Damages to the Façade of the Capanema Building caused by Thermal Action

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Resumo

Surveys carried out in the Gustavo Capanema Palace identified several pathologies that compromised the integrity of the façade and the flat slab in the Annex to the main building. Initially, the pathologies were evaluated and some criteria were established for performing the repairs of all identified damages. The pathologies were detected in the reinforced concrete structure and on the façade covered with granite stones. There were cracks on these granite stones and it was observed they were about to collapse. According to the analysis, the root cause of these pathologies was the thermal action because the building façade is composed of different materials and they behave differently when the temperature changes. The solution to eliminate this pathology was the execution of expansion joints, thus allowing the expansion of the materials without damaging the structure.

Keywords: granite façade; thermal action; expansion joints.

1 Introduction

The Gustavo Capanema Palace (*Palácio Gustavo Capanema* in Brazilian Portuguese) is a landmark of Brazilian modern architecture. It was designed by a team that included Lúcio Costa, Carlos Leão, Affonso Eduardo Reidy, Ernani Vasconcellos, Jorge Machado Moreira and Oscar Niemeyer, under consultancy of Le Corbusier, and with calculations made by Emílio Baumgarten (SÁNCHEZ FILHO, 2013a).

The Annex to this building is a structure on pilotis, on which there is a garden designed by Burle Marx. There was an intervention in this building in the 1990s but the documentation about this work was not obtained.

Some pathologies were analyzed and after consulting several opinions from inspection and prescriptions to solve the problems on the façade, a structural-focused survey was carried out in order to diagnose the causes of the movements that occurred and to eliminate the causes of the observed pathologies.

2 Pathologies observed on the façade

Based on the inspections carried out in the Capanema Building, it was verified that there were stones collapsing from the platband of the Annex's façade.

The structure of this Annex is peculiar. There is a mushroom slab with 32 cm of width and the capitals are inverted (Figure 1); on the slab there is a garden designed by Burle Marx. Between the capitals there is a filling of ceramic bricks, waterproofing sheets, earth and Portuguese pavement stones with a total width of 34 cm. A crack was found in the cladding stones and another horizontal one on the sides of the Annex but there were no displacements in the façade plane.

In the frontal façade there was a displacement between the coating stones of about 2 to 3 cm, making it clear that there was a relative displacement between the materials that make up the garden floor.

The differential longitudinal displacement generates a shearing process in the plates, with the collapse of parts thereof. This movement is due to moisture in the slab filling, which is transferred to the walls, and due to thermal expansion.

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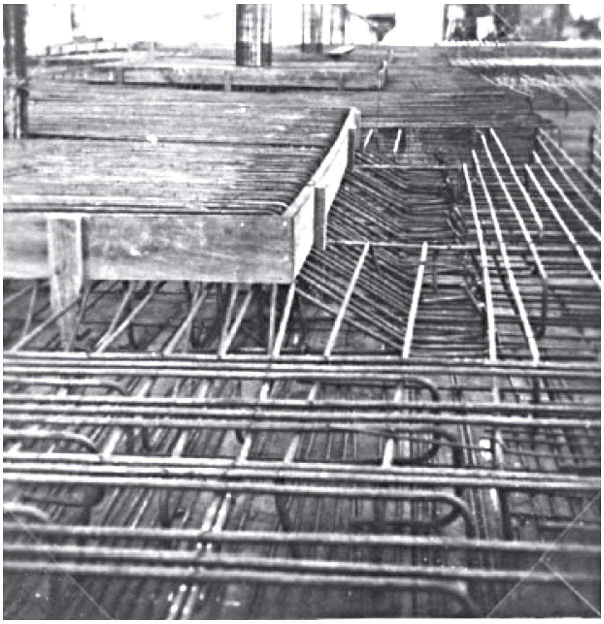
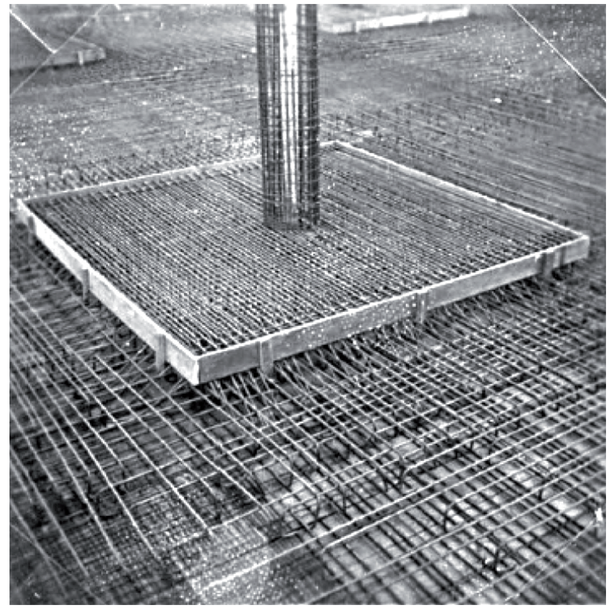


a)



b)

