TECHNIQUES FOR REHABILITATION OF MASONRY

CLEANING, PROTECTION, REPAIR AND STRENGTHENING

Sub-chapters:

Introduction
Cleaning and protection
Non-structural repair techniques
**Structural repair techniques**
Strengthening techniques
Chapter conclusions
STRUCTURAL REPAIR
TECHNIQUES IN STONE
AND BRICK MASONRY
1. Introduction

The structural repair techniques include the following tasks:

- consolidation - interventions meant to improve mechanical characteristics of existing elements and their cohesion, without adversely change the hydrothermal characteristics:
  - impregnation of consolidants in elements;
  - injection of binder grout in masonry;
  - reinforced render in masonry;
  - shotcrete / projected mortars in masonry;
  - ground consolidation.

Consolidation of stony surface
1. Introduction

- collage of detached fragments;
- injection / repairing cracks or fractures (stabilized and non-stabilized);
- stabilizing larger elements with stainless steel bars;
- replacement of affected elements;
- replacement of volumes / plastering.

Introduction of new stones
A) Consolidating actions:

They are intended primarily to minimize the degradation rate filling the voids.

Various types of consolidation are possible:
• chemical - the intervention may consist in a treatment of depth substances in solutions that after the solvent has evaporated, are fixed to the material, increasing the strength parameters;
1. Introduction

A) Consolidating actions (cont.):

- cortical or superficial - the same substances are applied locally or, more generally, on the surface of the material to restore the cohesion between the degraded fractions and the sound adjacent strata;

- structural - installation of rigid elements (by calculating and implementing new elements to be placed alongside the degraded elements) that release partially or completely the element of its static function, compromised by degradation or inappropriate to new service conditions (see also strengthening techniques: for instance, consolidation with metal tie rods).
1. Introduction

A) Consolidating actions (cont.):

The consolidation of masonry (especially suitable for the large architectural value ones) should be undertaken in an integrated manner, according to the following intervention levels:

- each material per se;
- elements with static functions directly responsible for the strength and structural stability;
- foundation grounds.

Consolidation of stone masonry
A.1) Consolidation of stone elements:

The consolidation is intended to reestablish the cohesion when the stone lost it in such a degree that is in danger of crumbling and only in this case should be applied. This process allows to increase cohesion between the constituent particles and the mechanical strength of the rock, reinstating the bond strengths.

Factors in choosing a consolidant:
- efficiency and durability;
- depth and uniformity of penetration;
- consolidated stone dilation coefficient similar to the nearby stone;
- not alter the external appearance of the surface after treatment;
- allow adequate vapor permeability.
A.1) Consolidation of stone elements (cont.):

The methods currently used result both from continuous improvement of techniques used in the past, as the constant emergence of new consolidant products especially in the field of organic chemistry.

Some application techniques:
• with a nebulizer (equipment capable of vaporizing the liquid under pressure by means of a pneumatic-oil pump);
• with a paintbrush or a soft brush, till the maximum saturation;
• by percolation (distributor placed on top of the surface to be treated, the product tends to descend by gravity, impregnating by capillary action);
STRUCTURAL REHABILITATION

2. Techniques

A.1) Consolidation of stone elements (cont.):

Some application techniques (cont.):

- coat the surface with paper sheets held down with lightweight gluing and constantly soaked in the consolidating product; evaporation is avoided by coating the surface with plastic sheeting;

- cover the stone to be impregnated with plastic sheet, creating vacuum; then, apply the consolidant which is thus more effectively absorbed
A.1) Consolidation of stone elements (cont.):

- the penetration depth must be such that the consolidating product reaches the sound stone, which is often difficult to achieve; it depends essentially on the stone porometry, the type of consolidant product and the application method;

- consolidants often fail to fill cracks with a width greater than a few tenths of a millimetre or join fragments of larger volume; in this case, it is necessary to resort to other (e.g.: appropriate putties and adhesives);

- in certain cases, protective treatments are needed instead of consolidation (e.g.: superficially eroded stone but still strong enough, preserving its cohesion).
A.1) Consolidation of stone elements (cont.):

Consolidants form, within the stone, compounds that establish connections between the stone grains, increasing its cohesion (reducing the porosity).

Mostly used inorganic consolidants:
• calcium or barium hydroxide; sodium or potassium silicate; ethyl silicate solutions.

Mostly used organic consolidants:
• aoxi-silanes solutions; silicones; acrylic polymers; epoxy resins; polyurethane.
A.2) Injections of binder grouts in masonry:

This consolidation technique consists of injecting, at variable pressures for each type of intervention, of a grout capable of filling the cracks and voids, replacing and / or integrating the original mortar.

