Referência

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Numerical Safety and Performance Analysis of a Multipurpose Building's Structure – Case Study

Análise Numérica de Segurança e Desempenho da Estrutura de Edifício Multiuso – Estudo de Caso

Leonardo da Silveira Pirillo Inojosa
ORCID: https://orcid.org/0000-0003-0745-6900
Universidade de Brasília – Dep. de Engenharia Civil e Ambiental, Brasíl
E-mail: leinojosa@unb.br

Márcio Augusto Roma Buzar
ORCID: https://orcid.org/0000-0002-1164-2784
Universidade de Brasília – Faculdade de Arquitetura e Urbanismo, Brasíl
E-mail: buzar@unb.br

José Humberto Matias De Paula
ORCID: https://orcid.org/0009-0009-4697-9254
Universidade de Brasília – Dep. de Engenharia Civil e Ambiental, Brasíl
E-mail: jhdepaula@unb.br

Lenildo Santos da Silva
ORCID: https://orcid.org/0000-0001-5099-6123
Universidade de Brasília – Dep. de Engenharia Civil e Ambiental, Brasíl
E-mail: lenildo@unb.br

ABSTRACT

This report presents a case study of a multi-use building situated in Brasília-DF. The building's structural model is made up of elements of a spatial portico and four-knot plate, measuring 25.75 by 25.75 m with a height of 11.65 m. The structure is supported by rotating pillars at the base. The ground floor has a ceiling height of 3.25 m, while the other floors have a ceiling height of 2.80 m. The closure is made of bored brick masonry. In this article, numerical analyses were conducted using the SAP2000 structural software to verify the structure's displacement, deformation, and stress. The study followed the ultimate and in-use limit state criteria for the Brazilian standard of reinforced concrete (NBR 6118). The report also presents the building's structural pathologies, detected through visual inspection. The main structural elements and their respective pathologies are described, and numerical tests are shown. Due to the presence of various cracks and other pathologies in the building, an elastic instability analysis was conducted using the Rankine-Marchant analysis model to verify the collapse load factor. After approximately 17 years of use, the building is revisited to assess the durability and performance of the recovered structural components and procedures.

Keywords: Pathology of buildings; Elastic Instability; Structural Analysis of Building;

RESUMO

É apresentado um estudo de caso de um edifício multiuso situado em Brasília-DF. O modelo estrutural do edifício é composto por elementos de um pórtico espacial e placa de quatro nós, medindo 25,75 por 25,75 m com uma altura de 11,65 m. A estrutura é apoiada em pilares rotulados. O piso térreo tem o pé direito de 3,25 m e os outros andares de 2,80 m. O fechamento é feito de alvenaria de tijolo furado. Neste artigo, análises numéricas foram realizadas utilizando o software SAP2000 para verificar o deslocamento, deformação e tensão da estrutura. O estudo seguiu os critérios de estado limite último e de uso para a norma brasileira de concreto armado (NBR 6118). São apresentadas as patologias estruturais do prédio, detectadas por meio de inspeção visual. Os principais elementos estruturais e suas respectivas patologias são descritos, e ensaios numéricos são mostrados. Devido à presença de várias fissuras e outras patologias na edificação, uma análise de instabilidade elástica foi realizada usando o modelo de análise de Rankine-Marchant para verificar o fator de carga de colapso. Após cerca de 17 anos de uso, o edifício é revisitado para avaliar a durabilidade e o desempenho dos componentes e procedimentos estruturais propostos.

