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NUMERICAL DAMAGE ASSESSMENT IN SARAYA EL-ADL CITADEL, CAIRO, EGYPT DUE TO OCTOBER 12, 1992 DAHSHUOR EARTHQUAKE

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Abstract

Although numerical damage assessment modeling uses simplified schemes of reality, it can explain general phenomena, and give, in conjunction with Subjective interpretation based on personal experience, a reliable safe evaluation and useful guidance for restoration and strengthening criteria. Another of the greatest values of numerical modelling is the possibility of carrying out parametric analysis of the benefit of remedial measures to find a cost effective, yet adequate, retrofit to assure material durability and damage prevention related to the artistic value of the monument. The masonry structure of Sarayael-Adl were classified as hasing been severely damaged by the Dahshuor 1992 earthquake. Most unsuccessful restoration efforts apparently focused on cosmetic treatments; engineering studies of these monuments, especially analysis of earthquake response, apparently were not undertaken. The objective of this paper is the investigation of the behavior of historic masonry structures of Saraya el-Adl subjected to seismic forces and stresses and the formulation of numerical models for use in structural analysis. The case study presented herein regards the static and seismic analysis of Saraya El-Adl (1813 AC) in Cairo Egypt, (damaged by the earthquakes occurred in October 1992). Firstly, we collected all data regarding the site, the geometry of the masonry structure, the characteristics of materials of construction, the structure and the soil medium, etc. The proposed Model is applied to the analysis of the Saraya El-Adl in Cairo. A non-linear model is developed, aiming to capturing the key in elastic mechanisms. The analytical model is implemented in the finite element code Autodesk® Robot™ Structural Analysis Professional and validated against experimental results. The results obtained suggest that for such structures non-linear static analysis provides a reasonable prediction of damage at the base of the Saraya el-Adl, but is not however suitable for predicting the overall damage along the Saraya's entire height. The conclusive aim of the project is then to develop guidelines for the evaluation of the static and seismic vulnerability of historic masonry structures. Ultimately, the analysis presents the optimal structural interventions to remedy the existing damage, also to prevent the formation of the same mechanisms under the action of future earthquake.

***Keywords**: Saraya el-Adl; Citadel, Historic Monuments; Damage Assessment; Structural analysis; Earthquakes; Seismic Performance*

Introduction

Although Egypt is a relatively low to medium seismic zone, it has experienced some devastating local shocks throughout its history, as well as the effects of larger earthquakes in the

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Hellenic Arc and the eastern Mediterranean region. In addition, it was damaged by earthquakes that struck southern Palestine and the northern Red Sea.

In Egypt, settlements are mostly concentrated along the Nile Valley and Nile Delta, therefore, earthquake risk is generally associated with medium-sized earthquakes over short distances (eg, MS 5.9, Cairo earthquake 1992), rather than larger earthquakes that are known to occur At great distances along the northern Red Sea, Gulf of Suez and Gulf of Aqaba (eg, MS 6.9, 1969 Shadwan, and MW 7.2, 1995 Gulf of Aqaba earthquakes), as well as the Mediterranean offshore (eg, MS 6.8, 1955 earthquake Alexandria).

On October 12, 1992, a medium-sized earthquake occurred near Dahshur, Egypt, about 20 km south of Cairo. Earth shaking intensity in Cairo's historic districts was VI-7 using the modified Mercalli scale, and 212 of the 560 impacts were reported in Cairo although none were destroyed. Damage to historical monuments can generally be described as resulting from the continuous deterioration of foundations and structural masonry from environmental impacts, especially groundwater, inadequate lateral structural resistance, and consequent mild to moderate seismic strength. Other large earthquakes affected ancient monuments in Cairo, but the most recent earthquake may have caused a disproportionate amount of damage due to poor structural conditions on a large scale. This study provides specific examples of how impacts ranging from 80 to 1,500 years ago respond, in different conditions, to near-field movements of a medium-sized earthquake and helps identify problems that research studies can solve. It also provides strong evidence for the adoption of a historical preservation strategy in Cairo that embraces scientific and engineering knowledge to understand these monuments and to suggest less intrusive repair and modification measures.

Dynamic response of masonry structures at low amplitudes (such as it is feasible to observe in tests) will be essentially elastic if the structure has suffered only limited cracking and otherwise still has a near-monolithic character. But the increased amplitudes associated with a damaging earthquake will lead to further cracking [1]. Elastic response will then progressively give way to one in which the blocks of masonry separated by the cracks and any other discontinuities will rock relative to one another, and this rocking will entail major changes in natural frequencies and in the forces that result from particular ground motions. Most seriously, there will be a tendency towards out-of-phase responses, with blocks alternately moving apart and coming together again. This will allow debris that falls into the cracks to jam them further and further open and will similarly allow arches and other spanning elements to jam their supports further and further apart. Or it may lead to repeated impacts where no such jamming can occur. Decreasing natural rocking frequencies as amplitudes increase will tend, however, to limit the movements, and any partial collapses of spanning elements will stabilise the supports by relieving their loading.

Egypt is rich in archaeological sites that span several civilizations, from the Pharaonic era to the modern era [2]. However, these archaeological sites are endangered due to natural and man-made impacts. An example of these effects is the earthquake that occurred at Tell Basta (2200 BC) and is believed to be responsible for the complete collapse of the Pharaonic temple located in the eastern Nile Delta, Sharkia Governorate [3].

Knowledge of historical structural behavior allows us to focus our attention on these macro elements and to assess whether retrofit interventions implemented and/or transformations over the years have mitigated or increased seismic vulnerability [4, 5].

