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A CONTRIBUTION TO THE CONSERVATION OF 20TH CENTURY ARCHITECTURAL HERITAGE IN KHEDIVAL CAIRO

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Abstract

Cairo Down-Town is known as Khedival Cairo. It is famous for its rich architectural heritage buildings designed by many European architects during the 19th and the 20th c. Many of these buildings have deteriorated due to misuse and lack of maintenance. In this paper, the survival of a historic balcony of one of these buildings (dating back to 1911) due to extensive intervention works is presented. The leaked water from air-conditioning resulted in corrosion of the steel beams carrying the balcony. Subsequently, the decorative units at the balcony bottom were detached and started to fall down. An intervention was carried out to allow the balcony to survive. The adequacy of the intervention was ensured by numerical analysis and in-situ static loading test. It was found that the adopted intervention represented a good example that could be applied to many other similar balconies widely found in Khedival Cairo.

Keywords: *Khedival Cairo; Architectural heritage; Deterioration; Intervention; Corrosion; Concrete; Static loading test; Model updating; Numerical analysis.*

Introduction

Cairo has a long history; it was founded in 634 A.D. and lived its most spectacular age during the Mameluke period from 1250 A.D. to 1517 A.D. After that period and until the end of the 18th century, Cairo became the premier Ottoman provincial capital, second only to Istanbul [1]. The westernization of Cairo started during the 19th c. under the reigns of Muhammad Ali and his successors. Muhammad Ali imported foreign teachers for European-Modeled schools, technicians for the factories, and education missions were sent to France. A new urban form was constructed. Wide Westernization steps took place through the construction of European-style palaces, in addition to changing the facades of buildings by using bare rectangular European windows [2].

What is called today the Khedival Cairo is the result of the westernization of the city catalyzed in Khedive Isma'il reign (1863-1879). He visited Paris in 1867 and admired it so much that he sent for the chief landscape architecture of Paris to help in the redesign of the city of Cairo [2]. During the British colonial rule (1882-1956), the city was forcibly linked the rising metropolis to its world system and introduced it to a host of new architectural and urban experiments [1].

After the 1952 revolution, Cairo started to lose its fine polished urban qualities. Historic buildings were subjected to rent freezes, leaving little capital for maintenance and repair. The

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ensuing exodus of a large part of the foreign community after the revolution contributed to further degradation in the quality of the urban space due to changing uses exercised by a burgeoning local community. An informal economy overtook these civic spaces developed for the cultural and foreign elite which led to the rapid deterioration of several buildings [3-4]. Till now, the buildings of Khedival Cairo are suffering from lack of maintenance and misuse. This resulted in a non-stop deterioration for many of these buildings. For this reason, the Cairo Governorate started an ambitious project for the restoration of Khedival Cairo buildings. It is worth mentioning that lack of maintenance is one of the main problems facing the Egyptian architectural heritage in general and not only Khedival Cairo [5-6].

This paper discusses the restoration works carried out to save a balcony in a historic building dating back to the beginning of the 20th c. The corrosion of the steel beams carrying the balcony resulted in severe problems and the decorative units at the balcony bottom were detached. An intervention was carried out in which the steel beams were cleaned from corrosion products and strengthened using newly added plates. As well, the decorative units were restored. For revealing the adequacy of the intervention, a static loading test was carried out. The interventions presented here represent a good example that could be applied to many other similar balconies widely found in Khedivial Cairo, in specific, and other similar floors made of steel beams and concrete.

Building and balcony description

The case study of this paper is a historic building designed by the Italian architect Antonio Lasciac in 1911. This architect contributed significantly to the modernization of Cairo and Alexandria (the second largest city in Egypt). He was the chief architect of the royal palaces in the regime of the Khedive Abbas Hilmy who ruled Egypt from 1892 to 1914 [7]. Lasciac designed a large number of buildings in Cairo and Alexandria in which the effect of Italian architecture is very clear like the Ramleh railway station, the facades of the Cairo station (with L. Iconomopoulus), Villa Princes Fatma El Zahra (presently the Crown Jewels Museum), complex of apartment buildings in Rue Sherif, the villa Laurens in Ramleh, the palazzina Aghion (presently the Ahram building) in Rue Rossette, among others [7].

The subject building of this paper is located in Cairo Down-Town and is known as “Omart Assicurazioni”. It is near to the famous Egyptian Museum located at Al-Tahrir Square. It consists of a basement, ground floor, four typical floors and some rooms at the roof (Fig. 1). The total area is about 1330m^2. It is built from stone masonry walls and with floors made of lightweight concrete supported on steel beams.