Figure 1 − Inverted capital of the mushroom slab in the Annex (JERMANN, 2013): a) shapes and hooks of the folded bars; b) a suspension reinforcement.

In order to resist the shearing stress, the plate must be fixed on only one of the elements with its upper part overhanging. Another solution is to saw the plate in the section where different elements are joined, thus separating it into two moving parts. These were the suggestions given by an external consultant.

After the previous procedures, an analysis was carried out to solve the problem of relative displacements. The evaluation of the pathologies, the conclusions and the recommendations for repairing such pathologies were consistent and adequate to the case under analysis (FILLIZOLA, 2013).

In order to confirm it, text presents the analysis of case that is similar to this one (THOMAZ, 2013), in which there are high levels of shearing stress in the stone mortar (Figure 2).

The root cause of the pathologies was the occurrence of high magnitude horizontal displacements in the slabs, but the cracks were formed in a similar way to that described in Thomaz (2013), which reports the following: 1) slow deformation and shrinkage due to concrete drying of the building columns is inevitable, and the mortar is subject to high tangential stress. As the stones do not have retraction or slow deformation, they do not go with the shortening of columns and thus remain compressed and buckled; 2) the thermal effect on the stones of the façade happens around 60 ºC, and the stones tend to dilate differently from the reinforced concrete structure, causing stress similar to that of retraction and fluency.

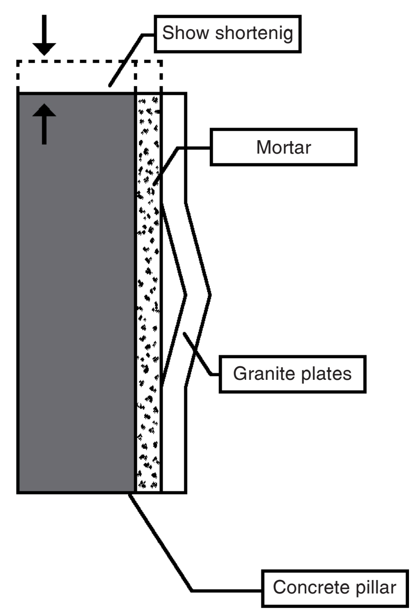
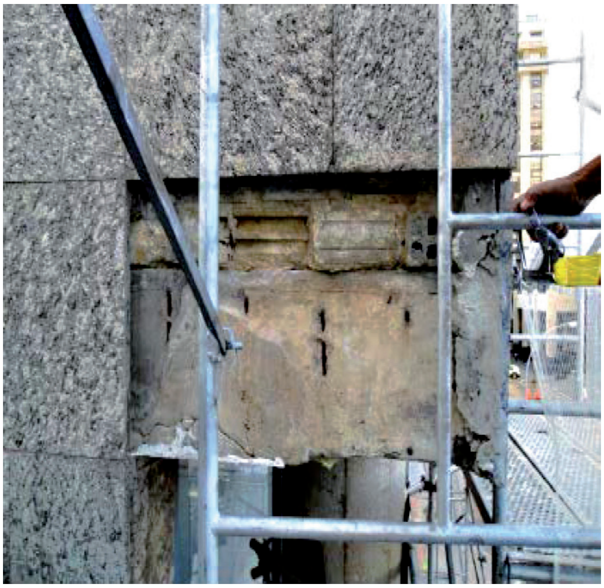


Figure 2 − Differential behavior of the materials in a façade with concrete substrate and granite coating (THOMAZ, 2013).