Recently, there is a growing interest in understanding the behavior of traditional structures that have survived over the century's often in earthquake-prone areas and in need of conservation [6]. Seismic assessment and risk mitigation of cultural heritage structures is one of the main features of the protection of monumental buildings [7]. Observation of damage mechanisms during past earthquakes as well as international literature highlights that the seismic behavior of architectural heritage can be properly reproduced by dividing the building into primary parts characterized by independent structural response (macro elements) [5]. It is very important to prevent historical buildings from future large earthquakes [8]. The severe damage suffered by Saraya al-Adl in Dahshur 1992 and the 1995 Aqaba earthquake (which may have determined the collapse of the structure), Table 1 shows the impact of the Dahshur earthquake on the monuments in Islamic Cairo.

Table 1. The Impact of Dahshuor Earthquakeon Monuments in Islamic Cairo [9]

Monument	Date	Level of Earthquake Damage	Intervention Degree of Urgency
Circassian Mumluk (1382-1517)			
- Mosque of Sultan Barquq	1384-1386	Light	Desirable
- Mosque and Sabil of al-Ashraf Barasbay	1425	Light	Desirable
- Minaret of as-Saghir Mosque	1426- 1427	**Severe**	Immediate
- Mosque of al-Ghuri	1504- 1505	**Severe**	Immediate
- Mosque of ad-Dashtuti	1506	**Severe**	Immediate
Ottoman Turks (1517- 1808)			Urgent
- Bayt as-Sihaymi	1648-1796	**Severe**	
Muhammad Ali Dynasty (1805- 1848)			
- Hassan pasha Tahir Mosque	1809	Moderate	Necessary
- Saraya el-Adl, Citadel	1811	**Severe**	**Urgent**
- Mint, Citadel	1812	**Severe**	**Urgent**
- al-Gawhara palace, Citadel	1814	Light	Necessary
- Mosque and Madrasa of Muhamed Ali al-Kabir	1848	None	N/A

Necessary mathematical models and analysis techniques become available for unsupported building structures. The analysis of these structures is usually carried out in flexible ways. Elastic analysis is a useful tool for identifying areas of high stress; However, it sometimes fails to capture the ultimate failure mechanism [10].

Intervention methods must not only be reliable and durable, but also be easy to monitor and remove, if necessary, the latter aspect consistent with the broadly common policy to protect existing buildings from inappropriate restoration interventions, with special reference to historical and archaeological constructions [11].

In earthquake conditions, structural components may pass into a hysteretic cyclic state after elasticity. This type of behavior is of great importance for the structural analysis in seismic conditions with respect to the accumulation of damage with the number of cycles [12].

Earthquake damage monitoring has highlighted that the collapse of out-of-plane masonry walls is the main method of failure in older buildings, especially due to ineffective contact with floors. In this case, the breakdown can be global, if the connection is completely ineffective or local when the lack of correlation is localized only in some parts of the structure. Similarly, there are two different types of in-plane collapse of masonry walls: the first type involves a combination of bending resistance and compression, and the second shear failure [13].

Only the equilibrium model directly indicates collapse. Since it ignores the possibilities of local failures at points about which rocking occurs, it may be expected to overestimate safety and to do so to a variable extent depending on local compressive strengths, though the available evidence does not suggest much overestimation for structures of high-quality masonry. In any event, the response is highly dependent on the precise nature of the input motions, which means that safety can be considered only in terms of probabilities of survival.

The elastic model cannot adequately represent the structural response after significant cracking, and the elastic response that it assumes is, by definition, a safe one. But it may be indirectly useful in helping to establish structural parameters that cannot be established more directly [2].

Saraya el-Adl, Historic Context

Saraya el-Adl is located to the south of the façade of the main entrance to Al-Jawhara Palace and to the proximity to the House of Multiplication within the southern section of the Cairo castle. The Governor of Egypt Muhamed Ali Pasha constructed these saraya to be the main court of the castle where they consider issues and grievances and the two monasteries gather to discuss the conditions of the country after having Iwan Qaitbay demolished its remains on the ground floor until today.

The date of the construction of this monument dates back to the year 1229 AH to 1813 AD as stated in that text on one of the doors on the second floor bearing this date and its text whoever believes in fate is safer than chagrin 1229 AH.

Muhammad Ali Pasha, the founder of the Alawite dynasty and the owner of the modern renaissance in Egypt, whose rule spanned from 1220 AH/1805 CE to 1255 AH 1848 CE Muhammad Ali Pasha came to Egypt with the Ottoman army who returned to it after the French withdrew from it, as bad as 1801 CE The political and the exclusion of his opponents from grabbing the state of Egypt especially for himself especially after his elimination of enemies the Mamluk princes in the massacre of the famous castle on the first of March 811 and did not last for 37 years as an absolute ruler in Egypt who owes my name to the Sultan in Istanbul, but the ruler inherited the sons after him During this long age, the castle regained its lost position after it became the official headquarter of the state and established an integrated group of buildings that continued construction for 40 years The headquarters of the rulers of Egypt from the dynasty of Muhammad Ali until the year 1874, when Khedive Ismail established Qasr Abdin and moved to it with their families and offices.

State of Preservation of Saraya El-Adl

The most recent massively damaged monument is located in the castle. These are the companies of justice and mint. Saraya al-Adl was the venue of the court's proceedings. This is the skeleton of a building adjacent to the Jewel Palace in the castle and its east. It is a two-storey structure (although there is only a façade at the front of the second floor) built in the preferred European style of the time. Figures 1-3 illustrate the design, layout models, and the exterior and interior views of the floor at Saraya al-Adl. The construction of walls with timber and mortar can be seen in the remains of the wall burning in a fire. It appears that the basic components of the earthquake motions were in an out-of-plane direction. Serious cracks can be clearly seen on the longitudinal walls inside and out [12].

