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STRUCTURAL REINFORCEMENT TECHNIQUES IN HERITAGE BUILDINGS FOR ADOBE MASONRY FOR A CORRECT INTERVENTION

TÉCNICAS DE REFORZAMIENTO ESTRUCTURAL EN EDIFICACIONES PATRIMONIALES PARA MAMPOSTERÍAS DE ADOBE PARA UNA CORRECTA INTERVENCIÓN

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ABSTRACT

This research presents a structural reinforcement method suitable for heritage structures featuring adobe walls compromised by fissures. The intervention involves the employment of traditional materials and techniques including: lime, clay, wild grass, and nopal mucilage for mortars and grouting. The applied methodology follows a quantitative approach, focusing on an experimental design, and was implemented in this structural reinforcement to restore masonry affected by cracks caused by settlements, seismic movements, or material fatigue within the wall, leading to a reduction in its mechanical resistance properties, such as compressive, flexural, and tensile strength. This indicates the need to restore the original mechanical properties of the masonry. The structural reinforcement was carried out following these steps: damage assessment of the wall, including an investigation to determine the presence of any mural paintings on the plaster. As no valuable paintings were present, the plaster was removed to expose the underlying damage, revealing a crack traversing the entire width of the wall. The crack's dimensions were measured, and the materials comprising the structure were identified. The preceding steps informed the choice of intervention and materials for the structural reinforcement. The work involved the disassembly and reassembly of the masonry, injection of mortar, and installation of wooden dowels reinforced with steel rods. Following these parameters, the result was a successful strengthening of the damaged masonry, achieving a faithful architectural restoration.

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Palabras clave:
morteros, mucilago, cal, llaves, inyecciones.

RESUMEN

Esta investigación muestra un procedimiento de reforzamiento estructural aplicable a edificaciones patrimoniales con muros de adobe afectados por fisuras, la intervención se realiza mediante el uso de materiales y técnicas tradicionales como: cal, barro, paja de monte y mucilago de nopal para morteros e inyecciones. La metodología que se aplicó tiene un enfoque cuantitativo que se focaliza en un diseño experimental y se aplicó en este reforzamiento estructural para recuperar los mampuestos afectados por fisuras producidas por asentamientos, movimientos sísmicos o fatiga de los materiales en el muro, provocando que este pierda su capacidad de resistencia mecánica, como: la compresión, flexión y tracción, esto indica que se debe devolver las características mecánicas originales del mampuesto. Para este reforzamiento estructural se realizaron los siguientes pasos: verificar el daño que afecta al muro, luego se investigó la presencia o no de pintura mural sobre los enlucidos, en este caso no se encontró pintura de valor, lo que permitió retirar el aplanado para determinar el tipo de afectación, se localizó una fisura que cortó todo el ancho del muro, debiéndose verificar su longitud y profundidad. Luego se identificaron los materiales con los que está construida la estructura. Estos pasos determinaron el tipo de intervención y materiales que se utilizaron para realizar el reforzamiento estructural; en este caso se procedió a ejecutar el descosido y cosido de la mampostería, inyección de mortero y colocación de llaves de madera reforzadas con varillas de acero. Bajo estos parámetros se ejecutó un correcto reforzamiento de la mampostería afectada, cumpliéndose una apropiada restauración arquitectónica.

Introduction

This study seeks to typify methods and systems of structural reinforcement for heritage buildings. The importance of this research lies in establishing the feasibility of the correct use of methods and techniques to recover the structures and perform an adequate intervention. Traditional materials that are similar to the originals are used to carry out the intervention techniques. In addition, traditional construction techniques are used so that, as far as possible, they help to maintain the values of the heritage building.

The reinforcement methods and techniques analyzed in this research have been applied in structures located in Quito, a city with a very important Historic Center, with an extension of 376 hectares and where a large part of its colonial architecture is located, such as the buildings of La Ronda Street (Fig.1). There are about 130 monumental buildings. As for religious buildings, there are 40 churches and chapels, 16 convents and monasteries such as the convent of Carmen Bajo (Fig.2), in addition there are civil constructions such as palaces and buildings that have a style that can be admired, from baroque to the most classic gothic (Universidad de Las Américas, 2016).

