Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 82 (1999)

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DOI: https://doi.org/10.5169/seals-62167

Dynamic Characteristics of Two Newly Constructed Curved Cable-Stayed Bridges

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Abstract

In the last decade, cable-stayed bridges have become more common for both medium-sized (120–300 m) and long-sized (300–800) spans and a large number of these bridges was built in Europe, Japan and North America. As a consequence of the increasing diffusion of cable-stayed bridges, significant attention was also focused on the dynamic behaviour of this kind of structures subjected to wind loads and earthquakes. In most publications the dynamic behaviour of cable-stayed bridges was investigated by using finite element or other theoretical models whereas a limited number of dynamic tests was conducted on full-scale cable-stayed bridges in order to directly estimate the modal parameters and to asses the accuracy of current analytical models.

Theoretical and experimental investigation of a couple of curved cable-stayed bridges is described in the paper. The analysed bridges (Fig. 1) were recently erected in Italy and are part of the road system carrying the traffic to the air terminal of the Malpensa 2000 (Milan) airport from the neighbouring highways. Each curved bridge girder has a centreline length of 140 m with two equal spans which are supported from the pylon by two sets of 2 stay cables. All the stay-cables are composed of strands having from 33 to 77 parallel wires, each of 15.7 mm (0.6″ super) diameter; the shorter stays (33 wires) are 27 m long while the length of the longer ones (77 wires) is 47 m. The cast-in-place concrete tower is A-shaped and 36.87 m high. The deck is a five-cell box concrete girder (11.75 m wide and 1.35 m high) which was cast in place and post-tensioned; the girder has 6% longitudinal slope and 4% transverse slope. The design of the tested bridges follows the tendency, which is actually growing in Italy, to use cable-stayed bridges for relatively short spans (60–150 m) with limited height of the deck since this kind of structures had proved to be quite stiff for traffic loads, aesthetically appealing and relatively simple to erect in few time. It is worth underlining that the two bridges are in principle perfectly equal; furthermore, their unusual geometric layout provided a strong motivation to choose these particular systems for dynamic testing.

The experimental program of field tests was conducted in three days (for each bridge) and included both traffic-induced and free vibration measurements which were recorded at a rate of 200 Hz using piezoelectric accelerometers. The main objectives of the tests were: (a) to identify principal modes of vibration of the structures using ambient vibration tests; (b) to assess the accuracy of modal parameters estimated from ambient vibration survey using free vibration tests; (c) to compare the modal behaviour of the bridges; (d) to correlate computer models with experimental results. In the paper, mainly the points (c)-(d) are addressed.

a)

b)

c)