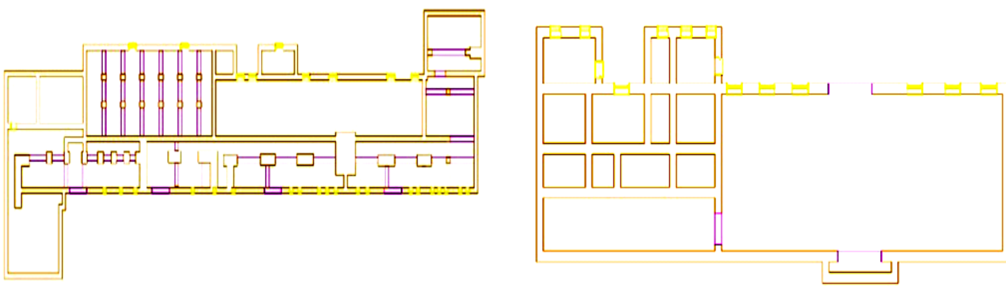

Fig. 1. Layout of the Saraya el-Adl: left - First floor, right - Second floor

Some examples are shown in figures 4-7. There is clearly a loss in the anchorage of one of the links at the top of the courtyard staircase. The floor structure inside the palace varies from a traditional wooden building (with a suspended ceiling) to a new reinforced concrete slab, which may have been installed to replace the part of the floor that was consumed by fire or deterioration. There are large vertical cracks in the sidewalks and there are large horizontal cracks on contact between the concrete ceiling of the first floor and the walls, as shown in figure 4-6. It is interesting to note that the wooden floor and stone walls adjacent to the three structural bays at the northeastern end of the building (just northeast of the hallway) were better than the concrete slab due to its lightness and the fact that the concrete in it did not anchor well into the walls. The uneven stiffness of the concrete and wood parts of the floor and the greater mass of the concrete floor hitting the facade in an out-of-plane direction caused greater damage to the northeastern end of the building. The dangerous nature of the damage is attributed to this substitution mismatch.

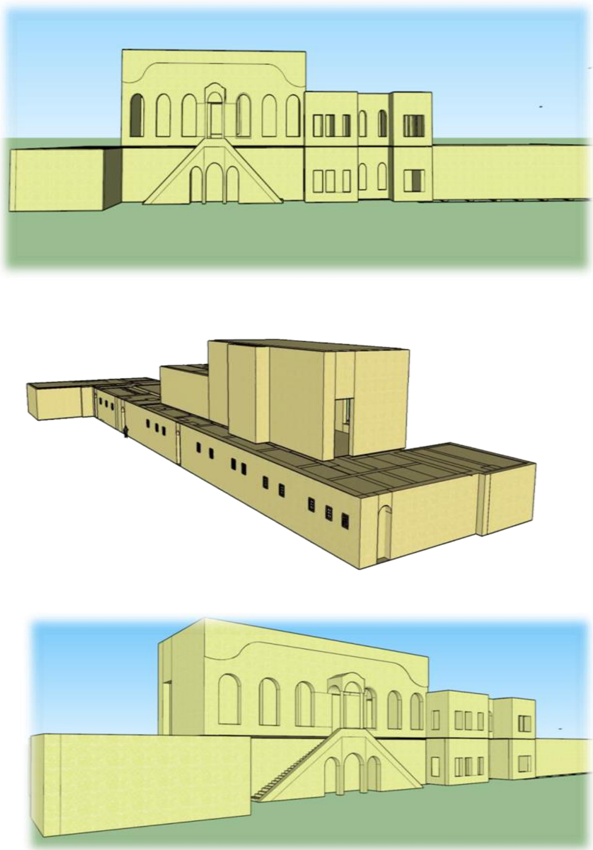

Fig. 2. Saraya el-Adl, Sketch Up Models

The main structural shortcomings of the vertical component of the structural system are: The superstructure and infrastructure of the palace were severely damaged due to the wide cracks associated with the settlement of the soil and the movements of the foundations that were subjected to shear failure associated with the great stability in the western and northern directions, as well as the center of Saraya al-Adl.

The cracks were 10-30mm wide and show periodic widening. The cracks had a preferential orientation in two main directions, EW, which includes typical views of large cracks in masonry walls and foundations. These effects are attributed to earthquake damage.

Irregularities in the clearance of door and window openings, along with the diversity of dimensions of these openings (both on L and ―T);

Fig. 3. Exterior and interior overview of Saraya El-Adl, Cairo, Egypt

Fig. 4. Saraya el-Adl. Showing large cracks and distortions

Fig. 5. Saraya el-Adl. Ceiling Collapse, Showing large cracks and distortions

Fig. 6. Saraya el-Adl. Showing Depression, Missing stones, large cracks and distortions

Fig. 7. Saraya el-Adl. Showing Depression, Showing Ceiling collapse, Missing stones, large cracks and distortions. Interior south wall of Saraya el-Adl looking up at contact between wall, arch, and concrete ceiling showing cracks, separation, and distortions

Three Dimensional Static and Seismic Structural Analyses

The present work was done to evaluate the stability of El Saraya El-Adl for risk assessment of static and earthquake loads as shown below in design criteria.

In order to meet the required structural evaluation, the following procedure was followed:

a. Collecting the required data from the different available reports like: seismic risk assessment, the geometrical and geodetically survey in the present state of El – Saraya El-Adl, the geotechnical investigation report, characterization and durability aspects of stones and another construction materials of El - Saraya El-Adl.

b. Using advanced structural analysis FEM program ― Robot Millennium‖ in the solid analysis.

