The 2020 World Congress on
Advances in Civil, Environmental, & Materials Research (ACEM20)
25-28, August, 2020, GECE, Seoul, Korea

Study of vortex induced vibrations of the Stonecutters Bridge by means of LES simulations

*A. J. Álvarez[1], F. Nieto[2] and S. Hernández[3]

[1),2),3)] *University of A Coruña, A Coruña, Spain*
[1)] *antonio.jose.alvarez@udc.es*; [2)] *felix.nieto@udc.es*; [3)] *santiago.hernandez@udc.es*

ABSTRACT

As vortex induced vibration (VIV) is a phenomenon that slender structures as cable supported bridges are prone to suffer, in this paper a computational approach by means of 3D LES turbulence models is presented to assess the feasibility of such methods to accurately reproduce this phenomenon. Firstly, static simulations for a zero degrees angle of attack are performed and the results are compared with available experimental data. After assessing the validity of the results yielded by the static simulations, new ones were conducted allowing the deck under study to freely oscillate in the heave degree of freedom. It has been found that the value of peak amplitudes and the range of reduce velocities at which VIV takes place is in fairly good agreement with the experimental data.

1. INTRODUCTION

The development of the multi-box deck concept has allowed the construction of cable-supported bridges with longer span lengths, as they are more stable against flutter. Nevertheless, these bridges are prone to suffer vortex induced vibrations (VIV), a non-destructive oscillation of the deck characterised by being both self-sustained and self-limited, with amplitudes of oscillation lower than half the height of the deck (Simiu & Scanlan, 1986). Although his phenomenon may not cause the collapse of the bridge, it is associated with serviceability and fatigue related issues (Shiraishi & Matsumoto, 1983). Therefore, it is of utmost importance to ascertain the VIV susceptibility at the early design stages of the bridge project to take pertinent countermeasures, if required. These analyses can be conducted by means of wind tunnel experimental campaigns, which is the standard approach, or by means of CFD simulations that require experimental validation, but provide a more complete description of the interaction between the structure and the flow.

In this paper, 3D LES numerical simulations are reported for the bare deck configuration of the Stonecutters Bridge deck, at a geometric scale 1/80, without including transversal beams. Also, the results obtained for the same application case adopting a 2D URANS approach combined with the Langtry-Menter 4-equation Transitional SST model (Langtry & Menter, 2009), previously published in Álvarez et al. (2019), are included for discussion. It has been found that the static force coefficients and Strouhal numbers are in good agreement with the experimental data for both the 2D URANS and 3D LES simulations. On the other hand, only 3D LES simulations have been able to provide an accurate VIV response, comparable with wind tunnel data. The CFD solver used has been OpenFOAM.

2. FORMULATION

2D URANS simulations rely on the Reynold-averaged formulation of the Navier-Stokes equations and the Boussinesq approximation for the Reynolds shear stresses (Wilcox, 2006). The four-equation Langtry-Menter Transitional SST turbulence model has been adopted herein due to the its ability to tackle transitional phenomena, that may be of importance for bodies with curved surfaces.

The 3D LES simulations conducted in this piece of research have been performed considering a 3D approach using the filtered Navier-Stokes equations (Sagaut, 1998), the Smagorinsky turbulence model (Smagorinsky, 1963) and the cubic root of the cell volume as filter ($\Delta V^{1/3}$). The purpose of the filter is to separate the large scale eddies of the flow, which are solved directly, from the smaller ones that must be modelled.

The sign criteria considered in this work for forces and movements are depicted in Fig. 1. Also, the labeling convention for the fundamental dimensions of the deck cross-section are provided.

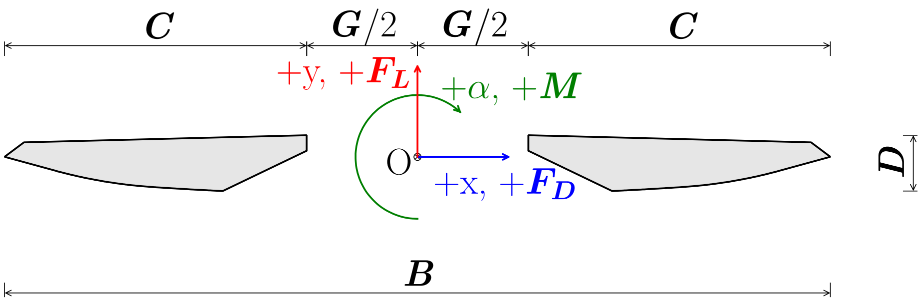

Fig. 1 Sign criteria and fundamental dimensions for the bare deck arrangement of the Stonecutters Bridge.

The expressions for force coefficients, Strouhal number (*St*) and pressure coefficients (C_p) are:

$$C_d = \frac{F_D}{\frac{1}{2}\rho U^2 C}; \quad C_l = \frac{F_L}{\frac{1}{2}\rho U^2 C}; \quad C_m = \frac{M}{\frac{1}{2}\rho U^2 C^2}; \quad St = \frac{fD}{U}; \quad C_p = \frac{p}{\frac{1}{2}\rho U^2} \tag{1}$$

In the following, the symbol " ~ " represents the standard deviation of the corresponding parameter.

