August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Experimental and numerical results on evaluation of flutter derivatives of twin-box bridge decks with large gaps.

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SUMMARY:
The aim of this study is to achieve aerostructural optimization of cable supported long span twin-box deck bridges with large gap to depth ratios. Computational fluid dynamics (CFD) has been extensively used to evaluate the aerodynamic force and moment coefficients as well as flutter derivatives evolving from the aeroelastic behaviour. A good agreement is observed between the CFD and the experimental results. Finally, a surrogate model, namely the radial basis function is used to interpolate and extrapolate the aerodynamic force and moment coefficients and the aeroelastic flutter derivatives over the entire range of chosen design variables that are related with the geometry of the boxes and the distance between the boxes.

Keywords: twin-box decks, wind tunnel, surrogate technique

1. INTRODUCTION

Twin-box decks are a good alternative to increase the critical flutter speed of ultra-long span bridges (Jurado, Hernández, et al., 2011). However, the aeroelastic response is dependent on the geometry of the deck, and very remarkably on the gap distance between boxes (Yang, Wu, et al., 2015; Yang, Zhou, et al., 2015). Experimental studies have addressed only a limited number of possible designs, and therefore only general trends in the wind response have been identified. The efficient design of these very challenging structures requires information about the expected aerodynamic and aeroelastic response over the whole design domain under consideration. In the past, this problem has been addressed by the authors adopting surrogate models for the aerodynamic response, and applying the quasi-steady formulation for the approximation of the flutter derivatives,which is valid for short gap cases (Nieto et al., 2020). In this work, forced oscillation simulations are adopted to accurately obtain the flutter derivatives of the samples considered in the development of a surrogate model for the aeroelastic response of large gap arrangements for twin-box decks.

2. TWIN-BOX BRIDGE DECKS DEFINITION AND DESIGN DOMAIN

With respect to geometry of the twin-box deck, three input variables are selected (see Fig. 1), namely the depth of the deck D the width of each box C and the gap to depth ratio between the two boxes G/D The deck is symmetrical about the vertical axis. There have been previous studies with smaller gaps between the two boxes of up to $G/D = 2.1$ (Nieto et al., 2020), however, in the current study, larger gaps ($2.5 \leq G/D \leq 6$) have been considered (see Table 1).

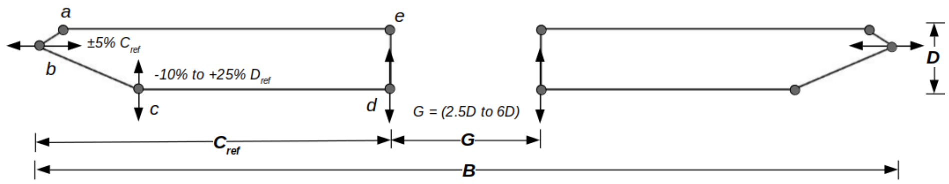
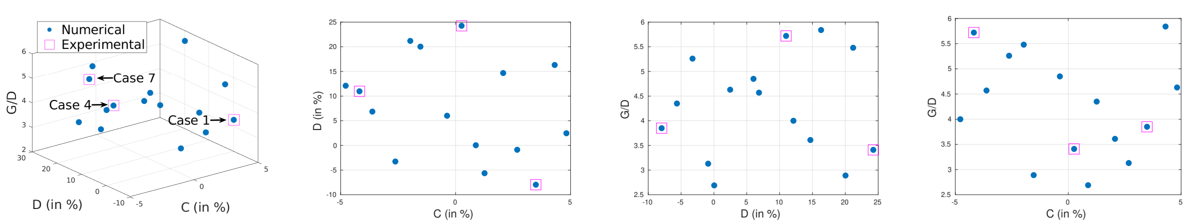


Figure 1. Cross sectional view of the twin-box deck showing the 3 design variables and their bounds.

Table 1. Design space with lower and upper bounds.

Variable	Symbol	Reference value	Lower bound	Upper Bound
Width	C	$C_{ref} = 14m$	$-5\%C_{ref}$	$+5\%C_{ref}$
Depth	D	$D_{ref} = 2m$	$-10\%D_{ref}$	$+25\%D_{ref}$
Gap/depth	G/D		2.5	6

To be computationally efficient and accurately represent the entire design space, 15 sampling sets with different inter-combination variables were created. To obtain an even distribution of points and spread the geometries over the entire design space selected, Latin Hypercube Sampling method was used. For assessing the aerodynamic behavior, each of the geometric sets was computationally evaluated for three angles of attack, namely $\alpha = -2^o, 0^o$ and 2^o; whereas for the assessment of the aeroelastic behavior, forced oscillation simulations at 5 different reduced velocities for pitch and heave degrees of freedom were conducted for each sample. Thus, the total number of simulations amounts to 45 aerodynamic simulations and 150 forced oscillation simulations. Further, for validating the computational results, 3 sets were selected to create the prototype and perform experiments in the wind tunnel. The distribution of all the sample space over the design domain is shown graphically in Fig. 2.