Design Criteria

I. Codes of Practice and Standards Egyptian Code Practice 2008;

II. Loading Criteria:

a.Dead Loads

Dead loads have been taken as the following. Self weight for floor and walls: actual weight, floor finish 200kg/m^2;

b. Live Loads

Live loads have been based on the above listed codes, with the following specified live loads: typical floors 500kg/m$^{2.}$

Live load reduction has been implemented according to allowance made by the code.

c. Wind Loading

For south zone: Basic wind speed 70mph (130km/h), Exposure C and Importance factor 1.0.

For north zone: basic wind speed 87mph (140km/h), Exposure B and Importance factor 1.15.

d. Seismic Loading

Seismic Zone has been based on ECP 2008 recommendations at project location [13]. Soil profile estimated based on the geotechnical report.

e. Earth Pressure Loads and Differential Settlement

The coefficient of earth pressure (ka, ko) has been taken based upon the angle of inertial friction of soil as determined by the geotechnical report.

The differential settlement for each structure has been determined on a case-by-case basis depending on the location of the building.

For rock, specific calculations will be done to take into account rock dip direction, dip angle. Such parameters will be done by geologist.

Load Combinations

Ultimate Load Combinations

Required strength U for all structural elements in this project should be at least equal to the effects of factored loads in the following equations:

Dead loads (D.L) = (self weight + Flooring) × 1.4

Live loads (L.L) = 1.5 × 1.6

U = 1.4 Dead + 1.6 Live

U = 1.12 Dead + 0.25 Live - Sx + 0.3 Sy

U = 1.12 Dead + 0.25 Live + Sx + 0.3 Sy

U = 1.12 Dead + 0.25 Live - Sy + 0.3 Sx

U = 1.12 Dead + 0.25 Live + Sy + 0.3 Sx

Material Properties

According to Characterization and durability aspects of stones and other construction materials of El - Saraya El-Adl. The allowable stress is 16MPa. The stone Young‘s modulus is 1.6GPa.

Software

Autodesk® Robot™ Structural Analysis Professional.

The software provides a country-specific, scalable analysis solution for the structural engineer to analyze many types of structures, including buildings, bridges, and civil and specialty structures.

Autodesk Robot Structural Analysis Professional calculates a variety of structures with a comprehensive set of design codes, delivering results in minutes, not hours. This structural engineering software is versatile enough for simple framework or complex finite element analysis, steel and reinforced concrete design and offers seamless interoperability with other structural engineering products from Autodesk or third-party applications.

Advanced finite element auto-entanglement capabilities: Powerful networking techniques allow the structural engineer to work with greater effort with even the most complex of models; Automatic network generation and manual definition of entanglement parameters can be processed independently for each panel, providing the ability to generate a high-quality finite element network for more accurate analysis results.

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Check the true linear and nonlinear behavior of any architecture. The program allows for simple and efficient analysis of many types of nonlinearities, such as P-delta analysis; Members of tension/pressure; Plastic brackets, cables and hinges. Also explore the response of your structures to dynamic loading such as harmonic frequencies, earthquakes, and earthquakes.

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Sophisticated fast dynamic solvents help ensure that structural dynamic analysis can be performed more easily for any size of structures. Autodesk Robot Structural Analysis Professional's most efficient analysis algorithms are designed and optimized for quad-core and multi-core computer processors, giving structural engineers the speed of computation to deliver more accurate results for required structures in minutes versus hours.

Modeling

Saraya Al-Adl is designed using the Solid Element Module, which is the Solid Element properties taken as defined above in the Design Standards.

The upper ceiling of the palace was designed using frame elements for columns and shell elements for slabs and domes with the same characteristics as in the above reports.

Rigid links are used to bind all walls together to function as a single unit, and rigid links are specified with very high torques of inertia and weightlessness.

Elements Cross Sections

Solid elements thickness varies from 75 to 150cm along the height.

Beams cross sections 15×15cm.

Columns diameter at the 30cm.

Slab thickness is 16cm.

Results of Numerical Analysis

Based on the structural analysis, the maximum stresses due to static and lateral loads exceed the actual stone stress (160kg/cm^2), for both the first and second floors, as shown in figures 8-23).

For the first floor:

Max. Stress

1.4 DL + 1.6LL = 8157kg/cm^2 < 160kg/cm^2(UNSAFE);

Max Stress

1.12DL + 0.5LL + Sx + 0.3Sy = 3596kg/cm^2 < 160kg/cm^2(UNSAFE);

Max Stress

1.12DL + 0.5LL + Sy + 0.3Sx = 2039kg/cm^2 < 160kg/cm^2(UNSAFE).

For the second floor:

Max. Stress

1.4 DL + 1.6LL = 8667kg/cm^2 > 160kg/cm^2(UNSAFE);

Max Stress

1.12DL + 0.5LL + Sx + 0.3Sy = 3750kg/cm^2 < 160kg/cm^2(UNSAFE);

Max Stress

1.12DL + 0.5LL + Sy + 0.3Sx = 2230kg/cm^2 < kg/cm^2(UNSAFE).

