

Wind Tunnel Tests and Normative Approaches of the ARC MAJEUR Subject to Vortex Shedding

Adrien Palm, Yves Duchêne

Bureau Greisch, Liège, Belgium

Contact: apalm@greisch.com

Abstract

The sculpture called “Arc Majeur” is a curved steel structure with a height of 60 meters and a 2,25 meters square section. Due to its slenderness, the structure is very sensitive to vortex induced vibrations (VIV). The initial design of the structure with the Eurocode is compared to wind tunnel tests of an aeroelastic model. These tests, performed afterward, validate the design and improve the safety margin of the structure. Both approaches show that a tuned mass damper (TMD) is necessary to damp the vibrations for structural safety reasons and fatigue lifetime, but experimental results allow a lower damping.

Keywords: vortex induced vibrations; wind tunnel tests; aeroelastic model; Arc Majeur

1 Introduction

Imagined in the 1980s by the artist Bernar Venet, the “Arc Majeur” (Figure 1) is erected in Belgium. The arc is not a continuous circular arch but a two-curvilinear-segments arc. It culminates 60 m above the motorway.



Figure 1. The “Arc Majeur” during erection

The structure is designed by Greisch office and can withstand wind gusts up to 52 m/s at ULS. The square section of the arc ($b = 2,25$ m) produces VIV for a wind speed around $V_{cr} = 16$ m/s. To reduce the vibration amplitudes, the main arc is equipped with a TMD, with a mass of 1500 kg, placed at its top. This paper compares VIV effects according to the Eurocode [1] to wind tunnel tests. These tests are carried out at the University of Liège with professors Andrianne T. and Denoël V.

2 Vortex Induced Vibrations

As the first critical wind speed of VIV is lower than the average wind speed on site, there is a risk of VIV. The amplitudes of vibration must be compared to the maximum admissible displacements at the top of the

arc: 0,44 m for structural integrity and 0,34 m for fatigue state. Aeroelastic properties of the arc without TMD are the following for in-plane response: the natural frequency $f_0 = 0,86$ Hz, the structural damping $\xi = 0,32$ %, the mass ratio $M = \frac{m_s}{m_{air}} = 332$, the numbers of Strouhal $S_t = \frac{f_0 \cdot b}{V_{cr}} = 0,12$, Scruton $S_c = \frac{4 \cdot \pi \cdot \xi \cdot m_e}{\rho_{air} \cdot b^2} = 10,3$, and Skop-Griffin $SG = 2 \cdot \pi \cdot S_t^2 \cdot S_c = 0,93$.

2.1 Eurocode approach

The amplitudes of vibration according to the method 2 of the Eurocode 1991-1-4 [1] and ANB [2] are equal to 1,15 m for a damping ratio $\xi = 0,32\%$ and 0,32 m for a damping ratio $\xi = 3,0\%$. The TMD provides an equivalent damping ratio of 3,6% and ensures both the structural integrity and the fatigue resistance.

2.2 Wind tunnel tests

Aeroelastic tests are performed in the wind tunnel facility of the University of Liège [3]. They allow to evaluate the vibration amplitudes and the lock-in range for different Scruton numbers by varying the damping of the model. This paper focus on the tests in a low turbulent wind in the direction of the motorway. The effects of wind turbulence, curvature and wind orientation are investigated [4] but are not presented here. The Figure 2 shows the aeroelastic model. It is made of an aluminium tube core and 3D printed outer volumes in plastic. The following similitudes are respected: the geometrical, the mass ratio, the Strouhal and the Scruton similitudes.



Figure 2. aeroelastic model in wind tunnel

The VIV responses of the model in a low turbulent flow are presented in Figure 3 in terms of relative amplitude Y_F/b as a function of the reduced velocity $V_r = V/(f_0 \cdot b)$, for five different Scruton numbers.