3. STATIC SIMULATIONS AT 0º ANGLE OF ATTACK

In table 1, a summary of the fundamental characteristics of the 2D and 3D grids used in this work is provided, being the size of the fluid domains used in both the 2D and

3D simulations the same: $(40C + B) \times 30C$, with the exception of the spanwise length that is equal to *C* in the 3D model.

Table 1. Grid discretisation characteristics. (Where y_1 is the total height of the first element of the boundary layer (bl), x_1 is the width of the first element of the bl, r is the growth ratio of the elements in the bl, l_{bl} is number of elements in height of the bl, y_{bl} total height of the bl, n_z number of elements in the spanwise dimension and n_{Total} is the overall number of elements of the mesh)

	y_1/C	x_1/y_1	r	l_{bl}	y_{bl}/C	n_z	n_{Total}
2D URANS (Álvarez et al., 2018)	$1.6432 \cdot 10^{-4}$	4	1.167	10	$3.5035 \cdot 10^{-3}$	1	664032
3D LES	$6.5727 \cdot 10^{-4}$	4	1.319	6	$8.8005 \cdot 10^{-3}$	48	3218112

The static deck simulations were conducted at a Re_D=$4.48 \cdot 10^4$, obtaining the results reported in Table 2, where available experimental data at the same Reynolds number are also included. The numerical results agree well with the experimental data, being the discrepancies explained by the differences observed in the mean C_p distribution (Fig. 2), that impact decisively on the moment coefficient obtained from the 2D URANS model. The ability of the 3D LES model to provide an accurate distribution of the fluctuating pressure coefficient must be highlighted (see Fig. 2), since fluctuating pressure distributions play an important role in the VIV response.

Table 2. Integral parameters for a 0º angle of attack

	Method	C_d	C_l	C_m	$\widetilde{C_d}$	$\widetilde{C_l}$	$\widetilde{C_m}$	St
Present study	3D LES	0.15	-0.26	0.21	0.03	0.21	0.09	0.24
Álvarez et al. (2019)	2D URANS	0.14	-0.27	0.02	0.06	0.53	0.12	0.28
Kwok et al. (2012)	EXP.	0.15	-0.23	0.27	-	-	-	0.28

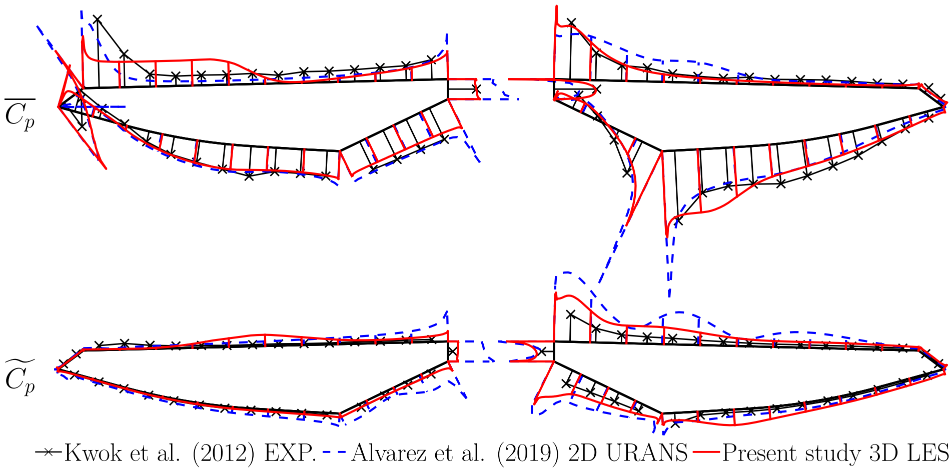

Fig. 2 Mean and standard deviation distributions of the pressure coefficients. (Gap width not to scale)

4. FREE OSCILLATION SIMULATIONS IN HEAVE

The phenomenon of vortex induced vibrations has been studied by conducting FSI simulations at a Scruton number of 32 $\left(Sc = (4\pi M\xi)/(\rho L D^2)\right)$ for a range of Reynolds numbers $Re_D = 2.85 \cdot 10^3 - 3.81 \cdot 10^3$. The coupling between the dynamic mesh, the fluid and the structure was accomplished by means of the conventional serial staggered scheme implemented in OpenFoam.

In Fig. 3, the amplitudes of oscillation of the deck are presented for different reduced velocities, for both 2D URANS (Álvarez et al., 2019) and 3D LES. The results show a fairly good agreement with the experimental data (Larsen et al., 2008) for the 3D LES simulations, being able to accurately reproduce both the maximum peak amplitude of oscillation and the range of reduced velocities at which VIV takes place. On the other hand, the 2D URANS approach provides remarkably larger amplitudes of oscillations, as well as a larger range or reduced velocities showing VIV susceptibility. This outcome highlights the importance of three-dimensional flow features, spanwise correlation and turbulence modelling characteristics to correctly simulate the complex interaction between vortex-shedding and the induced oscillation of the deck.

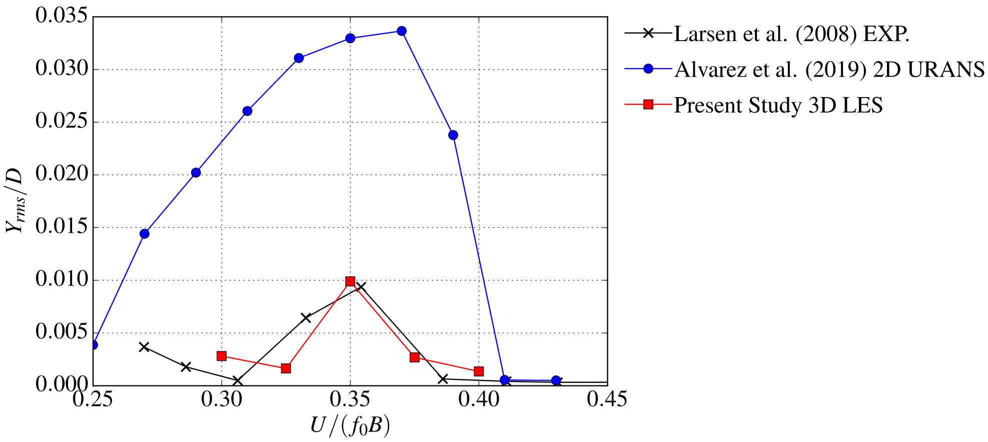

Fig. 3 Heave oscillation amplitudes for the bare twin-box deck.

5.CONCLUSIONS

In the present piece of research, simulations for the static and vertically free to oscillate Stonecutters twin-box deck adopting both 2D URANS and 3D LES approaches are reported. The 3D LES approach results in fairly good agreement with the available experimental data, as they are able to account for the inherent three-dimensionality of the flow features, spanwise correlation and complex turbulence behaviour, which are factors playing a key role in the VIV response. The usage of a 3D grid and a turbulence model of higher complexity has been able to yield results closer to the ones observed in experimental campaigns, although at the expense of higher computational costs, both in time and computer resources. The quality of the obtained results strengthens the feasibility of introducing these techniques at the design stage of long-span bridges, for analysing the risk of a certain design suffering VIV excitation.

ACKNOWLEDGEMENTS

This research has been funded by the Spanish Ministry of Economy and Competitiveness (BIA2016-76656-R) and the Galician regional government (ED431C 2017/72). Dr. Álvarez has been funded through BES-2014-068418 predoctoral contract grant, associated with the BIA2013-41965-P research project. The computations have been done at the Galician Supercomputation Technology Centre (CESGA).

REFERENCES

Álvarez, A.J., Nieto, F., Kwok, K., and Hernández, S. (2018), “Aerodynamic performance of twin-box decks: A parametric study on gap width effects based on validated 2D URANS simulations.” Journal of Wind Engineering and Industrial Aerodynamics, Vol. **182**, 202–221.

Álvarez, A.J., Nieto, F., Hernández, S. (2019), “Vortex induced vibration assessment of a twin-box bridge by means of 2D URANS simulations”, Proceedings of the 15th International Conference in Wind Engineering, Beijing, China.

Kwok, K., Qin, X., Fok, C., Hitchcock, P. (2012), “Wind-induced pressures around a sectional twin-deck bridge model: effects of gap-width on the aerodynamic forces and vortex shedding mechanisms.” Journal of Wind Engineering and Industrial Aerodynamics, Vol. **110**, 50-61.

Langtry, R. and Menter, F. (2009), “Correlation-Based Transition Modeling for Unstructured Parallelized Computational Fluid Dynamics Codes.” AIAA Journal, Vol. **47**(12), 2894–2906.

Larsen, A., Savage, M., Lafrenière, A., Hui, M.C.H., Larsen, V.S. (2008), “Investigation of vortex response of a twin box bridge section at high and low Reynolds numbers.” Journal of Wind Engineering and Industrial Aerodynamic, Vol. **96**,934-944.

Sagaut, P. (1998), Large eddy simulation for incompressible flows. Springer, Berlin.

Shiraishi, N. and Matsumoto, M. (1983), “On classification of vortex-induced oscillation and its application for bridge structures.” Journal of Wind Engineering and Industrial Aerodynamics, Vol. **14**, 419–430.

Simiu, E. and Scanlan, R. (1986), Wind effects on structures. John Wiley & Sons.

Smagorinsky, J. (1963), “General circulation experiments with the primitives equations. I: The basic experiment.” Month. Weath., Vol. **3.91**, 99–165.

Wilcox, D. C. (2006), Turbulence modelling for CFD. DCW Industries, La Cañada.