STRUCTURAL BEHAVIOUR AND DESIGN CRITERIA OF CABLE-STAYED BRIDGES WITH CURVED PYLONS UNDER PERMANENT LOADS

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INTRODUCTION

Cable-stayed bridges have been commonly adopted in the last decades for medium and long spans. With the experience gained, Santiago Calatrava has been capable of providing some of his bridges with a curved pylon and no backstays. This is the case of the Serreria Bridge in Valencia (Spain), the Samuel Beckett Bridge in Dublin (Ireland) and the Katehaki Footbridge in Athens (Greece). It is yet to be seen if it can become an efficient structural solution in forthcoming projects or it can only be considered in projects where aesthetics prevail.

METHOD AND APPROACH

The Serreria Bridge has been employed as a reference case throughout all the research. Its layout has been modelled using the visual programming language Grasshopper and latterly imported as a planar structure into the GSA software for the structural analyses. Both the pylon's and deck's sections are tapered, as it can be inferred from Figure 1. The stays are post-tensioned to cancel the bending moment in the deck. The pylon's shape has been first designed as a parabolic curve to be latterly matched to the antifunicular of the loads by means of an iterative process, Figure 2.

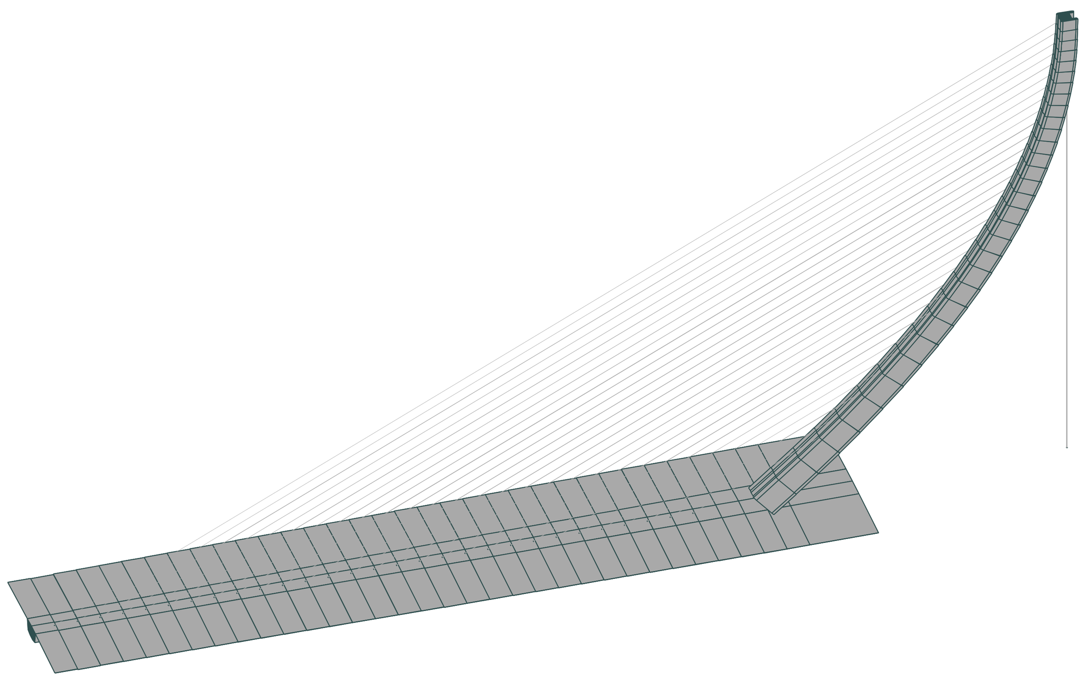

FIGURE 1: Model of the Serreria Bridge in GSA.

