Structural Degradation Assessment of RC Buildings: Application via Software of the method of assessment by integrity and safety - MAIS Method - in a Heritage Case Study in Brasilia

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Abstract. The assessment of an existing structure is a complex task that necessitates a thorough understanding of the materials involved, the applied loads, environmental aggressiveness, and various other factors to accurately evaluate its functionality and predict structural safety levels. This process is challenging due to the numerous uncertainties inherent in it, as buildings do not always reveal the condition of their internal components and materials. In response to these challenges, the Method of Assessment by Integrity and Safety - MAIS Method - has been developed over the past five years. One of the modes that the MAIS Method can be employed involves the utilization of a structural software. Through on-site surveys, data is collected, enabling the quantification of the integrity of each constituent element within the system. Subsequently, structural modeling is carried out using dedicated software for both the intact structure and the degraded structure, incorporating the integrity index directly into the elasticity index of each structural element. The software is then executed, and a comparative analysis is conducted between the two structural representations. The study focused on a building located in the Asa Sul region of Brasília, Brazil, recognized as a UNESCO World Heritage Site. The present research concludes that the MAIS Method is efficacious, facilitating visual identification of the structural condition. Furthermore, it establishes the feasibility of conducting both global and local analyses of the structure.

Key-words: MAIS Method · RC Buildings · Structural Assessment · Reliability · Risk Management

1. Introduction

The preservation of buildings and cultural heritage plays a fundamental role in society because it not only provides practical environments for work and habitation but also plays a psychological and emotional role in shaping the history and identity of a community as presented Choay [1]. However, although unrestricted protection for historical monuments is assumed, this is not the case in reality, whether as a result of human negligence or unforeseeable events. Due to the increasing demand for this, we currently find ourselves in a situation where researchers and construction professionals are redirecting their focus, giving more attention to the conservation of existing buildings. The conservation of a building, however, is not a simple task, as uncertainties are faced, many of them qualitative and difficult to quantify, which can affect the structural stability of buildings. These uncertainties can range from material deterioration to performance parameters, environmental impacts, human factors, labor experience, temporal influences, among others. In such a complex context, it is virtually impossible to predict all the variables that can affect the integrity of a historic monument. In view of this scenario, in 2021, the Method of Assessment by Integrity and Safety - MAIS Method - an approach developed by Oliveira [2], was introduced as a methodology to quantify the integrity level of an existing RC structure, as it will be explained in the next session.

2. Method of Assessment by Integrity and Safety – MAIS Method

The MAIS Method quantifies building integrity effectively. It accommodates data uncertainties, integrating degradation identification and structural resistance assessment. Overall, the MAIS Method represents a tool for assessing and quantifying the safety and integrity of buildings in a systematic, and scientifically sound manner, as outlined in Oliveira [3]. In essence, the MAIS Method follows a standard methodology, where an on-site inspection is conducted to gather data.

The data collected include, for each pathology identified in each element, is: the Damage Factor (F_d), representing the significance of the damage to the element's functionality. The value of this factor is predefined; The Intensity Factor (F_i) signifies the severity and progression of the damage, linked to the timing of the inspection and dependent on the environmental conditions. Lastly, the Extension Factor (F_e) gauges the extent of damage within the element. The calibration of these factors was made after many attempts and tests. Conclusions are that the most appropriate values are based on Heidecke's models [4] and correspond to the Equation 1. Assuming that integrity is the complement of damage, for the calibration, a 3D graph was created in *MatLab* software [5], illustrating the interplay between F_d and F_i in relation to Integrity, and the obtained result is depicted in Figure 1.

