EARTH AS A STABILIZATION AND CONSOLIDATION ELEMENT FOR BUILT-HERITAGE FOUNDATIONS: TWO CASE STUDIES IN BRAZIL

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Theme 7: Ancient/Historic and Innovative Solutions for Damage Prevention and Performance Improvement
Keywords: Foundations, recovery, tamped earth

Abstract

This paper deals with the use of earthen materials in the consolidation/stabilization of monument foundations from experiments conducted between 2001 and 2004, whose design and implementation were coordinated by the author. For both cases, the author adopted the methodology of her master's thesis, developed from her experience in conservation and restoration of historical Brazilian buildings. The case studies were characterized by characteristic fissure damage at the foundations.

Damage assessment was followed by trials and evaluation,which enabled diagnosis and the design of interventions for the project. The verification of disaggregation and high moisture content of the soil, along with the results of physical characterization tests, substantiated the option for a system of recovery of the structural capacity of the foundations.This occurred through the substitution of the soil with Cyclopean rammed-earth blocks positioned laterally to the foundations, to attain their lateral confinement. This system was compatible with the overall behavior of buildings, whose foundations are direct, continuous and of low depth.

The observation of current state of the two monuments proves that the system adopted was adequate to enhance the structural capacity, since there was no movement or deformation of the masonry. The intervention adopted in the case studies presented in this article preserves the integrity and the authenticity of the original foundation structure of the buildings. Moreover, it also allows its reversibility, as it can be removed without harming the historic building material.

1. INTRODUCTION

This paper presents the application of the methodology that the author developed as part of her master's thesis from the Federal University of Rio de Janeiro. This research was based on the experience of conservation and restoration works on buildings of historical and artistic value in Brazil (1). This paper demonstrates the restoration interventions on two monuments: the Igreja Matriz de Santo Antonio and the Cathedral of Valença, both in Brazil.

2. IGREJA MATRIZ DE SANTO ANTONIO

The Igreja Matriz de Santo Antonio is located in the city of Tiradentes, Minas Gerais, on a hill. In the back, there is an old cemetery. The church was constructed on rammed earth and dates back to the first half of the 18th century. The façade, however, was rebuilt in the second half of that century, using stone masonry with stone ornaments, in accordance to the project of Antônio Francisco Lisboa, also known as Aleijadinho (little cripple), the greatest Brazilian artist of the colonial period. The church is considered one of the most significant monuments of Brazilian Baroque (2).

In 1994, several signs of degradation were detected in the structure of the building, such as, cracks on the sidewalls, on the towers, and, especially in the main façade, where the fissures jeopardized a large swath of stone, on the façade sculpted by Aleijadinho. Also, a large deformation and displacement of the upper-perimeter containment wall was observed.

The IPHAN engineer, head of restoration and structural conservation was asked to solve the problem. Initially, temporary buttressing of the span over the front door was foreseen, to prevent rupture of the central section of the façade, while the repair projects were designed and financial resources required for the execution of the work were secured.

The next step involved documentary research in the archives of Minas Gerais and Rio de Janeiro, in order to obtain a complete history of the physical condition of the monument. Simultaneously, topographic surveys of the entire surface of the church envelope were addressed, and a series of mechanical and physical tests performed to better understand the condition and stability of the church. Geotechnical drilling, foundation inspection wells, installation of basal and deformation checkpoints, geotechnical surveys, analysis of non-deformed and deformed soil samples, and measurements of variation in the level of groundwater monitored for three years were completed. Control of the vertical alignment of the perimeter retaining wall was also addressed.

Fig.1 City of Tiradentes, Minas Gerais in Brazil; on the top right is the Igreja Matriz de Santo Antonio (credits: IPHAN Archive)

This phase was followed by the analysis and evaluation of the results of all studies conducted so far. It was found that the level of the foundations' base extended to 2.20m below the ground surface. The soil-strength test, SPT type, demonstrated that the soil had low capacity to support medium to high plasticity, with compressibility characteristics up to 5.00m deep. Monitoring of the foundation confirmed the existence of inhomogeneous settlement of the structure. The groundwater level monitoring also determined the existence of a large variation in level associated with the wettest periods, which was exacerbated by the excavations in the cemetery annexed to the church. Investigation of the vertical alignment of the perimeter wall showed a very small height ratio and, therefore, inadequate for ensuring the security of the structure.

