Quality Control Manual for Stone Cladding Facades

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1 Introduction

The aim of this work is the creation of a Quality Control Manual for natural stone in buildings facades cladding. This manual is intended to contribute to the reduction of the anomalies and pathologies that may occur during the lifetime of the buildings, caused or amplified by a bad choice or misapplication of the claddings.

Outside the scope of this study are, therefore, all the works that are not performed on site, such as the draft design of the anchors that must always be done previously.

Natural stone is one of the materials used in building construction, for a long time, due to its durability, strength and the final aesthetic quality of the buildings. Since the more widespread use of reinforced concrete structures, in the twentieth century, the stone turned to be used almost exclusively as cladding, losing its role of structural element of the building. Natural stone has not lost, however, its most appreciated features, such as the "nobility" of the building and quality as a cladding material, being therefore still often used nowadays.

Currently, there is a wide range of options available for choosing the type of stone and of its finishing, allowing many different claddings types. The evolution, over the years, of stone cladding went also along with a significant progress of the type of anchors used to support the stones panels. Different direct or indirect anchorage methods for the stones are now available and there is a suitable solution for any kind of stone or building. However, even taking into account good durability characteristics of the stone, it appears that some relatively recent buildings, with stone cladding, present anomalies or pathologies. Any anomalies in a building can give rise to problems, but when these anomalies are on the facades, the situation becomes more serious. The anomalies on the facades damage, in most cases, the aesthetics quality of the whole building and can cause problems of infiltration and poor insulation. When dealing with stone claddings in the exterior of the buildings there is another situation that cannot be neglected: the risk of detachment and fall of stones that can endanger people. Therefore, pathologies and defects in exterior facades can be extremely serious, so it us extremely important to minimize their causes.

Whatever the cladding techniques, a final result of good quality and durability requires the compliance of building procedures specific to the nature of the masonry backup where the stone is to be installed, the chosen anchorage method, the type of stone used, among other. However, often these procedures are not followed, either because they are not properly known or due to economic reasons, lack of training of installers, lack of supervision or other reasons. The incorrect application of a stone cladding, using a technique well known for its good results, may compromise the final outcome. These facts severely penalize the use of natural stones, disseminate incorrect information about the durability of the stone and create preconception to potential users. Many of the undesirable aesthetic and functional mutations observed during the lifetime of a building were stone cladding was used are not directly related to the stones themselves, but to the inappropriate choice or poor installation of the anchorage systems. These kinds of errors can completely cancel out the potential benefits of this building technique, giving raise to significant future expenses to correct the defects.
A good understanding of the procedures outlined in the Manual requires prior knowledge of the different types of natural stone – igneous, sedimentary and metamorphic rocks - and their main characteristics - porosity, compactness, permeability and hygroscopicity. The different types of finishes that can be applied to the stones - polished, bush-hammered, rough sawn, thermal finish, sandblasted, smoothed and scratched - should also be considered. To identify these characteristics we can rely on tests performed according to the Portuguese standard NP EN 1469. These tests allow to evaluate the suitability of the claddings to the conditions under which they are used and to the functions they will perform.

2 Types of facades

There are several kinds of stone claddings, depending on the nature of the anchorage system used to support the stone panels: methods of direct anchorage (bonding and sealing) and methods of indirect anchorage (with staples and points of mortar, with grout-in anchors and metal support substructure) are the most used.

2.1 Direct anchorage methods

This technique is characterized by the usage of a continuous anchorage product (such as mortar or cement-epoxy resin) binding the stone surface to the masonry backup where the stone will be applied. [1]

It is important to be aware of the correct ways of application and restrictions to the use of this anchorage method in order to obtain good quality results. French regulation on buildings with stone cladding facades "Cahiers du CSTB (Cahiers du Centre Scientifique et Technique du Bâtiment)" contains standards and guidelines that are followed by many installers and producers of materials for the application of stone. These rules deal, for instance, with the thickness and maximum size of the stone panels, the maximum height at which they can be installed and anchorage materials specifications [2].

There are two anchorage techniques commonly used to bind the stone panel to the masonry backup: collage by dots (the older technique, no longer used) and continuous anchorage of high, medium or thin thickness (the thin one is the more often used technique) [3].

