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Dimensioning metallic inserts of stone claddings: a case study

Dimensionamento de inserts metálicos para revestimentos de granito: um estudo de caso

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Abstract

This study proposes a methodology for dimensioning metallic inserts for the indirect fastening of granite claddings. The proposed methodology intends to solve an existing problem, observed in a case study analyzed in the city of Porto Alegre, Brazil. This case study is a residential building, which presents a severe detachment of the external granite cladding, generating serious materials' damage in the building, also compromising the users' safety. The pathology observed in this case study, evaluating the causes beyond the detachment of the granite cladding. The façades orientation and the exposure to prevailing winds could contribute to the claddings' degradation condition. Nevertheless, the design and execution conditions seem to be the main cause of the existing condition of the case study under analysis. The evaluation of the case study reveals that the absence of an intermediate layer of metallic inserts in association of the presence of strong winds in the region, lead to an overload of the granite plates in their midline, causing the rupture of the elements, and, consequently, to the partial detachment of the stone plates. This study thus reviews the technical standards applicable at the construction stage, proposing the development of a method for dimensioning metallic inserts of granite plates in stone claddings, based on isostatic principles and in the flexural strength of stone plates.

Keywords: Metallic inserts. Granite claddings. Detachment. Pathology.

Resumo

Este estudo propõe uma metodologia de dimensionamento de inserts metálicos para fixação indireta de revestimentos de granito. A metodologia proposta pretende resolver um problema existente, observado em um estudo de caso analisado na cidade de Porto Alegre, Brasil. Este estudo de caso trata de um edifício residencial, que apresenta desplacamento do revestimento externo de granito, gerando sérios danos materiais ao edifício e comprometendo a segurança dos usuários. A patologia observada neste estudo de caso, avalia as causas além do destacamento do revestimento de granito. A orientação das fachadas e a exposição aos ventos predominantes podem contribuir para a condição de degradação do revestimento. No entanto, as condições de projeto e execução parecem ser a principal causa da condição existente em análise. A avaliação revela que a ausência de uma camada intermediária de inserts metálicos, associada à presença de fortes ventos na região, leva a uma sobrecarga das placas de granito em sua linha média, causando a ruptura dos elementos, e, consequentemente, o desprendimento parcial das placas de pedra. Este estudo revisa as normas técnicas aplicáveis na fase de construção, propondo o desenvolvimento de um método de dimensionamento de inserts metálicos para revestimentos externos em granito, baseado nos princípios isostáticos e na resistência à flexão destas placas.

Palavras-chave: Inserts metálicos. Revestimento de granito. Desplacamento. Patologia.

1 Introduction

The degradation of the building envelope is one of the major concerns of stakeholders since in most cases maintenance actions are often based on the outward appearance of the buildings (i.e. building aesthetics) (BALARAS *et al*., 2005). In this sense, the cladding, as the most exterior layer of the building, is directly exposed to the degradation agents and therefore more prone to present various anomalies. These circumstances lead to the obsolescence of these elements (THOMSEN; VAN DER FLIER, 2011), with direct consequences on the quality of the urban space, on user comfort, on the costs of maintenance and repair (KIRKHAM; BOUSSABAINE, 2005).

Natural stone has been widely used as external cladding, in façades of higher-valued constructions in Brazil. It is expected that this superior cladding material will continue to be a primary cladding product in the future due to its aesthetic characteristics and durability. There are several studies, such as Emidio *et al.* (2014), Silva, Brito and Gaspar (2013, 2016a) and Silva *et al.* (2011, 2016b), which scrutinize the service life of this cladding solution.

According to BS ISO 15686-8/2008, a relevant diligence during the service life prediction is to present an interval of confidence for the estimated value (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO), 2008). Therefore, Silva, Brito and Gaspar (2016a) proposed several methods to estimate the service life of stone claddings. The authors suggest the range of service life values between 57 and 121 years.