Figura 1
Image of La Ronda street - Quito

Figura 2
Image of Carmen Bajo convent, Main façade view

The city of Quito was declared a World Cultural Heritage Site by UNESCO in 1978. The Historic Center, the largest in the Americas, has an unparalleled wealth of colonial architecture. In each of its stones is written the history of the city.

The beginning of the restoration activity in the city of Quito dates back to 1988, due to several earthquakes that caused structural damage to major religious monuments. Structural damage was mainly caused by the March 1987 earthquake. This major natural disaster was caused by a series of earthquakes, whose epicenters were located in the vicinity of the Reventador volcano. (Boxes, 2016)

The earthquakes severely damaged the historic heritage and, to a lesser extent, affected buildings constructed with contemporary materials. In most cases, there was cracking of the masonry and breakage of the masonry, as well as detachment of the eaves and coverings.

It can be determined in these colonial constructions that in certain aspects of their composition the materials are fatigued and structurally present the risk of future collapse. In order to maintain the safety of the inhabitants and the architecture intact, these buildings must undergo structural reinforcement without altering their composition, i.e., traditional materials and construction techniques must be used to safeguard the heritage.

This research aims to explain the correct use of traditional materials and construction techniques that should be used for the proper recovery of heritage, thus giving way to the recovery of knowledge of the benefits and peculiarities of traditional materials (lime, clay, stone, wood, thatch and cactus mucilage). This will show the effectiveness of these elements to be used in the structural reinforcements to be applied in the field of restoration of the built heritage.

Pacají Ruiz et al. (2015) stated that intangible cultural heritage is characterized by preserving the integrity and authenticity of cultural expressions and customs.

It is therefore important to preserve and rescue the knowledge of traditional construction techniques. In this case, for structural reinforcements it is necessary to use the expressions, knowledge and techniques related to ancestral buildings, as part of the use and training of specialized labor. In other words, this is a way to promote the rescue of social memory, the craft and knowledge of ancestral construction systems and materials.

Methodology

This research is supported by the experiences of the field work that has been carried out in different architectural restoration interventions. The aim is to disseminate the different types of damage and reinforcement interventions in adobe buildings, which will serve as a basis for further analysis and classification.

From these interventions, images are recorded of the types of damage that have occurred in the different types of masonry, and the degrees of degradation have been established. These can be determined by fatigue of its elements, by structural failure processes and by seismological phenomena. On the other hand, this in turn indicates the type of intervention to be applied to the affected parts.

Research Design

The methodology used is of a research type, with the purpose of establishing structural reinforcement methods for colonial structures. These reinforcements are characterized by the use of traditional materials that are compatible with the original components of the structures involved, i.e., the use of traditional techniques and materials such as adobe, brick, stone and wood and, as joint elements for mortars and injection of reinforcement, lime, mud and mucilage[2] of nopal are rescued.

In the Historic Center you can see buildings that still maintain the vernacular construction techniques that characterize colonial constructions. Due to their temporary nature and the type of materials used, these structures suffered structural damage caused, in some cases, by the fatigue of their components, time and the seismic movements supported by the structures, a situation that encourages them to be recovered, thanks to their compatibility, with the use of traditional materials.

Types of Effects

With the purpose of verifying and classifying the damages that have mainly deteriorated the adobe structures, which could reach a state of collapse, the following are

[2] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

mentioned: longitudinal shear cracks that generally affect the heads of the walls (Fig. 3), flexural cracking that can affect the arches of a wall (Fig. 4), horizontal cracks, vertical cracks, diagonal cracks, inter-wall cracks, wall collapse and wall head fatigue (Achig et al., 2013).

On the other hand, among the main types of damage generally suffered by the heritage buildings of the Historic Center of the city of Quito, several types of degradation of the masonry can be established, which have been produced by different agents that trigger them, such as: atmospheric agents, deterioration of the adobe due to material fatigue (Fig.5) and by the seismic movements suffered, which contributed to the processes of structural failures that produce cracks in the masonry (Fig.6) of the heritage monuments.

Figure 3
Image of longitudinal crack in the top of the Franciscan Third Order Chape

Figure 4
Image of fissure affecting wall arches (kidney) in the church of the Hospital Psiquiátrico Corazón de Jesús.