According to the choice of the binding material employed, two types of anchorage can be distinguished: bonding and sealing. [4] The bonding anchorage method uses adhesives such as cement paste, epoxy resins or mortar. [5] The sealing anchorage method uses lime based mortar or white hydraulic cement. Using this method, the likelihood of the appearance of stains is lower than in the case where traditional cements are used. [5]

In all methods it is advisable to use a deformable binding material settlement, consistent with the expansion and contraction of the stone panel caused by temperature changes and deformation of the facade. These phenomena may be amplified with the increase of the dimensions of the stone panels.

Nowadays, this method tends to be used in small areas such as walls and, less frequently, in the cladding of entire facades where methods of indirect anchorage are better suited. [6]
2.2 Indirect anchorage methods

This technique is characterized by the presence of several isolated elements of anchorage, binding the stones panels to the facade. These elements are usually made of metal and allow the absorption of the deformations that the stone panels might suffer. Therefore, the cladding, which is more fragile than the support in respect to deformations, suffers less stress. This type of anchorage has to withstand both the vertical forces (such as the weight of the stone materials) and the horizontal actions (such as wind). These methods create a free space between the stone panels and the building itself. Air circulation through this cavity avoids the concentration of moisture and condensation, keeps the natural stone panels dry, providing natural isolation for the building. [7]

The anchors used in the indirect method can be classified into three groups: staples and points of mortar, grout-in anchors or support substructure. [7]

Several factors should be taken into account to choose the best anchorage method for each case, such as the nature of the facade, the size, characteristics and weight of the stone panels, the existence or not of thermal or sound insulation between the stones and the building, the area of the facade, the price of labour, etc.

There are some rules common to the three anchorage methods, namely in what concerns the characteristics of the stones to use (such as its minimum thickness and maximum size) and the quality of steel anchors (depending on the natural features of the place).

For the proper application of indirect anchorage methods, the choice of the specific location of the brackets in the facade is very important: to avoid tension on both the anchors and the stone panel itself, the panel can not be anchored to two separate walls, that may suffer different deformations (close to expansion joints for example).[8]

2.2.1 Staples and Points of mortar

This particular method of indirect anchorage consists in the fixing of the stones panels to the building wall using staples made of circular section wires. The points of mortar are needed for the proper functioning of the staples and to allow the adherence of the panel stones. The wires, usually made of stainless steel, due to its durability, are wrapped in mortar.

This method is not compatible with the application of a continuous thermal insulation in the space between the wall and the panels, due to the presence of the points of mortar.

Usually the method consists in the use of four staples per stone panel: two staples for suspension and the other two for positioning. The staples of suspension are used to support the weight of the panel and are usually placed on the underside of the stone. The staples of positioning can be located on the top or on the sides of the panel. To fix the staples to the stones panels, it is necessary to drill circular holes on the edges of the stones to insert the staples.
2.2.2 Grout-in anchors

In this method, the stone panels are anchored to the buildings walls using metallic elements that may differ in shape, size and other features. These brackets are fixed to the walls through mechanical fixing methods such as screws (Figure 2.1) or through the use of mortar or cement (Figure 2.2). Grout-in anchors have dowel pins that are inserted into holes drilled on the top of stone panels to prevent them from moving.

![Fig. 2.1](image1)
![Fig. 2.2](image2)

Fig. 2.1 - Examples of body anchor using mechanical fixing methods [9]
Fig. 2.2 - Example of grout-in anchor fixed with mortar or cement [9]

The choice between these two methods depends, essentially, on the nature of the building facade where the stone panel will be applied.

Usually each stone panel is fixed to the wall using four anchors. Two of them are placed in the bottom base of the horizontal face of the stone; they have the dual function of supporting the weight of the stone and restrict its the horizontal displacements. The other two are placed in the top horizontal face of the stone and restrict the horizontal displacements. [10] Alternatively, the brackets can be fixed to the panel stones by the vertical faces.

This technique of cladding allows the benefits of thermal insulation in the space between the stones and the building facade, if installed before the anchorage of the elements. In this case, the insulation is usually made of extruded polystyrene foam, such as Wallmate.

The joints between the stone panels can be filled using elastic materials [4] or can be left open if the facade has been previously waterproofed [6].