Palavras-chave: Patologia das construções; Instabilidade Elástica; Análise estrutural de Edifício;

INTRODUÇÃO

Extensive research has been conducted by the Graduate and Postgraduate Program in Architecture and Urbanism at FAU, University of Brasilia, and the Laboratory of Rehabilitation of the Built Environment - LABRAC on the behavior of structural systems during project development, construction, and building performance. Similar works on this theme can be found in the reference section (INOJOSA, 2010; JÚNIOR, 2014; INOJOSA, 2019; INOJOSA *et al.*, 2022a; INOJOSA *et al.*, 2022a). This case study specifically focuses on a multi-purpose building located in Brasília, DF's North Supply and Storage Sector - SAAN, Block A, Quadra 3. The building is three stories high and measures 25.75 meters in length and width. Its total height is 11.65 meters, as shown in Figure 1. The foundation is supported by rotating and/or fixed columns, and the ground floor has a ceiling height of 3.25 meters. The other floors have a height of 2.80 meters. Bored brick masonry is used for the building closures.

Figure 1 – Main façade of the studied building, during the first inspection in 2005.

Font: Author's Photo in November 2005

In November 2005, the reinforced concrete used in the building was inspected using the Brazilian Standard NBR-6118/2003 (ABNT, 2003) to confirm its strength. To ensure overall stability, the Eurocode/2003 (EUROCODE, 2003) and the Brazilian Standard NBR-6118/2003, which utilize the Rankine-Marchant criterion to analyze elastic instability, were employed.

Despite encountering issues such as cracks and fissures on walls and slabs (Figure 2), the examination did not reveal any instability problems. The analysis of elastic instability indicated that the building has a stable structure, although deflections were observed above the standard limit, which contributed to the appearance of cracks in the masonry.

As per the survey, it was observed that the building and its surrounding areas were not sufficiently equipped to contain rainwater. As a result, the stormwater gallery had to be cleaned and waterproofed, which was identified as one of the primary reasons for the pathologies detected.

Therefore, it has been recommended that the building undergo preventive maintenance measures in order to guarantee its safety. This involved repairing the masonry and slabs, as well as addressing and treating all cracks. It is important to stress that preventative maintenance and restoration are essential not just for the safety of those utilizing the building, but also for the building's long-term resilience.

Figure 2 – Cracks and fissures observed in visual inspection in November 2005.

Font: Author's Photos in November 2005

GENERAL CONSIDERATIONS

Structural Model

The numerical analysis was developed using the structural software SAP2000 and considered the following characteristics for the Structural Model: finite elements of spatial gantry bars for the columns and beams and associated with 4-node plates for the slabs. For the support devices, models of connection of the columns in the foundations were considered as rotating or fixed columns on the base.

Physical characteristics of the building

- Length: 25,75m
- Width: 25,75m
- Height: 11,65m
- Support at foundations: rotating or fixed columns on the base
- Ground floor ceiling height: 3,25 m
- Other pav ceiling height: 2,80 m
- Mansory: In brick masonry

Technical Characteristics adopted.

Standards.

As part of our 2005 analysis, we adhered to the established guidelines of NBR-6118/1978 (ABNT, 1978) and NBR-6118/2003 (ABNT, 2003) to properly assess and determine the size of reinforced concrete components. Furthermore, we relied on the stability recommendations provided by EUROCODE/2003 (EUROCODE, 2003) and NBR-6118/2003 (ABNT, 2003) to conduct a thorough evaluation of potential global instability.

As for the estimation of actions and loads, the prescriptions established by NBR-6120/1984 – Loads for Calculation of Building Structures (ABNT, 1984) were obeyed.

Materials.

- Existing Concrete: fck =18 MPa e Ec = 21.000 MPa.
- Steel for Concrete: CA-50 e CA-60

TOPOLOGY

The concrete structure of the building is made up of spatial gantry elements and four-node plates, as seen in Figure 3. Floor plans for the ground floor, overstore, first and second floors, and roof can be seen in Figure 4. The analytical model in the SAP 2000 program is shown from a perspective in Figure 5.