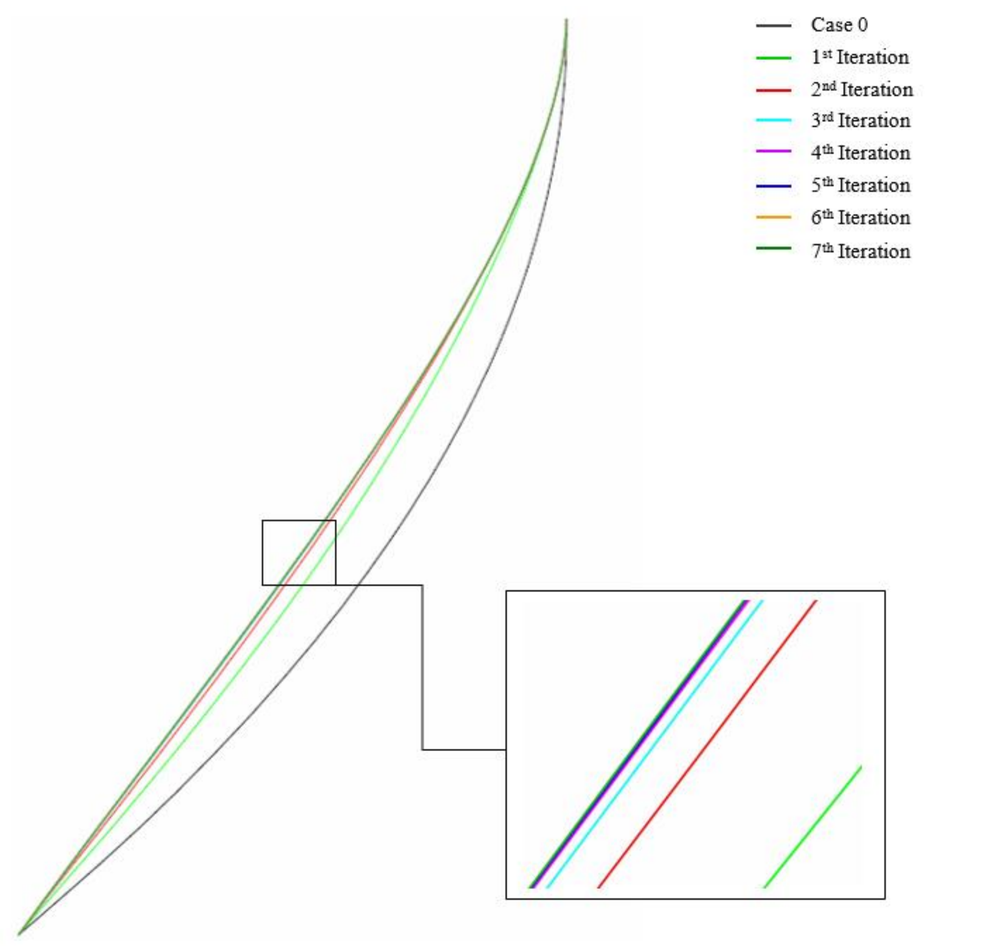

FIGURE 2: Pylon's shape after each step in the iteration process of the Serreria Bridge.

REFERENCE CASE: SERRERIA BRIDGE

Prior to undertaking the iterative process of achieving the antifunicular shape, the maximum bending moment in the pylon is 362 MNm and the displacement produced in the pylon's tip is 1.81 m. After seven iterations, these values have reduced to 330 kNm and 2.30 cm. Figure 3 shows the maximum eccentricity in the pylon after each iteration.

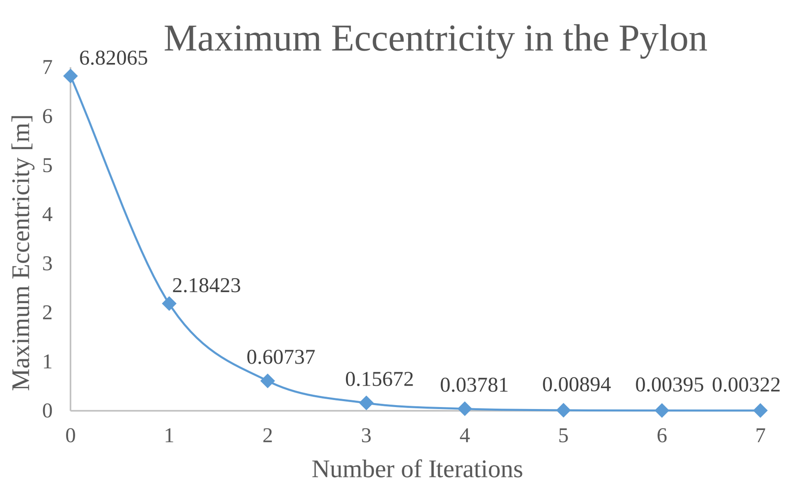

FIGURE 3: Variation of the maximum eccentricity in the pylon.