2.2.3 Support Substructure

Under this method the stone panels are fixed to the walls using a metallic structure that connects the cladding to the building facade (figure 2.3). This method allows the installation of heavier and larger stone panels than the methods previously described. Nowadays the structure is made of metallic materials such as stainless steel. The anchorage of the stones to the structure is performed through mechanical methods. The structure is fixed to a tough area of the building facade (using metallic anchors and cement or mechanic methods such as bolts). This structure consists of a grid of vertical and / or horizontal profiles that can be adjusted to fit to stones of different sizes.
This method possesses attractive properties not only because it allows the possibility of thermal insulation but also because it can be used in a wide range of situations. For instance, some systems only need to be attached to the structural elements of the buildings, whenever the condition and the nature of the buildings walls are not adequate. [11]

The following table (Table 2.1) shows the compatibility between supports and stones cladding methods. The data of this table were compiled from the information in the "DTU 55.2" (French technical regulations on stone cladding) [12] and "Description and General Classification of Cladding for masonry and concrete walls" [13].

<table>
<thead>
<tr>
<th>Material of the building wall</th>
<th>Anchorage Methods</th>
<th>Support substructural</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Staples and mortar points</td>
<td>Grout-in anchors</td>
</tr>
<tr>
<td></td>
<td>Using mortar</td>
<td>Mechanically</td>
</tr>
<tr>
<td>Concrete or reinforced concrete</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Light weight concrete</td>
<td>Yes</td>
<td>(1)</td>
</tr>
<tr>
<td>Bricks</td>
<td>(3)</td>
<td>(5)</td>
</tr>
<tr>
<td>Concrete blocks</td>
<td>(3)</td>
<td>(5)</td>
</tr>
<tr>
<td>Autoclaved cellular concrete blocks</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Natural stone</td>
<td>Yes</td>
<td>(5)</td>
</tr>
</tbody>
</table>

Table 2.1: Compatibility between supports and stones cladding methods [12] and [13]
(1) Procedure acceptable if the concrete strength at 28 days exceeds 15 MPa [12]

(2) This anchorage method requires conducting a detailed description in the specification and an engineering design. If the characteristics of the buildings walls are not fully known, it is required implementation of pullout tests on site. [12]

(3) This anchorage method can be applied only if some specific requirements related to the use of mortar are fulfilled

(4) This procedure can only be applied if the joints between panels are left open or filled with a resilient material

(5) In the "DTU 55.2" (French technical regulations on stone cladding) this type of attachment is only acceptable if a detailed description in the specification and an engineering design is carried out. However the "Description and General Classification of Cladding for Masonry and Concrete Walls" [13] refers that this type of anchorage is not feasible

3 Constructive methods

The elaboration of the design for buildings with stone cladding must specify the method of stone anchorage, the characteristics of the stones (for instance the type of stone and its the finishing, the type of anchors, the insulation type, the size of the joints between stones panels) as well as all other relevant aspects that guarantee that the minimums required criteria for safety and durability are fulfilled. [6]

3.1 Direct anchorage methods

When using continuous anchorage products, the first step is the assessment of the state of the building facade to check if it is clean, with no dust or oils [14] and ready to receive the stone panels. Besides, the drying time of materials used in the facade (mortars) must be followed in order to prevent shrinkage, stones staining and deterioration of the adhesive [15].

When mortars are used as an anchorage product it is important to ensure that the proper choice of the mortars has been made in terms of good adherence to the stone, its ability to support the weight of the stone and its adequacy to the local weather conditions. [16] Prior to its use, the building facade and the stone panels should be moistened to increase the resistance of the bind [2].

Under this method, the anchorage product should be spread both on the building surface and on the back of the stone panel, in small areas, to prevent exceeding the time of workability of the adhesive. The thickness of the layer should be in accordance with the recommendations of the manufacturer of the mortar. [14]

The process of stone anchorage must start from the bottom to the top and from one side of the wall to the other [3]. The joints between the stones must have a minimum thickness of 4 mm [2] and will be filled with elastic materials at least 48 hours after the end of the anchorage. [6] In the case of large areas it can be necessary to add additional joints in these facades [2]

3.2 Indirect anchorage methods

When staples and points of mortar is the chosen method, the first step is the marking, on the building facade, of the precise spots where the anchor are to be placed. Next, the required holes are drilled (with a minimum depth of 60mm and a recommended diameter of 40mm), cleaned and moistened. The holes
are then filled and mortar while the points of mortar are done (with a diameter of approximately 100mm). Meanwhile, it is recommended to prepare the holes on the edges of the stone panels (in the axis of the panel thickness, with a minimum depth of 30 mm [4]), and to place the staples on the stones. Finally, we bind the stone panels to the facade and its staples are inserted on the holes filled with mortar. The joints between stone panels must have a minimum thickness of 4mm, and can be filled with elastic products [4].

