Estimating the minimum thickness of earthquake-resistant vaults and catenary arches using a hanging chain

ABSTRACT:

This paper presents a procedure for estimating the minimum thickness of vaults and catenary arches to resist seismic in-plane horizontal loading. In order to define the shapes of the thrust lines resulting from the combination of the self-weight of the arches and an horizontal in-plane acceleration, the inverted shapes of a hanging chain have been used, inclining the line connecting its ends with respect to the horizontal direction. Subsequently, an iterative calculation is performed to find the minimum thickness of the catenary arches with constant section that inscribe the defined thrust lines. This procedure was applied to different arches considering ten values of horizontal acceleration. Consequently, graphs were drawn that relate the horizontal acceleration to the minimum thickness, contingent on the rise/span ratio of each arch, as well as the position of the hinges created in the collapse mechanism. Finally, it is shown the application in the intersection of several catenary arches.

KEYWORDS: Vaults and catenary arches, thrust line, minimum thickness, hanging chain, seismic loads.

INTRODUCTION:

The principle of using an inverted hanging chain to define the ideal shape of an arch or vault under self-weight loads (Hooke 1675) is a well-established concept which has been widely used since the 18th century (Graefe 2020). The Catalan modernist architect Antoni Gaudí took the literal interpretation of this principle to an extreme, using hanging models made of ropes and small sandbags to define arches and vaults with highly intricate shapes, as evidenced by his work on the Sagrada Familia temple in Barcelona and the crypt of the Colonia Güell (Huerta 2006). More than half a century later, the Swiss engineer Heinz Isler designed complex shell structures by inverting the shape obtained in models built with hanging nets (Boller et al. 2024). The shape obtained in models built with chains, ropes or hanging nets is independent of the scale and magnitude of the loads, but rather depends on the manner in which these loads are distributed along the hanging elements (Addis 2014). Currently, the use of hanging chain physical models remains a simple and precise method for obtaining funicular shapes such those that