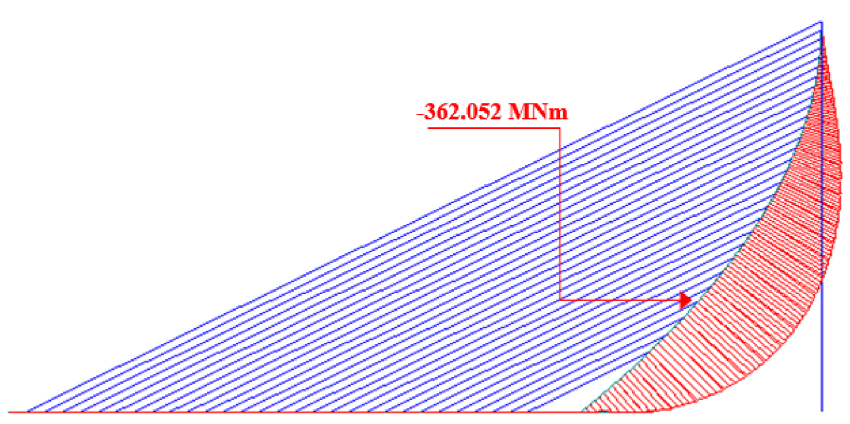

FIGURE 4: Bending moment diagram of Serreria Bridge with parabolic-shaped pylon.

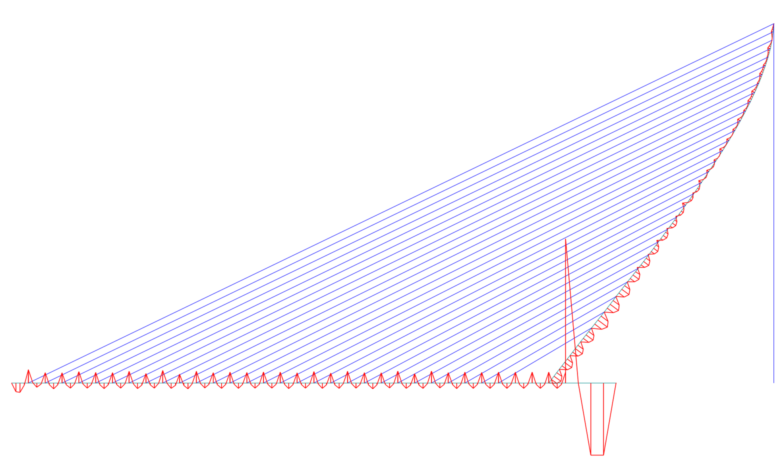

FIGURE 5: Bending moment diagram of Serreria Bridge with antifunicular shape achieved.

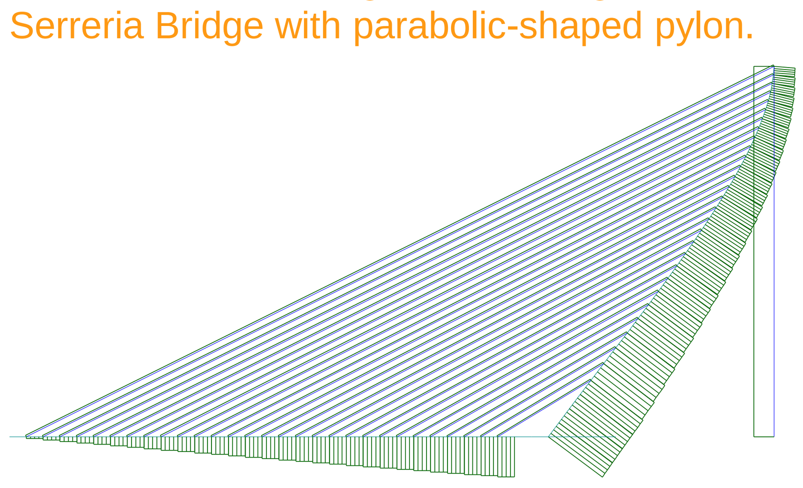

FIGURE 6: Axial force diagram of Serreria Bridge with antifunicular shape achieved.

REFINED PYLON

The iteration process of achieving the antifunicular shape consists on moving the nodes of the pylon by the eccentricity produced at each node. Hence, it is only possible to nullify the eccentricities in those points of the pylon in which a node is defined. Refining the pylon will help reduce the magnitude of the humps produced in the BMD of the pylon. A pylon with infinite nodes or, in other words, a pylon defined by a continuously differentiable curve, can reach a perfect antifunicular state for a given load case.

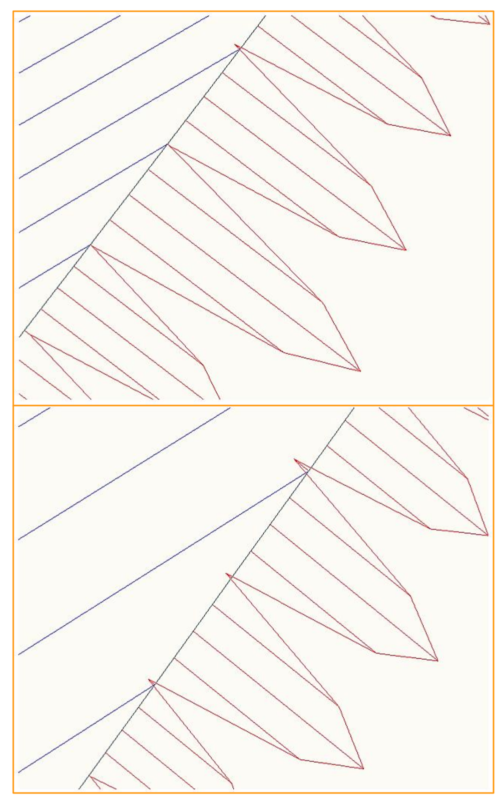

FIGURE 7: Humps in BMD when refining pylon.

PYLON'S SECTIONS MODIFICATION

The edge of the pylon's sections were modified in order to observe how the weight, the flexural rigidity and the cross-sectional area influenced the results. Together with further analyses, which employed section modifiers, it was seen that whilst the second moment of area did not influence the final shape of the pylon. However, it plays an important role in the pylon's deflections when the antifunicular characteristics are not achieved.

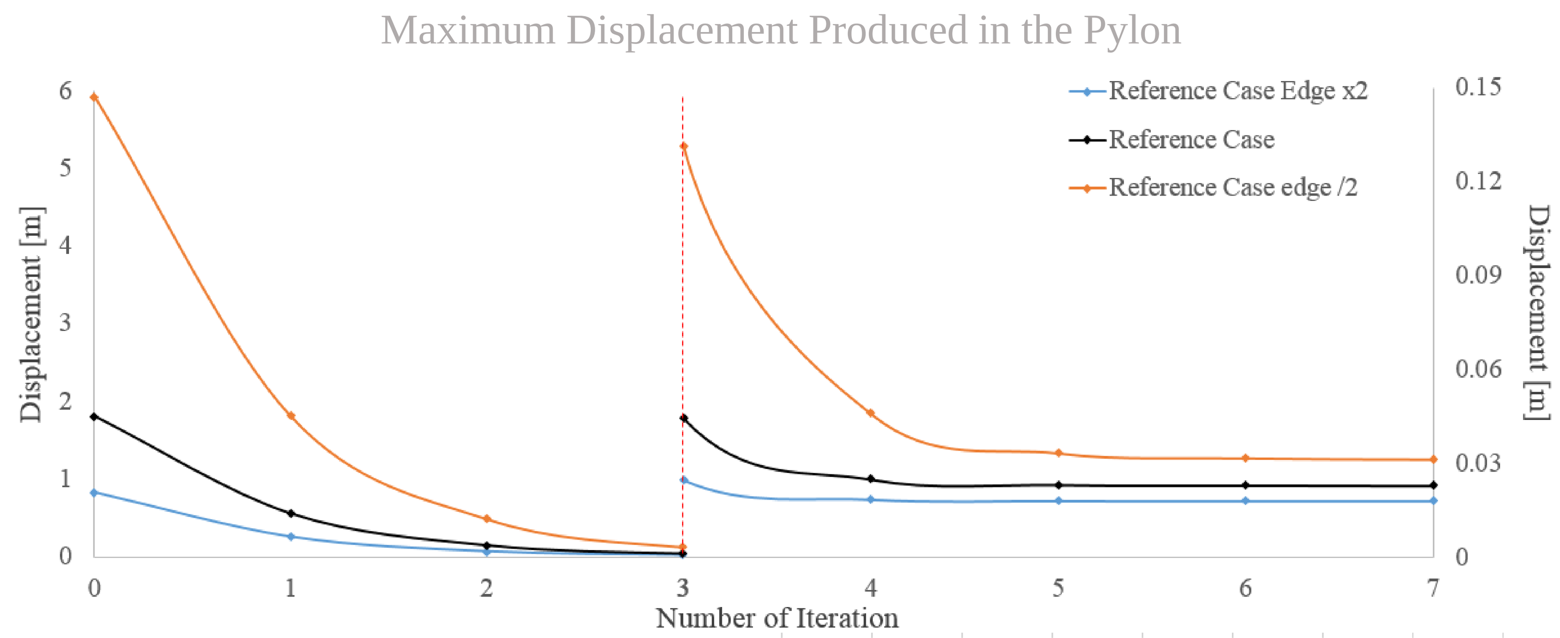

FIGURE 8: Maximum displacement produced in the pylon at each iteration for the three cases analysed.

ALTERNATIVE LAYOUT DESIGNS

The height, the inclination of the pylon and the angle of the forestays are parameters that were altered so as to come up with alternative layouts that could be compared to the Serreria Bridge. Also, although not displayed, different backstay inclinations were analysed for the reference case.

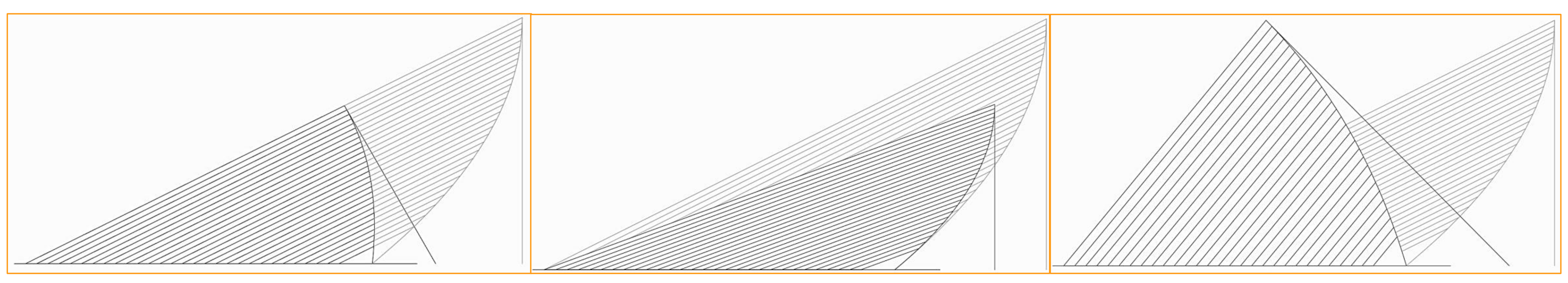

FIGURE 9: Alternative layout designs analysed.

CONCLUSION

To conclude with, it has been seen that the flexural rigidity does not influence the final shape of the pylon, although it is essential both for buckling and for the states in which the antifunicular characteristics are lost. Also, verticality of the forestays is key to limit the stresses of the forestays and the deck's compression. Therefore, inclining the pylon towards the main span, as the Samuel Beckett Bridge, can result significantly beneficial.

ACKNOWLEDGEMENTS

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