Figure 5
Image of the Casa de las Velas head fatigue

Figure 6
Image of vertical crack in wall Casa de las Velas.

Consequently, these affectations indicate the type of intervention that must be carried out for a correct reinforcement of the structure, in order to guarantee its permanence in time through the restoration and recovery of the affected monumental buildings that are in a process of degradation and destruction.

Description of the Structure and Properties of the Materials

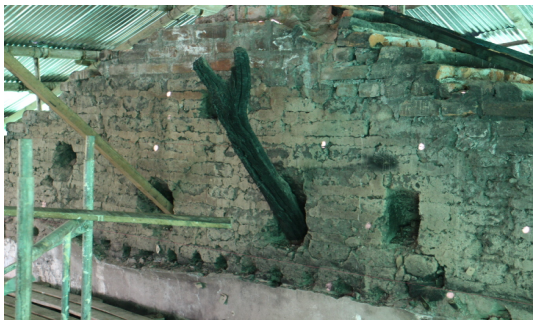
In architectural recovery and rehabilitation, one of the main activities is the structural reinforcement of heritage buildings. In this case, in the intervened buildings, the masonry is primarily made of adobe. They are masonry with an average width of 70 cm and an approximate height of 3 to 4 m high. These buildings have a system of mezzanine floors and roofs mainly made of wood.

The materials used for the masonry, mainly in heritage buildings, are made of adobe and, in certain parts of the walls, are combined with brick or stone. It is also worth mentioning that the roofs and mezzanines are made of eucalyptus wood, as can be seen (Figure 7).

Most of the walls are built on stone foundations, which is the element that is in contact with the ground. This foundation is responsible for transmitting the resulting mechanical forces directly to the ground.

Figure 7

Image of the adobe wall Franciscan Third Order Chapel



Degradation of the Walls

Among the main factors that can generate deterioration in a structure on land are:

- Direct attack by atmospheric phenomena, such as moisture absorbed by the wall by capillary action[3] into the interior of the wall and gradually degrading it.
- The erosive action caused by wind and rain that generates damage to the walls[4] of the building.
- Structural damage caused by its own weight, modification in the original ones, factors that cause cracking that can lead to the collapse of the structure itself.

That is to say, from these parameters arises the importance of using structural reinforcement systems that protect and reinforce adobe walls, so that the factories can be preserved and maintained indefinitely over time.

In this case, it is essential to use construction techniques such as baking and unbonding the wall in the affected area with traditional materials such as adobe and brick and reinforcing it with injections based on lime, sand, earth and mucilage[5]. This structural repair technique is adaptable to other buildings of the same characteristics and different geographical areas.

[3] Action or movement that a liquid can perform in order to be absorbed through porous materials.
[4] Vertical element that in architecture forms the wall.
[5] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

Selection of Traditional Materials to Be Used in Reinforcements

To perform a good structural reinforcement and achieve a good restoration of the building it is essential to use traditional materials that are compatible with the elements that make up the building, this requires knowledge of methods and application techniques that ensure a good intervention, i.e., it requires the analysis of physical-chemical analytical tests of the material, it is also essential to conduct an investigation of the traditional components that were used for its construction.

As stated by Ontiveros (2006), the ideal is to carry out previous studies to identify the original materials to be used.

However, to carry out this research we have taken into account the traditional knowledge that ideas are transferred orally, these have been acquired both academically and orally, as well as through experiences in interventions that have been carried out. From here, the starting point for a good intervention implies that the senior master, together with the professional specialized in restoration, transmits his knowledge to the new generations; it is also necessary to consider that the master builder does not keep writings with which he can disseminate his knowledge.

Structural Reinforcements in Masonry

Peña and Lourenco (2012) indicate that in structural interventions, specialized professionals, whether architects or engineers, have managed a variety of repair or support techniques to optimize the structural solution of historic buildings. Several of the execution techniques have been specifically carried out to help and improve the bearing capacity of the old structures to resist a new inclement event of nature. These techniques used on the original structures must not affect the integrity and authenticity of the original materials and structural characteristics, which is why materials compatible with the original materials of the building must be used.

