A SHORT NOTE ON THE DEGRADATION AND CONSOLIDATION OF MASONRY STRUCTURES

BY

SABINA SCRIPCĂ*

Gheorghe Asachi Technical University of Iasi, Faculty of Civil Engineering and Building Services

Received: February 15, 2023
Accepted for publication: May 09, 2023

Abstract. This paper discusses the factors that can lead to the degradation of masonry structures and provides an overview of the existing techniques for their rehabilitation and consolidation. The degradation of masonry is often related to negative actions of the environment, such as water penetration, freeze-thaw cycles, chemical attacks, and exposure to pollutants. These factors can lead to the appearance of cracks, scaling, erosion, and other types of deterioration of masonry. To preserve masonry structures, frequent monitoring and repairs (locally), preferably immediately after any degradation, are the most important measures. When degradation occurs, prompt action is necessary to prevent further deterioration and to apply appropriate rehabilitation and consolidation methods. Rehabilitating a construction involves replacing or restoring degraded elements to restore functionality to the pre-degradation level and to improve the overall performance of the structure. In contrast, consolidation focuses on strengthening an existing structure by adding new structural elements or by applying specific consolidation techniques with the aim of achieving increased structural capacity. These processes are often interconnected and part of a larger process of restoring or maintaining buildings or structures. Regarding traditional solutions for consolidating masonry elements and structures, these consist of

*Corresponding author: e-mail: sabinascripca9212@gmail.com

© 2021 Sabina Scripcă
This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).
repairing or rebuilding affected areas with classic materials, such as simple or reinforced mortars, welded meshes, dowels, steel bars and profiles. Traditional masonry repair works include filling cracks by injection, partial disassembly of walls followed by reconstruction, dismantling of mortar joints followed by deep filling, stitching of cracks with steel dowels, and reinforcing and facing with mesh or mortar. These techniques are applied according to the degree and type of degradation of the existing structure, as well as local and environmental conditions, with the aim of ensuring efficient and durable consolidation of the structure. The informed decision on the rehabilitation or consolidation solution used and how it is to be applied is usually made after extensive studies and consultations to achieve the best possible result. Generally, masonry structures are considered very resistant and durable, due to their history of over 6000 years. However, proper care and attention to detail are crucial to prevent degradation and to maintain masonry structures in good condition.

**Keywords:** brick masonry, consolidation, degradation, rehabilitation, strengthening.

1. Introduction

Masonry is considered to be one of the oldest structural systems invented by mankind, with a history spanning over 6000 years. Masonry buildings represent a large part of the built environment (be it current or historical/heritage), in much of the world. It remains a popular, traditional building material due to its favourable properties and diverse usage possibilities. Modern masonry has become energy saving and is more sustainable through its development (Kubica et al., 2020; Dipasquale et al., 2016).

Brick masonry is obtained by setting (bedding) of individual bricks in mortar, usually following a certain pattern, in order to obtain a homogenous element (ex. a brick wall), in such a way that the loads and stresses which may emerge afterwards can be evenly and efficiently distributed throughout the said element (or throughout the structure). Therefore, the mortar ensures the load distribution through the brickwork, secures the bricks together and has a role in the prevention of heat, sound and moisture transfer throughout the masonry (usually from the exterior to the interior). Obviously, there are factors which influence the performance and integrity of brick structures, such as the quality of bricks, the quality of mortar, the quality of the design and execution (Dipasquale et al., 2016).
2. The state of the art

2.1 Masonry degradation problems

Masonry is not exclusive to bricks (although the term can refer only to the “classic” red building bricks). Rather, it describes the structural system. Masonry can be realized from many other materials, such as stone, granite, concrete blocks etc. Although generally considered to be a highly resilient building method, it is not without durability issues. The properties of brick masonry as a whole are linked with the properties of its constituents (Larbi, 2004; Grimmer, 1984; Lourenco et al., 2014).

As such, the durability of the materials constituting brick masonry is a result of the chemical, physical and/or mechanical stability of its constituent phases. If there is a lack of stability, deterioration will usually start at a micro-level, without being noticeable in any obvious way. Once begun, it will continue to affect the material until said deterioration will eventually manifest externally, on the structure (Larbi, 2004). Degradations include: cracking, chipping, flaking, salt fretting, spalling etc.