Those results supported the diagnosis of the condition of the foundation's stability for the main structure of the church, especially in the area of the towers, where the geotechnical drillings implemented in the area of the foundations indicated that the topsoil had a very low-support capacity. This discovery led to the need for intervention, to improve the behavior of the foundations. Large variations in the groundwater level explain the existence of large gaps due to the undermining of the soil. These variations depend on the infiltration of rainwater, and the fact that the church is built on an area of surface waterdrains and on the slope of the hill. This increases the risk, in terms of the precariousness regarding the capacity of the foundation soil. These facts led to the recommendation of a drainage system throughout the area surrounding the building site, and the recovery of the street drain existing in the back of the church, which was heavily eroded. Excessive deformation of the perimeter containment wall showed failure of transverse inertia to ensure its stability, which led to a proposal for its partial dismantlement and its reconstruction with a suitable geometry, along with an efficient drainage system (Puccioni, 2010).

The proposals for strengthening the foundations of the monument sent to IPHAN by engineers of Minas Gerais highlighted the following: lateral reinforced-concrete bands at the foundations interconnected transversely; reinforced-concrete bands associated with piles that would work by lateral friction; and the implementation of a system of piles inserted directly into the foundation.

As the diagnosis suggested, the main cause of the damage to the structure was related to the low capacity of the surface soil to support the foundation, especially in the area at the front of the monument, which led to another intervention strategy. Whereas the foundation's resistance capacity was unproblematic, the ground around it was not. Therefore, the hypothesis arose of directing the intervention to the lateral soil supporting the foundation and not the foundation itself. The substitution of the lateral soil bordering the two sides of the foundation, by another soil with adequate physical and mechanical characteristics to perform the geotechnical functions necessary to promote stability of the monument was suggested; thereby increasing the resistance to breakdown through shear forces of the foundation soil. This would also reduce to acceptable levels the slow densification process of the foundation soil, while preventing degradation by short- and long-term phenomena.

The developed project consisted of protecting the area of lateral influence of the foundation by associating resistant and low-permeability veneer of rammed earth with an underground drainage system peripheral to the outer area of the monument. The drainage system was intended to eliminate or reduce the variation of groundwater levels, and incorporated surface drainage, which would allow a rapid evacuation of the accumulated water from the grass and paved areas, including the existing street at the back of the church.

Studies for the detailing and specification of the rammed earth veneer began with geotechnical studies performed in the laboratory, using samples of natural soil collected at two points at the level of settlement of the foundations in the region of the towers, in order to verify geotechnical characteristics, including permeability. It was proposed to stabilize the rammed earth veneer with the addition of a small amount of cement to reduce its permeability. Laboratory tests showed that the mixture of natural earth with cement resulted in a material with ideal permeability and resistance characteristics to reintroduce the mass of earth laterally bordering the foundation, indicating the success of the working hypothesis. This solution was linked

Fig.2 Rammed-earth veneer to protect the foundations of the Igreja Matriz De Santo Antonio (credits: Silvia Puccioni, 2000)

to a sewage system, accomplished through drainage channels adjacent to the rammed earth veneer to avoid layered stagnation of the water retained by the curtain.

The implementation of a rammed-earth veneer to protect the foundations was divided into three parts, starting from the part of the right tower, followed by the part of the left tower, and finally the central part of the façade (Puccioni, 1988). This sequence aimed to relegate to the last stage of intervention to the central section, the most sensitive area, being the veneer of Aleijadinho. Thus, the risk of structural movements was avoided during the accomplishment of the work on the façade, as the lateral sections were already stabilized.

The first stage of the work on the front section of the church consisted of dismantling the external and internal floors, whose stones were identified and stored for subsequent re-installation. This stage included the removal of mortars, fillers and other renderings.

The second stage involved the excavation of the two sides of the foundation in alternatingtrenches of 1.00 m length and 1.00 m width, in order to install the rammed earthveneer adjacent to the foundation. The excavation was carried out to the level of settlement of the foundation, and the removed material placed next to the excavation. In a third stage, the voids, gaps and failures of the foundation blocks were in-filled, using variably graduated stones.

Afterwards, the 'shearing tooth' was prepared, consisting of the removal and subsequent reinstallation of larger stones, greater than the interface of the block and rammed earth veneer.

The next phase comprised the immediate rebuilding with rammed earth, compacted in layers up to the height of the original floor. Finally, the rebuilding of external and internal floors, removed in the first stage, was completed.