If those service life ranges are not observed by distant periods, the chances of a construction claim between the stakeholders may increase. Claims often arise among contracting parties and are disruptive and unpleasant events in the construction industry. These is a burden for construction projects because they may lead to time delays, cost overruns, and an adversarial project environment (HO; LIU, 2004; REN; ANUMBA; UGWU, 2003; ZANELDIN, 2006). If claims are not properly solved, they may become an expensive and lengthy litigation process (LU; ZHANG; LI, 2015). Despite the availability of other claim resolution methods, most project participants often consider negotiation as the most cost-effective way to settle claims due to its informal, fast-tracked nature with a lower level of complexity (CHOW; KONG; CHEUNG, 2012).

This study proposes a methodology for dimensioning metallic inserts for the indirect fastening of granite claddings. The proposed methodology intends to mitigate the presence of defects, as the detachment of natural stone plates, which can be avoid through the adoption of adequate design measures. In this study, the application of the proposed methodology is discussed for a case study in the city of Porto Alegre, Brazil.

2 Case study

The stone plates cracking, with the consequent detachment from the substrate of a building with ten years of service is the pathological condition under analysis. Fortunately, only material damages were observed, resulting from the fall of heavy plates from more than 42 meters high. The anomalies occurred in the higher part of this fourteen-story building located in the city of Porto Alegre, in the southern region of Brazil. The owners wanted to know the origin of this anomaly and consequently who was the responsible for it. The building is vulnerable to the effects of prevailing winds, since is not protected by adjacent buildings. The cladding mainly presents a southeast orientation (Figures 1 to 5), and the detachment of the cladding occurred in a stormy day with strong winds (around 33.5 meters per second, from southeast direction).

Figure 1. View of the region with detachment of stone elements (façade facing southeast)

3 Building pathology

3.1 Inspection and other diligences

Different authors such Garrido, Paulo and Branco (2012), Gaspar and Brito (2008) and Vieira *et al.* (2015) emphasize that an inspection and collecting all the technical information available of the element, is an important part of the constructive diagnosis. A witness from the building across the street reveals that the first plates have broken, and then after the fall of one or two elements the remaining ones also detached, leading to a construction claim.

3.2 Research methodology

This study thus purposes the review of the Brazilian standards and some isostatic calculations for the element, in order to find out the detachment causes in the case study under analysis. Regarding the construction time (between 2005 and 2007), the standards that were applicable at the time were the ABNT NBR 6123/1988

(ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT), 1988) (which is still accepted nowadays but it was updated in 2013), ABNT NBR 13707/1996 and ABNT NBR 13708/1996 (this last two standards were replaced by ABNT NBR 15846/2010) (ABNT, 1996a, 1996b). In Brazil, compliance with ABNT technical standards is compulsory according to federal laws such as Consumer Protection Code, Civil Code, Civil Procedure Code and Penal Code.

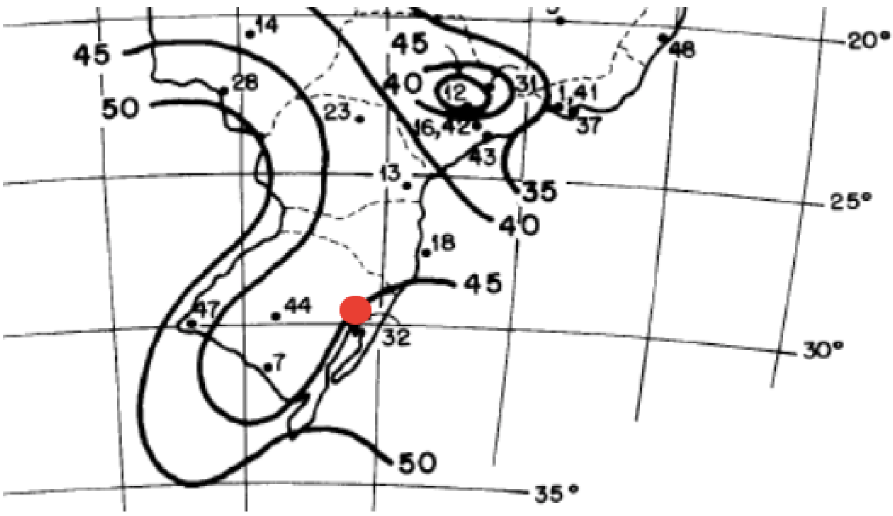
3.2.1 ABNT NBR 6123/1998 - Wind forces in buildings