By far, the most common (and most identifiable) type of degradation is represented by cracking. Cracking is usually equated with a state of tension present within masonry, but it is not always easy to “diagnose”. As far as damage goes, two categories can be identified: large cracks, which are indicative of large masonry dislocations and small cracks (but numerous), which point towards a certain degradation degree (Grimmer, 1984).

2.2 Masonry degradation causes

Of course, some causes for degradation can be identified. These include: material aging (for both bricks and mortar), lack of maintenance, condensation, seismic action etc (Muntean et al., 2009). But, it is possible to consider that the main factors which generate degradations are linked to:

- environment;
- materials;
- design;
- building and overall workmanship;
- maintenance.

The degradations stemming from environmental conditions (such as presence of water, frost, flooding, pollution, various salts etc.) are also influenced by the material properties. It can be said that, when talking about degradations caused by environmental conditions, the presence of moisture is one of the most important factors to be taken into account. Therefore, the main environmental factors are:
• moisture content: moisture occurrence can be due to rainwater, groundwater, surface water, frost/thaw cycles, floods;
• salt content: can be also carried by water/moisture or can be activated in the presence of water (salt efflorescence);
• the building operation also causes moisture and salt to appear (ex. stables, salt storage, de-icing activities);

While there are other environmental factors that can contribute to the degradation of masonry structures, such as fire exposure, soil settlement, earthquakes, vibrations, and others, their occurrence is often considered to be accidental rather than frequent (Grimmer, 1984; Lourenco et al., 2014; Van Hees, 2002; Garavaglia et al., 2020).

The main material factors are considered to be:
• mortar recipe and composition;
• the properties of the bricks, stones and mortar.

Together, the environmental factors together with the material factors can greatly influence the degradation process (Lourenco et al., 2014; Van Hees, 2002).

The design factors are considered to be:
• the initial structural design of the building and/or later modifications;
• the choice of building materials and combinations of building materials;
• building details (roof covering, water drainage, gutters, window sills etc);
• (if applicable) the proposition for repair methods and repair materials.

The workmanship and construction factors are considered to be:
• execution quality;
• on-site mortar preparation;
• on-site building material preparation (curing).

The maintenance factors are considered to be:
• lack of maintenance;
• inappropriate monitoring, intervention and repair scheduling.

To summarize, all the above-presented factors can be grouped in degradation actions, which are a result of the occurrence of one or more of the factors:
• freeze/thaw cycles;

A basic example of the danger of freeze/thaw cycles is when water can infiltrate in the materials. When below a certain temperature, the water will freeze and it will expand, thus degrading the material (sometimes from the inside out). This degradation is continuous if the water is not eliminated or the said
material/building element is not protected. Freeze/thaw cycles are a function of the permeability and porosity of the material and will affect its strength and deformability (Uranjek and Bokan-Bosiljkov, 2015).

- crystallization cycles.

Types of damage that may occur are:

- efflorescence and crypto-efflorescence refers to salt which crystallizes either inside a material or at an interface between two materials (or between a material and the outside environment, if the material is not properly protected). The presence of salt is indicative of a low quality of the material and such repeated cycles can cause spalling or push-out;
- the mortar components, if they contain salts, can be converted in other compounds with a larger volume, these again being detrimental to the building integrity (Van Hees, 2002; Garavaglia et al., 2020);
- other chemical conversions can occur, forming expansive compounds, for example in the case when air pollution is present;
- dissolution and leaching occurs in the case of excess water which can “flow” through cementitious materials, usually mortar. The water dissolves the free lime present in the mortar and then deposits it on the finish surface of the material, hence the starting point for this phenomenon is often represented by the joints of the masonry. If no repairs are undertaken, more serious degradations can eventually occur;
- wind and water erosion usually act in concert. Water, if it is flowing over the brick surface (and it can additionally be “driven” by the wind) can cause some lime to dissolve. Again, mortar deposits can appear on the surface of the material. Eventually, wind and water erosion will increase the porosity of the material and make room for more destructive actions;
- although less-encountered, biological degradations can appear. A fairly common example would be the emergence of moss on mortar joints, for example. Although moss in itself is not aggressive, it retains water, which can later lead to other degradations;
- swelling and shrinkage can be encountered too, if there are variations in temperature and moisture. The corresponding expansion and contraction of masonry leads to the accumulation of stresses in the brickwork, which may later crack;
- obviously, any sort of static or dynamic loading, settlements and creep will also be shown through cracking.

