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A CONCEPTUAL APPROACH TO DESIGN OF FUNICULAR SPATIAL ARCHES IN FOOTBRIDGES.

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A funicular spatial arch is a compression-only form free of bending stresses thanks to its warped geometry, i.e. which cannot be contained within a plane. Therefore, its design and construction may become more complicated than for classical planar arches. These type of arches were pioneered by the Ripshorst footbridge in Oberhausen, with a curved deck supported by a funicular warped arch (Fig.1-a), designed by J. Schlaich in 1997. These arches can be, simultaneously, very efficient in structural terms and aesthetically pleasing. However, the great potential of these type of structures has not been fully developed yet. So far, very few theoretical studies have been carried out, and only some design proposals have been eventually built, such as the Galindo Bridge in Spain (fig. 1-b).

a)

b)

Fig. 1. a) Ripshorst footbridge, Oberhausen b) Galindo Bridge, Bilbao, Spain. (Sources: N. Jandberg and Herrad Elisabeth Taubenheim; https://structurae.net)

This paper tries to help to understand, from a conceptual point of view, the design process and advantages of a funicular arch (the so-called *antifunicular*). The design process starts by selecting the load case for which the funicular form is found. For full-metal structures, a combination of permanent loads plus the 50% of live loads is proposed, since the bending moments oscillate between two extreme values depending on whether live loads act or not.

Four alternative methods for finding the funicular geometry of a warped arch are briefly described. They are, essentially, generalizations of methods originally applied to planar arches. Although the antifunicular geometries can be directly obtained considering three dimensions simultaneously, it is usually advantageous if the 3D form-finding procedure is resolved into two 2D procedures. The accuracy of these methods is shown in Fig. 2.

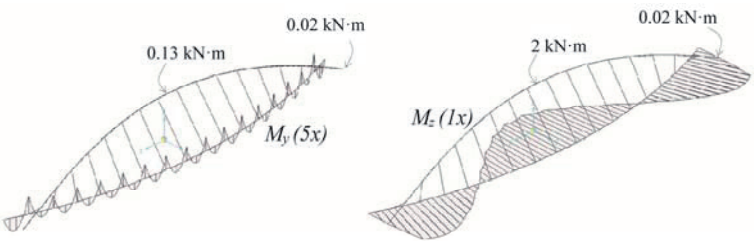

Fig. 2. Example of FEM output: Internal forces M_y and M_z drawn at the same scale for the arch and the deck.

The paper highlights how the form-finding process cannot select by itself the most efficient form, which must be selected by applying a secondary criterion, normally related to serviceability states.

Besides, the structure must fulfill any previous functional requirement defined by the designer, such as preventing the hangers from interfering the deck clearance. Additionally, the structure must respect any aesthetic previous decision regarding its appearance, such as the layout of the cable arrangement or the form of the deck plan. This checking may even lead, during the process, to redefine the topology of the structure, for example, by splitting the springing zone of the arch.

Fig. 3 shows how an arch attached to the centerline of the deck (fig. 3-a) must be corrected when the hangers are attached to the edge of the deck (Fig. 3-b). This bridge is modified again (Fig. 3-c), due to their interference with the clearance, and the hangers near the springings are anchored at the outer edge rather than at the inner edge.

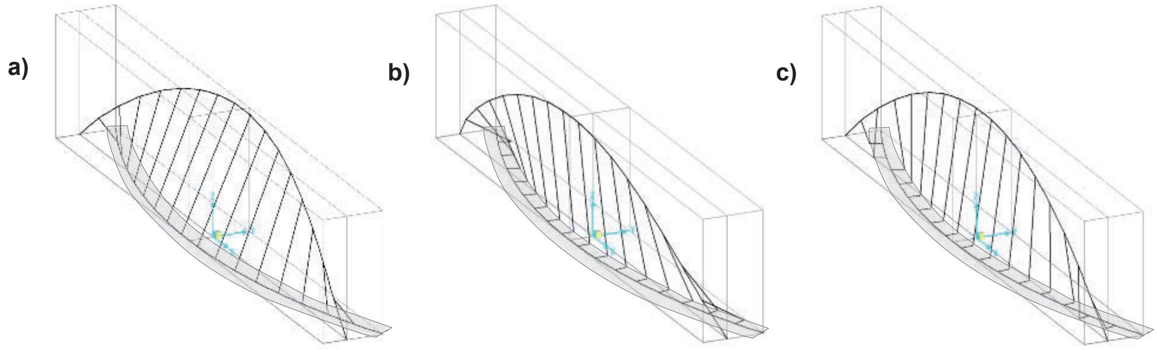

Fig. 3. Case A. Hangers attached: a) to centreline. b) to edge c) to edge considering clearance interference.

The form found as the result of the form-finding procedure will only be acceptable when structural requirements such as structural safety or serviceability states (i.e. ULS or SLS verifications) are fulfilled. Therefore, the final design is always the product of an iterative process: the structure obtained from the form-finding algorithm, and later modified to fulfill SLS and ULS verifications, becomes the input data in the next iteration. The form-finding process can be considered as a step of an iterative design process, described graphically in Fig. 4.

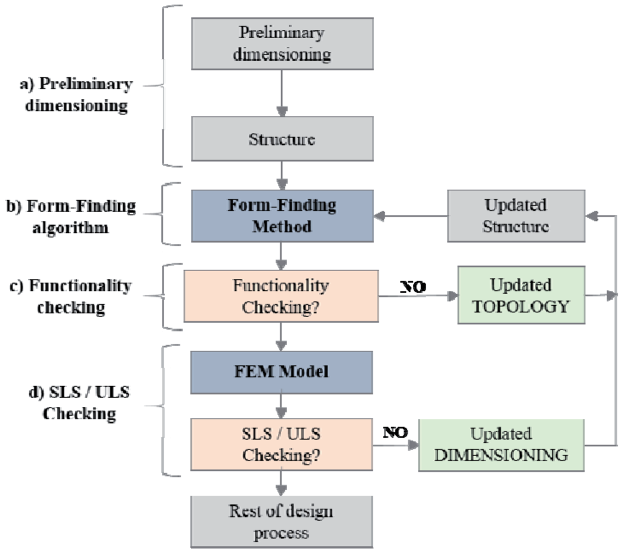

Fig. 4. The form-finding algorithm as a step of an iterative design process.