The structural intervention of historic buildings is and must be multidisciplinary, so apparently independent disciplines such as: Archaeology, Architecture, History, Engineering, Art restorers, etc. However, the lack of integration causes that, in several cases, a structural project does not adapt to the basic guidelines for the conservation of heritage buildings.

Structural Reinforcement Methods

Restoration and rehabilitation processes are the set of intervention methods and techniques applied for the rehabilitation of affected structures, these serve to recover their effectiveness, diminished due to some natural physical phenomenon (Garabito et al., 2015).

In order to achieve a good intervention, it is essential to use different reinforcement methods, according to the type of structure and the material of which the masonry is composed.

Thus, it can be indicated that the methods used in the different reinforcements are:

- Masonry uncoving and stitching.
- Wood anchorage with steel bars.
- Grout injections[6] of lime, additive and sand.

[6] Masonry technique for mixing various solid materials with liquid to obtain a semi-liquid fluid for injection into walls.

These reinforcement techniques have made it possible to correct the damage to the structural elements; to this effect, the compatibility of the original materials of the building was considered, which will not damage the original ones and will be maintained over time, guaranteeing safety and durability.

Methodology for Structural Reinforcement in Walls

Structural reinforcement works were carried out on different masonry of the buildings involved. The masonry walls are made of different materials, such as stone, brick or adobe; the damages that occurred in these walls were mainly cracking, these were externalized vertically and affected the walls, even to the point of cutting them completely in the thickness of the facing, affecting them structurally. Also, among other cases, the cracks caused damage to the arches of the lateral naves, and the walls were affected in their composition, which caused deterioration in their interior, a factor that led to the execution of a reinforcement by injecting mortar grout that would allow the structural recovery of the walls due to fatigue of their components, such as adobe, for example. In this way, its mechanical stability is restored, preventing further damage to the load-bearing wall structure.

As part of the *structural reinforcement of the walls*, the intervention on the masonry is explained on masonry that were structurally affected, these work as load-bearing walls. For the research, the heritage building of the Monasterio del Carmen Bajo is taken as an example.

First of all, we will explain about an affected wall on the first floor that has a vertical crack that cuts through its entire 1.10 m thickness, with an approximate height of 3.00 m.

In order to carry out the structural reinforcement on the cracked masonry, a methodological procedure was followed that respects the canons established by the restoration processes:

- First, the sectors where cracks were present were located.
- Then we proceeded to make coves[7] of prospection on the existing paint (Figure 8).
- Verification of the existence or not of mural painting on the mud plaster (Figure 9).

Figure 8
Image of coves that are made on the painting, the presence of mural painting is not seen

Figure 9
Image of mud plaster removal detecting the type of crack affecting the masonry

[7] Technique for the removal of existing paint layers on a wall

Once it was verified that there was no mural painting, coves were made on the plaster to check the type of crack in the masonry. In this way, a first diagnosis of the type of damage to the structure was obtained. With this, the type of material with which the masonry is made can be verified, which allowed the type of reinforcement to be applied to the structure to be defined (Figure 10).

After verifying the type of crack present in the masonry on the exterior side and the width of the opening, it is confirmed that this crack cuts the wall across its entire width. This determines the type of reinforcement to be performed on that crack. Then, the depth of the crack is measured. On the other hand, it is important to verify the length of the crack, for this purpose the plaster is removed[8], following the direction of the crack (Figure 11).

Figure 10
Image of coves that are made on the painting, the presence of mural painting is not seen

Figure 11
Image of mud plaster removal detecting the type of crack affecting the masonry

It should be noted that this process of verifying the presence of cracks by means of the shim method on the walls should be repeated on all the masonry to be subjected to a reinforcement process.

On the other hand, once it has been verified that the crack goes through the wall, the process is repeated on the other side of the wall. The type of material from which the masonry is constructed is then determined. In this case there is adobe and stone with mud mortar joints.

In this crack, which cuts the entire width of the wall, different intervention methods were used to consolidate and reinforce it, due to its complexity. The methods used were:

- Masonry uncoving and stitching.
- Anchoring wood or steel bars.
- Injections of lime grout, additive and sand.