The defects in masonry can be structural and/or non-structural (depending on the use of masonry in a structure). Structural degradations will usually affect the structural integrity of the building. Non-structural degradations will affect other aspects, such as the serviceability of a building. Moreover, structural defects can affect non-structural elements. The understanding of these interactions is key to the understanding and prevention of degradations (Sousa et al., 2014).
Fig. 1 Cracks in masonry walls due to foundation soil degradation (seismic action).

Fig. 2 Cracks caused by changes in the ground (degradation of the foundation soil); crust, efflorescence (the absence of sidewalks favored water infiltration at the base of the constructions through capillary rise, moistening the surfaces of the elements near the natural ground)
Fig. 3 Cross-shaped cracks due to seismic action

Fig. 4 Lack of mortar continuity in joints and expulsion of masonry and plaster (action of external factors)
Fig. 5 Stains and deposits caused by the contact of masonry with moisture and salts from the soil, rain, air pollution, and biological agents.

Fig. 6 Deterioration of the plaster, detachment of the plaster layer (external factors action); grinding of the masonry and its expulsion.
Fig. 7 Inclined cracks (oblique tensile forces, dynamic action on the foundation soil); grinding of the binding agent, efflorescence, detachment of plaster (external factors action)

### 2.3 Methodologies for strengthening and consolidation of masonry structures

Consequently, it is important to explore and understand the methods for rehabilitation and strengthening regarding masonry structures (Plesu et al., 2011).

Equally important is the identification of the proper repair/intervention solution. The decision on “what” and “how” to repair should only be taken after a proper assessment of the degradation(s) in question (Sousa et al., 2014).

As a general rule, the rehabilitation of a masonry building should take into account the following issues: eliminating the causes of material degradation, avoiding changes in the structural system, proper transmission of loads to the foundation elements, proper horizontal and vertical tie-in of the building elements (Muntean et al., 2009; Van Hees, 2002).

Some consolidation methods are (Van Hees, 2002; Branco and Guerreiro, 2011; Van Gemert et al., 2015; Plesu et al., 2011):

- the rebuilding of damaged/dislocated masonry;
- the partial concrete reinforcement;
- the filling and injection of fissures and cracks;
- the stitching of cracks with steel clamps;
- the coating of the walls with various materials;
the bordering of the gaps;
the binding of corner areas;
the insertion of ties and various metal elements.

Oftentimes, a combination of the above-listed intervention methods is used in order to implement the required rehabilitation solution. In the specialty literature, various check-lists were put forward in order to ensure the correct choice of diagnosis and repair (Sousa et. al., 2014). However, real-life rehabilitation experience (often found in more senior engineers, for example) is also of great help in diagnosis and repair activities.

Some common repair principles are:

- if internal stresses are too great within a masonry wall, it is a good idea to consider the creation of an expansion joint;
- if there is a transmission of forces between the two “sides” of a crack, it is a good idea to consider the “crossing” of the crack with anchors or steel ties;
- if no more significant motion or settlement will be present anymore, but the final finishing layer(s) can still be affected, it is a good idea to repair the cracks with non-bonded strips.

Standard P100-3 provides guidance for assessing the seismic capacity of existing structures, including those that have been affected by previous earthquakes or are vulnerable to seismic activity, and covers various types of buildings and structural and non-structural components. To select the appropriate intervention strategy and techniques, several factors are considered, such as the seismic hazard in the area, the characteristics of the building, the required performance level, and economic and technological possibilities. A feasibility study should analyze at least two intervention options and evaluate their effectiveness in reducing vulnerability to seismic hazards. Intervention measures must be adapted to the degree of material degradation caused by previous earthquakes, other specific operational actions, differential terrain settlement, or environmental factors. In the case of masonry buildings, the current state of the building is crucial in determining appropriate intervention measures. The type and quality of materials used in construction, the type of building, its age and function, the level of seismic activity in the area, and the seismic risk associated with the building must also be considered. The purpose of the intervention, whether it is modernization, rehabilitation, or consolidation of the building, requires a different approach and set of solutions. It is essential to consider available intervention solutions, including the technologies and materials used for consolidation. Cost, duration, and impact on building users are also essential factors to consider.

