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THIRD BOSPORUS BRIDGE AERODYNAMICS: SECTIONAL AND FULL-AEROELASTIC MODEL TESTING

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ABSTRACT

The aerodynamic performance of the Third Bosporus Bridge (BB3) has been assessed through tests in two different Wind Tunnels, at the CSTB and Politecnico di Milano (POLIMI) with different scale factors. The design process of a super long span bridge is strongly influenced by wind actions on the bridge itself and wind loads and wind induced dynamics cannot be defined without relevant experimental campaigns. The definition of the local wind characteristics is the first experimental stage and the final verification of the bridge response to turbulent wind is the last stage of the wind design. For the Third Bosporus Bridge all these activities have been undertaken in close collaboration by the two cited laboratories. The collaboration granted a cross check of the results and of the test methodologies and hence assured a good reliability of the collected experimental data-base. In particular, at CSTB two sectional models with different scale factors 1:100 and 1:25 have been tested to assess the bridge stability, the response of the deck to vortex-induced vibrations and to define the wind profile on the different lanes, and consequently the wind lateral loads on passing vehicles. Moreover, at CSTB a model of a tower has been tested in a very large scale and high Reynolds Number to understand the wind interaction between the two legs of the tower when free-standing during the erection stages. At the Politecnico di Milano the overall wind response has been tested using a full bridge 1:180 aeroelastic model to define the bridge response to turbulent wind and to check the bridge stability limit also during the erections stages. Finally a large 1:50 scale multi modal aeroelastic model simulating the torsional and vertical bending deck behavior was also tested in order to check possible vortex shedding induced vibrations at a larger scale as well as for a cross check with CSTB of possible Reynolds Number effects on the porous wind screens. The results of the experimental activities gave to the design team all the information needed to consider the wind response and highlighted the very good behavior of the bridge under wind actions from all the point of view: stability, vortex induced vibrations, wind loads and effects on the passing vehicles.

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Third Bosporus Bridge Aerodynamics: Sectional and Full-aeroelastic Model Testing

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ABSTRACT

The assessment of the aerodynamic performances of the Third Bosporus Bridge (BB3) has been realized through tests in two different Wind Tunnels, CSTB and Politecnico di Milano (POLIMI) and with different scale factors. The design process of a super long span bridge is strongly influenced by the wind actions on the bridge itself and the definitions of wind loads and wind induced dynamics cannot be done without relevant experimental campaigns. The definition of the local wind characteristics is the preliminary experimental test to be done and the final verification of the bridge response to turbulent wind is the last stage of the wind design. For the Third Bosporus Bridge all these activities have been undertaken in close collaboration by the two cited laboratories. The collaboration granted a cross check of the results and of the test methodologies and hence assured a good reliability of the collected experimental data-base. In particular, at CSTB two sectional models with different scale factors 1:100 and 1:25 have been tested to assess the bridge stability, the response of the deck to vortex induced vibrations and to define the wind profile on the different lanes, and consequently the wind lateral loads on passing vehicles. Moreover, at CSTB a model of a tower has been tested in a very large scale and high Reynolds number to understand the wind interaction of the stand-alone tower during the erection stages. At Politecnico di Milano the overall wind response have been tested using a full bridge 1:180 aeroelastic model to define the bridge response to turbulent wind and to check the bridge stability limit also during the erections stages. Finally a large 1:50 scale multi modal aeroelastic model simulating the torsional and vertical bending deck behavior was also tested in order to check in a larger scale possible vortex shedding induced vibrations as well as for a cross check with CSTB of possible Reynolds Number effects on the porous wind screens. The results of the experimental activities gave to the design team all the information needed to consider the wind response and highlighted the very good behavior of the bridge under wind actions from all the point of view: stability, vortex induced vibrations, wind loads and effects on the passing vehicles

Introduction

The static and dynamic behavior of a bridge under wind actions is a fundamental aspect that allows one to assess the performance of the structure and the effectiveness of its design. The accurate study of bridge aerodynamics is a very important since many wind-structure interaction problems may occur: vortex-induced vibrations [1], aeroelastic instabilities (divergence, galloping, flutter). Numerical studies, performed in the preliminary design of the bridge, must be validated against wind tunnel tests on scale models before the final go for the project (e.g. [2,3,4,5,6]). In this paper, we present an overview of the wind tunnel testing

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procedure used to study the aerodynamics of the Third Bosporus Bridge. Wind tunnel tests were performed exploiting two complementary facilities, Politecnico di Milano (Polimi) and Centre Scientifique et Technique du Bâtiment (CSTB), in order to define a wide set of tests covering all the fundamental technical issues.