If, alternatively, the selected method is that with grout-in anchors, the first step is also the marking on the building facade of the holes to insert the drips (holes with a minimum depth of 80mm and diameter of 40 mm). After drilling the holes, they must be cleaned, moistened and then filled with fast drying cement or mortar. In the case of ceramic bricks, the most usual is to use mash sleeves and injectable adhesive anchors. It is also possible to apply body anchors, using mechanical anchorage, such as metallic expansion anchors in cement walls. The holes on the edges of the stone panels can then be drilled. The lower grout-in anchor, together with its support pine, can be inserted on the hole drilled on the wall. The stone can now be placed on the anchor, making sure that the pines enter into its the lower holes. Then, the upper grout-in anchor (with its pin) is put in place and inserted into the upper hole of the building wall. The joints between the stones have a minimum size of 5 or 6 mm [4] and, in the case of large areas, it may be recommended to have additional joints. If desired, the joins can be filled with elastic materials.

Due to the existence of many types of substructures systems of indirect anchoring it is difficult to define general procedures for carrying out this method. Therefore the instructions provided by manufacturers of each type of anchors are the most appropriate recommendations since they take into account the specific features of the product.

4 Anomalies – Pathologies

The pathologies in the stone facades represent, nowadays, a serious problem in this type of construction, for safety, durability and aesthetics reasons. [17]

In the case of direct anchorage technique, the most frequent pathologies are the cracking or the spalling of the panels stones, staining in the stones (which can be caused by the penetration of substances, trough the building wall or the stone surface, or by the discoloration of the mineral component of the stone itself), efflorescence, and the degradation of the products used to fill the joints between the stones.

In building where stone cladding is done using staples and points of mortar, pathologies can also show up (some of them similar to those just described). The most common pathologies include the cracking or spalling of the stones panels, the stains located near the mortar point, the flaking of the stone close to the holes drilled to support the pins of the anchors, the water infiltration and the anchors corrosion. The stone cladding techniques using grout-in anchors or substructure systems allow the construction of more flexible claddings, which can thus absorb more deformations. However, some pathologies, just as those described, can still occur in these cases.
Additionally, whenever mechanical anchorage, such as metallic expansion anchors, is used several other different problems may occur when push-out tests are done on the anchors (such as failure in the expansion of the bolts, failure of the building walls, failure of the bolt itself or a fail caused by a deficient installation of the mechanical anchor).

5 Quality Control

As seen in the previous description of the different construction methods, to ensure a final result of high quality there are several aspects that should be considered when performing cladding facade. To simplify and systematize the inspection of the procedures, a Quality Control Manual should be implemented on site. This manual intends to ensure that the proper procedures of the cladding installation are followed, that the stone panels installed are fulfilling their role effectively, that the cladding respects all the required security rules and guarantees durability outcomes consistent with the expectations.

This manual embraces the different stages of the construction process, from the design, through the correct application of the cladding and to the final quality checks. The aim of the manual cannot be, however, the detection or the correction of mistakes that may have occurred during the structural design stages related, for instance, with incorrect choices of the anchorages or of the size and thickness of the stone panels.

First, we present the preliminary general checks to ensure that the required conditions to start the works are met, whatever the anchorage method adopted: check the existence of a detailed cladding design, the accessibility of workers and scaffolding safety, the existence and usage of adequate protective equipment and check that required materials were ordered in adequate quantities. Upon arrival of the materials on site we should check that they comply the order, are in good conditions, displays the CE marking and the name of the stone. The stones must also exhibit their correct size according to the tolerances allowed in the EN 1469-2004 (such as thickness, lateral dimensions, miter and flatness of the stone panels as well as the location and size of anchor holes). In what concerns facades, the required checks concern its flatness, its cleaness and adequacy to receive the cladding. Also, there is the need to ensure that the locations of activities that may produce dust are away from the area where the cladding is being installed. Once the works are initiated, they should be carefully and continuously supervised.