For the treatment of this crack with an average opening of 2.00cm and a height of approximately 3.00m, which also covers the entire section of the wall and verified the materials that make up the masonry (stone, adobe and brick), it was established that it must be intervened, first with the method of decoking and sewing in the sector of the crack, since its elements are cut and can affect the ability of the elements to work

[8] Coating layer placed on the walls to obtain a smooth surface

structurally, but this does not compromise the structure to stop performing it completely. The masonry must be worked on both the exterior and interior sides.

Masonry Reinforcement Procedure

Uncoring and stitching of the wall: the adobe bricks that were broken were removed and replaced with a new element, in this case with mambron brick, which is a material compatible with the adobe and the lime and sand mortar. It is essential that this process be started from the lower part of the wall, in sections of 4 or 5 courses per day, in order to prevent the masonry from settling and producing new cracks. The new bricks are placed one horizontally and the next transversally, so that the new elements are better anchored to the original wall (Figure 12).

This procedure is repeated along the entire length of the crack, one section per day, so that the new intervention is consolidated and does not cause settling and new cracks, the mortars used were prepared with traditional materials with the same characteristics as the original joint mortars (mud, lime and mucilage[9]), this process is repeated until the entire crack is intervened, this intervention procedure is performed on the internal and external side of the wall (Fig.13).

Figure 12
Image of sewn and unsewn crack exterior side

Figure 13
Image of the crack stitching process

An important fact to know is the compressive strength of the original adobe of the masonry being treated. The test was carried out at the PUCE materials laboratory[10] (Table 1), in order to establish the new strength of the masonry after the process of injecting the hydraulic mortars into the treated masonry.

[9] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.
[10] Pontifical Catholic University of Ecuador

Table 1

Table of compressive strength test results of the original adobe

Compression Test Results		
Adobe original		
Resistance (Mpa)		
Sample N 1	Sample N 2	Sample N 3
0.70	**0.70**	**0.70**
Average resistance (Mpa)		
0.70		

*Conversion factor: 1 Mpa = 10.2 kg/cm^2

Note. Materials Laboratory PUCE, 2021

In addition, it should be noted that, during the stitching and sewing process, ½ inch plastic hoses were placed every 20 to 30 cm of separation, which were connected to internal wall cracks (known as kidney). This is to fully consolidate the structure with grout injections into the internal cracking. The hoses must be laid out over the entire area to be treated, and then lime-based mortars must be injected.

According to Lanas and Alvarez (2006), lime mortar has a lower amount of soluble salts, which prevents damage to the bearing system of buildings; in addition, lime mixtures are more compatible with traditional materials, which are part of the building and are related to the chemical, structural and mechanical aspects. In addition, these mortars, in the case of new cracks, have the capacity to repair themselves by means of a self-sealing process, due to the humidity that they retain as a result of the changes in temperature and humidity in the environment, which are absorbed by the masonry.

Figure 14

Image of the process of unpicking and stitching of the affected masonry

Peñaranda (2011) suggests that for a good rehabilitation against the appearance of cracks affecting the walls of a heritage building, "*wooden keys*" should be used. These are essential to reduce the seismic risk to which the affected masonry of the construction is subjected. The application of this system is intended to prevent the collapse of the building in the event of new natural phenomena (earthquakes or seismic movements).