Step 1 of the wind tunnel testing procedure

The wind tunnel testing consisted of three subsequent steps. The first step is summarized in Fig.1. It mainly consisted in the testing of the preliminary deck (static and dynamic) and in the selection of its optimal configuration (Fig 2). Besides, towers were tested for static forces (Fig 3). From pressure distribution analysis (Fig 4), one can also see the vortex shedding phenomenon, which will be studied in step 2 using an aeroelastic model.

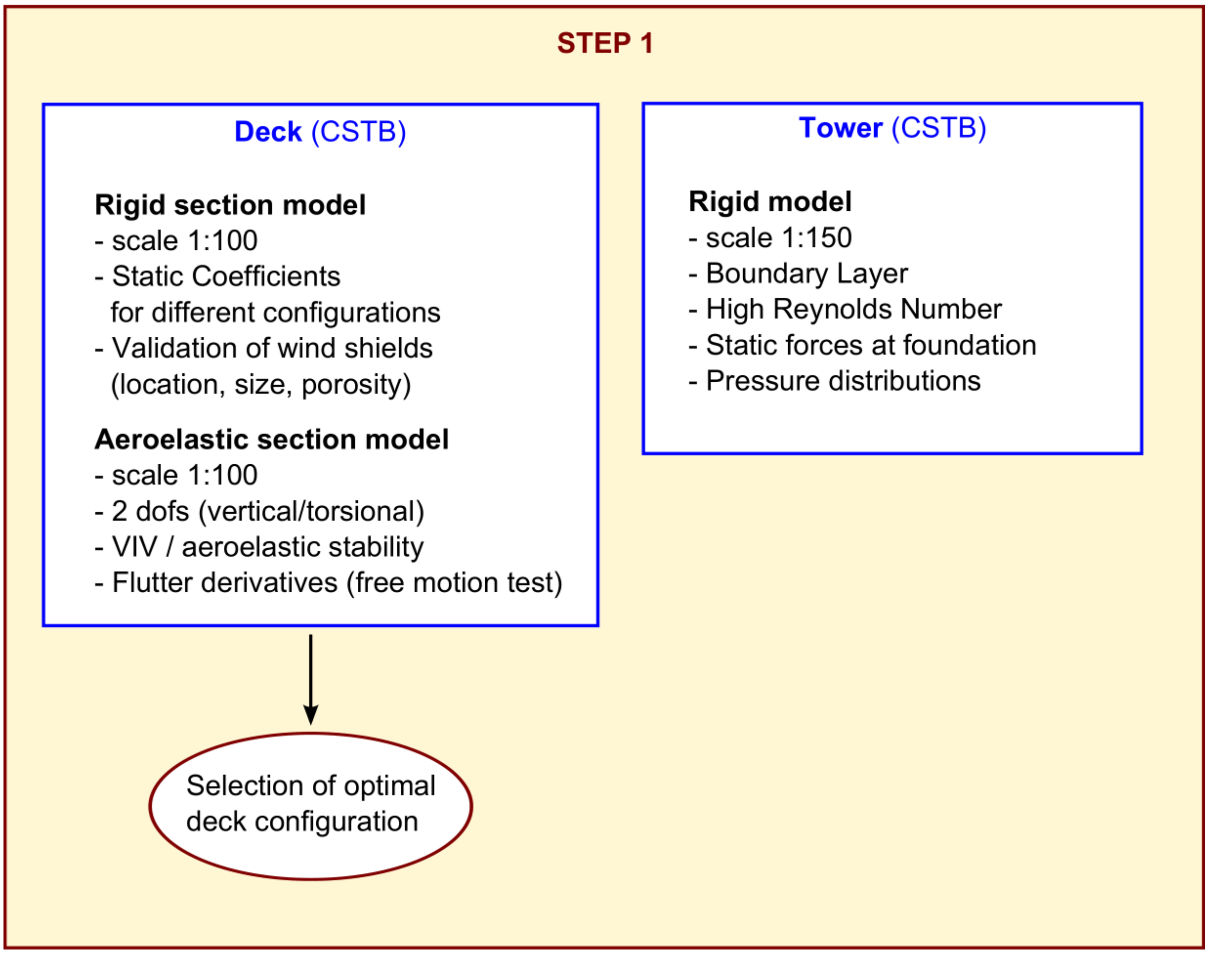

Figure 1. Step 1 of the wind tunnel testing procedure.