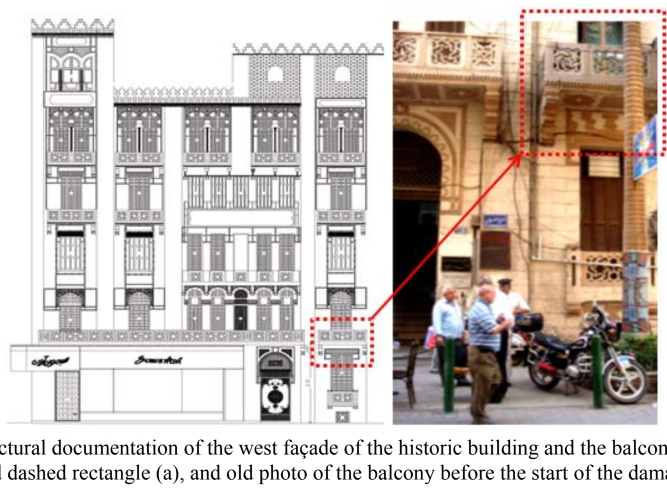

Fig. 1. Architectural documentation of the west façade of the historic building and the balcony is surrounded by red dashed rectangle (a), and old photo of the balcony before the start of the damage (b)

The building's facades are rich with decorative elements like the arched windows, the decorated parapets, and the wooden sheds. The balconies of the building, in specific, are well decorated with hunched corbels, parapets with hollow decorations and gypsum decorated units at the balconies bottom. The balcony of this research is at the west façade of the building, just to the right of the building's entrance (Fig. 1).

It is a cantilever with a span of 0.96m and the width is 3.16m with a parapet of 1.40m high (Fig. 2). The balcony's floor is composed of lightweight concrete made of cement, sand and slag aggregate. This concrete is supported by I-Shaped steel beams.

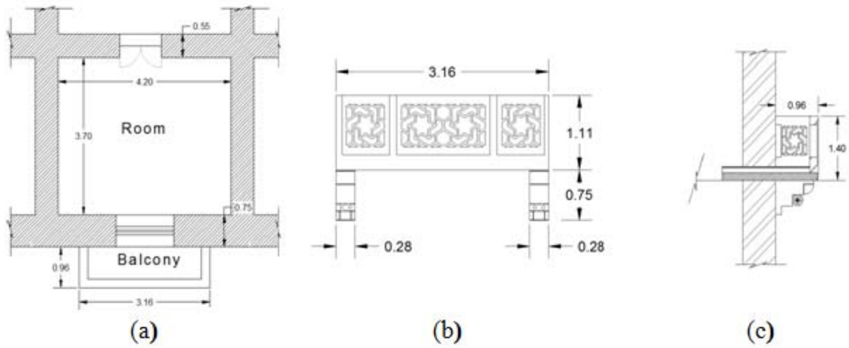

Fig. 2. Architectural documentation of the balcony: a. plan; b. elevation; c. side view (dimensions in meters)

Problems of the balcony

The air-conditioning unit installed in the balcony was the main source of the problems and the observed damage. The leaked water from the air-conditioning (Fig. 3a) infiltrated in the balcony's floor and resulted in series corrosion problems in the steel beams (Fig. 3b, c and d) and the steel bars used to reinforce the decorative units (Fig. 6).

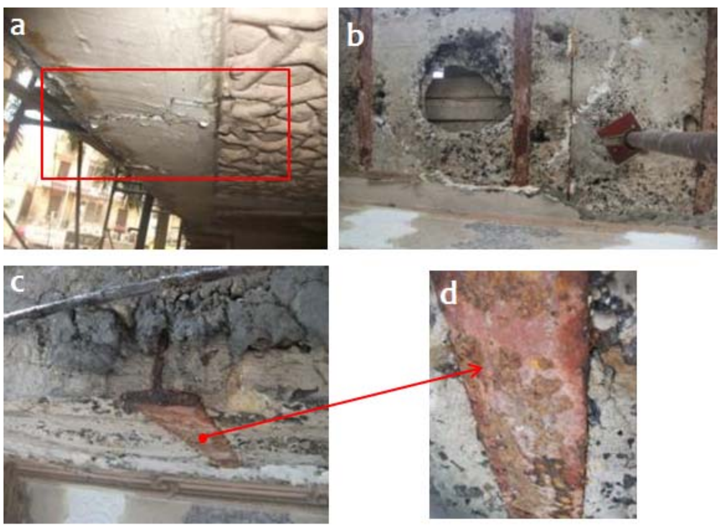

Fig. 3. Damage of the balcony floor: a. Source of damage: leaked water from air condition infiltrated to the balcony bottom; b. Losing of some parts of the floor and corrosion of beams; c. Zoom to a corroded beam; d. A zoom to the beam bottom flange showing the severe corrosion

In addition, a narrow crack developed between the parapet and the balcony floor due to the deflection of the steel beams (Fig. 4b).

