Realization of International Charters and Recommendations for Seismic Retrofitting of Historic Masonry Cultural Heritage: Integrity and Authenticity

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Abstract: Despite the development of engineering science, especially in application of modern engineered structural elements and materials, a significant proportion of the world population are living in masonry structures. Nowadays, the masonry construction technique due to its environmental sustainability, local availability of materials everywhere, simplicity in construction technique and cost-effectiveness will continue to be built everywhere in the world even in areas with high seismic risk. Meanwhile, the historic fabric of historic masonry structures represents the history and culture of people in a specific geographic location. So that the raw building materials had altered and assembled to form buildings which have displayed the modification and manipulation of natural materials by human labors. However, the preservation of world earthen architecture not only is the preservation of earthen buildings, but also is the protection of traditions and human genius applied to erect primary structures for specific requirements. Therefore, it is important to provide adequate upgrading to these vulnerable types of structures, both modern and historic ones. In this case, unlike modern masonry structures, the seismic improvement should ensure "life-safety protection", and at the same time it should also preserve the "structural integrity and authenticity". In this paper, it is tried to represent an intelligible review on the main international norms, charters and recommendations for seismic retrofitting of masonry cultural heritage properties.

Keywords: Historic Masonry Structures, Cultural Heritage, Earthquake, Seismic Retrofitting, Integrity, Authenticity

1. Introduction

Despite their past and present spread, and their long existence, masonry structures are intrinsically vulnerable against seismic loads, because of their overt and covert deficiencies, heterogeneity and asthenia characteristic of their constitutive materials (De Matteis et al, 2019). It is indispensable to spend many words to underline the importance of the preservation of the masonry cultural heritage all over the world, where based on their specific weather condition and limit access to construction materials, this type of construction technique with its special architectural typologies has had been recognized as the dominant pattern. Meanwhile, this construction practice is naturally simple and does not require any special energy resources (Rouhi et al, 2017a). In fact, the historic fabric of masonry architectural heritage represents the history and culture of people in a specific geographic location, so that these raw building materials had altered and assembled to form buildings which have displayed the modification and manipulation of natural materials by human labors. Therefore, the preservation

of world masonry architecture heritage not only is the preservation of earthen buildings, but also is the protection of traditions and human genius applied to erect primary structures for specific requirements. Currently, many cultural heritage properties need either emergency intervention or a comprehensive management plan. Nevertheless, the preservation of these places of culture, and preventing their gradual and definitive loss entails entry into force for the urgent intervention measures. Recent and historic data clearly shows that not only large-scaled earthquakes but also even medium and low sized earthquakes subjected to these types of buildings can have resulted in catastrophic destruction, dismal tragedies, high death toll and high loose of cultural heritage properties (Rouhi, 2016a). Basically, seismic retrofitting refers to the process of strengthening older buildings to make them earthquake resistant. According to conventional earthquake resistant design philosophy, the buildings must not suffer any considerable damage during small or frequent seismic motions, but they should just sustain only repairable damage during moderate earthquakes, and they should not be disintegrated during major earthquakes. In the case of seismic retrofitting of old masonry structures, it must be accepted that significant cracks and detachments may occur even during small and moderate earthquakes. However, the aim of seismic retrofitting measure is to limit the damages into a reparable level during moderate earthquakes, and to reduce the level of collapse during severe earthquakes or deferment of total collapse. Actually, historic masonry structures due to their age, considerable affectability of their materials from causes of deteriorations, brittle and fragile material characteristics, no appropriate foundations, long and tall walls without adequate supports, heavy roofs and lack of proper linkage at the connections of walls-walls and walls-roofs are very vulnerable during the seismic events. Regarding the mentioned defects, the technical solutions for seismic retrofitting of historic masonry structures should increase the persistency of the structure during an earthquake. In the world, there are some unmodified masonry structures, which have withstood severe repeated earthquakes without total collapse. In these cases, the temporary stability of surviving historically valuable masonry structures should not be the reason to ignore their seismic upgrading against the next possible earthquakes. Over time, these structures are confronted with more declines, thus a high attention must be considering for their seismic retrofitting. However, based on recent researches conducted, there is an inevitable question, i.e. which approaches concerning the seismic retrofitting of masonry cultural heritage is more efficient? In balance, the current paper aims to render the basic considerations for seismic retrofitting of these structurally vulnerable and superficially sensitive structures.