These injections can be made by pressure or by gravity, making judiciously some holes, where is inserted the grout (cement mortar stabilized with bentonite or lime; grout of potassium or sodium silicate; epoxy or polyester resins).

Applications:
- more cracked resistant walls with serious consolidation problems;
- localized crushing.
A.2) Injections of binder grouts in masonry (cont.):

Procedure:

1. opening the injection holes the drillings should be practiced in correspondence with mortar joints and with a distance of approximately 60 to 80 cm between them, depending on the thickness of the masonry; drill holes to, at least, half the thickness of the masonry.
A.2) Injections of binder grouts in masonry (cont.):

Procedure (cont.):

2. all cracks and small cracks, among the various elements, must be previously sealed;

3. before performing the injection, the masonry should be washed up till saturation, using pure water, preferably deionized and free of soil matter;

4. to control the volume of injected material, thin purge tubes should be used, through which excess material may exit;
A.2) Injections of binder grouts in masonry (cont.):

Procedure (cont.):

5. during the washing phase, additional operations must be performed (e.g.: joints repointing);

6. pre-consolidation, leaving a very fluid slurry flow through a funnel or a wide pipe;

Opening cut of degraded joints
A.2) Injections of binder grouts in masonry (cont.):

Procedure (cont.):

7. injection of grouts within the holes at low pressure; injections from the bottom up, in order to avoid weight imbalances and unpredicted static changes;

Injection of epoxy resin by pressure (caulk gun)
A.2) Injections of binder grouts in masonry (cont.):

Procedure (cont.):

8. the injection pressure is conditioned to the depth to achieve and to the wall deterioration degree; maintain a tight control over the amount of injected material and the volume of the wall to inject;

9. the pressure must be kept constant until the grout does not overflow out the adjacent holes to the pipes;

10. after the grout had hardened, the pipes are removed and the holes sealed with suitable mortar.

11. provide for a series of tests to verify its effectiveness (e.g. soundproof).
2. Techniques

A.3) Reinforced render in masonry:

The use of reinforced render with metallic mesh (protected against oxidation), glass fibres, etc., allows to confine / stirrup the masonry throughout the wall thickness, thereby ensuring the improvement of its existing structural functions.

It is the most common solution in rehabilitation actions of masonry traditional walls (e.g.: stone and brick bearing wall) - “consolidation with thin retention walls”.

Appearance while applying reinforced render with metal mesh.
A.3) Reinforced render in masonry (cont.):

When justified, this solution can be further strengthened with the use of anchors or transversal connectors, which best fix the layers of reinforced render to the support, thus ensuring a better confinement of the masonry (see strengthening techniques).

Procedure:
1. clearance and cleaning masonry;
A.3) Reinforced render in masonry (cont.):

Procedure (cont.):

2. replacement of degraded material;

3. injection of cracks (complemented or not with steel clamps);

Replacement of degraded material
Injection in cracks
A.3) Reinforced render in masonry (cont.):

Procedure (cont.):

4. placing a metallic reinforcement (galvanized or stainless steel) or glass fibre reinforcement (anti-alkaline protection) with or without locking connectors;

Metalic mesh

Glass fibre net
A.3) Reinforced render in masonry (cont.):

Procedure (cont.):

5. Application of render with mortar of suitable formulation.

Appearance while applying the render with metal reinforcement

Final appearance
A.4) Shotcrete / projected mortars:

For greater retention thicknesses (over 3 cm), one resorts to shotcrete concrete / projected mortars.

After regularization and preparation of the surface to be coated, one or more layers of projected product is applied, typically reinforced with a stretched metal mesh, galvanized (thickness of about 5 cm).
2. Techniques

A.4) Shotcrete concrete / projected mortars (cont.):

Procedure:
1. remove the coatings;

2. fix a mesh over the wall with overlays of at least 10 cm;

3. projected the product onto the mesh in order to obtain a dense and homogeneous mass;

4. the projection is performed with dual-chamber or rotor devices.

Metallic mesh - galvanized for one-coat mortars or in stainless steel for coating with lime mortars.
A.5) Ground consolidation:

One of the possible solutions, when it intends to consolidate foundations, is to intervene at the level of improvement of the mechanical characteristics of the foundation soil.

This terrain improvement can be done by:

- substitution, by removal, of the surface layer by a better characteristics layer, eventually compacted;
- the in situ compaction, where the treatment consists of inverting the soil, spread it in layers and compact it again;
- strengthening the ground by consolidation injections with cement, silica gel or polyurethane resins (hydroactive grouts).
A.5.1) Injection of cement grouts in the foundation grounds:

Increase of the load capacity of the ground, by densification or the creation of watertight and resistant to impulses curtains.

Procedure:
- Introduction on the ground of the grout, successively in different depth quotas and at controlled pressures.