Due to the great width and slenderness of the bridge deck, carbon fiber was employed in the production of the aeroelastic sectional model. This has the advantage of a high stiffness and low weight and therefore provides a higher natural frequency in the deck model itself than more conventional materials, providing the best possible approximation to the assumption of an infinitely rigid sectional model. The model was mounted upon a spring system and tested under low-turbulence conditions to examine the possibility of vortex-induced vibrations and to confirm deck stability under extreme wind speeds. The model was then retested in realistic turbulent wind conditions to quantify the static and dynamic behavior of the deck.

Figure 2. CSTB 1:100 deck sectional model

The tower model was fabricated to a high degree of precision from carbon-fibres and epoxy resin. The tower was equipped with 229 pressure taps allowing measurement of local pressures at every point on the tower. The model was mounted on a high-frequency base balance to measure the overall dynamic load on the tower.

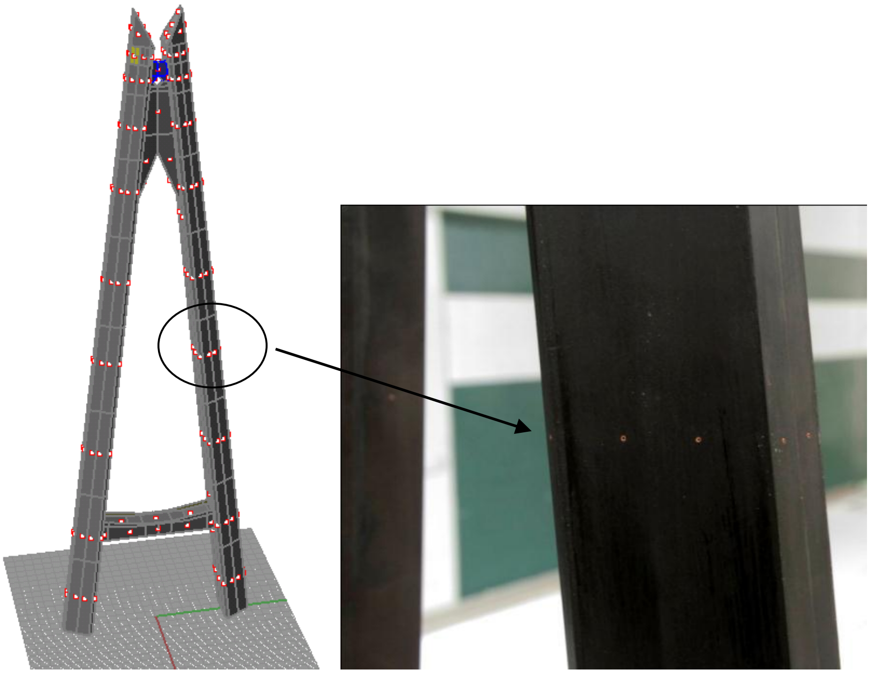

Figure 3 : Tower model tested in CSTB high Reynolds Number wind tunnel. Pressure taps distribution and surfaces discretization (left) - Ring of pressure taps on one of the legs of the tower (right)

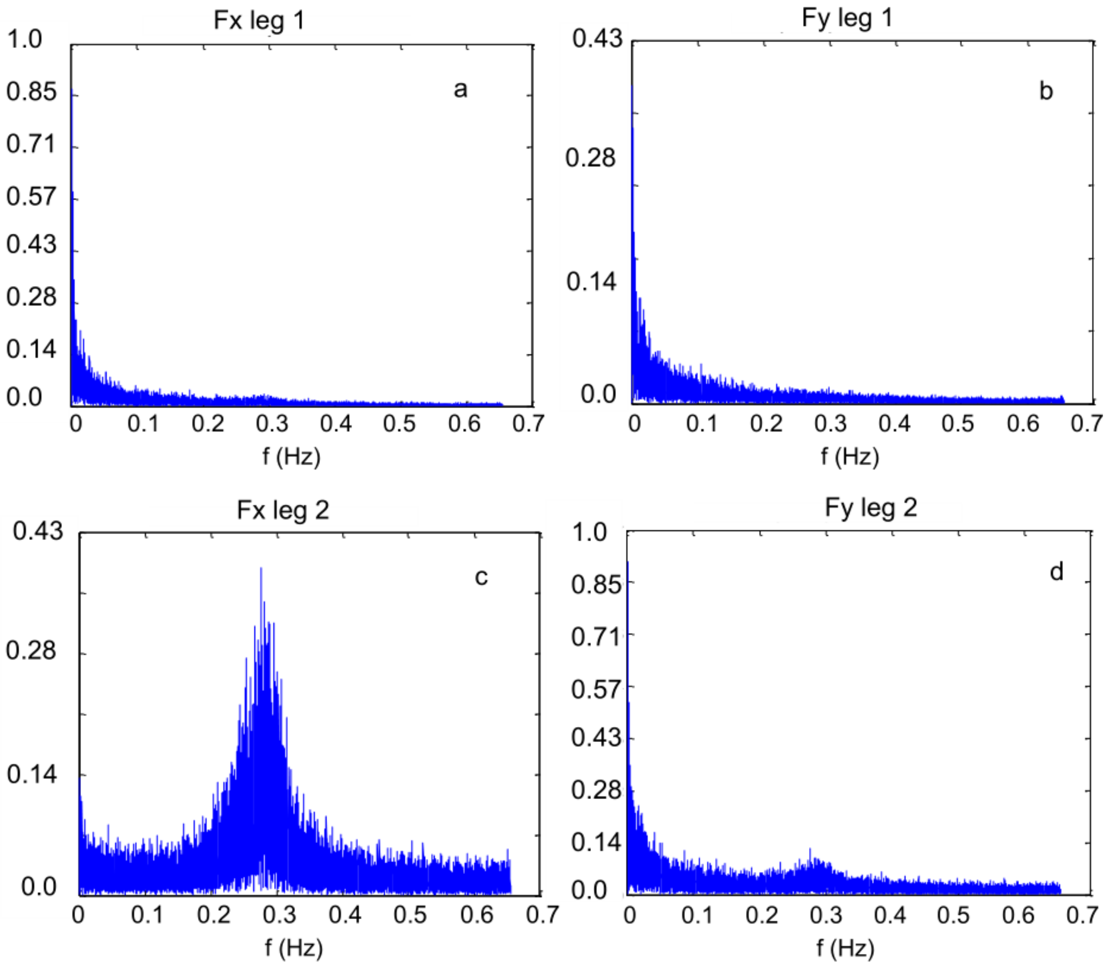

Figure 4. Spectral analysis of the instantaneous X and Y normalized forces on leg 1 (a and b respectively) and leg 2 (c. and d. respectively) at 80° (full scale frequency) evidencing the vortex shedding phenomenon

Step 2 of the wind tunnel testing procedure

The second step of the wind tunnel testing procedure was performed in the boundary layer wind tunnel of Politecnico di Milano. The tests performed are summarized in Figure 5. A set of aeroelastic models in scale 1:180 were built to investigate vortex induced vibrations, aeroelastic stability, and buffeting response. Different wind directions, with different turbulence characteristics were tested.

Figures 6, 7 and 8 show 2 different aeroelastic models tested: full bridge, , and the cantilevered-deck configurations. The models where designed using Froude similarity.

Typical results obtained from these kind of tests are reported in Figures 9, and 10: the first plot reports the trend of the acceleration of two different sections of the deck in turbulent flow as a function of the wind velocity, measured with accelerometers. The second one shows the mean and standard deviation of the bending moment at the tower foundations in turbulent flow, measured with multi-component balances. The tests confirmed the general positive performances of the bridge at in-service and in construction stages

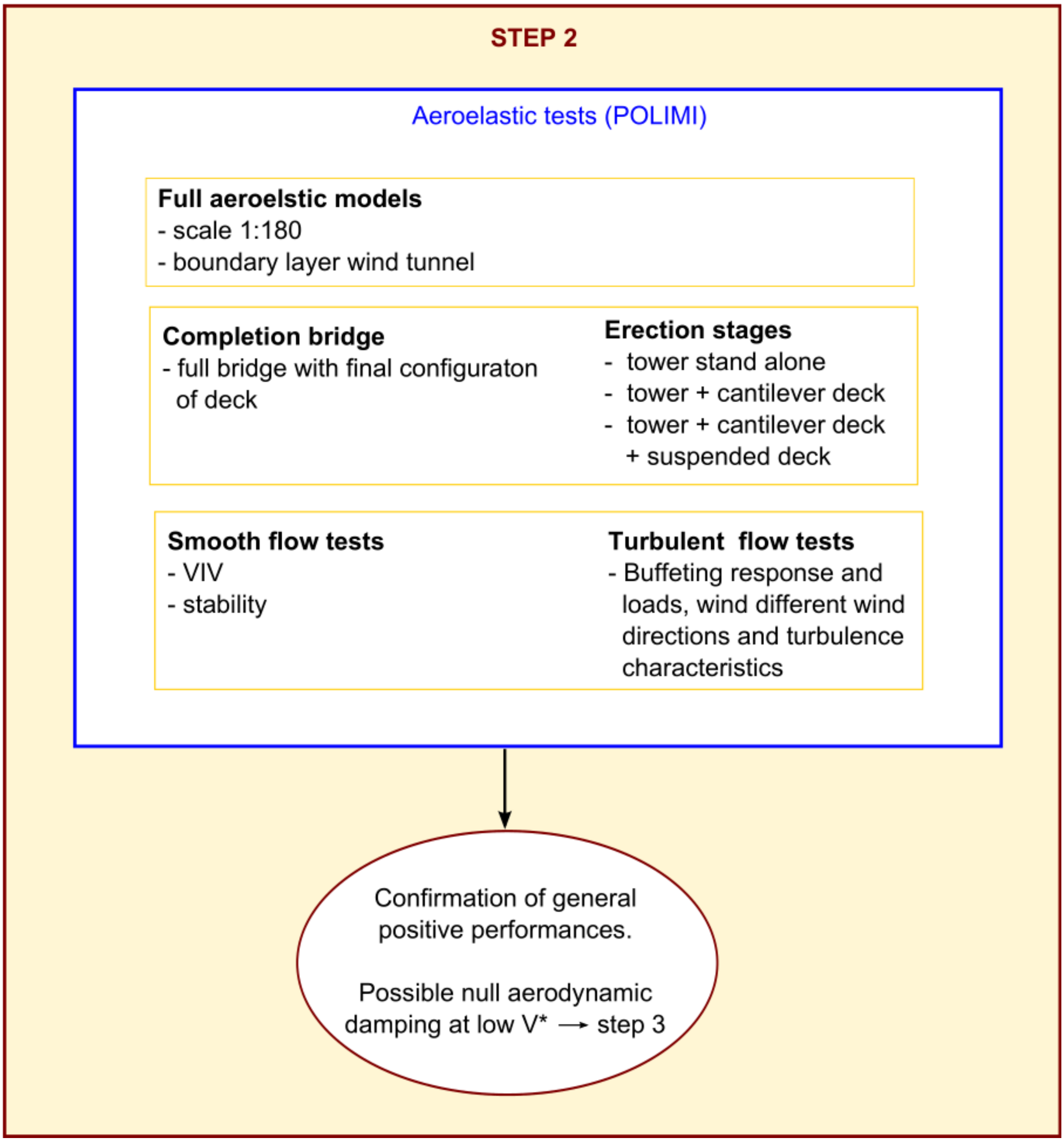

Figure 5. Step 2 of the wind tunnel testing procedure.

Figure 6. Aeroelastic model of the in-service configuration of the BB3 in the POLIMI wind tunnel

Figure 7. Aeroelastic model of the cantilever deck construction stage of the BB3 in the POLIMI wind tunnel with turbulent flow conditions

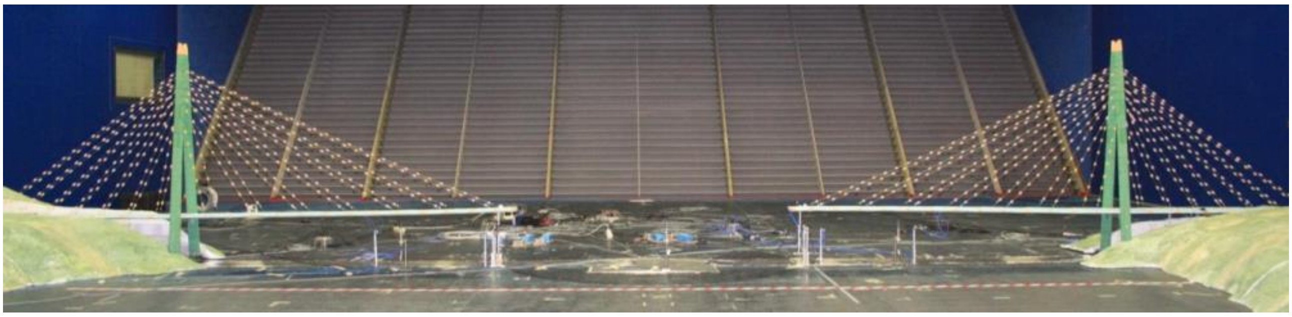

Figure 8. Aeroelastic model of the cantilever deck construction stage of the BB3 in the POLIMI wind tunnel

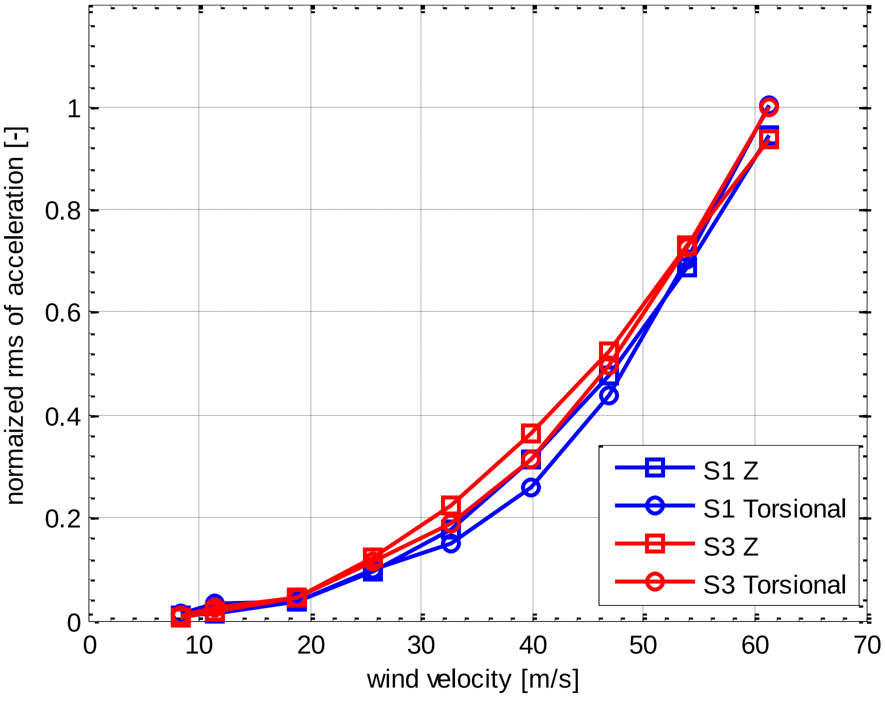

Figure 9. Example of results from boundary layer wind tunnel tests: normalized vertical and torsional accelerations (reported at deck edge) as a function of wind velocity in turbulent flow

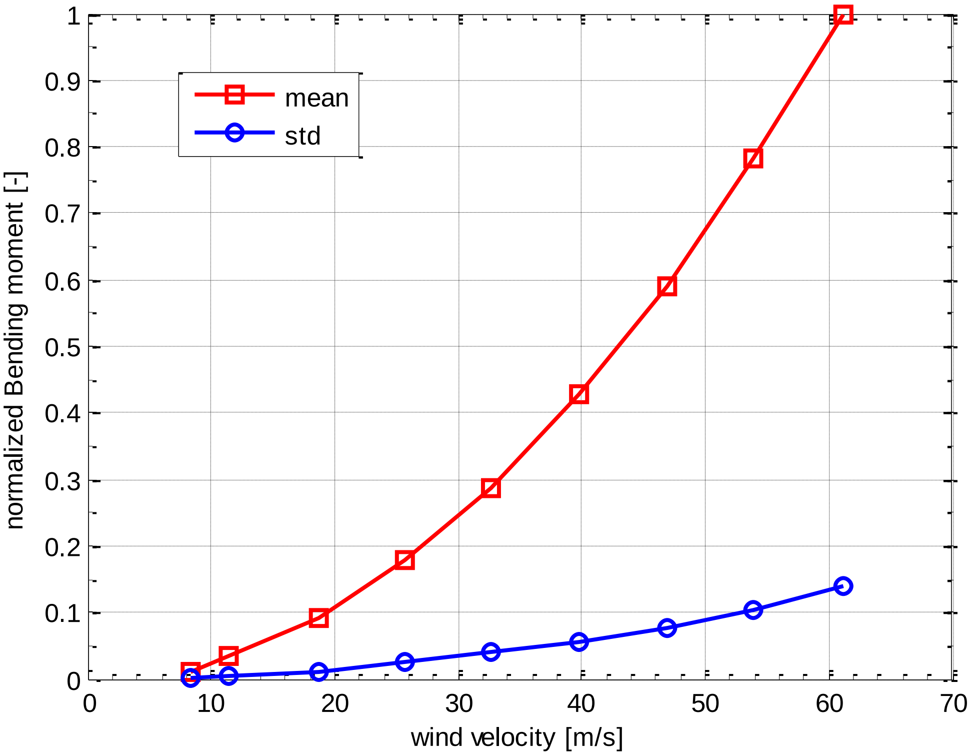

Figure 10. Example of results from boundary layer wind tunnel tests: mean and std value of bending moment at tower foundations in turbulent flow as a function of the wind velocity.

Step 3 of the wind tunnel testing procedure

Since the deck aeroelastic coefficients have a torsional aerodynamic damping at low reduced frequency that is very low (nearly null), further investigations were made on larger scale models to check for VIV possible problems at higher Reynolds number and with more detailed models. Moreover, because it is made of half circular elements, the wind screen performance under Reynolds Number effects was tested. Two different models were tested as summarized in Figure 11: at POLIMI an aeroelastic multi-modal deck model in 1:50 scale to study VIV (Figures 12 and 13), at CSTB a 1:25 rigid deck section model to study the wind screens at high Reynolds Numbers (Figure 14). Some comparisons between the models were done in terms of pressure distributions and vertical wind profiles to compare results with different Reynolds numbers. Figures 15 and 16 shows a comparison of the deck pressure distribution and of some vertical wind speed profiles between the two models that show a very good agreement.

These tests confirmed the good performances of the deck with respect to vortex induced vibrations, and allowed to have a fine characterization of the pressure field around the deck (to validate CFD models) and of the performances of different wind shields configurations.

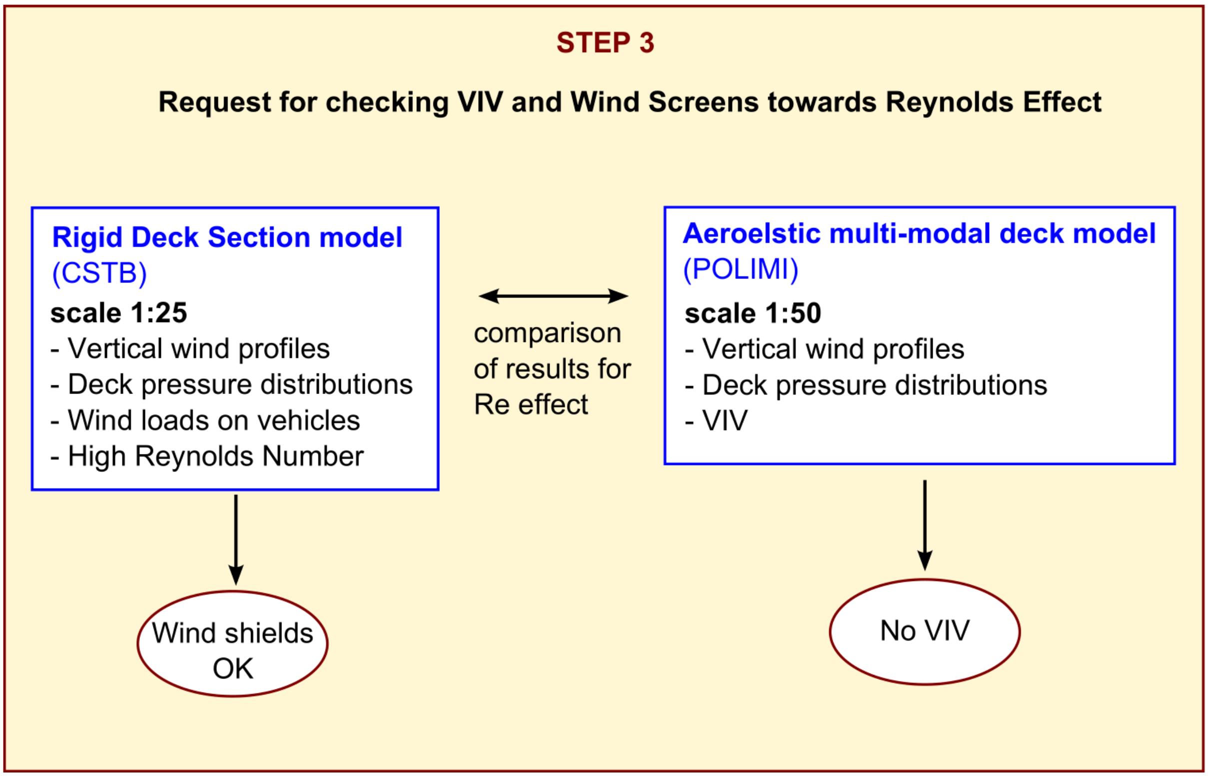

Figure 11. Step 3 of the wind tunnel testing procedure.