Figure 3 – Topology – Perspective of the structural model – SAP-2000 Program.
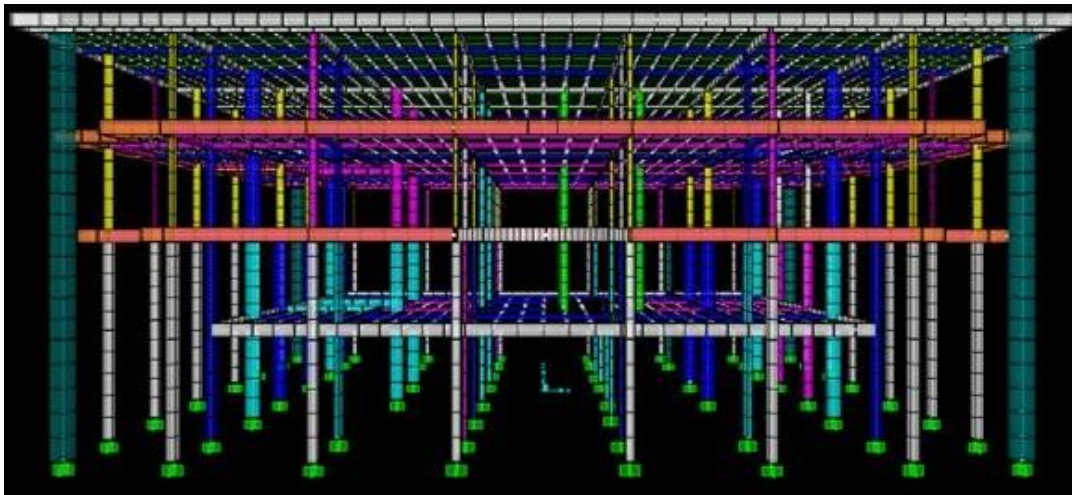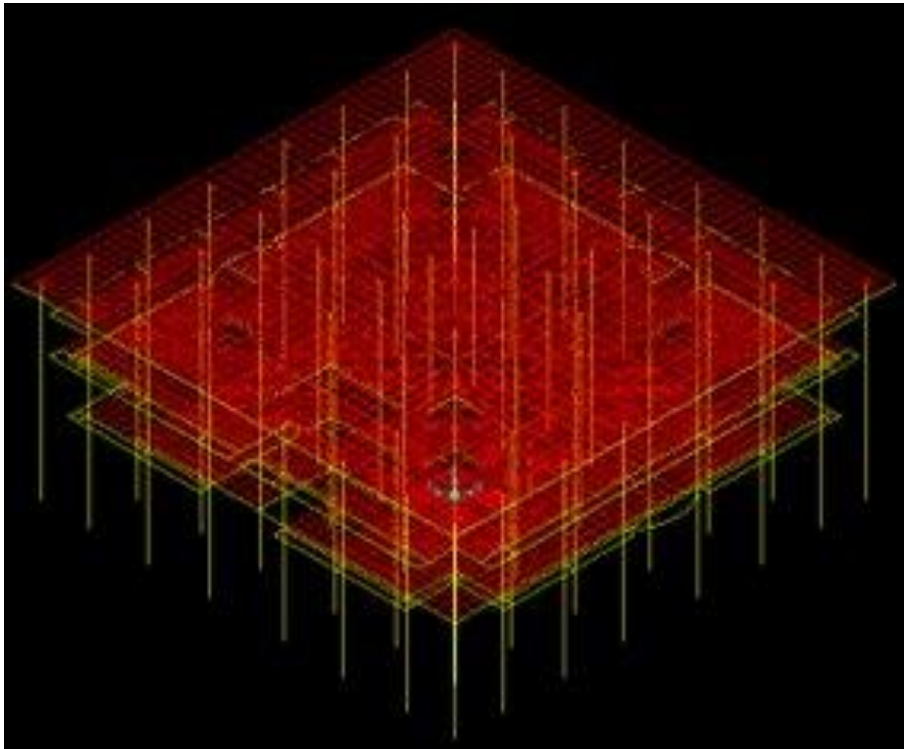