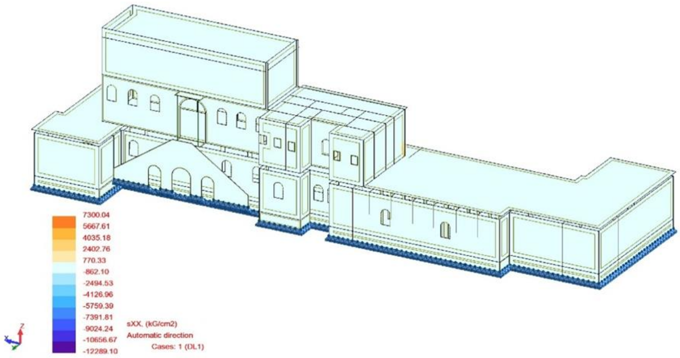

Fig. 8. Sxx, (kg/cm^2) automatic direction. Cases: 1 DL1

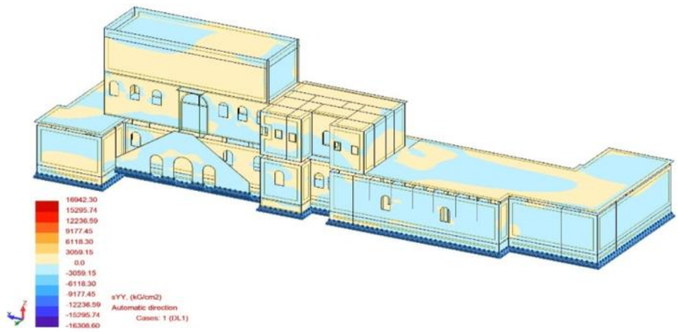

Fig. 9. Syy, (kg/cm^2) automatic direction. Cases: 1 DL1

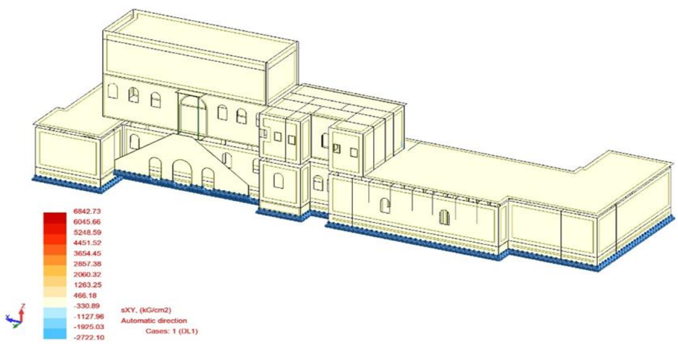

Fig. 10. Maps of solids. Effective horizontal compressive stresses σ/xy (kg/cm^2) Direction XY cases: DL1

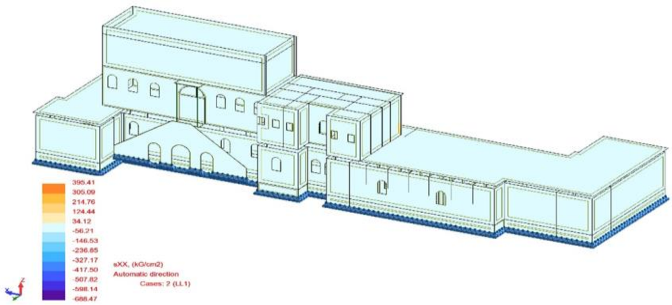

Fig. 11. Effective horizontal compressive stresses σ/xx (kg/cm^2)
Direction XX cases: LL1

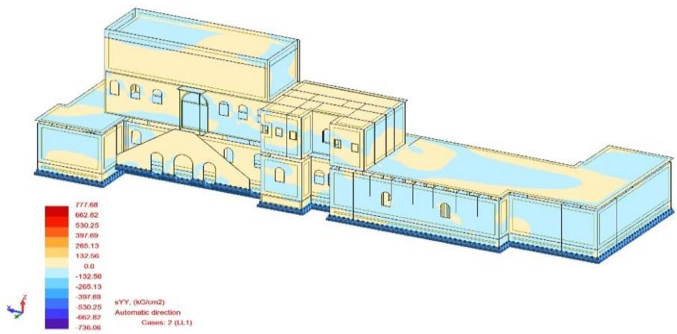

Fig. 12. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction YY cases: LL1

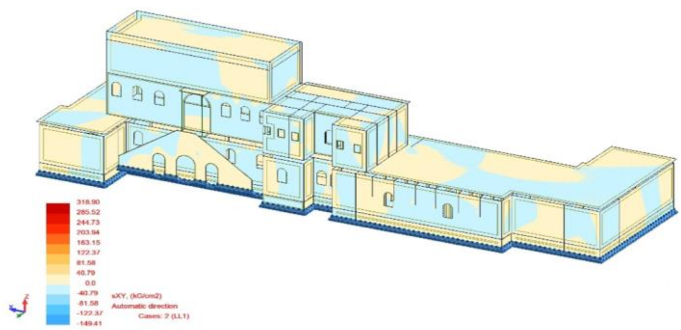

Fig. 13. Maps of solids. Effective horizontal compressive stresses σ/xy (kg/cm^2)
Direction XY cases: LL1

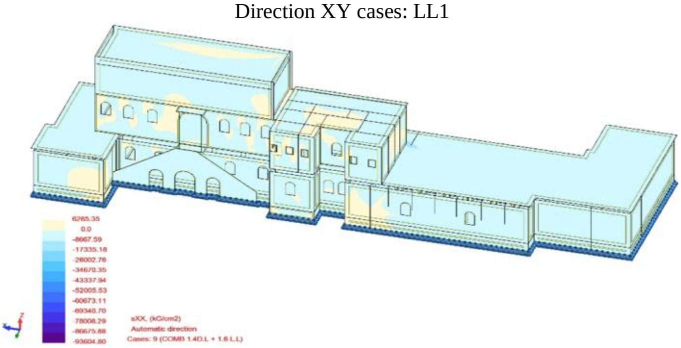

Fig. 14. Maps of solids. Effective horizontal compressive stresses σ/xx (kg/cm^2)
Direction XX cases: 1.4DL+1.6LL

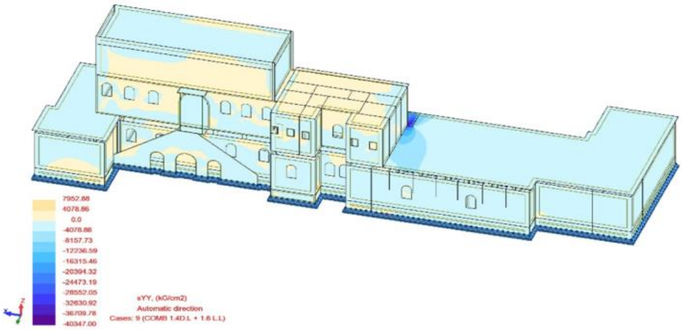

Fig. 15. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction YY cases: 1.4DL+1.6LL