The decorative units at the balcony bottom suffered from: 1) inappropriate previous interventions in which the arrangement of the decorative units was changed (Fig. 5); 2) peculiar materials, not similar to the original ones, were used in that intervention. Instead of making all the decorative units from gypsum, a mix of an internal layer of gypsum reinforced with linen and external layer of cement was used (Fig. 4c). To connect the decorative unit with the steel beams and also to reinforce it, a mild steel bar was used (Fig. 6). Peculiar paints were used on the external cement layer (Fig. 4d); 3) complete deterioration of some parts (Fig. 4a) and 4) corrosion of the steel bars used in connecting the units to the steel beams (Fig. 6). In the aforementioned intervention, the original gypsum parapets were replaced with reinforced concrete ones.

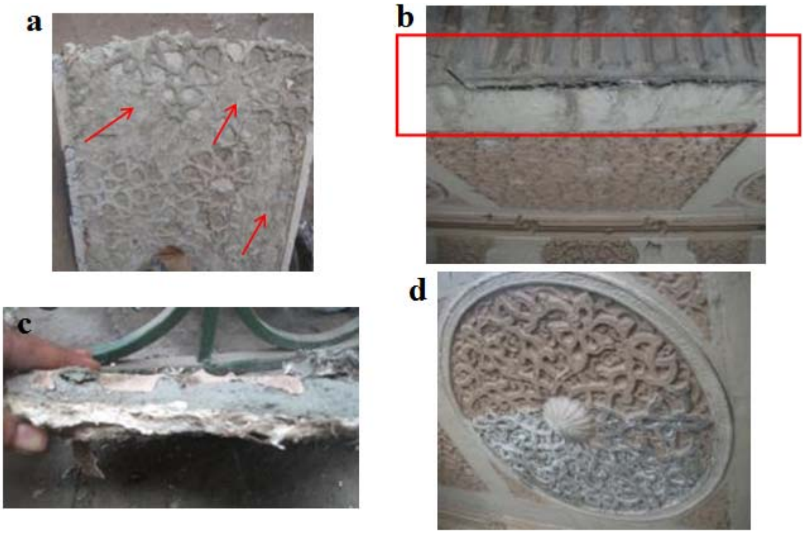

Fig. 4. Problems and damage of the decorative units: a. Disappearance of some parts; b. A crack between the parapet and the decorative units; c. Inappropriate materials used in previous intervention, internal layer of gypsum reinforced with linen and external layer of Portland cement; d. Using of peculiar paints

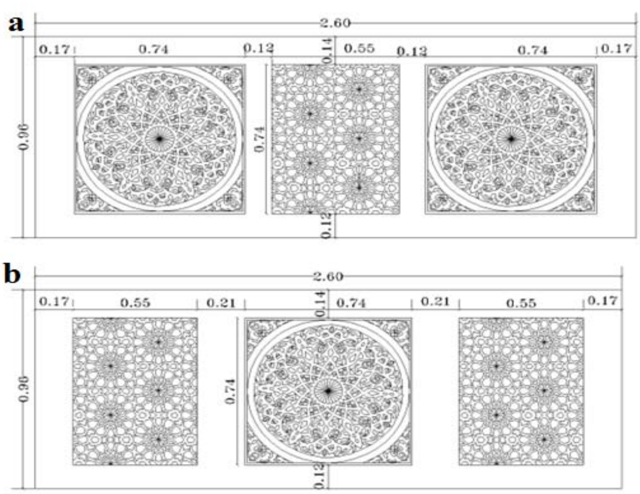

Fig. 5. The found arrangement of decorative units at the balcony bottom (a), and the correct arrangement (b) (dimensions in meters)