(a) 3-D view **(b)** C vs D **(c)** G/D vs D **(d)** G/D vs C

Figure 2. Distribution of the design sample space, (a) shows the 3-D view, (b) shows the projection plane of C vs D, (c) shows the projection plane of G/D vs D and (d) shows the projection plane of G/D vs C.

3. COMPUTATIONAL MODELLING AND VALIDATION

A computational approach is adopted to avoid the costs linked to the wind tunnel testing of 15 different geometries of twin-box decks. Moreover, performing 3-D scale resolved CFD simulations would be too computationally expensive, hence as an alternative, relatively less expensive, 2D URANS simulations are used in the current study to simulate the flow around the twin-box decks. Further, these simulations are performed in an open source solver, OpenFOAM. The k-ω SST turbulence model, in the frame of the incompressible Reynolds averaged Navier Stokes equations, is used for solving the flow around the twin-box deck.

Fig. 3 shows the validation between the numerical results and the experimental results for Case 1. The complete validation of the flutter derivatives has been reported in (Jurado, Badhurshah, et al., 2022). In general, the agreement between experimental and computational results is good.

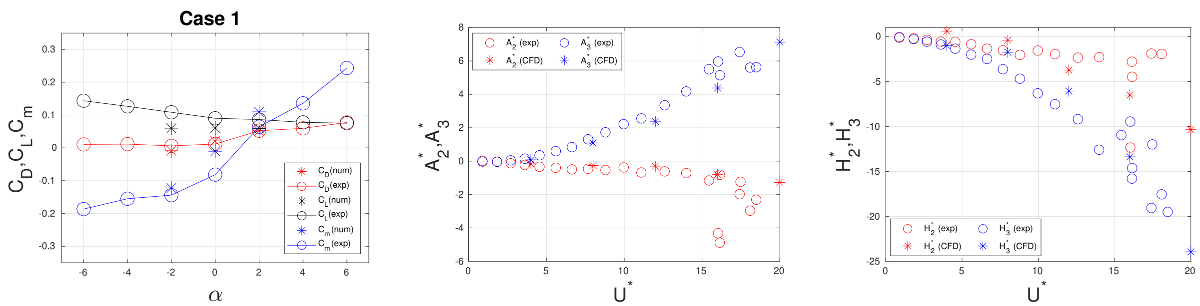
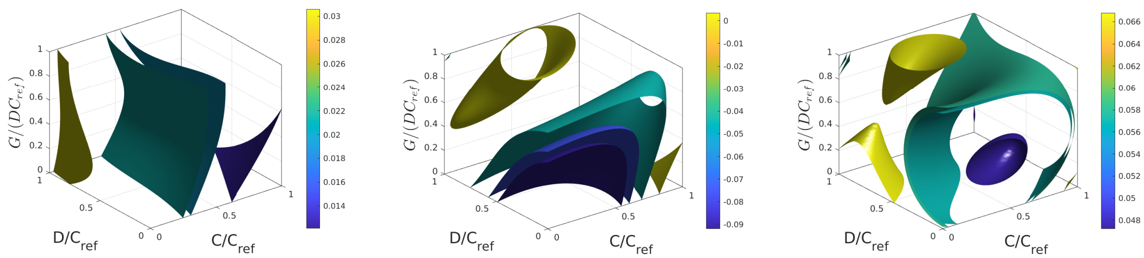


Figure 3. Validation plot for Case 1 for aerodynamic force coefficients and selected flutter derivatives.