$$D_i = (1.9738\ F_i^2 - 1.1187\ F_i + 0.1513)\ \ F_d\ \ F_e \tag{1}$$

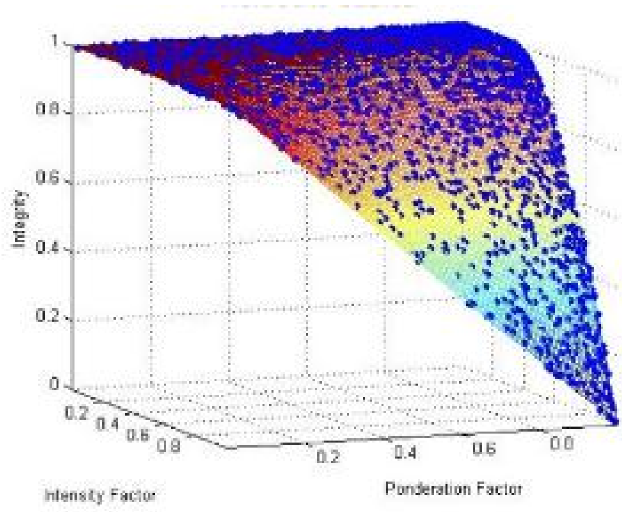

Figure 1. Integrity surface correlated to F_d and F_i.

Once the integrity of all and each element is found, a software must be used to generate the structure. When generating it, the elasticity (E) and inertia (I) values are adjusted to reflect the deterioration by applying the Element Integrity Index found to each element, improving result accuracy.

3. Modeling

The case study pertains to the structural assessment of a shop located in the CLS 105 block in the neighborhood of South Wing (Asa Sul), in Brasilia, the capital of Brazil, belonging to a UNESCO-protected region. The building is situated in an urban area with high pedestrian and vehicular traffic, in a sparsely wooded location with a gentle slope relative to the terrain. The heritage is a commercial RC structure consisting of two shops juxtaposed and separated by an expansion joint. It comprises the ground floor, the first floor, and the rooftop. Figure 2 displays an overview photo of the heritage.

Figure 2. Aerial and frontal view of the case study CLS 105, South Wing, Brasília.

After conducting the on-site inspection and gathering F_i and F_e values along with the integrity for each element, the next step is the modeling phase. The *Robot* software [6] was used for the linear analysis of the building. For this particular case study, Building 1 was modeled since some elements of Building ii could not be inspected. The software relied on Eurocode 2 (EN 1992) as evaluation parameters. The self-weight used was generated by the program itself for concrete with a strength of 25 MPa, and the considered live load was 1.0 kN/m² for the roof and 2.5 kN/m² for the rest, as recommended for commercial buildings. This allows for an analysis of how the MAIS Method influences the structure globally through the direct coupling of element integrity to its modulus of elasticity (E). Fifteen different combinations were tested by the software, following the SEI 7-16(ASCE) standard, as presented Oliveira [2].

3.1 Global Analysis

The values of normal force and acting moment in the intact and degraded structure are presented in Table 1, and visually on Figure 3. Upon possessing these informational tools in hand, analyzing the absolute and percentage values, the following conclusions can be drawn:

- All evaluated forces and directions have been impacted, with F_x and M_x being the least affected, with variations of less than 10%. This is due to the redistribution of loads that occurs when the structure's elements degrade;
- Notably, the moment forces have incurred the most significant impacts, exhibiting variations approaching 80% for M_y and 60% for M_z;
- The x-direction was the least affected since, despite F_x increasing by 44.7%, in absolute values, this represents less than 1 kN;
- Regarding the location of the global extremes of the structure, for the maximum values, only F_y had a change in the bar and node location. However, for the minimum values, three (F_x, F_y e M_z) out of the six analyzed forces had their positions altered. This fact confirms that there was a redistribution of forces because it is a hyperstatic structure;
- Most of the global extremes belong to the 5th force combination.

Table 1. Normal forces and acting moments - global extremes.

Structure	Data	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Intact	**MAX (kN)**	155,1	3,6	43,51	15,07	13,86	9,7
	Member	3	2	27	31	6	4
	Node	5	3	16	11	6	8
	Case	5 (C)	5 (C)	5 (C)	5 (C)	5 (C)	5 (C)
	MIN (kN)	-2,08	-3,87	-37,82	-14,87	-33,8	-9,66
	Member	25	4	31	31	27	7
	Node	13	7	14	14	16	8
	Case	5 (C)	5 (C)	5 (C)	5 (C)	5 (C)	8 (C)
Degraded	**MAX (kN)**	153,13	4,77	40,3	16,08	24,7	15,68
	Member	3	13	27	31	6	4
	Node	5	19	16	11	6	8
	Case	5 (C)	8 (C)	5 (C)	5 (C)	5 (C)	5 (C)
	MIN (kN)	-3,01	-5,66	-38,39	-15,6	-34,23	-14,72
	Member	36	9	31	31	27	9
	Node	6	13	14	14	16	13
	Case	5 (C)	8 (C)	5 (C)	7 (C)	5 (C)	8 (C)

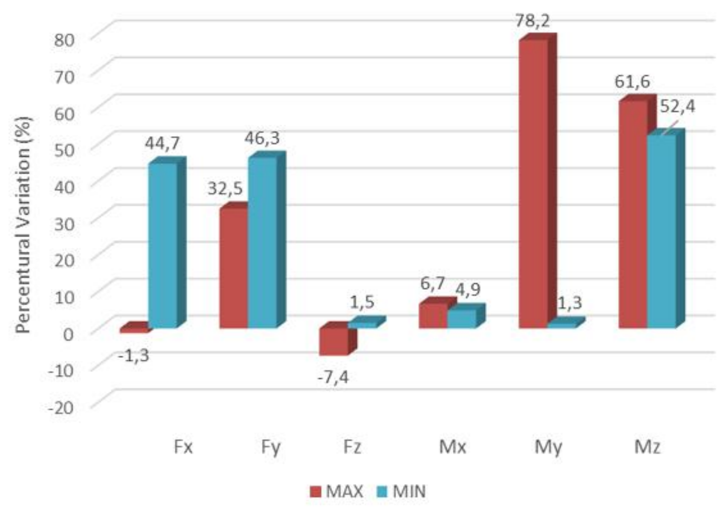

Figure 1. Normal forces and acting moments variation - global extremes.

In order to visually demonstrate these changes in the distribution of forces from the intact structure to the degraded one, force maps were created for the 5th combination case, which most of the global maximum forces occurred. Figure 4 and Figure 5 depict the maps of normal forces in the x and y directions. The first scale on the legend refers to forces in the members (beams and columns), and the second scale refers to forces in the slabs.

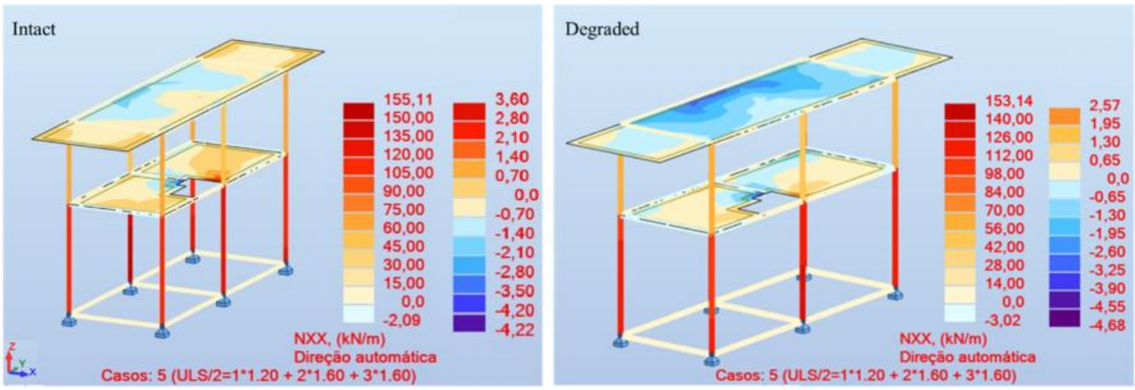

Figure 2. Normal force map for the x-axis.

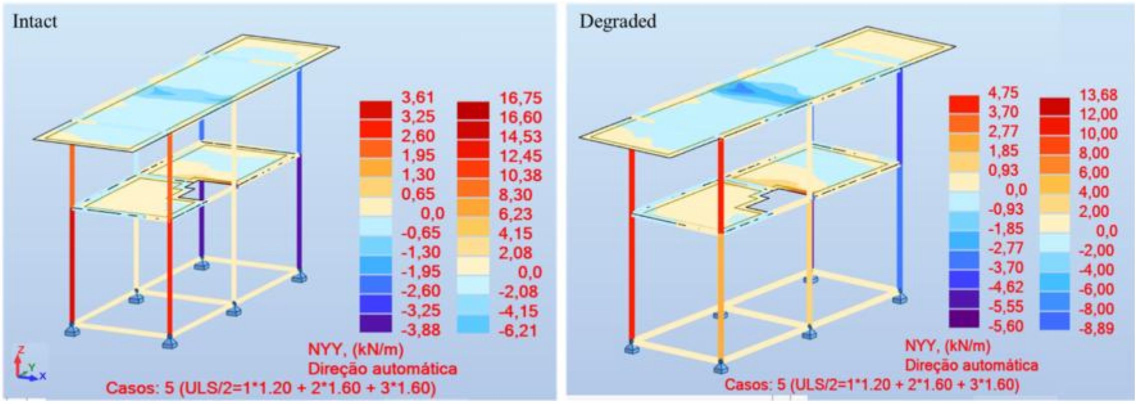

Figure 5. Normal force map for the y-axis.

Regarding the map of forces in the x-direction, it can be observed that the slabs underwent the most significant redistribution of forces, both the upper slab and the one on the first floor. The forces in the columns remained within the same range. In the case of normal forces in the y-direction, the central upper beam experienced an increase in its force with the degradation of the structure, as did the columns on the first floor. Figure 6 and Figure 7 depict the force maps of the intact and degraded structures for the moment forces in the x and y directions.

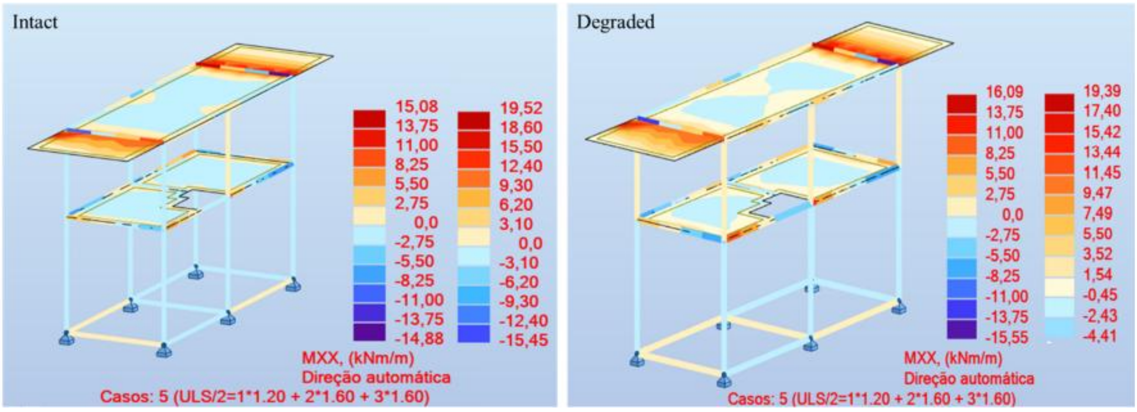

Figure 6. Acting moment forces for the x-axis map.

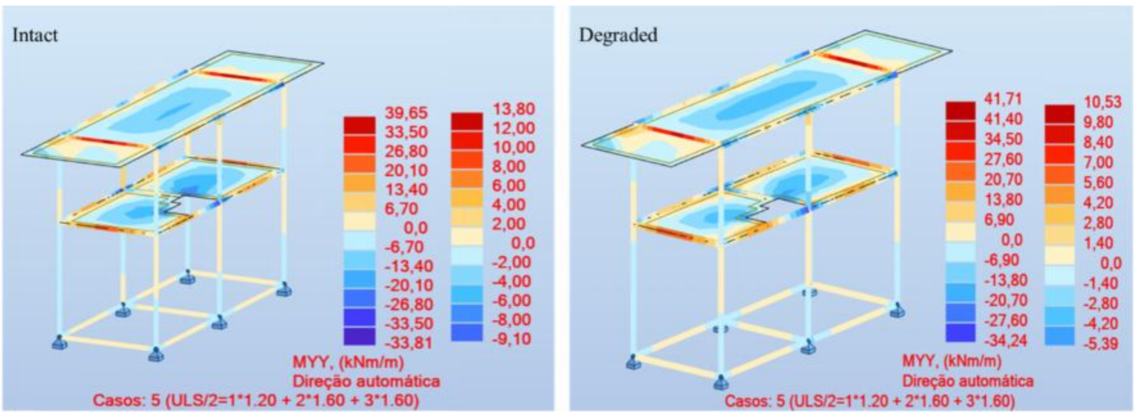

Figure 7. Acting moment forces for the y-axis map.