Along with the improvement of adjacent soil to foundations, an underground drainage system was also designed, encircling the entire structure, in order to direct groundwater away from the perimeter of the church. This project involved the implementation of a deep drainage channel, adjacent to the outer perimeter of the foundations and the rammed-earth veneer, providing a boundary wall for quick drainage of water from groundwater percolation, which might rise to a higher surface level in the area planned for the structure of the church. This could be detrimental to the stability of the foundations, especially in times of heavy precipitation, when the highest and most undesirable levels of groundwater occurred.

3. CATHEDRAL OF NOSSA SENHORA DA GLÓRIA

Given the success of the previously described experience, a similar solution was applied in 2003-2004, on the restoration of the Cathedral of Nossa Senhora da Glória, in the town of Valença, in the State of Rio de Janeiro (Lyra, 2006). The construction of this church began around 1820 and was completed in the second decade of the 20th century. Its construction system was composed of stone masonry bearing walls joined with lime, clay and sand mortar (3).

In this case, the issue involved stabilizing the area of the foundation of the towers that were in precarious condition. The instability of the towers, which had already fallen, was related to the precarious condition of the soil at the foundations, which included disaggregation and high humidity. Another cause was the mismatching base due to the extraction of soil in the second decade of the 20th century, when it was undermined by the construction of a square on the adjacent plot. The restoration of the support of the foundation through the reconstruction of a section was implemented on the sides and fronts of the towers in the adjacent plot, by installing a rammed-earth veneer, and thus restoring the original ground level. With this resolution it was possible to re-stabilize the church without further intervention in the square.

The recovery of the foundations of the churches was performed using the following steps: removal of the floor, digging in alternating trenches with variable widths; in-filling voids, gaps and failures along the foundation blocks; re-pointing of the foundation masonry; linking of elements between the earthen veneer and the existing foundation. Immediately afterwards, infill with cyclopean rammed earth was accomplished. Finally, the original floors removed in the first stage were rebuilt. A system of surface and underground drainage was built as well, in order to maintain a constant level of subsoil moisture.

4. CONCLUSIONS

The use of this methodology for diagnosis, preceding the work itself, was essential for the accurate identification of the causes of deterioration of the monuments. Thus, applying this methodology in the initial phase of the work, including the collection of archival