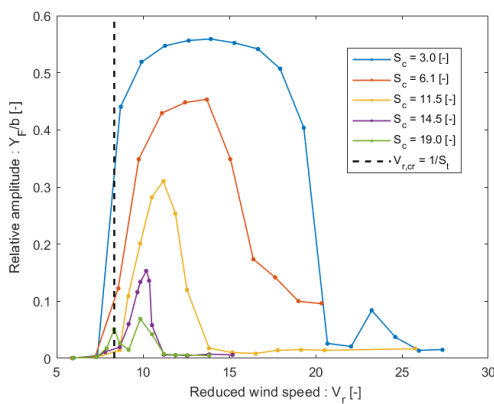


Figure 3. VIV response for different Scruton numbers

These results are summarized in terms of maximum relative amplitude as a function of Scruton number in Figure 4 with the blue curve. These tests predict a vibration amplitude of $Y_F = 0,34 b = 0,77 m$ the “Arc Majeur” without TMD ($S_c = 10,3$) and a lock-in range from $V = V_r \cdot f_0 \cdot b = 16$ to $26 m/s$.

2.3 Comparison of both approaches

For validation of the present experimental results, they are compared, to references tests from the literature and to the experimental Skop-Griffin curve in black, in Figure 4.

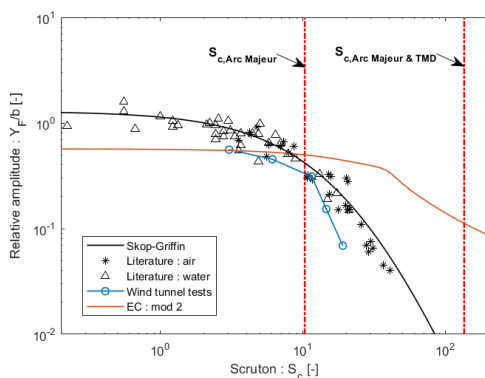


Figure 4. Comparison: tests, Eurocode, literature

According to Figure 4, the transition zone between high and low vibration amplitudes occurs for lower Scruton numbers according to the tests results (in blue) than with the Eurocode (in red).

To check the fatigue lifetime, stresses variations at critical points are compared to the S-N curves given by the Eurocode EN 1993-1-9. The numbers of cycles are estimated with Hansen's formula [2]. Figure 5 displays the fatigue lifetime as a function of the damping ratio. Based on the Eurocode, a minimum critical damping ratio of 2,75% is necessary to ensure a lifetime of 50 years. Based on wind tunnel tests, a damping ratio of 0,46% would be sufficient.

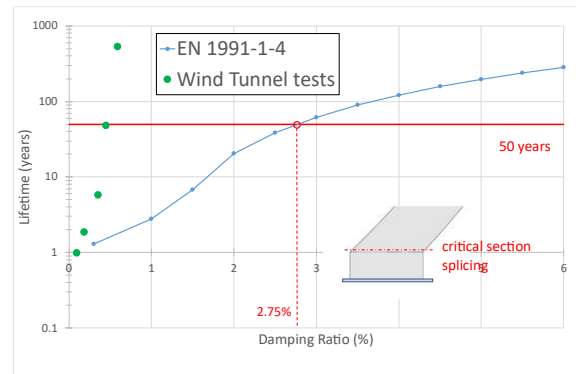


Figure 5. Lifetime vs. critical damping ratio ξ

3 Conclusions

Firstly, the arc has been designed according to the recommendations of the Eurocode 1991-1-4. Then, aeroelastic tests in a wind tunnel showed that the transition zone between self-exciting response (at high amplitude of vibrations) and forcing response (at low amplitude) appears at too high Scruton number with the Eurocode method 2. So, according to the wind tunnel tests, the structural damping provided by the TMD could be lower and still ensure the safety of the structure.

References

- [1] Eurocode 1991-1-4. *Actions on structures- Part 1-4: General actions – Wind actions*. April 2005.
- [2] NBN 1991-1-4 ANB. *Eurocode 1 - Part 1-4: National annex*. 2010 (F).
- [3] ULiège, *The University of Liège Wind Tunnel Facility: Technical description*, 2009, <https://www.wind-tunnel.uliege.be>.
- [4] Palm A., Duchêne Y., de Ville de Goyet V., Denoël V., Andrianne T., *Design, Wind Tunnel Tests, Normative and Theoretical Approaches of the ARC MAJEUR Subject to Vortex Shedding*. Eurodyn 2023, Delft, 2023.