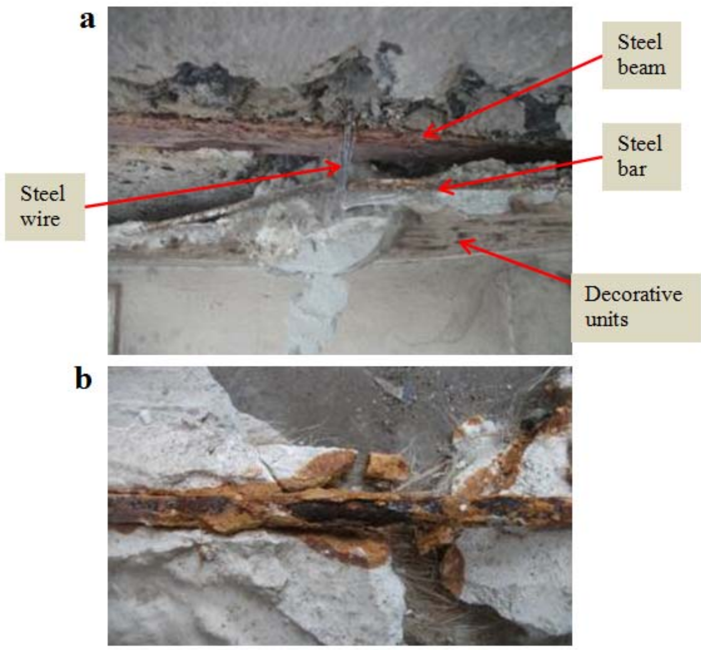

Fig. 6. The corrosion of the steel bar connecting the decorative units to the steel beam (a), and zoom to the corroded bar (b)

Analysis and examination of construction materials

Samples were taken from the fallen concrete of the balcony floor and from the fallen parts of the decorative units and were analyzed using X-Ray Diffraction (XRD) and studied by Scanning Electron Microscopy coupled with Energy Dispersive X-ray (SEM-EDX) and Scanning Electron Microscopy (SEM). The objective was to know the morphological composition of the used materials including the binding materials and the aggregate as well as the corrosion products.

XRD analysis results

Eight samples in total were analyzed using XRD analysis method, three samples from the slag aggregate, three samples from the binding material, and two samples from the decorative units. The slag aggregate's samples showed that the main component was Hematite (ferric oxide, Fe_2O_3), as an example in Figure 7. Also, Quartz was found as filler. Calcite and Gypsum were found due to the binding material surrounded the slag sample. As for the samples of the binding material, it was found that the binder material (Fig. 8) composed mainly of Gypsum, Calcite, and Quartz. Some traces of hematite were found due to the slag aggregate existence. Due to the infiltrated water, the dehydrate was found. Regarding the samples of the decorative units (Fig. 9), it was observed that these units were composed of Gypsum, Calcite and Quartz.

SEM-EDX analysis results

Five samples were examined and analyzed using SEM-EDX, one sample from slag aggregate, two samples from the concrete binding material and two samples from the decorative units. Table 1 reports the weight found for each element (W_t) in each sample. For the slag sample (Fig. 10), the Fe element was found and the SEM image shows the characteristic particle composition of slag. The samples of the concrete binding material showed that the Portland cement was used because of the existence of the elements of Al, Si, Fe, S and Mg,

Table 1 and Figure 11. These elements are the main elements of Portland cement. As for the decorative units' samples, the corrosion products of the steel bar used in a previous intervention was evident as the Fe element was found with a high percent (Table 1). Additionally, the existence of the elements S and Ca showed that the gypsum is the main component of these units as found by the XRD (Fig. 12).

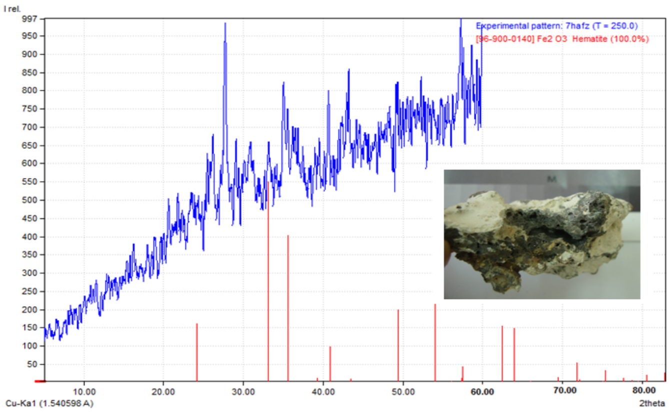

Fig. 7. XRD analysis of one of the slag aggregate's samples.