4. RESULTS AND DISCUSSION

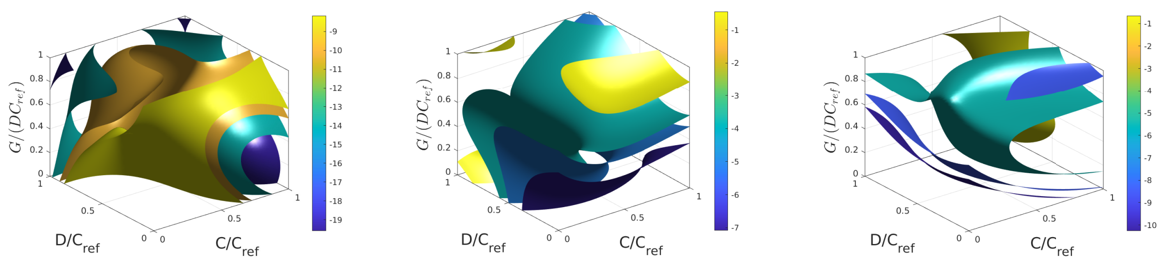
In the current study, the radial basis function surrogate is used to interpolate the corresponding output values and create the surrogate hyper-surfaces. The input variables used in the surrogate model are the width (C), depth (D) and gap to depth ratio G/D of the deck, which are fed into it in non-dimensional form. The force coefficients, moment coefficient and the flutter derivatives over the considered range of reduced velocities are the outputs. Fig. 4 shows the 3-D plots for the three input variables and the corresponding output isosurfaces for the force coefficients. Three isosurfaces are shown: yellow surfaces represent the zone with the maximum value of that particular output, dark blue surfaces shows the isosurface of the lowest value, green-blue surfaces represent the histogramic value (maximum spread) of that respective coefficient. It can be observed that, with higher deck depths, the moment coefficient remains higher. Also, higher depth and larger gap-to-depth ratio increases the lift coefficient. In Fig. 5, the isosurfaces of the various flutter derivatives at $U_r = 12$ are shown. In the conference, the complete set of results will be reported. From the figures, it can be inferred that the trend for each of the flutter derivatives is complex, and certainly dependent on the considered geometric variable of the deck. For the range of reduced velocities considered, H_1^* and H_2^* are always negative, indicating a low risk for galloping and coupled flutter. On the other hand, it should be noted that values close to zero are obtained for A_2^* for low values of D and G/D, but also at high gap-to-depth ratios when both the width C and dept D of the individual boxes are large. The flutter derivative A_3^* shows low sensitive with the geometry of the deck.

The surrogate model created using CFD simulations for 15 different samples for the geometric design of a twin-box deck shows a complex scenario for the impact caused by modifications of the shape of the deck in the aeroelastic performance. It is clear that all the considered design variables are playing a role, but very remarkably the slot between boxes. This surrogate model would enable the application of optimization techniques to identify the deck design providing the most efficient design, capable of satisfiying the aeroelatic requirements of a certain project.

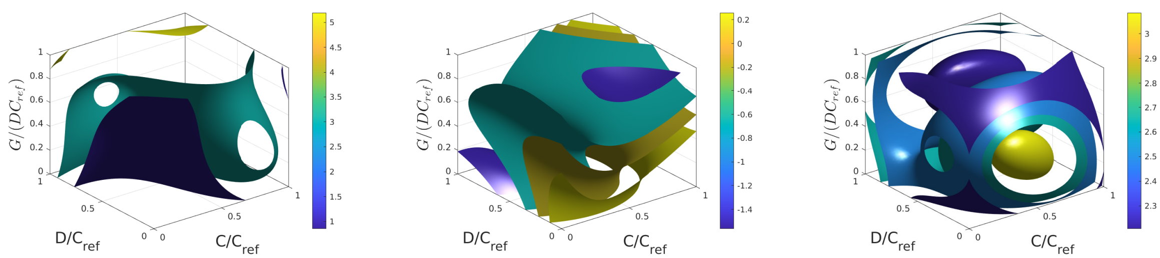


(a) Isosurface for C_m **(b)** Isosurface for C_L **(c)** Isosurface for C_D

Figure 4. Isosurface of aerodynamic coefficients for the three design variable. Yellow surface show the maximum zone, dark blue shows the minimum zone while green-blue represents the histogramic value.



(a) Isosurface for H_1^* **(b)** Isosurface for H_2^* **(c)** Isosurface for H_3^*



(d) Isosurface for A_1^* **(e)** Isosurface for A_2^* **(f)** Isosurface for A_3^*

Figure 5. Isosurface of flutter derivatives from the aeroelastic tests for the three design variables at $U_r = 12$.

ACKNOWLEDGEMENTS

This research has been funded by the Spanish Ministry for Science and Innovation, in the frame of the research project PID2019-110786GB-I00.

REFERENCES

Jurado, J., Badhurshah, R., Hernández, S., and Nieto, F., 2022. Wind tunnel tests for the validation of the CFD obtained flutter derivatives of twin-box bridge decks. XVII International Conference of the Italian Association for Wind Engineering IN-VENTO 2022 Milan, Italy.

Jurado, J., Hernández, S., Nieto, F., and Mosquera, A., 2011. Bridge aeroelasticity: sensitivity analysis and optimal design. Vol. 10. WIT press.

Nieto, F., Montoya, M. C., Hernández, S., Kusano, I., Casteleiro, A., Alvarez, A. J., Jurado, J. Á., and Fontán, A., 2020. Aerodynamic and aeroelastic responses of short gap twin-box decks: Box geometry and gap distance dependent surrogate based design. Journal of Wind Engineering and Industrial Aerodynamics 201, 104147.

Yang, Y., Wu, T., Ge, Y., and Kareem, A., 2015. Aerodynamic stabilization mechanism of a twin box girder with various slot widths. Journal of Bridge Engineering 20(3), 04014067.

Yang, Y., Zhou, R., Ge, Y., Mohotti, D., and Mendis, P., 2015. Aerodynamic instability performance of twin box girders for long-span bridges. Journal of Wind Engineering and Industrial Aerodynamics 145, 196–208.