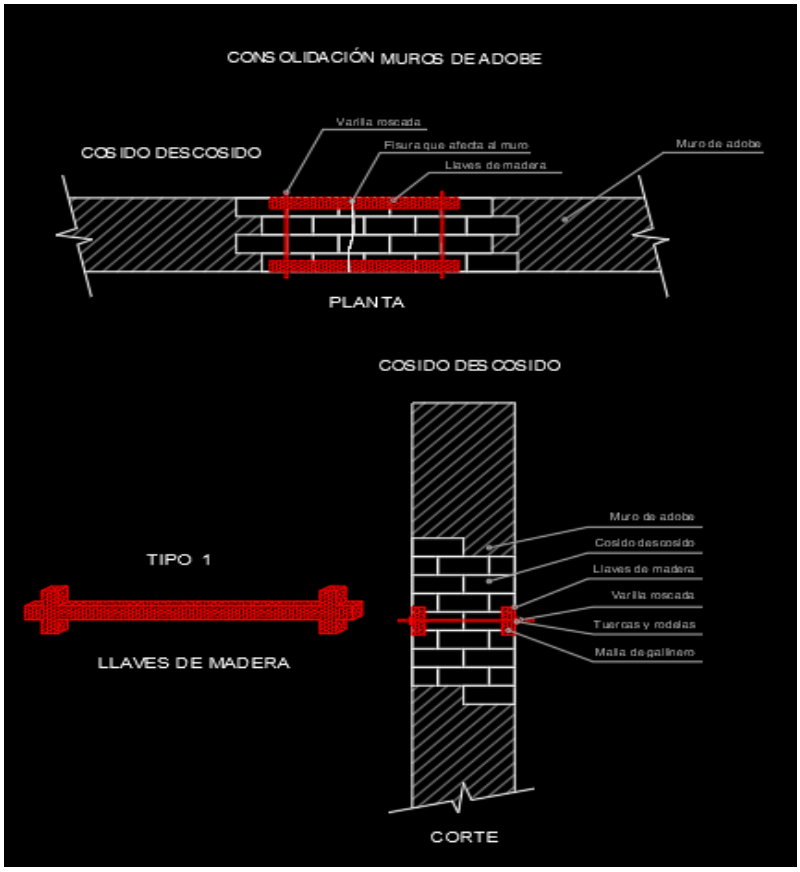
This reinforcement technique is based on the installation of wooden boards or strips arranged horizontally and vertically on the exterior and interior face of the walls, secured together by means of a tensor, in order to increase the resistance of the masonry and maintain the consistency and unity of the structure.

With these considerations and the type of crack that was intervened, we proceeded to the placement of the *wooden keys.* These elements have the function of anchoring the wall to prevent the crack from becoming active again. Wooden keys were placed in both the lower and upper thirds of the crack. These elements were made of colorado wood and the measures used in this case were 7x7x120cm. At the ends of each key, displaced about 10 cm inward, pieces of 30 cm in length were placed vertically. These are placed in the middle of the wood, are glued and in the center of the crossing are drilled to secure the internal keys with the external ones by means of an adjustable tensioner to be able to give the tension required by this element to fix the system.

For the placement of the faucets, the wall was drilled to embed the wooden modules. Then, these were fixed with a threaded rod as a tensioner and adjusting nuts were placed at each of their ends to secure the keys on the exterior side with the module on the interior side of the wall, in this way the crack was embraced, improving its mechanical resistance to compression.

Figure 15

Graphical representation of structural reinforcement - placement of wood keys



These keys were cured with *quimocide*[11], to prevent them from being attacked by termites[12], then they were painted with asphalt paint to protect these new timbers from the humidity absorbed by the walls and eliminated by condensation.

The anchorage of these keys was made with 12mm steel rod. These steel bars are placed along the entire thickness of the wall and are anchored at each end of the battens with flat washers and lock washers secured with nuts on each side (Fig.16 and 17).

In addition, these new wooden elements, which are embedded in the wall, were also protected with mesh[13] to adhere to the ***new plaster*** made with traditional materials: mud / lime / mucilage[14] / straw. This mortar was placed in the entire intervened area of the structural reinforcement of the affected wall.

[11] Chemical for wood curing against xylophages.

[12] *Termites* feed on wood and can cause significant damage to wooden structures.

[13] Steel mesh that is expanded and used in construction for cladding structures and other elements

[14] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

Figure 16
Image of wall perforation for anchoring of wooden keys

Figure 17
Wooden key image protected with asphalt paint and wrapped with mesh. Anchoring with steel rod

Once the stitching and unpicking was completed, the wooden keys were attached. Next, the plastering work was done to seal the masonry and then consolidate the wall with the mortar injection process.

Arriola (2009) states that mortar is a constructive element of the building and accounts for approximately 15% of the total volume of a masonry. It is a basic part that helps to absorb the compressive strength, since they are designed to resist this type of stress. The *mortars* in the walls help to withstand the flexural and shear forces caused by wind or seismic forces (frequent in our environment). When masonry undergoes this, the mortar plays a significant role, as the plastering mortar is responsible for working as a compact structural element, which is why great care must be taken in the preparation of the mortar. In the case of restoration it is very important to work with traditional materials compatible with the original ones that make up the building, thus avoiding future damage with the degradation of the original masonry.

