Chapter 25
Strengthening of Historic Masonry Structures with Composite Materials

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ABSTRACT

Existing un-reinforced masonry buildings made of vaults, columns and brick and multi-leaf stone masonry walls, many of which have historical and cultural importance, constitute a significant portion of construction heritage in Europe and rest of the world. Recent earthquakes in southern Europe have shown the vulnerability of un-reinforced masonry constructions due to masonry almost total lack of tensile resistance. Composite materials offer promising retrofitting possibilities for masonry buildings and present several well-known advantages over existing conventional techniques. The aim of this work is to analyze the effectiveness of seismic-upgrading methods both on un-damaged (preventive reinforcement) and damaged (repair) masonry building. After a brief description of mechanical and physical properties of composite materials, three different applications have been addressed: in-plane reinforcement of masonry walls, extrados and intrados reinforcement of masonry vaults/arches and masonry column confinement with composite materials.

INTRODUCTION

Recent earthquake occurrence in northern Italy (2012) and in Greece and Turkey (2012) indicated that historical buildings, essentially constituted by stone- and brick-work masonry structures, are scarcely resistant to horizontal loads and highly vulnerable to seismic actions. This is mainly due to significantly low tensile resistance in "masonry material". On the other hand, the stone and brick-work, when correctly assembled, is essentially effective with respect to vertical static loads resistance.

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Masonry constructions in many countries worldwide are characterized by inadequate resistance to earthquakes loading. This behaviour is due to the low strength resistance exhibited by mortar to applied horizontal forces. Mortars consisting of different binder types have been used in construction for many years. However, the experienced variation in the content of historic mortars is remarkably large with huge inconsistencies, depending on location and construction time periods. The most common binder type in the construction history until about the end of the 19th century was lime, until its use was replaced gradually by different natural cement types and later by Portland cement, which is nowadays the dominant binder type in the construction industry. However, in a lot of rural areas across Europe, America and Africa the use of lime-based mortars was predominant until the 1950s.

Lime mortars can be classified into two important categories: aerial lime-based and hydraulic lime-based mortars. The differences between the two kinds of mortar are very important with regard to the mechanical properties. It was discovered that limestone, when burnt and combined with water, produced a material that would harden with age. Although the beginning of the use of lime in mortars is not clear, it is well documented that the Roman Empire used lime based mortars extensively. The Roman Architect, Vitruvius, provided basic guidelines for aerial-based lime mortar mixes (Rowland & Howe, 1999). It should be noted that the mechanical properties of aerial-based mortars are usually very low and generally mortar tensile resistance is sometimes assumed to be equal to zero and compression strength is in the range of 0.5 and 5.0 MPa. In addition, water, a major degradation factor for old mortars, has the capacity to dissolve mortar constituents and thereby facilitate reactions that promote the formation of weaker elements.

Differentiating between aerial or hydraulic based mortar is usually not difficult: the consistency and strengths of hydraulic mortar are higher; with darker color due to the presence of calcium silicate and calcium aluminate hydrates while aerial mortars are usually inconsistent and light colored due to the addition of lime sand.

The most common material used for construction starting from 11th century in Europe was stone with usually very scattered mechanical properties. Hardstones present extremely high compression strength, comparable or higher than that obtainable in concrete, but softstone (tuff, sandstone, etc.) is relatively soft and characterized by poor mechanical properties, making it easy to carve. Most sandstone is also not particularly resistant to weathering and historic constructions made of sandstone often require repair and replacement. In Western Europe, with the exception of rare Roman-period military and civic structures, the most ancient masonry constructions date back to the beginning of the 11th century when the romans extensively adopted bricks for constructions. This extensive use of brick did disappear in Europe for over 15 centuries as a direct consequence of the collapse of the Roman Empire.

The development of the brick industry mainly started in Europe in the 16th century. Bricks were only used on important constructions while most part of constructions was still made with barely cut or uncut stones until recent times. For example, traditional farm buildings are among the most abundant of historic building types in the countryside but only a small proportion of these buildings are currently protected through government listing.

The importance of understanding the mechanical properties of historic stone masonry as well as the structural behaviour of these constructions has been underestimated in the past. This has led to the adoption of inappropriate repair/refurbishment techniques which have impacted upon the construction either by causing damage to the intrinsic character, or, in some cases, promoting structural failure of the resisting elements (walls, vaults, floors, etc.).