traveling with truck passing under the footbridge was studied. While this kind of loading is not found considered by any loading code, it was noted (Firth, Footbridges 2002) as a possible barrier for making footbridge decks very lightweight. 2D and 3D transient CFD calculations with moving meshes were performed using Fluent 6.0 CFD software. Two truck - trailer configurations, three truck speeds, three structural clearances and three configurations of truck convoys (for periodic excitations) were studied. A selected loading case was evaluated with transient structural dynamics solver (SOFiSTiK Dyna) for estimation of accelerations and displacements of footbridge deck. The resulting accelerations were considered noticeable but not critical for pedestrian comfort ($0.33 m/s^2$ peak vertical acceleration)

Conclusions

An effective procedure that helps designer in tuning natural frequency of structure is presented. Application of this procedure in footbridge design allows easy solution to problems of resonance with pedestrian loading. Most commercial FEM systems can be easily adapt to extract mode shapes and internal forces from mode shapes. When properly implemented, this procedure might be a worthy addition to footbridge designer's toolbox.

The impact from compression wave of traveling truck has been quantitatively estimated. Following numerical simulations showed that accelerations of maximum peak amplitude of $0.33 m/s^2$ can be observed due to truck passing under footbridge. This level of accelerations is perceptible by pedestrians but it is not unacceptable. Several possibilities of reducing this effect are presented within parametric study. Full scale testing with dynamic pressure transducers is advised to verify predictions of CFD code.

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