Font: Author's Design

Figure 4 – Topology – Floor plans of the building. (a) Overlap, (b) First Floor, (c) Second Floor, (d) Coverage – SAP-2000 Program.
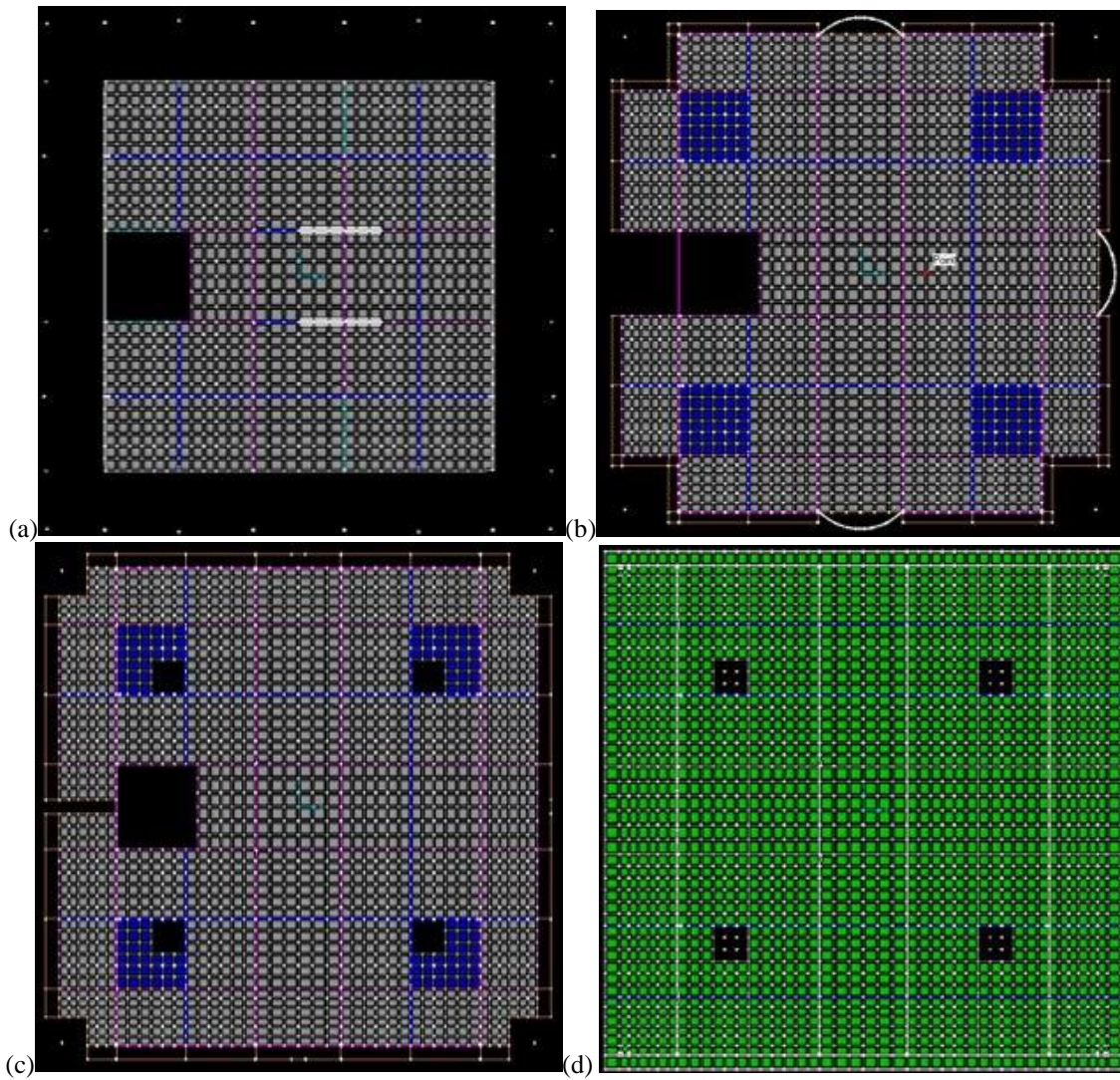
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Figure 5 – Topology – Perspective of the analytical model – SAP-2000 Program.

Font: Author's Design

ACTIONS

Permanent Actions (D)

- Own Weight: slab 175 - 200 Kgf/m2
- Coating: 100 Kgf/m2
- Masonry: 546 Kgf/m

Action Arising from Use (L)

The overload resulting from the use of multipurpose buildings (L) is of a different nature from the overload on the roof (Lr) required for maintenance. Therefore, the probability of occurrence of each of them is also different. However, in concrete structures, as the proper weight is significant compared to the overload, both loads were considered by the calculators of the same nature.

- Ground floor: L=200 kgf/m²
- Shop and Floors: L=200 kgf/m²
- Coverage: Lr=L=200 kgf/m²

Loads Combinations

- Ultimate Limit State:
  - 1.4 *Permanent Loads

      ○   1.4 * Perm + 1.4 * Overload

      ○   1.2 * Perm + 1.6 * Overload

- Service Limit State:
  - Permanent Load
  - Perm + 0.7 Overload

STRUCTURAL ANALYSIS OF SAFETY AND PERFORMANCE

Analysis of Elastic Instability

In the field of structural design engineering, elastic instability analysis is not a common practice. However, due to the technical characteristics of a particular structure, the engineers who evaluated it back in 2005 decided to perform this type of analysis. They utilized a reliable mathematical model implemented in the SAP2000/v10 - Structural Analysis Program - Non-Linear software to conduct the analysis. The analysis aimed to determine the collapse load factor of the three-dimensional structure using the Rankine-Marchant analysis model.

The results of the elastic instability analysis obtained show that the structure can be considered safe in terms of overall stability, since the slenderness coefficient (λcr) is 12.64, An analysis of elastic instability of the three-dimensional structure was performed to verify the collapse load factor, using the Rankine-Marchant analysis model (Table 1).

Table 1 – Stability analysis model - Rankine-Marchant

Rankine-Marchant	
LCR < 6.4	Very slender structure
$6.4 < \lambda cr < 14.0$	Moderately slender structure
LCR > 14.0	Rigid structure

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The results of the elastic instability analysis indicated that the structure is safe in terms of overall stability. The slenderness coefficient (λcr) was found to be 12.64, as shown in Table 2. This value places the structure in the moderately slender category, as it falls within the range of 6.4 to 14.0, which is considered the most unfavorable combination.

Table 2. Elastic Stability Analysis (Rankine-Marchant). Analyzed Structure

| Combination	λcr = Mode 1 (Direction x)
1 – D	$\lambda cr = 17.82 > 14.0$
2 – D + L	$\lambda cr = 12.64 < 14.0$

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It's important to note that the values presented in Table 2 may not fully account for the stability of the building, as it does not account for the contribution provided by masonry.

