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INNOVATIVE SOLUTIONS FOR LONG-SPAN SUSPENSION BRIDGES

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1 INTRODUCTION

The present work deals with fluid-structure interaction of long-span bridges with multiple-box deck. These flexible structures are very sensitive to wind-induced loads, within both serviceability and ultimate limit states. In particular, it is extremely important to guarantee a reliable safety margin with respect to the collapse due to flutter. This aim can be pursued by improving the system stability from the aerodynamic point of view: multiple-box girder decks are known to be an effective solution in this direction (see e.g. Ref. [1]). Another common way to delay flutter instability is to increase the frequency separation (see e.g. Ref. [2,3]), thus working on the structural dynamics side of the problem.

An innovative solution would be the total inhibition of the flutter instability mechanism, at least concerning the lower modes, that is in the wind speed range of interest. This achievement could be very useful for future very-long-span bridges, for which any traditional countermeasure against flutter could have limited effects. The basic idea is to avoid classical flutter by inverting the vertical bending and the torsional natural frequencies of the lower modes with similar shapes (that is to obtain torsional-to-vertical bending frequency ratios lower than one). As a matter of fact, if this was possible and compatible with all the design constraints, the effect of fluid-structure interaction would be the reduction with the wind speed of the torsional frequency and, at the same time, the increase of the vertical bending frequency: the modes would tend to further separate instead of coupling and consequently they could not give rise to classical flutter. This result is theoretically well known (see e.g. Ref. [2]) but completely unexplored in practice.

A feasibility numerical study has been the first step in this direction, in order to understand if it is possible to conceive a reasonable structure with these characteristics (Ref. [3]). In particular, the examined bridge solutions are based on the 1992-design of Messina Strait

Bridge (see e.g. Refs. [4,5,6]). Keeping the main design philosophy, different configurations have been studied by varying the deck section and the cable suspension system. The solution showing a twin-box girder deck, with main cables closer to each other and masses mainly placed on the outer sides of the suspension system, allows the suppression of flutter instability by inverting the vertical bending and torsional natural frequencies.

2 FEASIBILITY STUDY

Two different suspension bridge typologies have been studied starting from the design of Messina Strait Bridge. The main span (3300 m), the sides spans (960 m and 810 m), the maximum sag of the suspension cables (300 m) and the tower height (around 380 m) have not been changed, while the deck geometry, the distance between the main cables and the shape of the towers have been varied in order to obtain the following two configurations (Ref. [3]):

(a) bridge with three suspension cables (Fig. 1);

(b) bridge with two suspension cables closer to each other and masses mainly placed on the outer sides (Figs. 2 and 3).

The original grids between the boxes have not been considered within this study. Moreover, the total number of lanes have been reduced from three to two for each line of march.

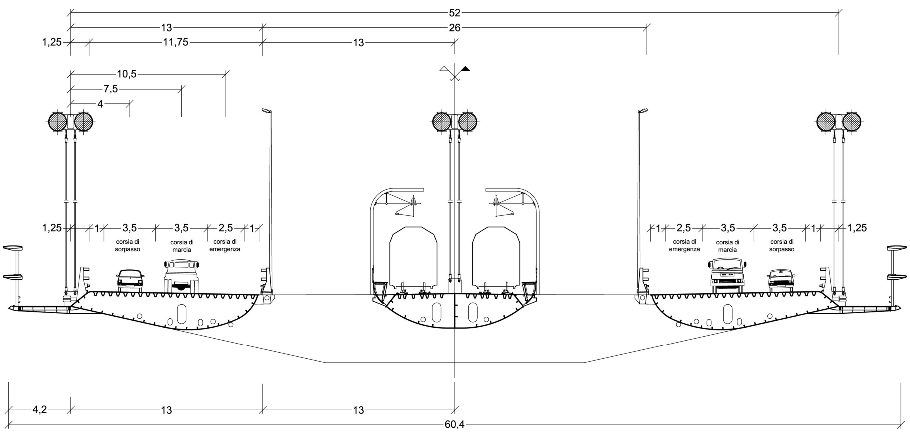

Figure 1: Three-box girder deck with three suspension cables

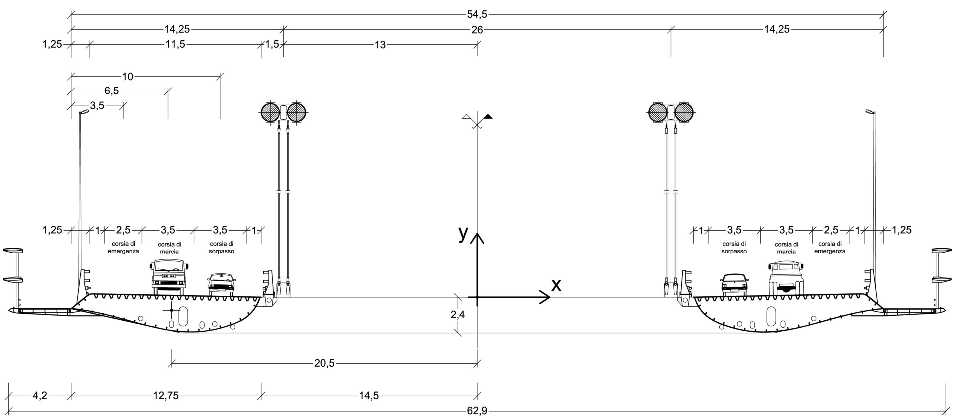

Figure 2: Twin-box girder deck with two suspension cables (spaced 26 m apart), without railway

In the case of configuration (a), the shape, the dimension, and the position of the road and railway boxes are the same as in the original design of 1992 (apart from the small widening of the railway box due to the introduction of a third hanger), whereas the cross beam can be conceived with reduced thicknesses (Fig. 1). The overall mass of the cables has been kept unchanged.