Equation (1) allows evaluating the wind loads on the stone plates that had broken and subsequently detached from the cladding. The determination of the dynamic effects of the wind is obtained from Figure 2, which determines the V_o of the region, for further calculation of the final value of wind effect (V_k), which has three weighting factors named S1, S2 and S3 (Equation 1).

$$Vk = Vo \times S1 \times S2 \times S3 \quad \text{Eq. 1}$$

Figure 2 shows that the region under analysis (highlighted in red) has a Vo of 45m/s. According to the ABNT NBR 6123/1998 standard, the buildings are divided into categories I to V and classes A to C. Based on this standard, the building under analysis belongs to Category V (land that is covered by several large, high and narrowly spaced obstacles, such as tall tree forests, isolated crowns, large city centers) and Class B (building or part of a building for which the largest horizontal or vertical dimension of the front surface is between 20m and 50m).

Figure 2. Basic speed Vo Isopleths (meters/second)



Fonte: Da autoría.

In order to obtain V_k, factor S1 has three variations in relief. The studied location (in slopes and hills suggests a S1 = 1.0). From the analysis of Table 1 and considering also that the case study is into category V and class B, the factor S2 can be calculated using the Equation (2).

$$S2 = b \times Fr \times (z_g/10)^p \qquad \text{Eq. 2}$$

Where, *b* and *p* are constant parameters, *Fr* is the burst factor (always corresponding to category II) and the above expression is applicable up to height *Zg*, which defines the upper contour of the atmospheric layer. Using the Equation (2) with the suggested values in Table 1, the S2 obtained is 1.33. The third factor, S3, can be estimated from Table 2, group 2, which is equal to 1.0. Using the estimated factors from Equation (1) it is possible to obtain the Vk for the region of the sinister, that is 60.20 m/s. This value, in theory, represents the minimum speed of the wind that any building of this region of the city must support without presenting anomalies, or without compromising its safety or ability to fulfil its requirements.

Table 1. Meteorological parameters

Category	zg (m)	Parameter	Class A	Class B	Class C
I	250	b	1.1	1.11	1.12
		p	0.06	0.065	0.07
II	300	b	1	1	1
		Fr	1	0.98	0.95
		p	0.085	0.09	0.1
III	350	b	0.94	0.94	0.93
		p	0.1	0.105	0.115
IV	420	b	0.86	0.85	0.84
		p	0.12	0.125	0.135
V	500	b	0.74	0.73	0.71
		p	0.15	0.16	0.175

Table 2. Minimum values of statistical factor S3

Group	Description	S3
1	Buildings whose complete or partial ruin may affect the safety of relief to persons following a descriptive storm (hospitals, fire and security forces quarters, communication centers, among others)	1.10
2	Buildings for hotels and residences. High-occupancy buildings for commerce and industry	1.00

Group	Description	S3
3	Low occupancy industrial buildings and facilities (warehouses, silos, rural buildings, etc.)	0.95
4	Fences (tiles, glass, sealing panels, among others)	0.88
5	Temporary buildings. Groups 1 to 3 structures during construction	0.83

3.2.2 ABNT NBR 13707/1996 - Design of covering of walls and structure with stone cladding - Procedure

This standard stipulates that clamping devices, among other functions and shapes, must fix the plates to the bracket and each other, withstand the coating's own weight, wind action and all other possible loads, prevent the tipping of the plates and absorb the differential deformations between the coating and the support in order to reduce the stresses introduced in the coating. Subsequently, the stone plates, as well as their fastening devices, are subjected to different requirements for loads parallel to the plane (own weight of the plate; possible weight of any thermal insulation layer), loads perpendicular to the plane (wind action; accidental impacts; plates own weight when placed horizontally; and relative movement of the support and liner, due to deformations caused by hygrothermal variations, or permanent deformations due to shrinkage and slow concrete deformation. Wind stresses (pressures and suctions) shall be calculated in accordance with ABNT NBR 6123/1988 (ABNT, 1988).