Injection phase

(Cóias, 2007)

Placing the dual injection plugging device
B) Collages of stone elements:

In the collages (fixing detached fragments), appropriate pulps and glues are used, it may be added a pigment to obtain the stone color;

- pulps are usually comprised of a binder and a suitable powder;
2. Techniques

B) Collages of stone elements (cont.):

- epoxide resins have been largely used for its power of collage; however, are likely to yellowing and weaken by the action of light and some atmospheric actions; its use is recommended for treating areas in depth, subsequently using acrylic resins for the surface finishing;
2. Techniques

B) Collages of stone elements (cont.):

• in cases of voids resulting from significant detachment, it is usual to inject hydraulic fluid mortar with a low content of soluble salts;

• sometimes, only lime mortar is used; cements are completely inadvisable because they are rich in sulfates and alkali salts favoring crystal formation.
2. Techniques

B) Collages of stone elements (cont.):

Procedure:
1. the surfaces to be joined must be well cleaned and degreased;
2. the glue or resin is applied in points, and should not cover more than ¼ of the connecting surfaces;
3. during the drying time, both parts must be anchored so as not to move and to put pressure on the glue or resin.
2. Techniques

C) Treatment of cracks/ fractures:

- injection of cracks / fractures in bearing masonry or in the constituents elements;
- bridging with mastic, mortar or synthetic paint;
- repairing with mechanical connection with a "bridge" reinforcement or the introduction of metallic elements.
2. Techniques

C.1) Injection of cracks / fractures:

The epoxy resins have long been used for its power of collage; however, are susceptible to yellowing and weaken by the action of light and some atmospheric actions; its use is recommended for treating areas in depth, subsequently using acrylic resin for the surface finishing.

Drilling holes to proceed to the crack filling
2. Techniques

C.1) Injection of cracks / fractures (cont.):

Small cracks (less than 0.1 mm thick) can be filled with epoxy or polyester resin, using the following techniques:

• gravity;

• pressure.
C.1) Injection of cracks / fracture (cont.):

Procedure:
1. deep cleaning with compressed air for cracks / fractures of greater depth;
2. the crack / fracture must be well dry and degreased at the time of the resin injection;
3. sealing the joint through a reversible non-greasy material and the continuous injection of epoxy resin, through properly located and executed holes;
STRUCTURAL REHABILITATION

2. Techniques

C.1) Injection of cracks / fractures (cont.):

- Crack cleaned and sealing with lime
- Threaded stainless steel rod
- Drillings grouted with epoxy resin

Note: the fracture is not “glued”

Injection of crack in a stone element

Injection of crack in a solid brick arch
C.1) Injection of cracks / fractures (cont.):

Procedure:

4. After drying the resin, the crack / fracture surface must be plastered with proper mortar.
C.2) Crack-bridging with mastic, mortar / paint:

Restore the initial structural resistances and / or prevent the penetration of water through the crack / fracture bridging with:

- polyurethane mastic;
- hydraulic binder mortar, synthetic resins, silica and silica fumes;
- synthetic paints.
2. Techniques

C.2) Cracks-bridging with mastic, mortar / paint (cont.):

Advantages:

• prevent water penetration;
• absorb any crack movements (e.g. mastic);
• do not require skilled labor.

(Martins & Pereira, 2006)
C.3) Introduction of mechanical connection:

Restore the initial structural strengths and / or prevent the penetration of water, through the introduction of mechanical liaisons in non-stabilized cracks / fractures with:

- resort to a "bridge" reinforcement over the crack;
- introduction of metallic elements.

Metallic bars
C.3) Introduction of mechanical connection: (cont.)

Resort to a "bridge“ reinforcement over the crack:
- metallic;
- plastic;
- fiber glass.

Application of mesh in areas with different materials

Separation layer and coating reinforcement
C.3) Introduction of mechanical connection: (cont.)

Resort to a "bridge" reinforcement over the crack:
C.3) Introduction of mechanical connection: (cont.)

Introduction of metallic elements:

- metallic bars;
- anchors (dowels or cramps).

Cramp (generally complementary to the crack injection)

Metal bars, with a length of 500 mm on each side of the crack, and grout or resin injections in the mortar joints.
2. Techniques

D) Stabilizing elements with stainless steel bars:

Process used in case there are larger unstable elements. Usually, bolts are used in stainless steel threaded bars, soaked in epoxy resin, with diameters and lengths suited for various situations. Finally, the repointing of fracture lines is made with a suitable mortar.

Reinforcement of a guardhouse (Belém Tower) with steel bars
2. Techniques

E) Replacement of affected elements:

This type of solution consists in removing the affected elements and in its posterior reconstruction. It is used in cases with very advanced damage and when the resistance of the elements in question is already reduced.

