Finite element modelling and operational modal analysis of a curved cable stayed bridge in Venice

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Summary

This paper summarizes the analytical and experimental dynamic analysis carried out to assess the "as built" behaviour of a curved cable-stayed bridge, recently erected in the Commercial Harbour of Porto Marghera (Venice, Italy). The paper also aims to highlight that integrated CAD-FEA activity is especially suitable in modelling and investigating complex structural systems.
Keywords: cable-stayed bridge; operational modal analysis; finite element modelling.

1. Introduction

Among the few existing cable-stayed bridges with curved composite steel and composite decks, a new one was recently built in the Commercial Harbour of Porto Marghera (Venice, Italy). This bridge (figure 1) is also characterised by an inclined pre-stressed concrete pylon and a single set of cables with spatial arrangement.

The peculiar structural architecture of the bridge added significant difficulties in both accurate structural analysis and assessment of "as built" behaviour. The main goal of the paper is the development of a finite element (FE) model, including the available information on geometry and the characterization of materials, exhibiting appropriate correlation with the modal behaviour identified [5] during the reception tests so that the model could be adopted as a suitable "starting point" for procedures of systematic tuning [6] or structural identification [3], [7].

2. Description of bridge

The bridge includes six generally curved spans (42 m + 105 m + 126 m + 30 m + 42 m + 42 m) but only the two main spans are suspended by cable-stays connected to the centreline of the steel and concrete composite deck which has a total width of 23.70 m. All steel girders are 1.90 m high.

Composite action is achieved by an overlaying cast-in-place concrete slab (25-27 cm thick). The cast-in-place inclined tower is 75 m high (fig. 1). Pre-stressing action was introduced to reduce the eccentricity of the vertical dead load due to the deck curved layout and to the tower geometry itself. The tower is characterized by a triangular cross section that varies both its base and depth dimensions along the main longitudinal axis.

3. CAD and FE modelling

A smart strategy was adopted in order to model the bridge with as much detail as possible and to represent both the geometric and the structural form according to construction drawings. An appropriate CAD (fig. 2) model was first developed from the design drawings. subsequently the "geometric model" was refined in a FEA system to transform it in a real "structural model".

The model has a total of 4375 nodes and 5100 elements, namely 2946 beams, 18 trusses, 732 shells and 1404 bricks (fig. 2).

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4. Experimental results and correlation with the FE model

The reception tests of the bridge included ambient vibration survey [5]. Since the tests were performed before the bridge was opened to the traffic, two different series of ambient vibration data were recorded for each set-up: in the first series, the excitation was only provided by the wind and the micro-tremors while in the second series the traffic excitation was achieved by means of two-axle trucks, crossing the bridge with symmetric and eccentric passages. In the following, these two different series of ambient vibration data will be recalled as AV1 (micro-tremors and wind) and AV2 (simulated traffic). The output-only modal identification was carried out by using the Frequency Domain Decomposition [9] technique in the frequency domain (*FDD*), available in the commercial program ARTeMIS. As expected, several vibration modes were identified in the investigated frequency range from both the AV1 (fig.3) and AV2 data series. FE model implementation largely took into account the geometric and structural complexity of the viaduct. Main uncertainties are related to the actual behaviour of the constraints and to the Young's modulus of the concrete elements such as deck (E_D), piers (E_P), tower and basement (E_T). Hence, some preliminary dynamic analyses were performed to check the similarity between experimental and theoretical modal parameters. In these analyses, different values of Young's modulus, ranging from 34 to 42 were used. A first manual tuning provided the following values: $E_D = E_T = 40.0$ GPa; $E_P = 36.0$ GPa. The modal characteristics of the model are compared with the experimental data through the absolute frequency discrepancy $D_F = (f_{FEM} - f_{FDD})/f_{FDD}$. Details are given in the full paper. It was observed that, although a couple of experimental modes are not correctly reproduced by the model, the relative error between natural frequencies is rather small. In addition the measurement-based mode shapes and computed mode shapes exhibit a good match as well.

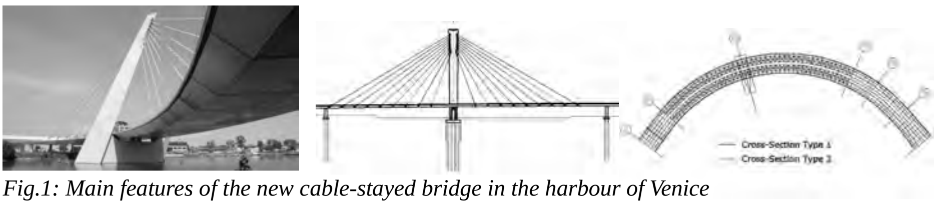

Fig.1: Main features of the new cable-stayed bridge in the harbour of Venice

Fig.2: CAD and FE model of the bridge

f_{FDD} = 0.645 Hz f_{FDD} = 0.996 Hz f_{FDD} = 1.133 Hz f_{FDD} = 1.191 Hz

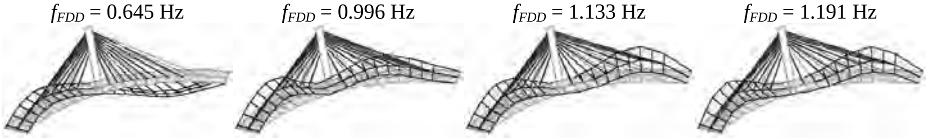

*Fig.3: Selection of identified vibration modes from **AV1** ambient vibration measurements*

5. Conclusions

Following conclusions are taken: 1) within the frequency range 0–9 Hz, 23 vibration modes were clearly identified using the FDD technique; 2) given the geometric complexity of the investigated bridge, an integrated CAD-FEA approach was successfully adopted to implement a 3D FE model of the bridge; 3) the developed model, after some manual tuning, showed fairly good correlation with the experimental results (natural frequencies and mode shapes) and is a suitable "starting points" for more refined procedures of sensitivity analysis and structural identification.