In conclusion, selecting the right intervention strategy and techniques for masonry buildings is a complex process that involves considering several criteria. It requires a thorough understanding of the building's condition, the materials used in construction, the level of seismic activity in the area, and the goals of the intervention. The feasibility study should analyze multiple options.
and evaluate their effectiveness in reducing vulnerability to seismic hazards. The chosen solution should consider the most critical criteria and should be economically and technically feasible. Ultimately, the goal is to ensure the building's safety and performance while minimizing the impact on its users.

### 2.3.1 Floor strengthening

A common rehabilitation scenario in masonry buildings, especially in older ones, where floors were mainly made of timber. The idea is to replace the timber and pour a reinforced concrete slab (commonly of 20 cm thickness). This ensures the achievement of “rigid washer” effect on the structure and helps with distributing the lateral forces to the vertical load-bearing elements. Moreover, a spatial mechanical character is gained. Oftentimes, this solution implies other interventions, such as the strengthening of the walls themselves and/or of the foundations (Sucala, 2013; Sousa et al., 2014).

![Fig. 8 Floor strengthening (doi: 10.5772/intechopen.69439, 2017)](image-url)
2.3.2 Horizontal steel ties

Horizontal steel ties (or steel profiles) of diverse designs are commonly used in order to stiffen various elements. They are arranged in well thought-out patterns and are connected with metallic plates and mechanical connectors (Sousa et al., 2014).

![Horizontal steel ties](https://www.helifix.com.au/applications/seismic-upgrades/)

**Fig. 9** Horizontal steel ties

2.3.3 Reinforced mortar coating

Yet another fairly common method is to coat the masonry walls with a reinforced mortar (mortar which embeds welded nets or bars in a net pattern).

![Reinforced mortar coating](http://www.construieste.info/?p=134)

**Fig. 10** Reinforced mortar coating
The method is time-consuming, yet it is considered to be a “classic” rehabilitation solution. The coating of the walls with welded nets (or bars in a net pattern) allows for an increase in the load-bearing capacity of the structure and helps to better tie-in the entire structure. Crack injection can be applied together with this method. Sometimes, shotcrete is used instead of mortar. Of course, the method requires extensive preparation, cleaning of the cracks, joints etc.

2.3.4 Reinforced concrete diaphragms

Yet another fairly common method is to coat the masonry walls with a reinforced mortar (mortar which embeds welded nets or bars in a net pattern). The method is time-consuming, yet it is considered to be a “classic” rehabilitation solution. The coating of the walls with welded nets (or bars in a net pattern) allows for an increase in the load-bearing capacity of the structure and helps to better tie-in the entire structure. Crack injection can be applied together with this method. Sometimes, shotcrete is used instead of mortar. Of course, the method requires extensive preparation, cleaning of the cracks, joints etc.

![Reinforced concrete diaphragms](https://doi.org/10.1061/(ASCE)ST.1943-541X.0000513)
2.3.5 Local masonry restoration

For example, if the damage is not extensive to an existing structure, it is possible to attempt a local masonry restoration. In such a case, bricks with similar characteristics to the initial ones should be used (Sucala, 2013).

![Fig. 12 Local masonry restoration](http://www.nra.gov.np/uploads/docs/hK3E3YCy1b170925085057.pdf)

2.3.6 Crack injection

Crack injection will fill up the gaps of a masonry wall and thus will restore the continuity and proper load-carrying patterns of a structure. In many cases it is only a solution from a pack of several proposed ones (Sucala, 2013). Crack injection can be realized with injection mortars or with epoxy resins.

