CFD VERIFICATION OF AERODYNAMIC DEVICES PERFORMANCE FOR THE MESSINA STRAIT BRIDGE

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Abstract. Aerodynamic design of bridge deck sections is a key issue in order to guarantee a feasible performance of wind prone bridges. For years, experimental tests of the proposed Messina Strait Bridge have been carried out in the wind tunnel facilities of the Politecnico di Milano. Those exhaustive and detailing testing campaigns have allowed the identification of potential problems related with the bridge behavior under wind loads. In fact, tender designs of the bridge cross-section had shown risk of one degree of freedom torsional instability due to the negative slope of the moment aerodynamic coefficient for the so-called bare bridge deck section, which is the reference section for this work. The adopted strategy for the mitigation of undesirable wind effects has been in certain occasions the introduction of aerodynamic devices. Experimental test of a certain set of aerodynamic devices are costly, both in terms of time and money, although they give invaluable insight information regarding the effects on the bridge deck behavior. However, a question to be solved is the role that CFD (computational fluid dynamics) can play in the anticipation of the aerodynamic effects that a certain device can produce upon the bridge deck aerodynamic performance. A positive answer to the later question would mean that CFD can be the right tool that allows avoiding costly extensive testing campaigns. In this work CFD has been employed to obtain the aerodynamic coefficients of the Messina Bridge reference section, reference section plus trip wire and reference section plus a third winglet over the wind shield. The obtained numerical results are not far from the experimental ones, thus a wide room opens for the use of CFD in the tender design stage of cable supported bridges.
1 INTRODUCTION

An extensive wind tunnel testing campaign has been developed for years at the Research Centre for Wind Engineering (CIRIVE) of Politecnico di Milano in order to obtain a feasible girder geometry. In that respect one of the key tasks is the measurement, for a given bridge deck shape, of the drag, lift and moment aerodynamic coefficients depending upon the angle of attack.

Aerodynamic coefficients are very significant as lift and moment coefficients should have positive slope to avoid one degree of freedom instability using the convention of Fig. (1). Additionally, greater these derivatives are, smaller is the flutter speed [1].

Along the design process the effect of several aerodynamic devices have been tested in the wind tunnel, making clear the sensitivity of the aerodynamic performance of the cross section regarding the installation of any device [2]. A comparison among the tested devices has been presented in [1].

To date, the most reliable and accurate method for studying bridge aerodynamics has been wind tunnel tests, even though they are in cases expensive and time-consuming. However, recent developments in bridge oriented computational fluid dynamics (CFD) make numerical simulations a smart strategy for certain design problems because they are cost-efficient and can provide relatively accurate results.

The motivation for this work is to verify if CFD is an adequate tool to obtain the qualitative effect of an aerodynamic device in the aerodynamic performance of the Messina Bridge cross section. If that is the case, the aerodynamic coefficients obtained computationally should have a different layout for each considered aerodynamic device. Moreover, the computational results can be validated with the ones obtained in the wind tunnel in order to have an idea of the degree of accuracy of the numerical solution. If the concordance from a qualitative point of view is judged as good, that would mean that CFD is becoming a feasible tool in real aerodynamic design environments. As a matter of fact, in the future instead of carrying out a complete wind tunnel test campaign of the candidate aerodynamic devices, CFD can be employed to evaluate numerically the aerodynamic coefficients of the cross-section with each appendage. This allows the designer to filter in a first stage those aerodynamic devices that produce an improvement in the cross section performance, discharging those that do not introduce any improvement. Thus detailed studies can be carried out experimentally focusing just on those appendances that have shown numerically a good aerodynamic performance. This would mean important savings in terms of funds and time along the design process.
2 THE MESSINA STRAIT BRIDGE GIRDER SECTION

The deck cross section shape chosen as reference for the Messina Bridge in this work is the same as in [1], and it is shown in Fig. (2). The experimental moment coefficient of the reference section shows a negative slope ranging between -3° and 5° which is unacceptable as denotes a possible one degree of freedom torsional instability. Thus, the effect of two aerodynamic devices is going to be studied through the aerodynamic coefficients of the section. Their performance is going to be considered adequate if the slope of the moment coefficient of the cross sections turns into positive. The appendances to be studied are: trip wire under each road box and a third winglet over the original two airfoils of the edge wind shields.