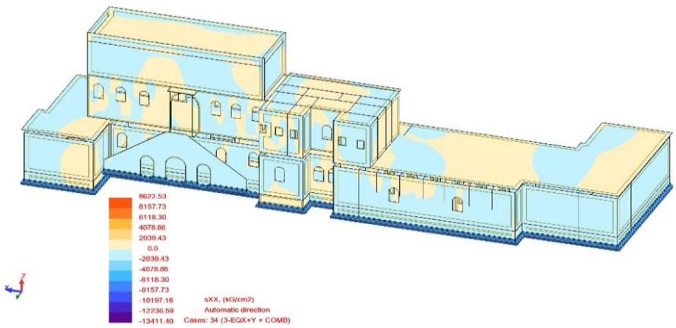

Fig. 16. Maps of solids. Effective horizontal compressive stresses σ/xy (kg/cm^2)
Direction XX cases: 3-EQX+Y+COMB

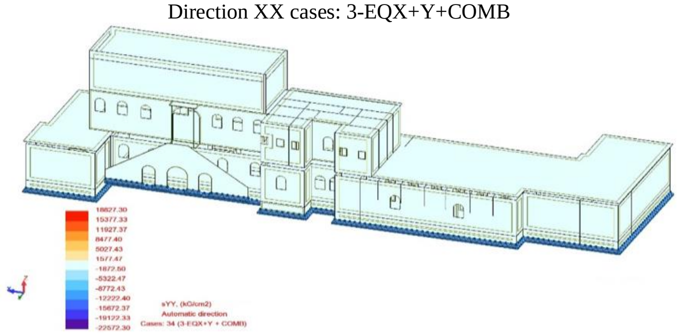

Fig. 17. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction YY cases: 3-EQX+Y+COMB

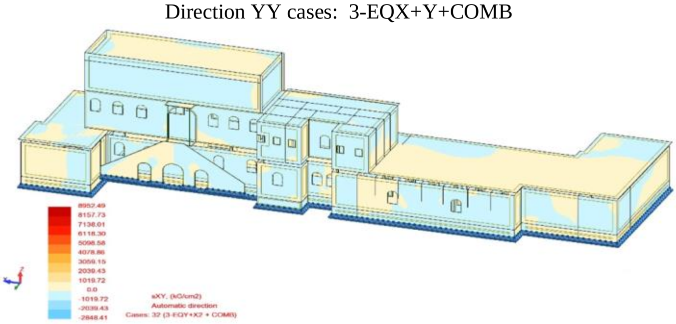

Fig. 18. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction XY cases: 3-EQX+Y+COMB, Direction YY cases: 3-EQX+Y+COMB,
Direction YY cases: 1.12DL+0.25LL-Sx+0.3Sy

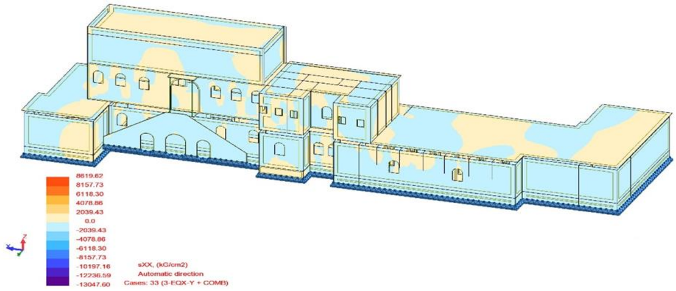

Fig. 19. Maps of solids. Effective horizontal compressive stresses σ/xy (kg/cm^2)
Direction XX cases: 1.12DL+0.25LL+Sy+0.3Sx

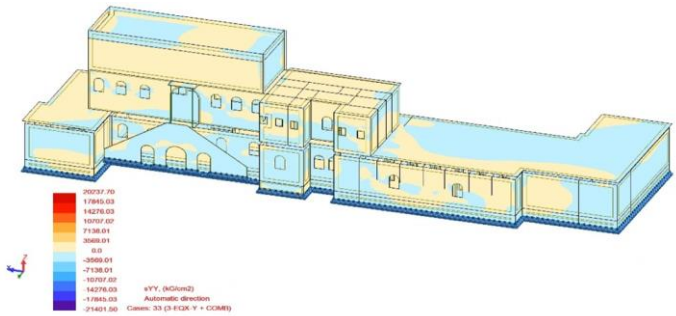

Fig. 20. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction YY cases: 1.12DL+0.25LL+Sy+0.3Sx

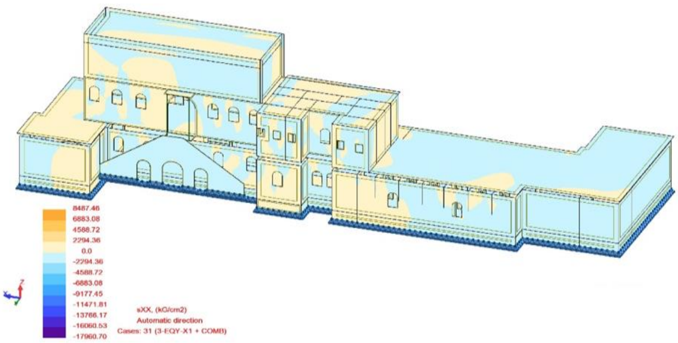

Fig. 21. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction XX cases: 1.12DL+0.25LL-Sy+0.3Sx