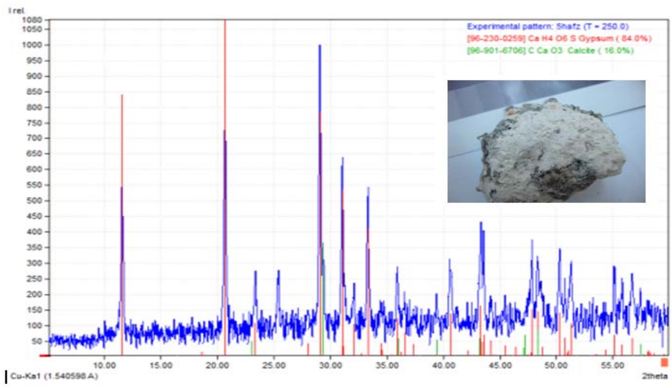

Fig. 8. XRD analysis of one of the binder material's samples.

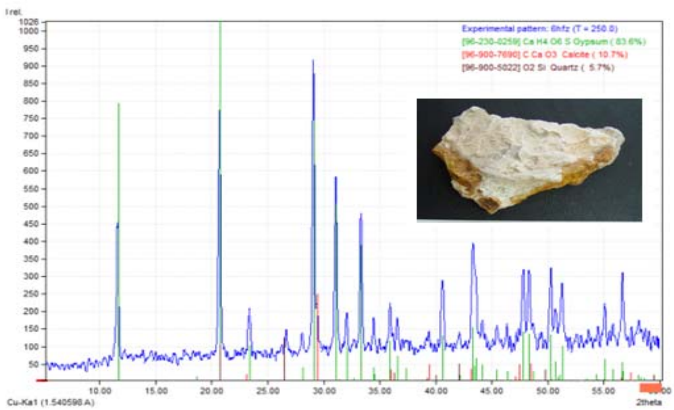

Fig. 9. XRD analysis of one of the decorative units' samples.

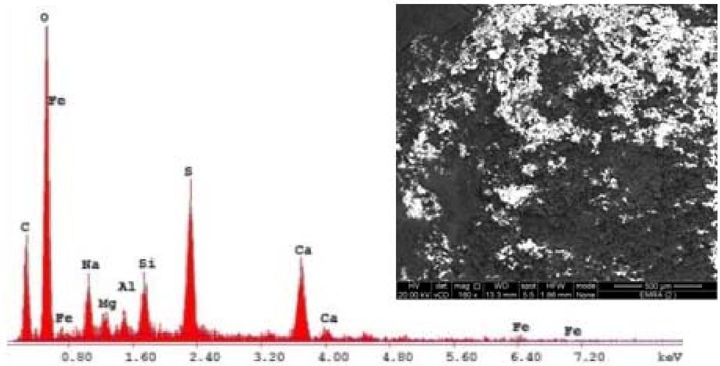

Fig. 10. Slag sample (sample no. 1): EDX analysis, and SEM image.

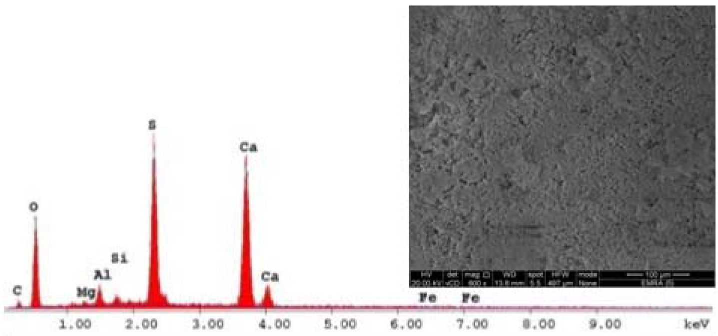

Fig. 11. Binding material in the concrete (sample no. 3): EDX analysis, and SEM image.