Regarding the pathologies on the blind wall (façade), control joints should be created in the external covering in order to prevent its collapse by assimilating the differential displacements of the materials and distributing these differences in sections of smaller dimensions (thus, smaller cracks). Figure 3 shows several elements that make up the façade and the damages at the interface between the mushroom slab and the finishing stone.



a)

b)

Figure 3 *− Damages to the stones on the pilotis façade (FILLIZOLA, 2013): a) constituent elements of the façade; b) details of the edge of the mushroom slab with exposed reinforcement.*

There was differential displacement between the slab and the ceramic brick filling:

1) coating plate made of stone;
2) ceramic brick filling layer made with a width of 34 cm;
3) reinforced concrete slab with a height of 32 cm.

It was observed that the metallic element used to block the granite stones in the ceramic brick masonry platband was corroded (Figure 4). One factor that caused the corrosion was the moisture in the joint between the stones. These metal elements had no corrosion treatment.

a)

b)

Figure 4 *− Corrosion of the metal element used to block the stones: a) rust stain; b) metal insert (FILLIZOLA, 2013).*

Figures 5 and 6, respectively, show the stains observed and the dimensions and depths of the insert. The removal of pieces from the stones was subsequently replaced with the same material, i.e., powder of the original granite from the surface, according to the prescriptions of Salles and Garros (2013).

a)

b)

Figure 5 − Removal of stones: a) dark color indicating moisture; b) removal of parts of the stained stones (FILLIZOLA, 2013).

a)

b)

Figure 6 *− Corrosion of the metal element that blocks the stones: a) depth of the insert; b) exploration to verify the dimensions of the insert (FILLIZOLA, 2013).*

a)

b)

Figure 7 *− Cracked in the junction between the transverse and longitudinal walls: a) overview; b) detailed highlight of slit size (SÁNCHEZ FILHO, 2013).*

3 Thermal Action

The structure of the Annex is made of reinforced concrete and its façade is covered with granite stone plates and these plates were detaching from the masonry walls supported by the concrete mushroom slab. Two possible causes were identified:

1) slow deformation and drying retraction in the concrete of the structure. This deformation is inevitable because the mortar in the walls is subject to high shearing stress. The stones do not retract nor deform slowly and, therefore, do not follow the differential displacements that occur between the concrete and the masonry;
2) the sun can heat the façade stones up to temperatures of 60 ºC, in contrast to the internal temperature of the building which ranges from 25 ºC to 30 ºC. The stones tend to dilate differently.
3) in order to solve the problem of the precariously fixed stones, it was determined that this fixation was carried out using anti-corrosion metallic clips. It was found that there are no control/expansion joints along the entire length of the ceramic brick walls and also at the junction between the mushroom slab and the building tower. Some cracks appeared on the platband corners, evidencing the existence of differential displacements between the structure (mushroom slab with inverted capitals) and the masonry (Figure 7).

Control joints must be placed in the joints between materials of different elasticity modules (columns and masonry walls). Sealants with an expansion of 50% should be used to fill these joints. However, in the expansion joints a mastic-based sealant with an expansion of 25% was adopted because it requires a higher width (ASTM C1193 – 16, ASTM C920, ASTM – SPT 1069, NBR 6118:2014).

Moisture in masonry walls induces displacements ranging from 0.02% to 0.075% of the element's length and produces an irreversible expansion. Thus, the average value of 0.05% results in:

− transverse wall

$$\Delta\ell_{u1} = 0.005\% \times 23800 \cong 11.9\,mm \tag{3.1}$$

− longitudinal wall

$$\Delta\ell_{u1} = 0.005\% \times 49280 \cong 24.6\,mm \quad (3.2)$$

Assuming the following data for the thermal expansion of the elements:

− masonry brick and plastering

$$\alpha = 6 \times 10^{-6}\, mm/mm/{}^{0}C \quad (3.3)$$

− structural concrete

$$\alpha = 9 \times 10^{-5}\, mm/mm/{}^{0}C \quad (3.4)$$

Based on a thermal expansion of

$$\Delta\ell_T = \ell.\alpha.\Delta\theta \quad (3.5)$$

and a temperature variation of

$$\Delta\theta = 20\,{}^{0}C \quad (3.6)$$

the following values are considered

− transverse wall

$$\Delta\ell_{t,par1} = \ell.\alpha.\Delta\theta = 23880 \times 6 \times 10^{-6} \times 20 \cong 2.9\,mm \quad (3.7)$$

− longitudinal wall

$$\Delta\ell_{t,par1} = \ell.\alpha.\Delta\theta = 49280 \times 6 \times 10^{-6} \times 20 \cong 5.9\,mm \quad (3.8)$$