It is noticeable that in M_x , despite the variations in the maximum and minimum global extremes being less than 7%, the modeling design reveals an impact on the distribution of forces, particularly within the slabs. It is also evident that the beams connecting the cantilevered slabs to the structure are the most heavily stressed components in this analysis. In the case of M_y the upper slab appears to be visually the most affected, where the negative moment increased in area distribution. Finally, another highly interesting analysis to perform is the displacement in all three directions, as it is shown on Table 2.

Table 2. Displacements – Global extremes

Structure	Intact			Degraded		
Data	UX (cm)	UY (cm)	UZ (cm)	UX (cm)	UY (cm)	UZ (cm)
MAX	0,2	0	0	0,6	0	0
Node	173	20	3	138	3	3
Case	5 (C)	5 (C)	4 (C)	5 (C)	4 (C)	4 (C)
MIN	0	0	-2,8	0	-0,1	-4,4
Node	3	8	127	3	14	127
Case	4 (C)	4 (C)	5 (C)	4 (C)	5 (C)	5 (C)

The displacements in the x and y directions were small, at most 0.6 cm. However, U_z deserves more attention. While in the intact structure, the displacement is nearly 3 cm, this value increases by 57%, reaching 4.4 cm when degraded, as shown in Figure 8. Therefore, the displacements in the z-axis are an excellent way to assess the structural damage, and it was deemed interesting to generate its map.

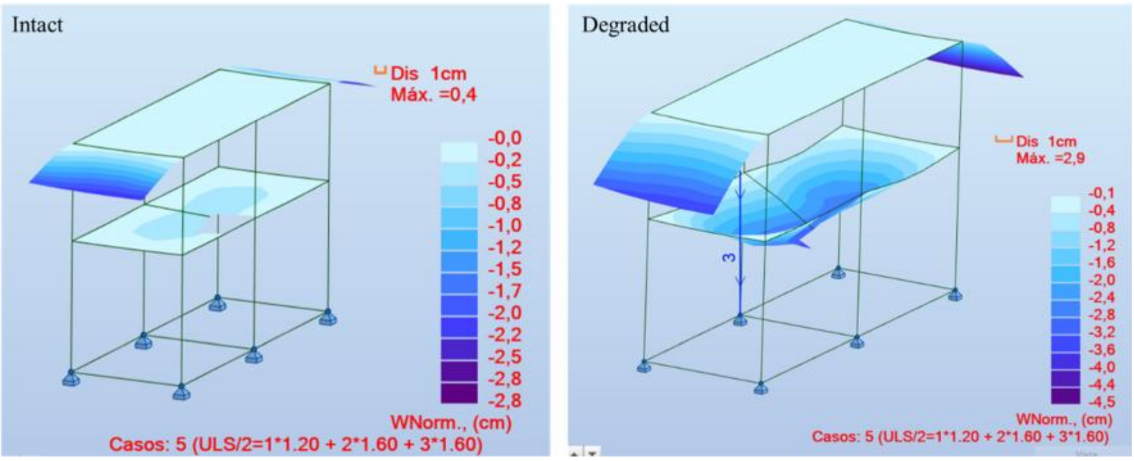

Figure 3: Displacements on the z axis.

On the 2nd floor, it is evident that the cantilevered ends of the slabs are the critical locations, where there is the most significant deformation, increasing from a maximum displacement of 0.4 cm for the intact structure to 2.9 cm in the deteriorated condition, which represents an increase of 7.25 times. However, the deformation of the slab on the first floor is even more critical, as these elements were genuinely deteriorated, and the deformation is visibly significant, increasing from 0.5 cm to over 4 cm. Thus, deformation and displacement in the z-direction are excellent parameters for assessing the degree of integrity of a structure. In addition to the global analysis, the individual local analysis of each component is also possible, which will be presented in the next section.