For monumental buildings, in this intervention the *plastering of traditional materials* was used; its components were: slaked lime, mud, straw, mucilage[15] and water (Barbero, 2011). The thickness of the plaster varies from 1 to 3 cm. To apply this mortar, the surface must first be moistened with mucilage (it can also be moistened with calcium hydroxide) (Fig. 18), so that this process will help the new mortar to adhere better and even seal the possible micro cracks that may occur due to the drying process of the masonry (Fig. 19).

[15] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

Figure 18
Image of masonry moistened with mucilage to receive the mortar

Figure 19
Image of masonry plaster

Vargas-Neumann et al. (2010) indicated that the injection procedure consists of inserting a fluid mortar with the same characteristics as the original materials that make up the masonry into the kidney (inside the wall) of the affected masonry. That is, with the same chemical, physical and mechanical characteristics, with the purpose of consolidating the affected walls to reestablish the original mechanical characteristics. The injections in the walls allow the consolidation of the wall and increase its compressive strength to improve its stability and improve the mechanical working capacity of the intervened masonry. Injections are used to achieve cohesion of the walls and get them to work together again

As a next step, once the plastering has been completed, the injection process continues in the masonry, to consolidate the interior of the walls by *injecting hydraulic lime mortar*. This is due to the fact that the masonry is made of adobe and brick. This mortar for the injections was prepared with the following materials and proportions: hydrated lime 3, red or brown pozzolana 1, washed river sand 2, water 3, stabilizing additive 2% of the weight of the pozzolana (Instituto Metropolitano de Patrimonio [IMP], technical specifications for execution of works, 2021).

Thus, all these materials were placed in a large vat, first the sand, then it was mixed with hydrated lime, then the pozzolan was added with the stabilizing additive and mixed dry, finally the water was added to make the total mixing of the materials and to obtain a homogeneous mixture, the mixing was done mechanically, then, once the mortar had the optimum fluidity, it is subjected to a sieving using a fine mesh in order to remove the coarse aggregates. This filtered mixture was placed in another container where the mortar to be used for injecting into the walls was deposited.

After separating the coarse aggregates, the mortar is deposited in the cylinder-type tank (injection equipment), where the hoses will be connected to inject the mortar by means of the pressure of a compressor. This system works with the air that enters the container where the mortar to be injected is located and, by means of a hose, reaches the injection gun that is placed in the hoses installed in the masonry.

The filling process starts with the lower hoses and as they are filled, the process continues to the upper hoses. Once they are filled, they are temporarily covered with paper to prevent the injection fluid from leaking out; the next day the injection process is

repeated so that any vacuum that may have occurred due to fluid settling is filled with this new filling (Figure 20).

Figure 20
Image of the mortar injection process using an injection gun

It should be noted that these injection mortars used for structural reinforcement were subjected to PUCE laboratory mechanical tests[16], in order to measure their compressive strength. The values obtained allow the mechanical properties of the mortar tested to be assessed.

The following table shows the results of the Compressive Strength of the mortars that were injected into the wall, here it is evident that as the days go by their resistance increases and the adhesion of the new material with the old one is achieved, due to its compatibility; thus, according to the result, the resistance is obtained in Mega Pascals (MPA[17]) where 1 Mpa= 10.2 kg/cm^2 which is the conversion factor to have the resistance of the mortar inside the wall, for example:

- Resistance at 28 days: 1.30*10.20 kg/cm^2= 13.26 kg/cm^2

[16] Pontifical Catholic University of Ecuador
[17] Mega Pascal conversion factor

Table 2

Table of test results for mortars Compressive strength

Compression Test Results of the new mortars					
Sample N 1		Sample N 2		Sample N 3	
Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)	Age (days)	Resistance Average (Mpa)
14	0.34	14	0.96	14	1.29
21	0.34	21	1.02	21	1.32
28	0.39	56	1.08	56	1.22

Average compressive strength (Mpa)		
Age (Days) 14	Age (Days) 21	Age (Days) 28
0.36	**1.00**	**1.30**

*Conversion factor: 1 Mpa = 10.2 kg/cm^2

Note. PUCE Materials Laboratory[18], 2021

To finish the reinforcement process of the intervened masonry, the excess of the hoses used for the injections was cut in order to paste the masonry, for which slaked lime was used. So that the wall is not completely smooth, the slaked lime is applied with a sponge trowel, in this way the finish is slightly irregular and its appearance is similar to the original, this has the purpose of not altering the original characteristics of the old plaster.

Once the stucco is completely dry, the masonry is prepared by sanding and sealing it with water resin. The final finish was made with traditional white paint, this was prepared with: mucilage[19]1/2u + lime 1u + salt in grain 1/10u + milk1/2u, as it was a restoration, it was decided to use a lime-based paint, salt and milk were included because they provide consistency and resistance to the final product once applied on the masonry. (Abrajan, 2008)

Results and Discussion

The application of the procedure to be followed to carry out a structural reinforcement of a cracked masonry in a heritage building, must be supported with mechanical resistance tests to compression carried out in the laboratory, in order to technically establish its improvement and the stability of the structure. By applying and following the established method, damage to other elements that may be part of the masonry is avoided, thus it is indicated that by performing coves as the first activity on the affected wall, damage to a possible existing mural painting on the plaster is avoided. Once the state of the plaster is verified, the state of the crack is checked, this indicates the

[18] PUCE - Pontificia Universidad Católica del Ecuador.

[19] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

type of procedure to be used in the reinforcement, where the use of traditional materials and techniques is established, thus rescuing ancestral knowledge. Tests on the injection mortars showed that the mechanical characteristics of the affected walls were improved. According to the methodology proposed in the intervention, results of resistance and improvement of the walls were obtained at different ages: 14, 21 and 28 days. According to the established mortar test times, it was possible to establish that the dosage presents an ascending behavior, increasing the wall's resistance in relation to the age of the test.

In summary, the methodology used: verification of the cracks, prospecting coves, unpicking and sewing of the wall, placement of wooden keys, injection of lime mortar, plastering and painting, allowed for a correct structural reinforcement to improve the stability of the wall, which has a mixed system of adobe and stone construction. For their stitching, handmade mambron bricks, lime mortar, mud and mucilage were used[20], due to their compatibility with the original materials. On the other hand, the use of traditional techniques and materials allows the continuity and improvement of their mechanical characteristics, thus improving the physical characteristics of the structure. Thus, the dosage of the injection mortar in unit proportions was: hydrated lime 3, red or brown pozzolan 1, washed river sand 2, water 3, stabilizing additive 2% of the weight of the pozzolan, which increases the stability of the reinforced wall. (Silva & Uría, 2024)

Conclusions

Once the structural reinforcement has been completed based on an execution methodology, it can be concluded that it is feasible to determine the type of intervention necessary to avoid affecting the heritage building. Also, an adequate methodology allows for the definition of the materials to be used. In fact, this method made it possible to use materials that were similar and compatible with the original components of the wall, which resulted in a correct intervention.

On the other hand, the methodology was used to determine the quality of the cracked wall adobes. This was done with mechanical compression tests. Through these tests, which were carried out in the laboratory, it was established that the elements are no longer of good quality. Due to their age, they presented fatigue in their composition, with low results in laboratory tests.

The type of intervention, the quality of the materials and the nature of the crack, which affected the wall, indicated that this masonry should be consolidated. In this case, a hydraulic lime mortar was used to restore the compressive strength of the wall. Laboratory breakage results at 14, 21 and 28 days showed that the progressive increase in strength improves the quality of the masonry.

This intervention, based on the development of an execution methodology, aims to establish guidelines for the use of traditional techniques and materials in the structural reinforcement of the masonry. These techniques are applied in heritage restoration procedures to avoid the use of contemporary materials that alter and damage heritage buildings. On the other hand, this methodology can establish a general basis for the use of traditional materials and techniques to carry out a correct restoration and recovery of the architectural heritage.

[20] Organic substance of viscous texture, similar to gum, extracted from nopal cactus.

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