− transverse dimension of the slab

$$\Delta\ell_{t,laje1} = \ell.\alpha.\Delta\theta = 23880 \times 9 \times 10^{-6} \times 20 \cong 4.3\,mm \quad (3.9)$$

− longitudinal dimension of the slab

$$\Delta\ell_{t,laje2} = \ell.\alpha.\Delta\theta = 49280 \times 9 \times 10^{-6} \times 20 \cong 8.9\,mm \quad (3.10)$$

For the differential displacement due to thermal effects between these elements, the following values are considered for each end of the masonry wall

− transverse dimension

$$\Delta\ell_1 = 0.5(4.3 - 2.9) \cong 0.7\,mm \quad (3.11)$$

− longitudinal dimension

$$\Delta\ell_2 = 0.5(8.9 - 5.9) \cong 1.5\,mm \quad (3.12)$$

Thus, the total displacement at the diagonals of the wall joints is given by

$$\Delta\ell_{total} = 0.5(11.9 + 24.6 + 0.7 + 1.5) \cos 45^{0} \cong 13.7\,mm \quad (3.13)$$

Considering a joint inclined at 45º, a tolerance of 10 mm in the dimensions and a mastic-based sealant with an expansion of 25%, results will be as follows:

$$\Delta\ell = \frac{100}{\%mastic \;\; mov.} \sum movements + tolerances = \quad (3.14)$$

$$tolerances = \frac{100}{25} \times 13.7 + 10 = 65\,mm$$

The width value obtained for the expansion joint is high, thus using only one joint in the diagonal position of the joints between the transverse and longitudinal walls is unviable. The best option found was to apply three joints: one in the joint with the tower, another one in the middle of the longitudinal wall and the next one at the joint between this last-mentioned wall and the transverse wall. The sum of the widths of these joints was higher than 65 mm (Figure 8).

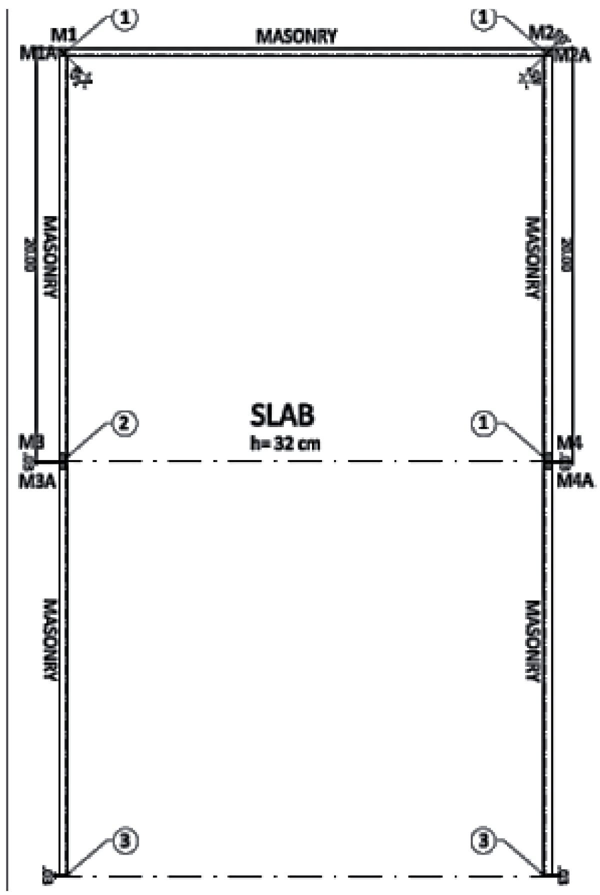


Figure 8 − Expansion joints designed (SÁNCHEZ FILHO, 2013).

4 Conclusions

The pathologies on the façade stones of the Annex were all corrected according to the prescriptions of Salles and Garros (2013). It was concluded that the differential displacements between the slab and the parapet walls, and the lack of expansion joints in walls corners generated the observed slits. Based on the dimensioning of the displacements of the reinforced concrete mushroom slab and the masonry walls around it, the required joint width was designed. However, due to the large width value obtained from this process and considering that the Annex's length is higher than 40.00 m, three joints were created: the first one between the tower and the Annex; the second in the middle of the mushroom slab's length, and the last one in the joint between the longitudinal and transverse walls.

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