EACWE2022

8th European-African Conference on Wind Engineering

20-23 September 2022 | Bucharest, Romania

Aeroelastic responses of the Hyperloop structure

Elena Di Silvestro[1)], Sigrid Jacobs[2)], Raphaël Dubois[3*)], Thomas Andrianne[4)]

1) Program Leader, CRM Group, Belgium, elena.disilvestro@crmgroup.be
2) Expert, ArcelorMittal, Belgium, sigrid.jacobs@arcelormittal.com
3) PhD Candidate, University of Liège, Belgium, raphael.dubois@uliege.be
4) Head of the Wind Tunnel Laboratory, University of Liège, Belgium, t.andrianne@uliege.be

ABSTRACT: The aeroelastic phenomena taking place on the Hyperloop structure are investigated on the basis of static aerodynamic and aeroelastic scaled models tested in wind tunnel. The post-critical regime is reached through the adjunction of roughness on the surface of the cylinders. The aeroelastic responses are analysed and the corresponding critical galloping and VIV wind speeds are compared to aeroelastic measurement data.

Keywords: Aeroelastic response, VIV, Galloping, Wind tunnel.

1. INTRODUCTION

The twin-tube tracks of the Hyperloop concept (Fig. 1) represent a particular illustration of a two-cylinder configuration in the post-critical flow regime. It is characterised by large dimensions (diameter ranging from 3 to 5 m) and windspeeds (above 30 m/s), resulting in high Reynolds numbers (above 10^7). In this flow regime, the boundary layers, shear layers and the wake are fully turbulent. A few authors (Zdravokovich (1985), Kim et al. (2009), Assi et al. (2010), among others) investigated the aeroelastic behaviour of twin cylinders but only in the sub-critical flow regime.

The purpose of this work is to investigate the aeroelastic responses of the cylinders, elastically mounted on springs, in the post-critical flow regime. The damping ratio of the prototype has been estimated to 0.2% based on the Eurocode. It is believed that this value is very conservative because it corresponds to fully welded steel (Hyperloop). Thus, the damping ratio of the experimental model is varied between 0.3% to 1.1%. The resulting aeroelastic phenomena will be commented/explained on the basis of the lift, drag and Strouhal number measured on a static set-up.

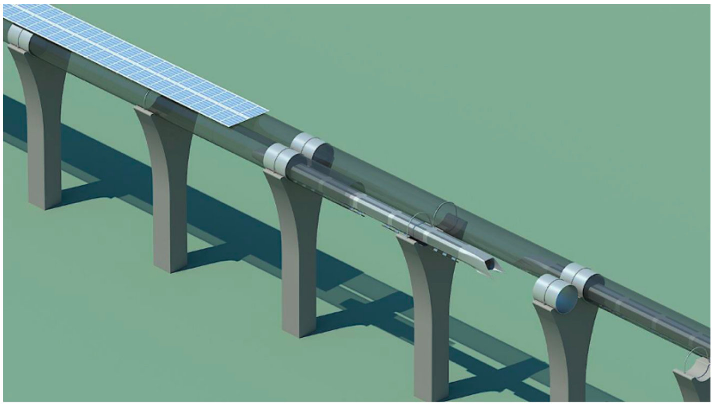

Figure 1. Twin-tube structure of the Hyperloop project (Musk (2013)).

*) *Corresponding author*

2. METHODOLOGY

The approach consists in an experimental test campaign on two rough cylinders in the low-subsonic wind tunnel of the University of Liège. The two experimental apparatus are shown in Fig. 2, where the left set-up is static and the right set-up is dynamic, i.e. suspended to extension springs.

Surface roughness is added to the cylinders in order to reach the post-critical flow regime at lower Reynolds numbers. In this study, the cylinders are closely spaced: L/D = 1.2-1.56. L is the centre-to-centre distance between the cylinders and D is the external diameter. This configuration is representative of the Hyperloop structure.

Lift and drag forces are obtained through spatial integration of the pressure fields measured on each cylinder at 48 taps linearly distributed at mid-span. A hot-wire probe is located in the wake of the tandem arrangement to measure its frequency content. The static set-up is extensively described by Dubois and Andrianne (2022).

Figure 2. Experimental set-up installed in the wind tunnel of the University of Liège.

3. RESULTS FOR *L/D*=1.2

Figure **3** shows the amplitude of vibration A, normalized by the diameter of the cylinder D, which results from the aeroelastic effect, when the tandem cylinders are submitted to the flow. It is observed that the aeroelastic vibrations start for a reduced velocity U_r around 4. This critical wind speed is close to reduced velocity for which VIV (Vortex Induced Vibrations) takes place (1/St = 1/0.25 = 4) and it is independent of the amount of structural damping present in the system. In addition, the shape of the response curve corresponds to a monotonous increase only. For these reasons, we conclude that the aeroelastic phenomenon responsible for this response is an interaction between VIV and galloping.