Under the action of the wind, the plates are submitted to flexural stresses. Depending on the extent of contact of the clamping devices with the plate, these supports will or may not be considered punctual. The plates are also subjected to puncture and shear stresses that tend to chip the stone in the regions where the clamping devices are installed. Clamping devices must be designed to withstand the stresses to which they will be subjected, to allow free movement of the plates, so that no significant stresses are transmitted to the cover plates due to the different hygrothermal movements between the cover and the support.

3.2.3 ABNT NBR 13708/1996 - Execution and inspection of covering of walls and structures with stone cladding – Procedure

To avoid duplication of content the themes already described in ABNT NBR 13707/1996 (1996a) (analyzed in the item 3.2.2) will not be presented. This standard, among other guidelines, recommends that the necessary safety precautions should be taken, recommending the use of qualified workers, aware of the accidents that may occur in the event of failures due to inadequate execution conditions.

3.2.4 The proposed method for dimensioning metallic inserts of granite plates in stone claddings

For the elaboration of the proposed method[1], the concept of an isostatic structure is used to dimension the necessary number of metallic inserts. The natural stone cladding detached was a yellow ornamental granite piece with the dimensions of 1.88m x 0.70m (Figure 3).

Figure 3. View and dimensions of the detached stone plates (according to architectural designs)

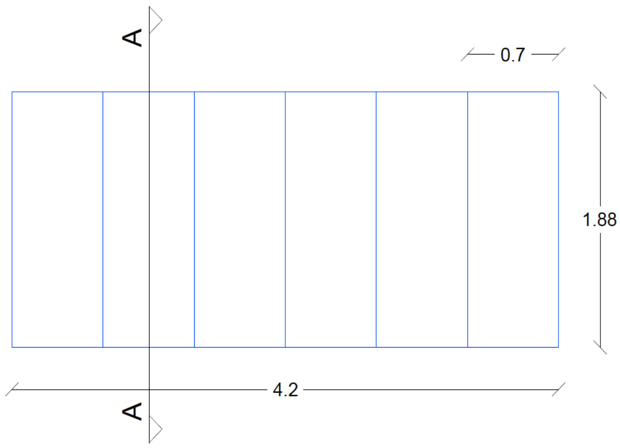
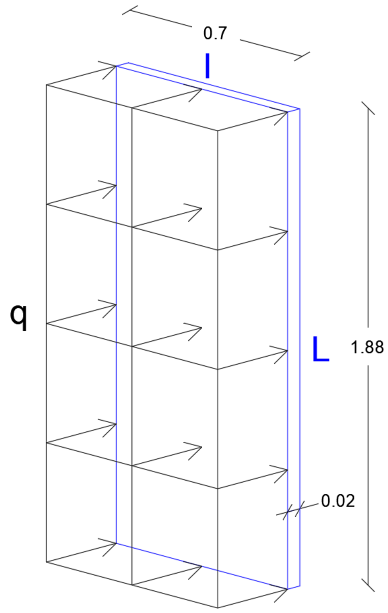


Figure 4. View of the quantity and disposition of the metallic inserts (according to local)

From Figures 1 and 3, as well as the calculation obtained from Equation (1), it is possible to estimate the suction effect generated in the granite plate, as shown in Figure 5.

1 Methodology suggested by Gran-Prometal Granitos, Projetos e Metais Ltda. (http://www.granprometal.com.br).

Figure 5. View of the distributed wind load over the granite plate



According to ABNT NBR 6123/1988 (ABNT, 1988), the Equation (3) is used to determine the perpendicular uniformly distributed load applied on each plate. Thus, from Vk of 60.20 m/s, the load in N/m² can be obtained, and, consequently, in kgf/m². From the Equation (3), a force of 2,221.54 N/m² or 222.15 kgf/m² is obtained.

$q = 0.613 \text{ x } Vk^2$ Eq. 3

From the equations of the moments acting on an isostatic structure, the load distributed on the stone plate is transformed by the flexural moment equation according to the smallest dimension (l), such as Equation (4).

$y = q \text{ x } l$ *Eq. 4*

After obtaining y of 155.51 kgf/m in Equation (4) we proceed to the maximum moment. Once the load applied uniformly in one direction is estimated, the section AA' is presented in Figure 6.