3.2 Local Analysis

Individual analysis of each structural element is also possible using structural calculation software and the MAIS Method. For this purpose, Pillar 101, located on the first floor at the top left corner, was selected to illustrate this assessment, and its intern stress diagram was generated, as presented in Figure 9.

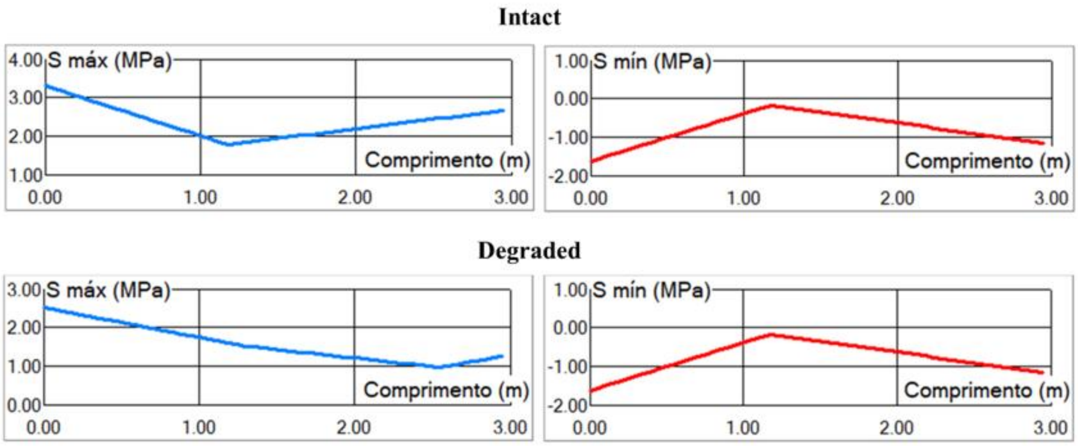

Figure 9. Intern stress diagram for column 101.

It is of significant interest to observe the variances in stress behavior as the structure deteriorates. This is likely due to the new distribution of efforts. While the maximum extreme ($S_{máx}$) decreases in the deteriorated structure, at the minimum extreme, its behavior changes, also modifying the location of its points. It is also clear that, with the intact structure, the stresses present a more linear and organized behavior than in the deteriorated structure, demonstrating that the deteriorated structure has a more unpredictable behavior.

4. Conclusions

After this comprehensive study and analysis, it can be concluded that the MAIS Method is a significant academic contribution with the potential for practical application, as it aids in visualizing the behavior of degraded structures. It is highlighted that the analysis of the displacement in the z-direction yields great information and the most accurate data, and other valuable pieces of information are also part of the range of results offered by the method, such as the internal and external efforts of the structure. Furthermore, the successful examination of internal forces in both intact and degraded elements demonstrates that the method can be applied effectively for both global and local analyses.

5. References

[1] F. Choay. "A alegoria do patrimônio". Edições 70 LDA. Lisboa (PT). 1999.

[2] A. L. de Oliveira. "Método acoplado integridade e segurança – Método MAIS - para a avaliação de patrimônios históricos em estruturas de concreto armado". PhD. Thesis. Faculty of Architecture and Urbanism, University of Brasília. Brasília, 2021.

[3] A. L. de Oliveira, J. Pantoja and H. Varum, "Structural degradation assessment of RC buildings: application of the method of assessment by integrity and safety—MAIS Method—in a heritage case study in Brasilia". J*ournal of Building Pathology and Rehabilitation. Springer Link.* Vol 8, 2023.

[4] F. J. P. Lucio. "Avaliação do Imóvel Café Majestic. Mestrado em Engenharia Civil. *Instituto Superior de Engenharia do Porto (ISEP).* Porto (PT), 2017.

[5] MathWorks, Inc. MATLAB. 2021.

[6] Autodesk, Robot Structural Analysis 2022.

6. Acknowledgements

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