2. Theoretical Background

From past to the present, lessons learned from structural behaviour of buildings during destructive earthquakes have been used to advance construction techniques, and more recently, such lessons have fostered the development of methods and techniques to have more engineering interventions on

historically or culturally important structures (Rouhi et al, 2017b). The international charters of UNESCO and its related Advisory Bodies (IUCN, ICCROM and ICOMOS) on the subjects of cultural heritage conservation and restoration are documents, principles, norms and guidelines engendered by the General Conference, and principally intended to appoint standards and recommendations for interventions on historic monuments and sites (Rouhi, 2016b).

As the result of researches conducted for seismic retrofitting of historic masonry structures, the options available for their retrofitting have recently been developed. Nowadays, the new engineered techniques are intended to product stronger masonry buildings in the future, using: (i) internal and external reinforcement (e.g. synthetic wire meshes and rods, tying, anchorage etc.); (ii) structural design (e.g. buttresses and pilasters, robust layout, solid foundation, tapered wall (wide at base and thin at top), ring beam, etc.); (iii) stabilization of masonry mortar using chemical stabilizer and natural fibers; and (iv) diagnostic investigation (e.g. realization of hidden cracks, weaknesses, declines, etc.), see Aveta et al. (2017) where innovative techniques proposed during the reconstruction process of Bam Citadel (the largest adobe complex in the world) damaged by the 2003 Bam earthquake were explained. As Rouhi (2017c) conducted a SWOT analysis in two different intervention plans applied on Bam Citadel, to select the ideal intervention model, many factors such as the condition prevailing of the sites, the importance of monument, the technical options available, financial aspects, and also project durability, cost efficiency and time required should be taken into account. Contrary to the modern masonry buildings, dealing with historical and cultural masonry architectural heritage encounters some restrictions on the level of the interventions, through which the authenticity of the monuments should not be disputed. Due to the dependence of the restoration on the preservation of the aesthetic and historical values of the masonry monuments, techniques, materials and design procedures in use for their structural reinforcement encounter many limitations, which is a real challenge for the engineers and architects.

3. Methodology

Seismic retrofitting measures in historically or culturally masonry architectural heritage should be based on a series of criteria conducted to manifest the efficiency of the interventions together with their compliance with recommended restoration criteria, the criteria that are imposed in international documents such as the Venice Charter (1964), and in a more specific way, in the ICOMOS/ISCARSAH (2003). Although the criteria proposed in these documents cannot be known as absolute requirements, but those basic principles developed will assist in conceiving and designing both efficient and respectful interventions. In this prospective, the seismic retrofitting of historic masonry structures absorbs some basic principles, which regardless of the location of the monuments and sites, and their constituent materials, they can guide the design of interventions contemplated for structures with high historical value. In the next paragraphs, the main initial points of the issue are presented.

4. Comprehensive Study

The restoration of architectural monuments is particularly complicated. Whatever approach is adopted, all treatments should embrace the conservation goal of maximum retention of historic fabric to preserve authenticity and should be preceded by a systematic, multidisciplinary investigation of the building (Tolles et al., 2002). Hence, an appreciation of some external and certain unknown factors demands a profound knowledge of history, a true understanding of the present and an ability to anticipate the future (Gazzola, 1972). In seismic retrofitting of masonry cultural heritage, the first and fundamental principle is to know the structure as a whole. The consideration of this point can specify other basic principles, such as minimum intervention necessary, alternatives' compatibility and reversibility, and it also has a significant role in elimination of a conjectural response to intervention works. In fact, when either the physical state of damage or the effectiveness of solutions is unknown, the results of the interventions will be unpredictable. Generally, as recommended in ICOMOS/ ISCARSAH (2003), "knowledge of the structure requires information on its conception, on its constructional techniques, on the processes of decay and damage, on changes that have been made and finally on its present state." This knowledge can usually be reached by the following steps (ICOMOS/ ISCARSAH, 2003):