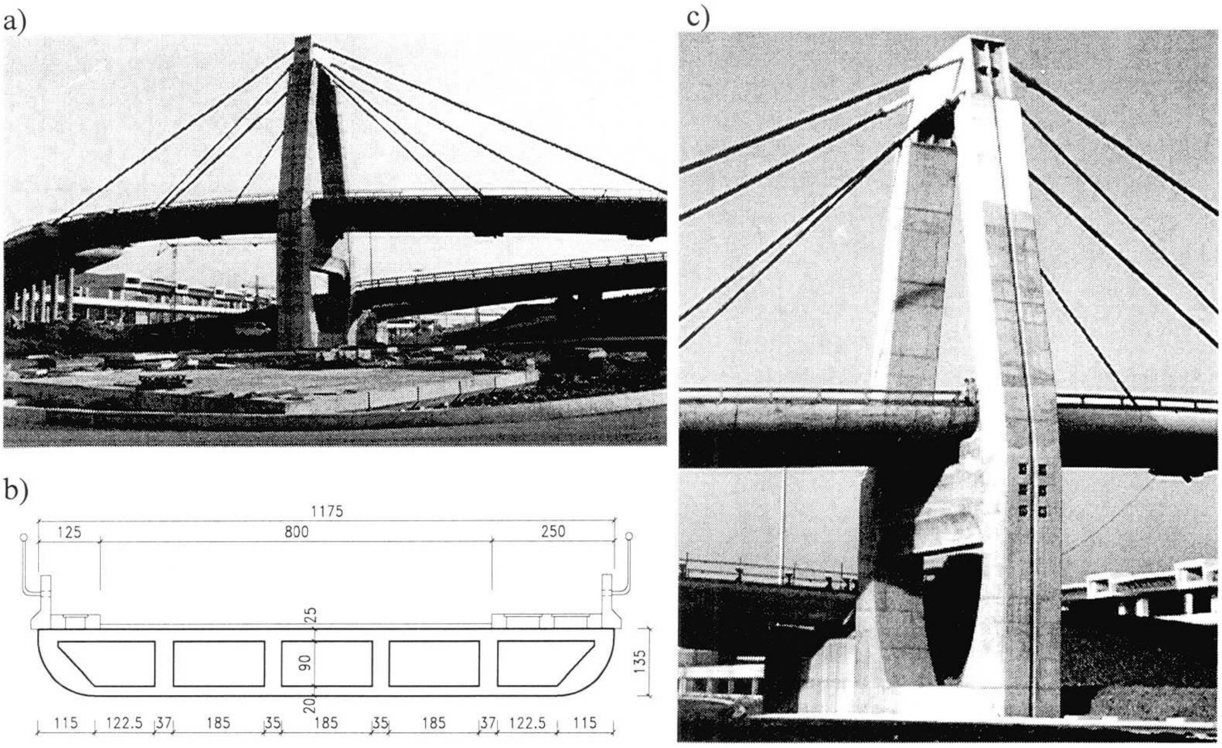

Figure 1. a) View of the north-side bridge; b) Cross-section; c) View of the tower

For both bridges, 11 vibration modes were identified from ambient vibration survey in the frequency range of 0–10 Hz. The identified modal behaviour was strongly dominated by the vertical components (either pure bending or torsion) being the ratio of the maximum vertical and transverse modal amplitude of the deck always greater than 5.0.

The two bridges exhibit very similar mode shapes. The correlation between the corresponding mode shapes of the two bridges was investigated by using standard techniques such as *MAC* (Allemang & Brown, 1983), *NMD* (Waters, 1995) and *COMAC* (Lieven & Ewins, 1988). By comparing the natural frequencies and mode shapes of the two bridges, the following comments can be made:

1. there is a one-to-one correspondence between the observed vibration modes of the bridges, being the natural frequencies of the south-side bridge slightly higher than the corresponding ones of the north-side bridge. The frequency discrepancy ranges from 3.06% to 5.92%, with a medium value of 4.79%. Since the environmental conditions during the test of the bridges were controlled and nearly equal (ranging the temperature from about 11°C to 15°C), the above difference in natural frequencies is possibly related to structural behaviour;
2. the first two mode shapes are practically equal (being the *NMD* less than 3%) while the other modes generally exhibit an average difference of about 10%;
3. by examining the local correlation of mode shapes through the *COMAC* in order to highlight the locations where the two sets of mode shapes mainly differ, a nearly uniform distribution of values was found, ranging the *COMAC* between 0.980 and 0.996.

The nearly uniform distribution of discrepancies in both natural frequencies and mode shapes suggests that the differences of modal behaviour could be related to different elastic properties of the concrete in deck and tower of the two bridges. This hypothesis was confirmed by using experimental data to evaluate the optimal value of Young moduli of three-dimensional finite element models. Once the models were established, the structural parameters were refined in order to enhance the match between theoretical and experimental modal parameters. The basic difference between the two bridges was found to be related to the deck Young modulus. The optimal value of this parameter turned out to be about 30000 N/mm^2 for the north-side bridge and 34000 N/mm^2 for the south-side bridge while about the same value (40000 N/mm^2) was determined for the elastic modulus of the towers.