Figure 12. Aeroelastic multi-modal deck model of the BB3 in the POLIMI wind tunnel scale 1:50

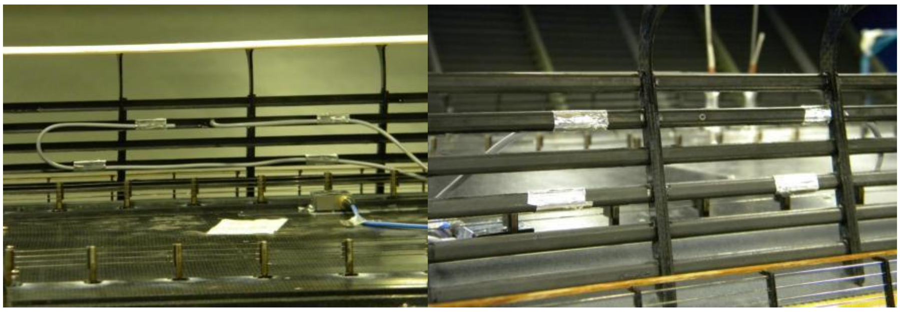

Figure 13. Details of the aeroelastic multi-modal deck model of the BB3 in the POLIMI wind tunnel

Figure 14. Rigid deck model of the BB3 in the CSTB wind tunnel scale 1:25

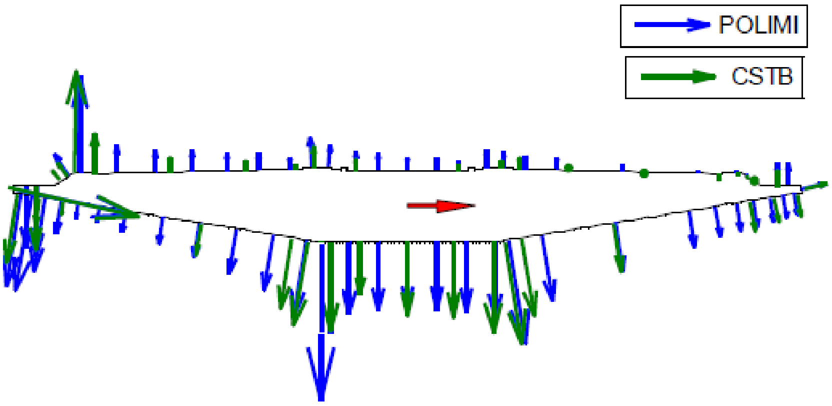

Figure 15. Comparison of normalized mean pressure coefficients along the bridge deck: POLIMI and CSTB results

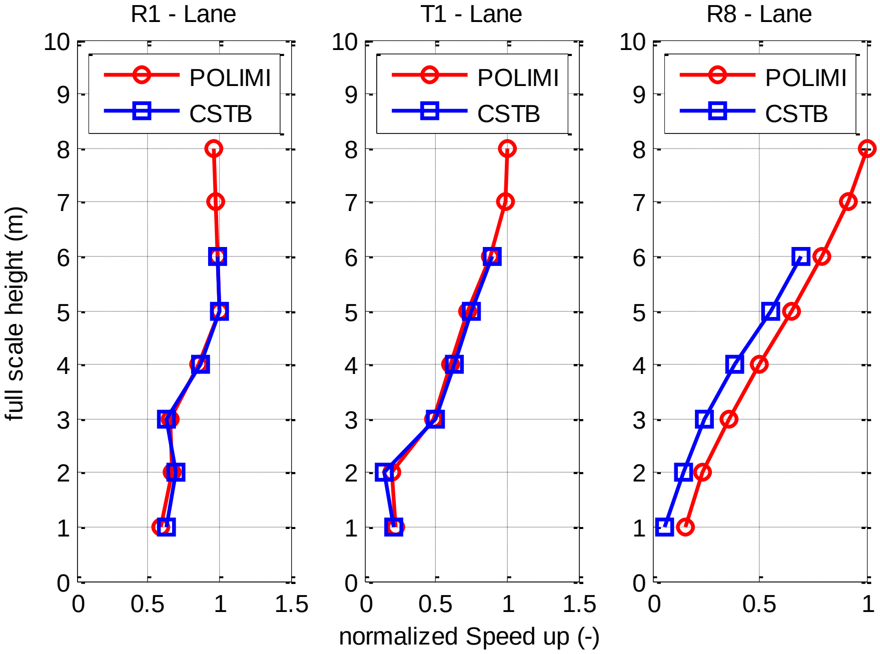

Figure 16. Comparison of normalized wind speed up for a specific deck configuration with wind screens: POLIMI and CSTB results

Conclusions

The wind tunnel testing procedure for the Third Bosporus Bridge has been presented. The cooperation of two complementary wind tunnel laboratories (CSTB and POLIMI) has been exploited to perform a complete aerodynamic and aeroelastic characterization of the bridge. The results of the experimental activities gave to the design team all the information needed to consider the wind response and highlighted the very good behavior of the bridge under wind actions from all the point of view: stability, vortex induced vibrations, wind loads and effects on the passing vehicles.

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