- definition, description and understanding of the building's historic and cultural significance;
- a description of the original building materials and construction techniques;
- historical research covering the entire life of the structure including both changes to its form and any previous structural interventions;
- description of the structure in its present state including identification of damage, decay and possible progressive phenomena, using appropriate types of test;
- description of the actions involved, structural behaviour and types of materials;

A 'pre-survey' of both the site and the building should guide these studies.

In professionally managed projects, the pre-survey knowledge can be preceded via a systematic and multidisciplinary investigation group including architectures, archeologists, historians, engineers, geographers, etc., through in-site and laboratory experimental investigations, structural analysis using appropriate methods and techniques. In earthquake prone areas, the information is also including studies about past earthquakes, macro-zonation, and the results of geotechnical site investigations. As an interdisciplinary study, the documentation and investigation of the experience between two earthquakes should be in such a way that it considers the pre/post-earthquake information of the monuments. In some cases, unfortunately, inadequate attention to that important principle has caused that empirical restorers who due to lack of proper training, professional jealousy and oversimplification have started

intervening in the historic structures in a kind of aesthetic surgery, without any detailed knowledge about the structures and their weakness, as a consequence the results are to be deplorable e.g. as what happened on pre-earthquake restored Citadel of Bam during the 2003 Bam earthquake.

5. Respect to Original Materials and Authentic Documents

As mentioned by Jokilehto & King (2000), "The issue of authenticity is not only an administrative verification of truth; it is above all the critical foundation for the conservation and restoration of this heritage." The problem for the seismic retrofit of historic structures is to find the balance of interventions that reduces the risk for injury or property damage to an acceptable level without unduly destroying the historic fabric (Thomasen, 1993). In the meantime, historic monuments not only are interesting because of their tangible values, but also because of their inherited intangible values.

As stated by Correia & Fernandes (2006), "it is essential to refer that in earthen architecture, there are more values that should be taken into account. Sometimes, some earth buildings walls have apparently no value. Their unique character and reason for restoration can be a social, religious or even political value, but also the unique construction technique that built it or the fact it can be one of the unique buildings made of earth. A reality still authentic in many places of the world, like it was 2000 years ago, so the maintenance of the knowledge and know-how is still an important value for earthen architecture: it is the guarantee of an identity and continuity of the cultural tradition."

In such cases, the importance of retaining the historic fabric of an adobe structure varies with each specific building and depends on what type of treatment is appropriate for that building: stabilization, preservation, restoration, rehabilitation, or reconstruction (Tolles et al., 2002). However, since our approaches in any of these types of treatments is diverse from one to another, the conservation should involves protection and restoration using "any methods that prove effective in keeping that property in as close to its original condition as possible for as long as possible" (Walston, 1978).

6. Minimal Intervention

Interventions or alterations are minimized to preserve as much of the significant fabric of the building as possible, thereby safeguarding its authenticity while accomplishing whatever goal motivated the initial decision to make alterations (Tolles et al., 2002). As mentioned by Correia & Fernandes (2006), "It is indispensable, when following the principle of minimum intervention to research and acquire a good knowledge concerning the object, material and its techniques, so adequate interventions are applied. This principle also helps to keep the unity, but especially the authenticity of the original object." Consequently, among all possible seismic retrofitting measures, the one that have minimal alteration should be preferred.