![Fig. 13 Crack injection](https://www.helifix.com.au/applications/crack-stitching/)
2.3.7 Gap bordering

Gap bordering also addresses older buildings, which had, for example, no lintels above the windows when they were originally built. It is possible to border the gap with metal elements, to jacket the gap or sometimes to insert premade/precast lintels above the opening, following the creation of a slit.

![Fig. 14 Gap bordering (DOI: 10.1016/j.engstruct.2020.111341)](image)

3. Conclusions

It can be concluded that the most important steps towards the conservation of masonry structures are frequent monitoring and (local) repairs, preferably immediately after any damage occurs. Common experience shows that a lot of degradations can appear from years of neglect and, when an intervention is finally due, the costs can spiral out of control. Otherwise, cracking, water penetration and local degradations remain amongst the most common degradation causes. Structural stability is a somewhat less of a concern, since historically speaking, masonry structures have proven to be very resilient. However, when the masonry load-bearing structure is finally affected, then the choice of rehabilitation and strengthening should take the reestablishing/improvement of the load-bearing capacity as a prime factor in turning out the proper solution.

A collection of rehabilitation procedures and techniques are present, to serve both as a reminder and as a short guide in the proper selection and application of such a solution. The informed decision regarding “what to use and how to use it”, in terms of a rehabilitation solution, is usually taken after extensive studies and consultations, in order to settle on the best possible outcome.
REFERENCES


O SCURTĂ NOTĂ DESPRE DEGRADAREA ȘI CONSOLIDAREA STRUCTURILOR DIN ZIDĂRIE

(Rezumat)

Această lucrare discută factorii care pot duce la degradarea structurilor din zidărie și oferă o prezentare generală a tehniciilor existente pentru reabilitarea și consolidarea acestora. Degradarea zidăriei este adesea legată de acțiuni negative ale mediului înconjurător, cum ar fi penetrarea apei, ciclurile de îngheț-dezgheț, atacurile chimice și expunerea la poluanți. Acești factori pot duce la apariția fisurilor, descuamării, eroziunii și altor tipuri de deteriorări ale zidăriei. Pentru a conserva structurile din zidărie, monitorizarea frecventă și reparațiile (locale), de preferință imediat după apariția oricărei degradări, sunt cele mai importante măsuri. Atunci când apare o degradare, este necesară o acțiune promptă pentru a preveni deteriorarea ulterioară și aplicarea metodelor adecvate de reabilitare și consolidare. Reabilitarea unei construcții presupune înlocuirea sau refacerea elementelor degradate, cu scopul de a reînnoi funcționalitatea la nivelul anterior deteriorării și de a îmbunătăți performanța globală a structurii. În contrast, consolidarea se concentrează pe întărirea unei structuri existente prin adăugarea de elemente noi de structură sau prin aplicarea de tehnici specifice de consolidare, cu scopul de a obține o capacitate structurală crescută. Aceste procese sunt adesea interconectate și fac parte dintr-un proces mai larg de restaurare sau întreținere a clădirilor sau structurilor. În ceea ce privește soluțiile tradiționale de consolidare a elementelor și structurilor din zidărie, acestea constau în repararea sau refacerea zonelor afectate cu materiale clasice, cum ar fi mortare simple sau armate, plase sudate, scoabe, bare și profile din oțel. Lucrările tradiționale de reparație a zidăriilor includ umpleri ale fisurilor prin injectare, desfaceri parțiale ale pereților urmate de rezidiri, desfaceri ale rosturilor de mortar urmate de chituirii în profunzime, coaseri ale fisurilor cu scoabe de oțel, bordări și cămășuri armate. Aceste tehnici sunt aplicate în funcție de gradul și tipul de deteriorare a structurii existente, precum și de
condițiile locale și de mediu, cu scopul de a asigura o consolidare eficientă și durabilă. Decizia informată cu privire la soluția de reabilitare sau consolidare utilizată și modul în care să fie aplicată este de obicei luată după studii extinse și consultări pentru a obține cel mai bun rezultat posibil. În general, structurile din zidărie sunt considerate foarte rezistente și durabile, datorită istoriei lor de peste 6000 de ani. Cu toate acestea, îngrijirea corespunzătoare și atenția la detalii sunt cruciale pentru a preveni deteriorarea și pentru a menține structurile din zidărie într-o stare bună.