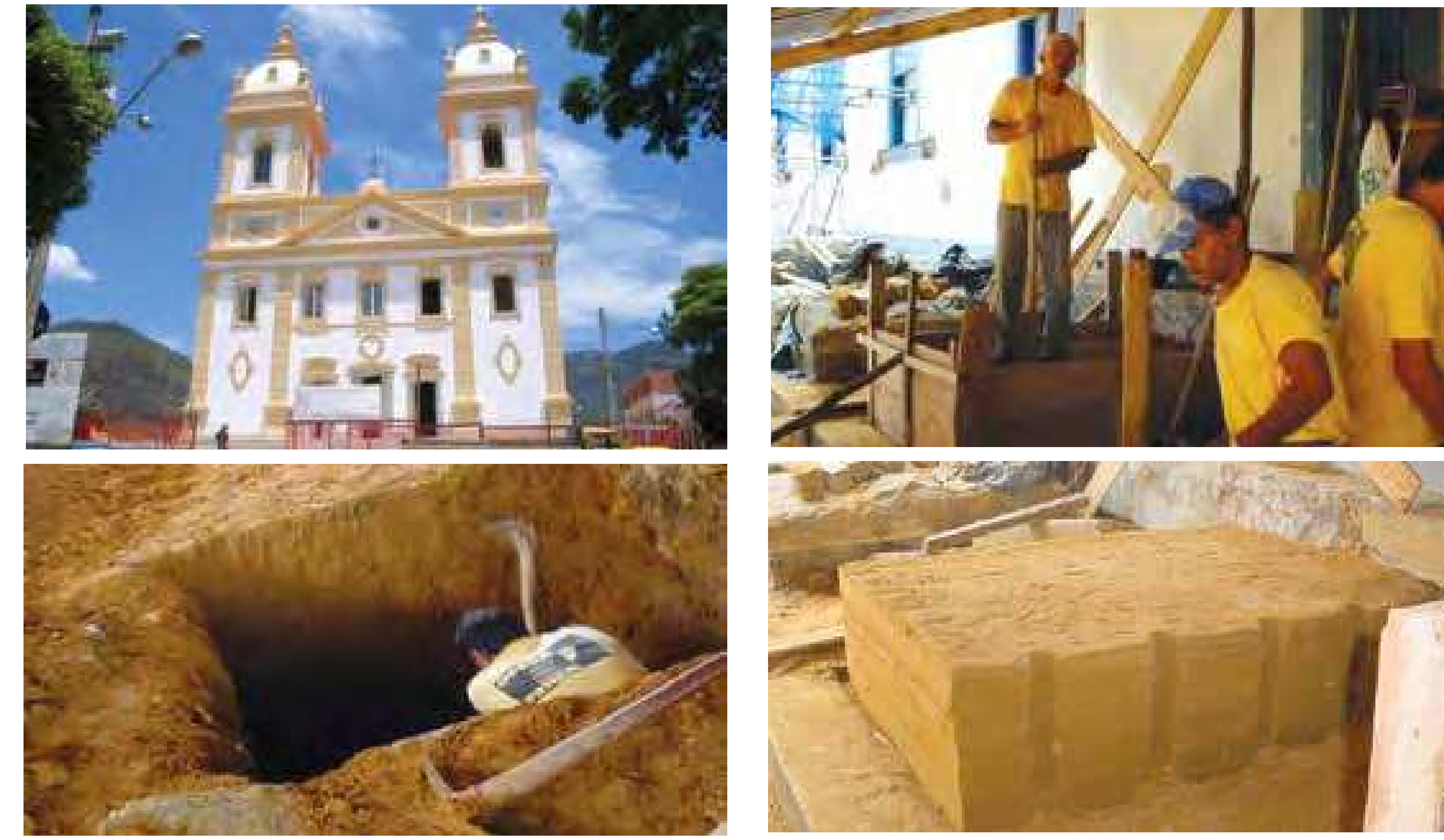

Fig.3 Cathedral of Nossa Senhora da Glória in Valença, Rio de Janeiro, Brazil. Rammed-earth veneer at the bottom of the façade is observable (credits: Silvia Puccioni, 2000)

documents and information about the building, followed by geotechnical tests enabled the realization of an accurate diagnosis. This, in turn, supported the intervention plans. Whereas the foundation was unproblematic in terms of resistance capacity, the ground around it was not. Therefore, the hypothesis for intervention was directed toward lateral soil to support the foundation, as opposed to the foundation itself. In addition, the substitution of the confining lateral soil on two sides of the foundation by another soil with physical and mechanical characteristics adequate for the geotechnical functions performance was proposed.

Eleven years after the implementation of the stabilization at the Igreja Matriz de Santo Antonio de Tiradentes, and seven years after the work on the Cathedral of Nossa Senhora da Glória in Valença, the system of stabilization of foundations with the use of a rammed-earth veneers was found to be suitable to the structural behavior characteristics of foundations in traditional Brazilian buildings, since no new movement or deformation of the masonry has occurred. This recovery system preserves the integrity and authenticity of the original foundation structures of the buildings, and has the characteristics of reversibility, since it can be removed without damaging the building materials that have a relevant historical value.

Notes

(1) The thesis was developed within the Master's of Architecture course developed by the author in 1994-1997 at the Federal University of Rio de Janeiro, Brazil.
(2) The Iglesia Matriz de Santo Antonio was registered in the *Livro do Tombo das Belas Artes of IPHAN*, the Institute for Historical and Artistic Heritage. It was registered as an heritage asset of cultural relevance on November 29, 1949, as N°329.
(3) It is a historical and artistic monument protected by the laws of the State of Rio de Janeiro, through the registration of the historic center of the town of Valença in the Livro de Tombo of INEPAC, the State Institute of Cultural Heritage. It was registered as a heritage asset of cultural relevance in the year 2004.

References

Lyra, C. (ed.) (2006). Renovação de Uma Catedral. Rio de Janeiro, Brazil: Ed. Design Casa 8.

Puccioni, S. (1988). *Patologia das Estruturas.* Salvador, Brazil: CECRE.

Puccioni, S. (2010). Um novo paradigma para a estabilização de fundações de monumentos antigos. In Olinto R. Santos Filho. *A matriz de Santo Antonio em Tiradentes.* Brasilia DF, Brazil: Iphan/Monumenta.