7. Compatibility and Durability

As clearly recommended in ICOMOS Charter (2003), "The characteristics of materials used in restoration work (in particular new materials) and their compatibility with existing materials should be fully established. This must include long-term impacts, so that undesirable side-effects are avoided." Regrettably, there are difficulties both in the efforts to conserve structures and/or the efforts to prevent the structure from decay, in part, because of the lack of information concerned with the compatibility of the materials and techniques (Correia & Fernandes, 2006). Since these types of structures are very sensitive structures, the use of identical, or similar but compatible materials in the repairing and retrofitting of deteriorated features to obtain similarity of performance has of great importance. However, during trying to restore the authenticity of the masonry cultural heritage to unity requires, a deeper focus on the compatibility of suggested materials must be implemented. Compatibility problem in historic masonry structures may be related to chemical, physical, mechanical, thermal, and rheological phenomena. On the other hand, the aim of seismic retrofitting measures is to enlarge the seismic resistance of these types of structures within a reasonable timeframe. Hence, the suggested techniques and materials must also be satisfactory durable, which can be compromised as the overall safety of the structure and the durability of the original fabrics.

8. Reversibility

The use of processes which are reversible, or substantially reversible, when undertaking works to a protected structure is always preferable, as this allows for the future correction of unforeseen problem should the need arise, without lasting damage being caused to the architectural heritage (Environment Planning Guidelines No.9, 2011). As Tolles et al. (2002) pointed out, "Reversibility allows for the use of improved technologies as they are developed and the removal of inappropriate alterations. This principle encourages alterations of an additive nature and discourages the removal of material or architectural features. In addition, the permanent storage of any removed material or feature is important, to provide the opportunity for future replacement."

9. Non-Invasivity

According to the ICOMOS Charter (2003), "No action should be undertaken without having ascertained the achievable benefit and harm to the architectural heritage, except in cases where urgent safeguard measures are necessary to avoid the imminent collapse of the structures (e.g. after seismic damages); those urgent measures, however, should when possible avoid modifying the fabric in an irreversible way."[…] "The choice between "traditional" and "innovative" techniques should be weighed up on a case-by-case basis and preference given to those that are least invasive and most compatible with heritage values, bearing in mind safety and durability requirements." Therefore, among possible

alternatives, the least invasive one should be preferred to more invasive alternatives.

10. Distinguishability

According to Article 12 and 13 of Venice Charter (1964), "Replacements of missing parts must integrate harmoniously with the whole, but at the same time must be distinguishable from the original so that restoration does not falsify the artistic or historic evidence." […] "Additions cannot be allowed except in so far as they do not detract from the interesting parts of the building, its traditional setting, the balance of its composition and its relation with its surroundings". In this way, concealment of retrofit measures (interventions) has been of paramount importance, and this principle has contributed to rejection of the time honored, visible fixes traditionally used (buttresses, tie-rods, wall or joist anchors, cables, etc.) (Tolles et al., 2002).

11. Conclusion and Discussion

However, there are many masonry cultural heritage properties that overtime because of lack of adequate attention have been faced with reparable damages. Meanwhile, there are many structures that because of inadequate scientific interventions have suffered considerable structural damages. Based on surveys conducted about the causes of damages induced on historic masonry structures during 2016 central Italy earthquakes, most of these structures have not sufficiently been reinforced to withstand seismic events. Although nowadays the technologies to rehabilitate historic buildings are rapidly developing in the world, but the loss of certain technical expertise is rarely compensated by up-to-date know-how.

Meanwhile, although earthquake is recognized as the main cause of losses of historic masonry structures, with respect to the importance of the issues of authenticity and integrity of such structures after intervention works, the evaluation of available seismic retrofitting measures are sporadic, and relatively few published technical papers have dealt with these issues. At best, the current international guidelines and standards along with striking range of styles, details, clarities, and intent are characterized by using inadequate criteria and measures to guide the efforts. Given the existing shortages, there is need to do a special attention on the evaluation of available retrofitting measures, so that simultaneously satisfies the stability of such structures from one side and respects to their authenticity and integrity from other side.

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