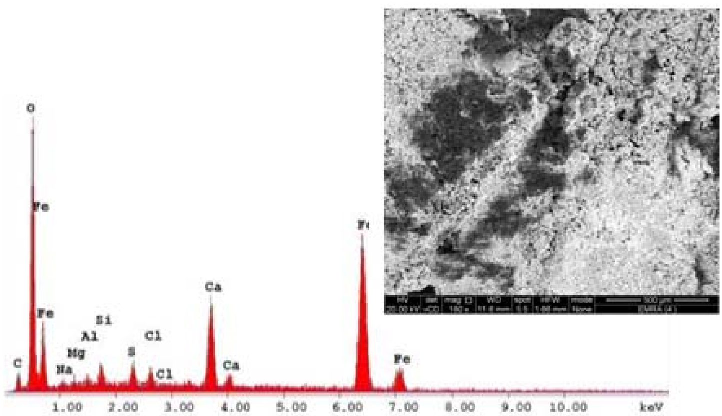

Fig. 12. Decorative units' sample (sample no. 4): EDX analysis, and SEM image.

It is worth mentioning that SEM investigation showed that there was a clear interference between the concrete components (aggregate and binding material) and the corrosion products resulted from the corrosion of the steel beams (Fig. 13). Similarly, it showed the interference between the decorative units' components and the corrosion products of the corroded steel bar (Fig. 14).

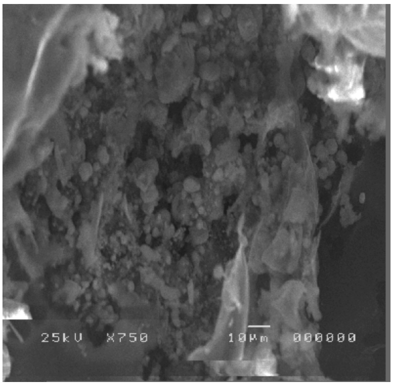

Fig. 13. SEM image showing the interference between the concrete (dark color) and the corrosion products (light color).

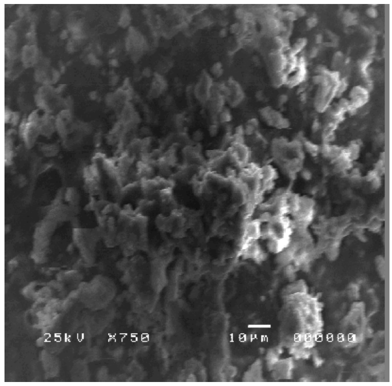

Fig. 14. SEM image showing the interference between the decorative units' materials (dark color) and the corrosion products (light color).

Table 1. Results (W_t%) of the EDX analysis.

Sample no.	Sample type	Elements									
		C	O	Na	Mg	Al	Si	S	Cl	Ca	Fe
1	Slag	25.91	47.76	4.66	1.58	1.29	3.17	8.5	0.0	6.36	0.76
2	Binder material	48.4	20.43	0	0.74	1.33	1.99	10.08	0.0	13.81	3.22
3		5.44	42.23	0	0.69	2.21	0.95	19.63	0.0	28.21	0.65
4	Decorative units	5.84	33.52	1.02	0.78	0.9	1.77	1.62	1.38	8.5	44.66
5		2.81	39.07	0	0	0	1.08	13.19	0	15.53	28.32

Intervention

Description

The intervention in the concrete floor of the balcony was carried out in the following sequence:

1) Supporting the balcony using lightweight scaffolding;
2) Dismantling of the decorative units from the balcony bottom (Fig. 15a);
3) Removing the old tiles from the balcony top (Fig. 15b);
4) Cleaning the top and the bottom flanges of the steel beams from corrosion products and dust;
5) Strengthening of the steel beams by adding steel plates of thickness 4mm perpendicular to the top and the bottom flanges and then connecting all the beams using steel plates of thickness 4mm from top and bottom (Fig. 15c and d and Fig. 16);
6) Filling the missed parts of the concrete floor using new concrete;
7) Adding flooring layers: steel mesh (Fig. 15e); cement mortar (Fig. 15f); water insulation (Fig. 15g); sand, cement mortar and ceramic tiles (Fig 15h), see also Figure 16.

For the decorative units, the following intervention sequence was followed:

1) Mechanical and chemical cleaning from peculiar colors and dust;
2) Fixation of pieces of gauze on the decorative units (Fig. 17a) and then sheets of foam and timber under the pieces of gauze for securing during dismantling process;
3) Dismantling of the decorative units (Fig. 17b) and then saving them in boxes;
4) Reproduction of the missed units using polyester molds created based on existing complete units found on other non-deteriorated decorative units in other balconies (Fig. 17c and d);

5) Re-attaching the decorative units to the balcony bottom using first stainless steel Fisher bolts (Fig. 17e), and then using gypsum mortar (Fig. 17f);
6) Recoloring using the same degree of old colors (Fig. 17g) and finishing (Fig. 17h).

Fig. 15. