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Experimental study on the behaviour of masonry pavilion vaults on spreading supports

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Abstract

Over the years, historic unreinforced masonry vaults have been proved to be particularly vulnerable to dynamic actions and large displacements. This paper focuses on the investigation of the structural behavior of a pavilion vault on spreading supports by means of experimental tests on a 3D-printed scale model made of discrete blocks. Both the collapse mechanisms and the ultimate displacement capacity are analyzed. The reliability of this method for investigating the collapse of vaulted structures is validated by drawing analogies with crack patterns of real vaults. The experimental data are compared with the results obtained by thrust line analysis. A good prediction is obtained by making specific assumptions that take into account three-dimensional effects, which demonstrates the importance of thrust line analysis also for 3D collapse.

Keywords: masonry pavilion vaults, experimental tests, 3D-printed small-scale models, displacement capacity, thrust line analysis

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1. Introduction

Historical unreinforced masonry structures have long been shown to be vulnerable to earthquakes, soil settlements, and climatic conditions, whose effects are often enhanced by bad maintenance, inadequate retrofitting interventions, change of loading conditions, etc. In the last few decades, the interest in their safety and conservation has been increasing, not only because of a growing cultural awareness of the necessity of preserving our historical heritage, but also because of their economic and social implications. Moreover, since a large portion of the world's population still resides in unreinforced masonry buildings, better knowledge of their behaviour ultimately means improved ability to save human lives.

This paper focuses on the study of unreinforced masonry vaults, which are some of the most common floor types found in both ordinary and monumental historical buildings. In particular, they suffer from the effects of dynamic actions and large displacements, and their instability is a common cause of failure, more so than the material strength [1]. Masonry is also affected by sliding. Neglecting this mode of failure may lead to an overestimation of the capacity of a structure. The complex three-dimensional behaviour of vaults, such as the one shown in **Fig. 1**, makes the problem even more of a challenge to understand.

In particular, this paper analyses the behaviour of pavilion vaults on spreading supports. Similar to a cross vault, the shape of a pavilion vault (also known as a cloister vault) is composed by joining four cylindrical surfaces named webs, which are determined by the orthogonal intersection of two barrel vaults. The distinction between the two types of vaults lies in the shape of the webs from which they are comprised, as shown in Fig. 2. Despite their similar geometrical origins, the two typologies show completely different structural behaviour, starting from the distribution of horizontal thrust, which is continuous along the entire perimeter of the supporting walls for the pavilion vault, but concentrated at the corner piers for cross vault.

The use of pavilion vaults has its roots in the ancient Roman imperial period. Through the development of a new construction material, the *opus caementitium*, Roman builders could experiment on wide shapes of vaults. Some of the earliest vaulted structures are found in the *Tabularium* (78-65 B.C.), in the Hercules sanctuary in Tivoli (80-85 B.C.), in the *Domus Aurea* (64-68 A.D.), in the *Domus Augustana* (81-92 A.D.), in the *Villa Adriana* in Tivoli (117 A.D.) and in several thermal baths ([2] and [3]). After the decline of the Western Roman Empire, economic restriction lead to impoverishment of construction materials and techniques. Massive concrete vaults became too expensive and too heavy to be supported by weak masonry walls and therefore they were replaced by lighter vaults, often made of bricks or lightened with other techniques ([4] and [5]). Although pavilion vaults were frequently used to solve the intersection between transept and central aisles of medieval churches (see, for example, the Sant'Ambrogio church in Milan, 4th-6th centuries and the San Michele church in Pavia,