Now we refer some additional checks, specific to the direct anchorage method, such as: verifying that the cement of the buildings is properly dried before applying the stone cladding, checking that flatness and the roughness conditions of the walls are appropriate, verifying that each stone panel is not attached to supports of different nature. Concerning the adhesive materials, the information provided by their manufacturer must be met and the adhesive strips should be crushed, when binding the stones, to prevent any voids between the stone and the wall. In this method, the joints between the stone panels should have adequate size and should be filled only after the complete drying of the adhesive materials used in the stones. Finally the weather conditions must always be taken into account during the works.
The additional checks needed for the indirect anchorage methods include the compatibility between the cladding design and the engineering discipline designs, as well as other technical requirements: ensuring that stones are not fixed to supports of different nature, that the stones are laid horizontally, that the holes in the walls and in the stone panels have been correctly drilled, that the size of the joints is appropriate and that the drying times are fully respected.

After completing the installation of any kind of cladding, we should check that all the works were made accordingly to the design (allowing for the tolerances accepted), that the materials in surplus in the joints have been cleaned and that the areas on top of the facades were protected to avoid water infiltrations.

6 Case study

As a case study we selected a building in Lisbon where we could observe several errors in the application of the cladding. Due to these errors, the potential benefits of indirect anchorage vanished. The building’s facade were maid of “moleanos” limestone panels, attached to the masonry with grout-in anchors where we could detect some of pathologies already described in this report. Therefore, this case study could be used to implement the quality control manual proposed. In this building, long before the end of the expected product service life, important works had to be carried out involving the complete removal of all the stones and fixing anchors and their replacement. This works were required by the deterioration of the safety conditions of the building when stones from the cladding threat falling. This problem was caused by errors committed during the cladding installation and not by the deterioration of the anchors themselves. Some of these errors could be clearly detected during the visits to this construction site such as the incorrect location of grout-in anchors, the incorrect choice and poor installation of the anchor pines (figure 6.1), the wrong fixing of the grout-in anchors near the windows and balconies and the underestimate of the joints thickness (figure 6.2).

During the several steps of the works done to repair the claddings, we could test the applicability of the Quality Control Manual described earlier as good mechanism to prevent errors.

Fig. 6.1 - Incorrect installation of a grout-in anchor

Fig. 6.2 - Joint between stone panels with underestimate thickness
Conclusion

This study allows us to conclude that most of the anomalies and pathologies that can be detected in facades are due, mainly, to the incorrect choice or misapplication of cladding materials. These errors can take place either in the design or implementation of the claddings.

In the design stage, it is crucial to carry out a complete and detailed study, including the selection of the anchoring method, the type and finishing of the stone panels, the accurate design of the anchors and an exhaustive description of the construction methods (including, for instance, the number and dimensions of joints). In this stage it is also required to ensure the compatibility between the cladding design and the others engineering discipline design, to avoid damaging steel frames or pipes when drilling the walls and to avoid fixing a single stone panel on two different supports.

During the construction, proper training of installers and close supervision of the works can prevent major errors. These are key conditions to guarantee the proper handling of materials and the follow up of the projects according to the contract specifications.

The Quality Control Manual, such as the one described, is an adequate and powerful tool to present all the required checks that have to be done, both in the design and implementation stages. However, this document is not aimed to replace the design or the description of the constructive methods. In the case study considered, this manual proved to be quite useful to summarize all controls to be performed.

The use of a Quality Manual such as the one presented is highly recommended: it does not involve high costs but can give rise to significant benefits, improving the cladding final quality and reducing the likelihood of anomalies throughout the building lifetime, as well as extra expenses.

This Quality Control Manual can be further developed and other verifications can be added whenever required. The study of a wider range of buildings and their pathologies would provide a deeper understanding of this subject allowing the formulation of a more detailed manual. Additionally the manual can also be extended to account for other cladding techniques less frequently used.

The maintenance of the buildings and their facades is crucial to preserve the quality of the construction and extend their lifetime. Unfortunately, we notice that the maintenance of the buildings is often neglected, due to lack of awareness or to economic reasons. Therefore, the elaboration of a maintenance manual for buildings with stone cladding could be useful, describing the key maintenance operations recommended as well as their frequency and would be useful complement to the Control Quality Manual presented here.
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