Resistance Analysis

Extensive analysis was conducted to verify the utmost safety and stability of the structure. This involved examination of the slabs, beams, and columns to assess their capacity to withstand external forces, as well as to confirm their maximum horizontal and vertical displacements. A visual representation of the Nominal Axial efforts in the structure's columns is shown in Fig. 6 which displays a schematic cut.
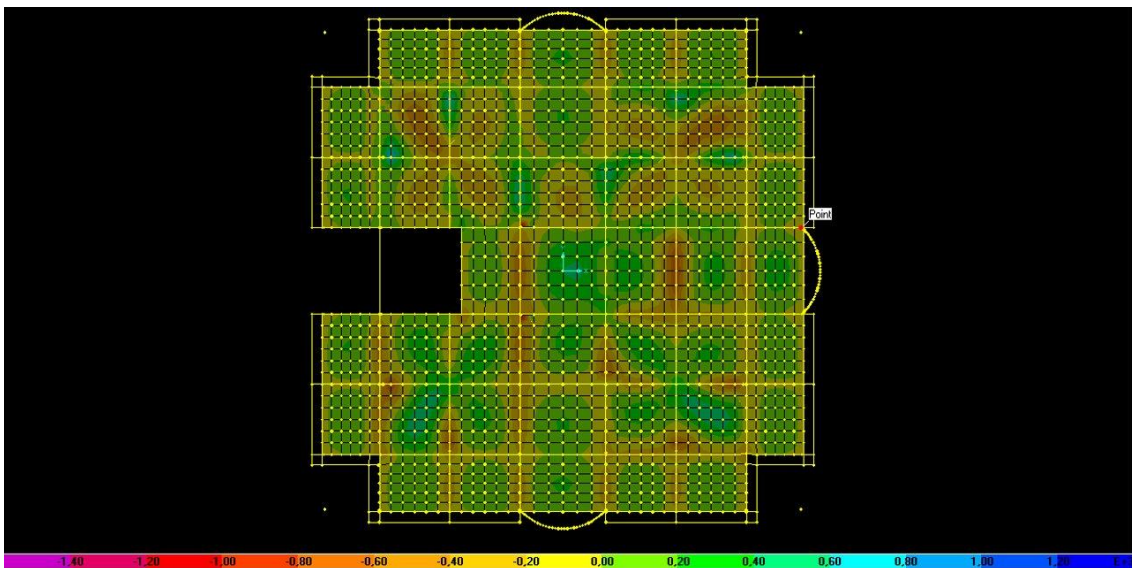
Figure 6 – Nominal Axial Efforts in the Internal Columns.
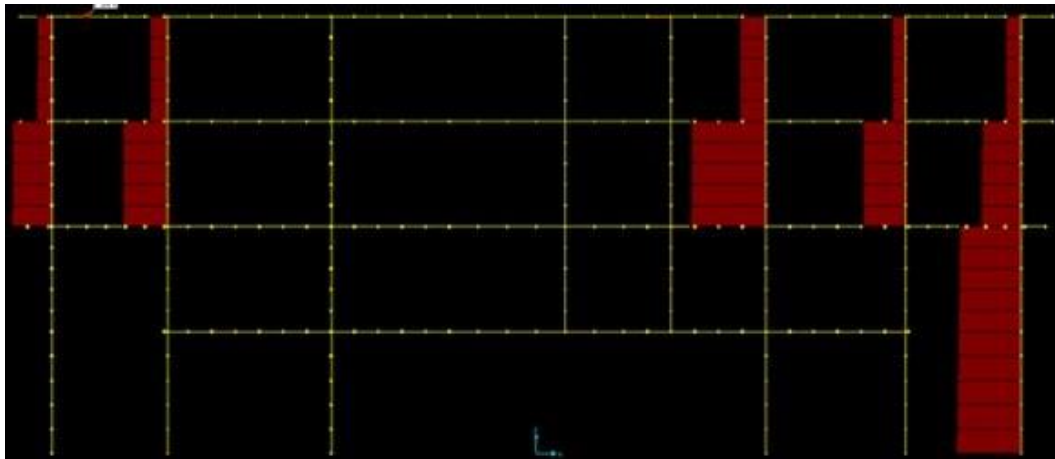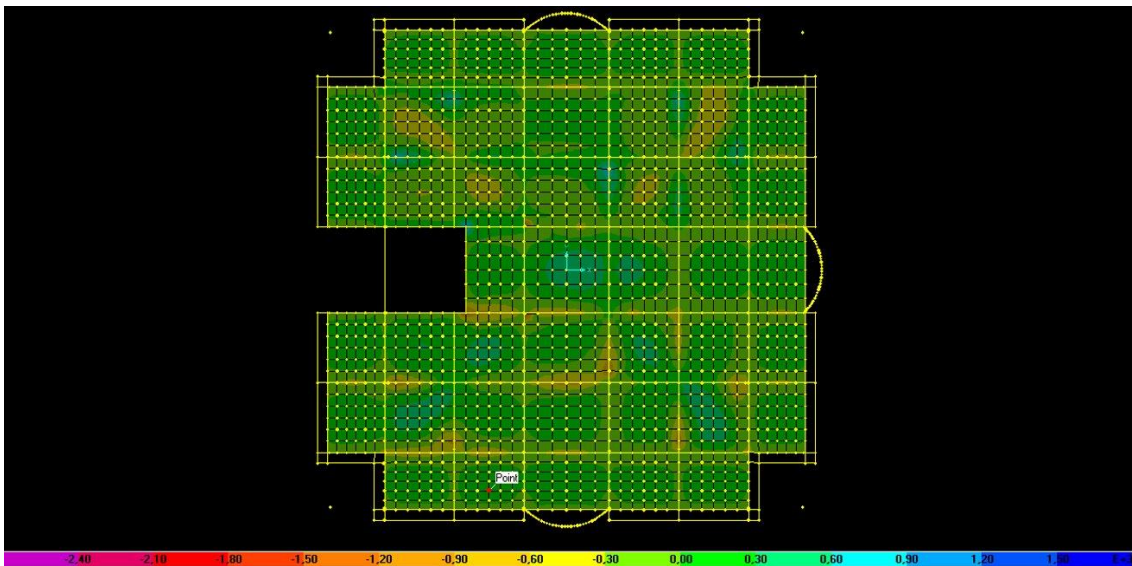