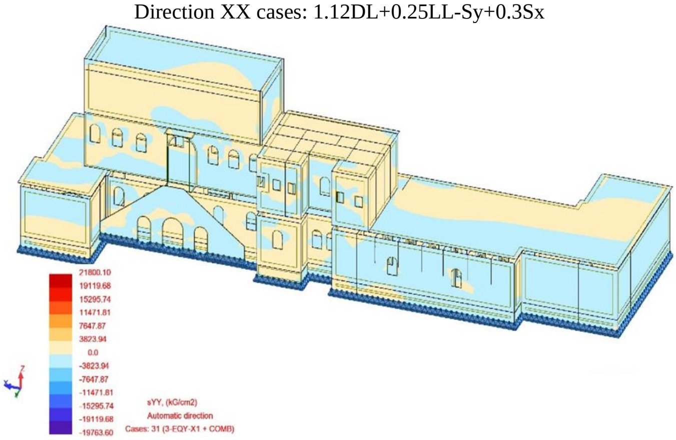

Fig. 22. Maps of solids. Effective horizontal compressive stresses σ/yy (kg/cm^2)
Direction YY cases: 1.12DL+0.25LL+Sy+0.3Sx

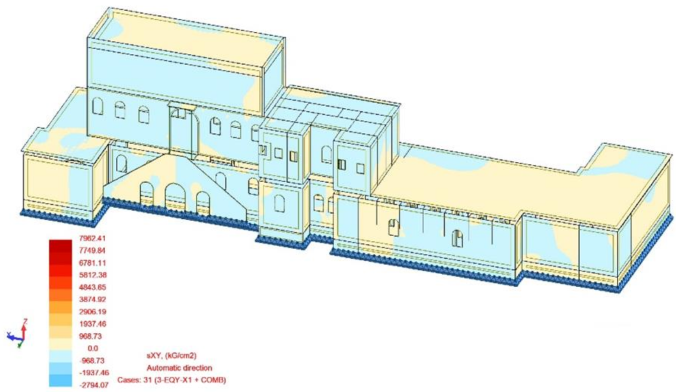

Fig. 23. Maps of solids. Effective horizontal compressive stresses σ/xy (kg/cm^2)
Direction YY cases: 1.12DL+0.25LL+Sy+0.3Sx

Maps of solids- shows the distortion and ceiling collapse which is caused by 1992 (Fig. 24). Dahshuor earthquake Rad (Degree) Direction XY cases: (1.12DL+0.25LL+Sx+0.3Sy).

Technical evaluation showed that almost all of the masonry's structural walls presented a brittle pattern of failure and the type of weak and soft stories.

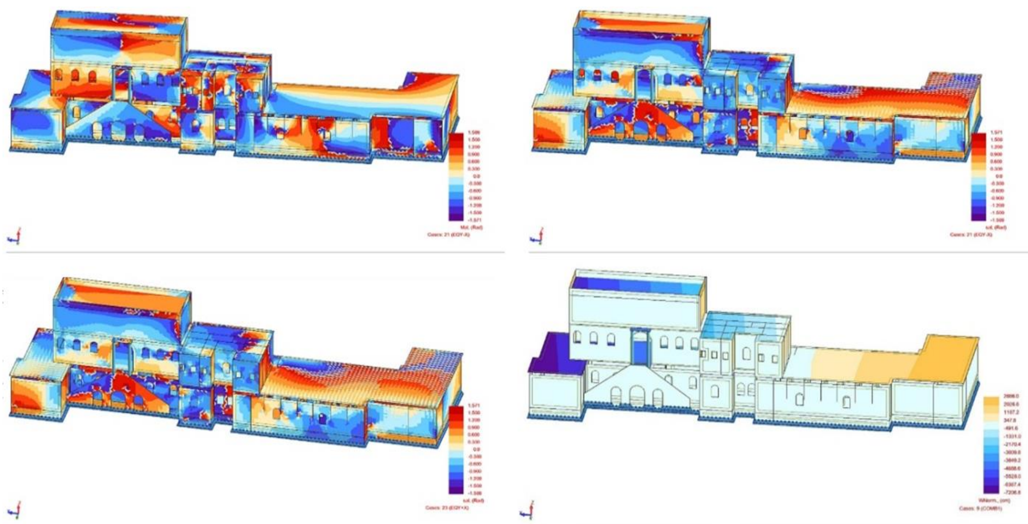

Fig. 24. Maps of solids. shows the distortion and ceiling collapse which is caused by 1992 Dahshuor earthquake Rad (Degree) Direction XY cases: 1.12DL+0.25LL+Sx+0.3Sy

In addition to the major deficiencies in the vertical and horizontal components of the structural system, the building has been classified as seismic hazard class 1 Rsl‖ according to the Egyptian technical legislation (a building with a high level of collapse risk in the event of an earthquake corresponding to the seismic intensity code of the city of Cairo (A = 0.16 g) [13-15].

Placing the building's structural system at spectral positions unfavorable to inelastic response spectra.

For the period of vibration, Tn = 0.4s and for two CB values, y = (0.2 and 0.13) large values of displacement can be observed.

These unfavorable "spectral positions" (in both directions) led to an exaggerated value of the required ductility factors.

Preservation Strategy

Carrying out restoration work without proper scientific and engineering notes, investigations, and model testing, especially with regard to earthquake hazards, is rash. Earthquake damage to historical monuments will continue to be severe, even to those that have been restored, unless proper study and active seismic modification measures are taken.
Scientific and engineering assessments should include six basic steps: i) Historical surveys; ii) Direct notes; iii) surveys and model studies; iv) evaluation of viable alternatives; v) Document the previous steps; and only then, vi) restoration, repair and modernization. Some of these activities are currently underway. However, other elements and interaction between activities must also be taken into consideration. Emergency response activities are also important [16-20].