The maximum moment (M_{max}) that this granite plate would be subjected to resist for two supports at 15cm of its end can be calculated by Equation (5). From the Equation (5), the M_{max} is equal to 48.53 kgf/m or 4,852.62 kgf/cm.

$$Mmáx = \frac{y \text{ } x \text{ } L^2}{8} \quad \text{Eq. 5}$$

Then, the flexural strength modulus (Wx) is equal to 4.66 x 10^{-5}m³ or 46.67 cm³, according to Equation (6). The pressure acting stress (ح) on the axis of the damaged plates is equal to 103.98 kgf/cm² or 10.40 MPa (Equation 7) and should resist the value obtained by the flexural strength quotient and the maximum moment.

$$Wx = \frac{e^2 x\, l}{6} \qquad \text{Eq. 6}$$

$$\tau = \frac{Wx}{Mmáx} \qquad \text{Eq. 7}$$

Thus, using the safety coefficient (*c* = 3) recommended in ABNT NBR 13707/1996 (1996a), the granite plate should support a load of 31.20 MPa. If an intermediate metallic insert were used as suggested by the red dashed line in Figure 7, the numbers obtained in Equations (5) and (7) would reduce, respectively, to 12.13 kgf/m or 1,213.15 kgf/cm and 26 kgf/cm² or 2.6 MPa. Thus, maintaining the safety coefficient (*c* = 3) recommended in ABNT NBR 13707/1996 (1996a) the granite plate now should be capable to support a load of 7.8 MPa.

Figure 6. Detail of section AA' of Figures 3 and 5

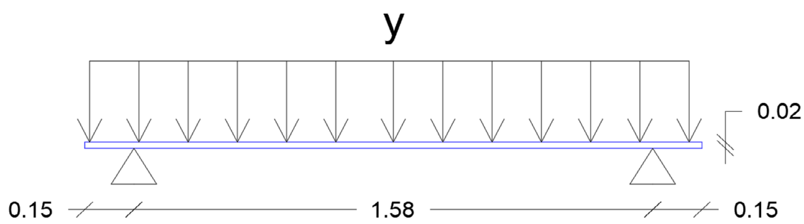
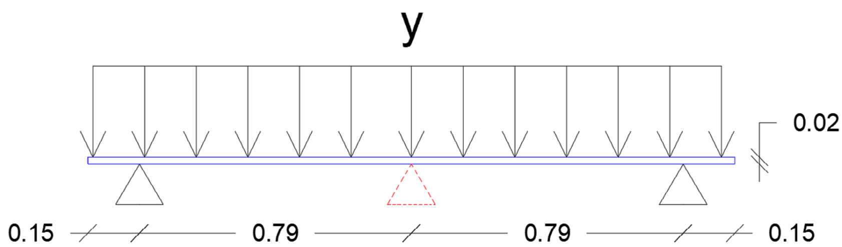


Figure 7. Detail of section AA' of Figure 3 and 5 with an extra metallic insert



4 Conclusions

The analysis of the case study reveals that the detachment of the stone plates mainly occurred due to inadequate design and poor execution conditions, such as the non-elaboration of a project for the metallic inserts, as due to the non-compliance with the recommendations of the applicable and mentioned standards. Thus, based on the *in situ* survey, the following conclusions can be drawn:

a. The coating was not properly fixed in place due to the lack of an intermediate horizontal fixation layer between the metallic inserts, which according to wind solicitations (calculated with ABNT NBR 6123/1988) (ABNT, 1988) and isostatic principles demonstrates that the granite plate would have resisted to a perpendicular stress of 31.20 MPa instead of a 7.80 MPa load;

b. Considering that, according to Vidal (2002), ornamental granites have a flexural strength greater than or equal to 10 MPa by the American Society for Testing and Materials, as well as that Yellow Massapé and Cabaças granites have resistance of 20 MPa and 10.57 MPa, respectively, it is possible to estimate that the average of this type of granite is around 15 MPa of flexural strength, which explains the cracking of part of the cladding and its consequent detachment;
c. The calculations suggested in this research determined the number of metallic inserts to be installed to fix the granite plates in compliance with the analyzed guidelines. The proposed methodology intends to emphasize the importance of a project, in design stage, to mitigate eventual execution errors, and to reduce the risk of failure in this type of cladding.

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