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The graphs below, Fig. 7 and Fig. 8, show moments M11 in the X direction and M22 in the Y direction of the overlay floor. These were obtained from the analysis made in 2005 using the SAP 2000 program.

Figure 7 – Bending Moment M11 – X (Overstore)

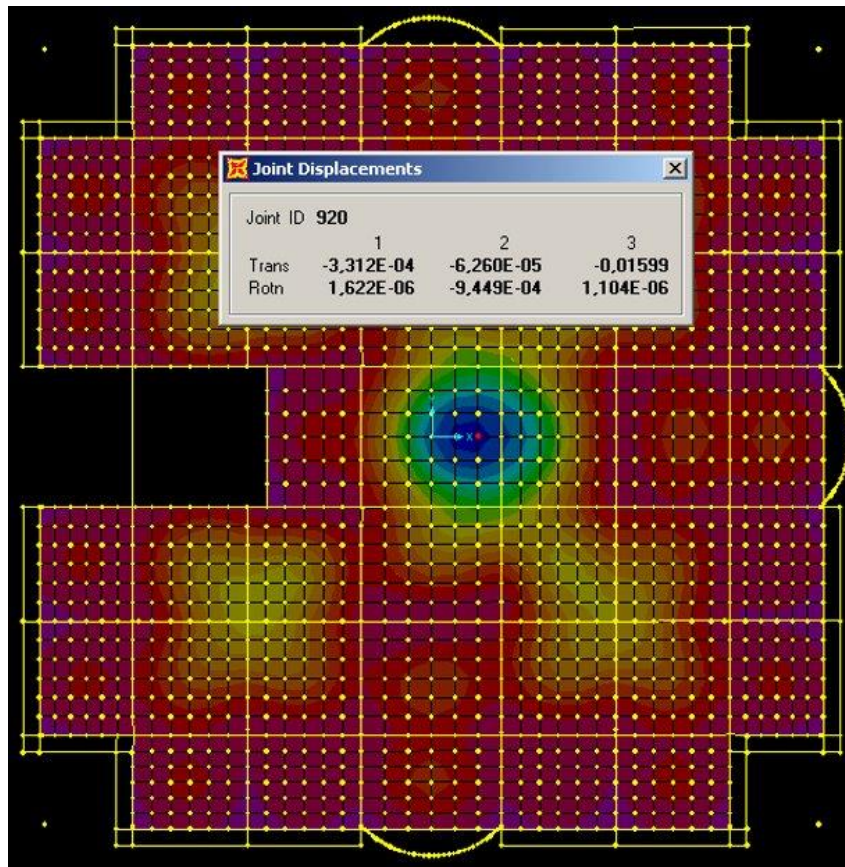Font: Author's Design in SAP 2000 Software