- the original materials must be respected and an efficient connection between new and existing elements be ensured.
E) Replacement of affected elements (cont.).

Procedure for stones replacement:

1. mark the location of the stones to remove of the wall;
2. place the attachment pieces on the stone rear, through holes in the stone; the number and size depend on the stone (place two units at least);
3. inject resin into the holes, avoiding completely cover the stone rear.
E) Replacement of affected elements (cont).:

Procedure for bricks replacement:

1. take out the damaged bricks, removing the mortar residues and debris off the cavity;

2. wet the surface and apply the mortar;
2. Techniques

E) Replacement of affected elements (cont):.

Procedure for bricks replacement (cont.):

3. place the brick, previously wet and with mortar on top;

4. remove excess mortar;

5. give the final shape to the joints.
F) Replacement of volumes and plastering:

The replacement of volumes can be of two types:
- traditional method (replacement of the missing stone similar to the existing one), coming from the quarry;
- replacement with "artificial stone", obtained from mortar (most current).

The plastering (mortar filling) is applied at lower thicknesses; also have the function of cover shallow cracks and discontinuities on the surface of the stone.
2. Techniques

F) Replacement of volumes and plastering (cont.):

Properties of restoration mortars:
- ease to work with;
- similar to the stone texture and coloration;
- minimal setting retraction;
- good permeability to water vapor;
- maximum resistance to atmospheric agents;
- contain minimal soluble salts;
- mechanical strength similar to the stone to be replaced;
- not retractable.

Restoration mortars binders: limes, hydraulic, mineral of two component, synthetic of two component, or solution polymers.
F) Replacement of volumes and plastering (cont.):

Procedure for replacement of volumes (artificial stone):

1. pre-consolidate the stones which are not repaired;
2. cleanse the surface by removing fragments, dirt and other substances;
3. moisten the stone;
4. prepare the mortar according to the manufacturer's instructions;

Should be tested small samples of mortar, so that they can comply fully with the adjacent stone (chemically and chromatically).
F) Replacement of volumes and plastering (cont.):

Procedure for replacement of volumes (artificial stone) (cont.):

5. replacements of large dimensions, “skeletons” should be made in threaded bars, stainless steel wire, polypropylene fiber mesh, as well as successive fillings with weaker mortars;

6. apply the mortar (thickness not exceeding 3 cm from each time) through small hand tools;

Joint sealing, skeleton in threaded bar
2. Techniques

F) Replacement of volumes and plastering (cont.):

Procedure for replacement of volumes (artificial stone) (cont.):

7. shape the surface;
8. joint sealing between the stones with suitable mortar;
9. repointing.
STRUCTURAL REHABILITATION

2. Techniques

What is the correct sequence for replacing volumes?
2. Techniques

STRUCTURAL REHABILITATION

1 2 3 4
2. Techniques

Know the facade rehabilitation of the Campo Pequeno bullring

2. Techniques


Condition prior to cleaning

Cleaning phase

Partially destroyed terracotta bricks
2. Techniques

1 - Identify the technique of structural repair
INJECTION OF BINDER SLURRIES IN MASONRIES

2. Techniques

By gravity

By pressure (pump)
2. Techniques

2 - Identify the technique of structural repair
2. Techniques

**CONSOLIDATION**

- **Consolidation of masonry with sprayed mortar**
  - Welded mesh

- **Injections for ground consolidation**

- **Impregnation of consolidants**

- **Surface consolidants by brushing**
STRUCTURAL REHABILITATION

2. Techniques

3 - Identify the repair techniques
2. Techniques

TREATMENT OF CRACKS / CREVICES

Injection of cracks with epoxy resin

Bridging of non stabilized cracks with fiberglass mesh

Bridging cracks stabilized with mastic
2. Techniques

4 - Identify the technique of structural repair
STRUCTURAL REHABILITATION

2. Techniques

REPLACEMENT OF AFFECTED ELEMENTS

Occasional substitutions. The new stones subjected to wear shall look, after a few decades, similar to the existing ones.
2. Techniques

5 - Identify the repair technique
2. Techniques

STABILIZATION WITH STAINLESS STEEL BARS
### STRUCTURAL REHABILITATION

#### 3. Conclusions

Some techniques:

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3. Conclusions

. Interventions in brick masonries (holed or solid) may include: cleaning, consolidation, protection (water repellents), repairs, replacements and reinforcements (to the gravitic and seismic actions).

. Any intervention should respect the following principles: be reversible, do not prejudice any future intervention, do not change the visual appearance, be documented, maintain the historical evidence, minimal intervention and stability to chemical agents.

. The repair and reinforcement techniques are used when you want to restore the initial level of structure performance and increase the bearing capacity of the structure, respectively.
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