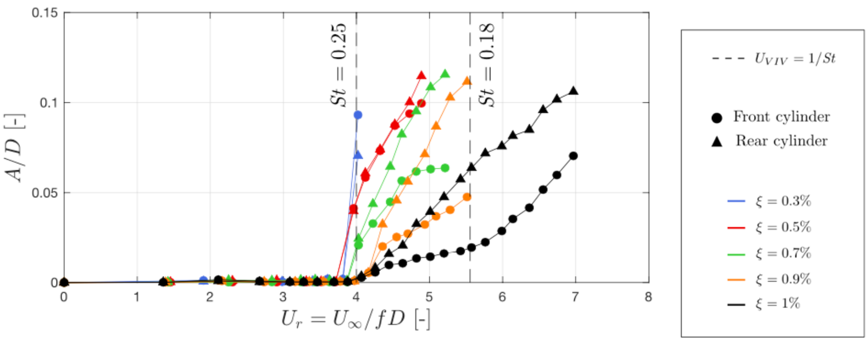

Figure 3. Aeroelastic responses of the cylinders in tandem arrangement (L/D=1.2 / AoA=0°).

Figure **4** shows the effect of the wind incidence on the aeroelastic response of the cylinders for a fixed value of the structural damping (0.7%). In this figure, the angles of attack of 0°, 2° and 4° show the same behaviour as the previous figure. The shape of the response curve is different for 6°, where a typical VIV response is clearly observable, followed by a typical galloping curve. The change of shape of the curves could be explained by the appearance of a strong gap flow between 6° and 8° which impacts the vortex shedding phenomenon. The similar observation is done for 8°, while no observable aeroelastic vibration is reported for 10°.

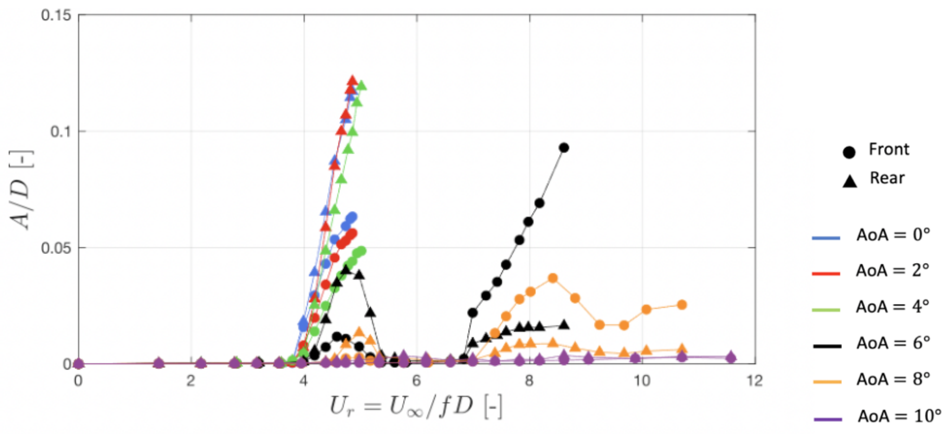

Figure 4. Aeroelastic responses of the cylinders for different wind incidences, a constant damping value (0.7%) and L/D=1.2.

4. CONCLUSIONS & FURTHER WORK

The aeroelastic testing of a generic Hyperloop structure shows a combination of VIV and galloping phenomena, which depends on the wind incidence. This observation will be explained in the full paper to be presented at the EACWE conference thanks to aerodynamic data measured on a static model. The scaling of the aeroelastic model (aerodynamics and dynamics) will be also presented in order to propose a complete aeroelastic analysis of this unique structure.

Acknowledgements
The authors would like to thank ArcelorMittal and the CRM Group which are the industrial partners of this project.

References

Assi, G. R., Bearman, P. W., & Meneghini, J. R. (2010). On the wake-induced vibration of tandem circular cylinders: the vortex interaction excitation mechanism. Journal of Fluid Mechanics, 661, 365-401.

Dubois, R., & Andrianne, T. (2022). Flow around tandem rough cylinders: Effects of spacing and flow regimes. Journal of Fluids and Structures, 109, 103465.

Kim, S., Alam, M. M., Sakamoto, H., & Zhou, Y. (2009). Flow-induced vibrations of two circular cylinders in tandem arrangement. Part 1: Characteristics of vibration. Journal of Wind Engineering and Industrial Aerodynamics, 97(5-6), 304-311.

Musk, E. (2013). Hyperloop Alpha. [online] SpaceX. Available at: http://www.spacex.com/sites/spacex/files/hyperloop_alpha.pdf [Accessed 18 March 2020].

Zdravkovich, M. M. (1985). Flow induced oscillations of two interfering circular cylinders. Journal of Sound and Vibration, 101(4), 511-521.