![Fig. 2. Messina Bridge reference section.](image)

![Fig. 3. Aerodynamic devices analyzed for the Messina Bridge.](image)

3 CFD TECHNIQUE

The aerodynamic coefficients are obtained considering a 2D steady simulation employing the commercial software FLUENT by ANSYS. As the purpose of the work is to evaluate qualitatively the effect of the aerodynamic devices, the 2D model is considered adequate, thus the 3D effect introduced by the transversal grids connecting the road and rail boxes has not been included.

The turbulence model adopted is the k-ω SST, that has shown good results in several research works such as [3]. According with [4] k-ω models are superior to k-ε because the later over-produces the turbulence kinetic energy near the wall and may radically change the flow patterns. The adopted turbulence intensity adopted for the oncoming flow is 2%.

The average size of the analyzed models is around 300000 elements.
4 REFERENCE SECTION

The first step has been the computational calculation of the aerodynamic coefficients for the reference section reported in Fig. (2). The aim of this task was to verify that the qualitative aerodynamic behaviour of the cross section was being reproduced computationally, thus the aerodynamic coefficients should be close to the experimental ones and particularly a negative slope interval in the moment coefficient should be obtained. Moreover, this first simulation was employed to adjust the turbulence model and the solver options.

A lot of time has been devoted to produce the mesh of the fluid domain due to the special geometry of the Messina Bridge cross section. In Fig. (4) and Fig. (5) two images of the mesh are presented.

Fig. 4. General view of the fluid domain mesh for the Messina Bridge reference section.

Fig. 5. Detail of the fluid domain mesh for the Messina Bridge reference section.

The aerodynamic coefficients obtained computationally for the Drag, Lift and Moment are presented in Figs. (6), (7) and (8) altogether with the experimental results obtained in the CIRIVE wind tunnel at Politecnico di Milano. General speaking a qualitative agreement is
reached although the exact reproduction of the experimental results has not been obtained. In fact, the discrepancies observed in the moment coefficient must be judged taking into account the low numerical values of the coefficient which are included in an interval (-0.03, 0.02). In any case, a negative slope interval between 2º and 8º has been obtained computationally which is not far from the negative slope interval obtained from -3º to 5º in the wind tunnel.

Fig. 6. Drag coefficient for the reference section.

Fig. 7. Lift coefficient for the reference section.
5 REFERENCE SECTION + TRIP WIRE

With the aim of improving the aerodynamic performance of the original section, that is avoiding the negative slope interval in the moment coefficient, several aerodynamic devices were considered. One has been a trip wire, which is a tube with circular cross section of 0.4 m diameter at real scale. The effect of the trip wire is to fix the separation point of the flow attached at the lower part of the road boxes. In Figs. (9) and (10) the lift and moment coefficients evaluated numerically are compared with those obtained in the wind tunnel. It can be seen as the effect of the inclusion of the trip wire has been captured as the negative slope interval for the moment coefficient has vanished while the lift coefficient has not suffered important changes from the values obtained for the reference section. In this work the effect of the trip wire on the vortex shedding excitation has not been studied although experimental results showed a great increase of the vortex induced vibrations.

Fig. 8. Moment coefficient for the reference section.
The inclusion of a 3rd winglet at the edges of the cross section has the aim of improving the bridge aerodynamic performance with no effects on vortex induced vibration. In the reference section two winglets inside the wind shield were included. The third winglet is located over the wind shield in free stream. In this work the analyzed chord has been 2.4 m installed at 0°
referring to the sign convention of Fig. (1). The results show that the negative slope in the moment coefficient does not vanishes in the interval (2°, 6°), although the numerical solution is close to the experimental one. The reason for this situation is a slightly overestimation of the moment coefficient for 2° angle of attack and a subestimation for 6° angle of attack. In Figs. (11) and (12) the numerical and experimental results obtained for the aerodynamic coefficients are presented.

Fig. 11. Lift coefficient for the reference section + 3rd winglet.

Fig. 12. Moment coefficient for the reference section + 3rd winglet.
7 CONCLUSIONS

- The aerodynamic coefficients for the Messina Bridge reference cross section and two additional configurations including a trip wire and a 3rd winglet have been obtained using a commercial CFD package.
- A general qualitative agreement is presented between experimental and numerical results.
- For a tender design stage CFD has proved to be a feasible tool to analyze preliminarily the effect on the section aerodynamic performance of a set of aerodynamic devices. On the base of those results several appendances should be discharged while other should be studied in depth including extensive wind tunnel campaigns. This allows designers to focus just on those devices that have shown a good behaviour.
- The inclusion of the vortex shedding in the set of CFD studies would represent a major step as it would provide designers with key information to judge the feasibility of any aerodynamic device in a cost-effective manner.

REFERENCES