Figure 8 – Bending Moment M22 – Y (Overstore). SAP-2000 Program. Author's Drawing
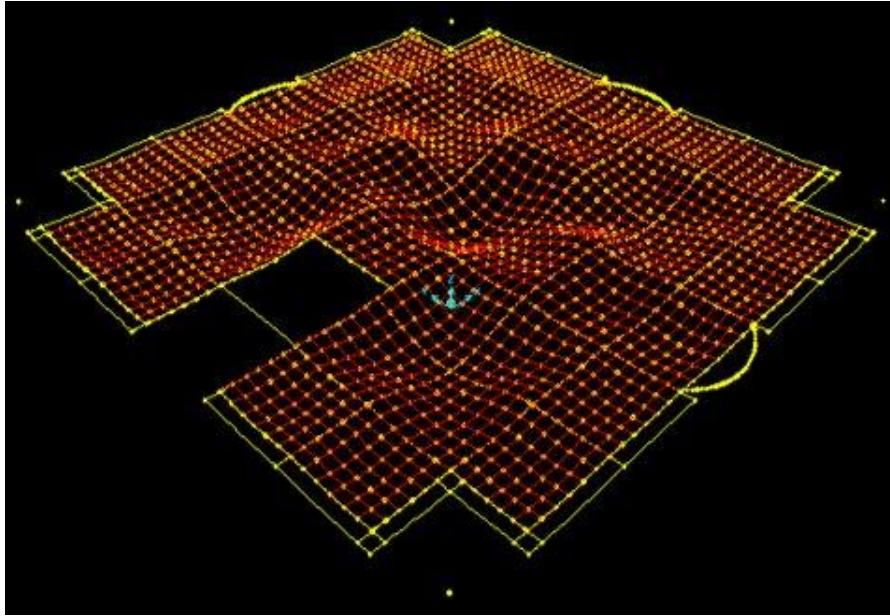

Font: Author's Design in SAP 2000 Software

Figures 9 and 10 show the maximum vertical displacements of the bar elements at the overstore level. As shown, the displacement of certain beams has exceeded standard limits, which led to the development of cracks and fissures in the masonry.

Figure 9 – Plan of maximum vertical displacements (Z) for Overstore slab.

Font: Author's Design in SAP 2000 Software

Figure 10 – Perspective graph of the maximum displacements in the vertical direction – Z (Overstore).

Font: Author's Design in SAP 2000 Software

CURRENT STATE OF THE BUILDING

In April of 2023, the building underwent another inspection, a full 17 years after its previous inspections and interventions. The results were favorable. During this visit, it was discovered that despite changes in usage and occupancy, the building had undergone preventive maintenance as recommended. Structural elements and treatments were kept intact, and measures were taken to prevent the formation of new pathologies. Figure 11 shows the condition of the building's structural elements.

Figure 11 – Main façade of the studied building. Author's Photo in April 2023

Font: Author's Photo in April 2023

The treatments performed in the building adhere to the principle of designing them based on the identified causes of problems found in the surveys. In this case, the improper containment of stormwater in the building and its surroundings was the cause. This principle allows the interventions to be successful in suppressing or minimizing as much as possible the elements that cause the pathologies (THOMAZ 2006). As preventive measures for new occurrences are adopted, we can see in Figure 12 the efficiency of repairs, 17 years later.

Figure 12 – Actual conditions of the treatments for cracks and fissures, observed in visual inspection in April 2023.

Font: Author's Photo in April 2023

CONCLUSIONS

Upon evaluation of the multipurpose building's safety, it was determined to be sturdy. However, some deflections had caused cracks in the masonry. To address these concerns, it was suggested that the masonry be restored, and preventive maintenance be performed. Additionally, it was essential to clean and waterproof the stormwater gallery to prevent further foundation damage caused by stormwater leakage. The slabs required repair, and the strength of individual components (slab, beam, and pillar) needed to be verified.

After revisiting the building, 17 years later, it was found that the recommended measures had been effective. The building is in excellent condition, and the interventions not only resolved the visible issues but also contributed to the durability of the building's adequate status.

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