Conclusion

Earthquake damage to historical monuments can generally be described as resulting from the continuous deterioration of the structural construction, insufficient lateral resistance, and the subsequent imposition of light on the moderate earthquake forces. Observations of earthquake damage opened discussion and brought worldwide recognition of the degradation and progressive deterioration of building materials for these monuments. The results of numerous studies over the past 90 years document this crisis.

Technical evaluation and strengthening of unsupported monumental stone building are areas in which decisions are made based on risk analysis, in order to reach a compromise between historical value and cost of investigations.

It has been shown that the building tends to locate damage in the second and third levels, with the development of an impact - weak and weak levels - (a situation that corresponds to a general gradual collapse probability.

At the moment, the reinforcement solution is required, retrofit work and the rehabilitation of the Justice League is pending, as the owner will allocate the necessary funds.

References

[1] R. Mainstone, *Characteristic and assessment of old masonry structures. In Structural conservation of stone masonry,* **International Technical Conference**, Parcelona, 1989.
[2] S. Hemeda, *Non-linear static analysis and seismic performance of modern architectural heritage in Egypt,* **Mediterranean Archaeology and Archaeometry, 16**(3), 2016, pp. 1-16.
[3] A. Khalil, *Use of geophysical and seismological techniques for aiding in rehabilitation of monumental sites,* **5th International Congress on ―Science and Technology for the Safeguard of Culture Heritage in the Mediterranean Basin,** 22-25 November 2011, p. 119.
[4] S. Lagomarsino, S. Podesta, *Seismic vulnerability of ancient churce. Part1: Damage assessment and emergency planning,* **Earthquake Spectra**, **20,** 2004, pp. 377-394.
[5] S. Podesta, A. Brignola, *The seismic behaviour of the ―Santi Marciano, E. Nicandro, Church in l, Aquila (Italy) after the 6th of April 2009 Earthquake,* **4th International Congress on ―Science and Technology for the Safeguard of Culture Heritage in the Mediterranean basin,** 8-9 December 2009, pp 184- 189.

[7] R. Cardoso, M. Lopes, R. Bento, *Seismic evaluation of old masonry buildings. Part 1: method description and application to a case-study*, **Engineering Structures**, **27**(14), 2005, pp. 2024-2035.

[8] D. Gergova, I. Iliev, V. Rizzo, *Evidence of a seismic event on Thracian tombs dated to the Hellenistic period, Sveshtari, NE Bulgaria*, **Annali di Geofizica (Italia)**, **38**(5-6), 1995, pp. 919-926.

[9] D.W. Sykora, D. Look, G. Croci, E. Karaesmen, E. Karaesmen, *Reconnaissance report of damage to historic monuments in Cairo, Egypt, Following October 12, 1992, Dahshur earthquake,* **NCEER-93-0016,** National Center for Earthquake Engineering Research, Buffalo, NY, 1993.

[10] L. Kouris, A. Kappos, Seismic performance of ancient timber-framed walls, **5th International Congress on —Science and Technology for the Safeguard of Culture Heritage in the Mediterranean Basin,** 8-9 December 2009, pp. 119-126.

[11] F.M. Mazzolani, A. Mandara, *Seismic Protection of historical buildings: the PROHITECH Project,* **5th International Congress on —Science and Technology for the Safeguard of Culture Heritage in the Mediterranean Basin,** 8-9 December 2009, pp. 197- 208.

[12] Z. Peraskovic, S. Sedmak, *Fatigue of structural components in DC 90 seismic during earthquake,* **5th International Congress on —Science and Technology for the Safeguard of Culture Heritage in the Mediterranean Basin,** 22-25 November 2011, p. 125.

[13] * * *, **Egyptian Code. Egyptian code of Practice (ECP-2008)** for estimating loads and forces, 2008.

[14] M. Gamal, A. Noufal, *A Neotectonics model and seismic hazard assessment for Egypt,* **8th International Conference on Geology of the Arab World, Cairo University Egypt,** 2006, pp. 13-16

[15] S. Podesta, E. Curti, *An integrate approach for the evaluation of the seismic safety of S. Maria Antiqua Church,* **5th International Congress on —Science and Technology for the Safeguard of Culture Heritage in the Mediterranean Basin,** 8-9 December 2009, pp. 178- 183.

[16] S. Hemeda, A. Sonbol, *Sustainability problems of the Giza pyramids,* **Heritage Science, 8,** 2020, Article Number: 8. https://doi.org/10.1186/s40494-020-0356-9.

[17] S. Hemeda, *Engineering failure analysis and design of support system for ancient Egyptian monuments in Valley of the Kings, Luxor, Egypt,* **Geoenvironmental Disasters, 5**, 2018, Article number: 12, https://doi.org/10.1186/s40677-018-0100-x.

[18] S. Hemeda, *3D finite element coupled analysis model for geotechnical and complex structural problems of historic masonry structures: conservation of Abu Serga church, Cairo, Egypt,* **Heritage Science,** 7**,** 2019, Article Number: 6, https://doi.org/10.1186/s40494-019-0248-z.

[19] S. Hemeda, K. Pitlakis, *Serapeum temple and the ancient annex daughter library in Alexandria, Egypt: Geotechnical–geophysical investigations and stability analysis under static and seismic conditions,* **Engineering Geology, 113**, 2010, pp. 33-43.

[20] S. Hemeda, *Geotechnical and geophysical investigation techniques in Ben Ezra Synagogue in Old Cairo area, Egypt,* **Heritage Science,** 7**,** 2019, Article Number: 23. https://doi.org/10.1186/s40494-019-0265-y.

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