In the case of configuration (b), two different types of deck have been studied, that is with or without railways (Figs. 3 and 2 respectively). In the case of Fig. 2, the geometry of the road boxes is the same as the original one. However, in both cases the bending moments acting on the cross beam are lower than for configuration (a), so that the latter can be designed significantly smaller. The situation is even better in presence of the railways (Fig. 3).

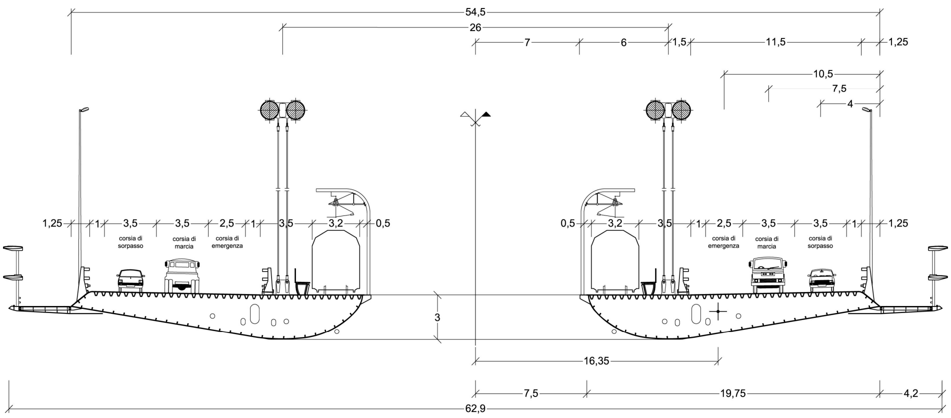

Figure 3: Twin-box girder deck with two suspension cables (spaced 26 m apart), with railway

An extensive study on the modal behavior of long-span suspension bridges, reported in Ref. [3], shows that the torsion-to-vertical bending frequency ratio is influenced not only by the mass distribution but also by the stiffness of the deck (usually considered as negligible with respect to the cable stiffness).

Modal analyses have been performed on the previously described configurations denoted as (a) and (b), with the aim of identifying the scheme in which the frequency ratio is lower than unity. In configuration (a) the presence of the central cable does not allow to invert the natural frequencies. As a matter of fact, it is possible to obtain a frequency ratio equal to 1.10 only by assigning almost the total mass (90 %) to the central cable, which is obviously just a mathematical abstraction.

Conversely, it is possible to invert the modal frequencies by adopting the configuration (b) displayed in Fig. 2. This holds true also if the distance between the cables is increased from 26 m to 39 m: in this case, the bending moment on the cross beam slightly increases, whereas the deck rotation reduces of about 50 %.

In view of the results summarized herein, configuration (b) is retained as an effective solution to design long-span suspension bridges with frequency ratios lower than one. In order to widen this study, further analyses are underway on both serviceability (concerning for instance the maximum vertical and rotational deflections of the deck) and ultimate limit states. It is also worth noting that twin-box girder sections have been recently selected or taken into account for several large bridge designs (e.g. Refs. [7,8]), due to their aerodynamic efficiency.

3 EXPERIMENTAL AND NUMERICAL CAMPAIGN

The proposed approach to suppress flutter is at present still unexplored and therefore the actual aeroelastic behavior of decks with frequency ratios lower than one has to be carefully investigated through wind-tunnel experiments and numerical simulations. In particular, it is important to be sure that unknown or unexpected phenomena do not appear and that the improvement with respect to flutter instability does not imply, for instance, a worse response to turbulent wind.

Both static and aeroelastic tests are underway in the CRIACIV Boundary Layer Wind Tunnel in Prato, Italy, on the aforementioned twin-box girder section model. Aerodynamic coefficients are measured and they represent the input of time-domain numerical simulations. In addition, the ambient response of section models with various frequency ratios, larger and equal to unity, is recorded and analyzed.

4 CONCLUSIONS

In this paper the possibility of avoiding flutter instability by inverting the vertical bending and the torsional eigenfrequencies is investigated. The preliminary numerical study shows that such a bridge can be reasonably designed and the selected solution is a twin-box girder deck with masses mainly placed externally with respect to the suspension system. It is worth noting that this typology of multiple-box deck sections can be also very performing from the aerodynamic point of view, if correctly designed. The aeroelastic behavior of structures with frequency ratios lower than one is both numerically and experimentally studied.

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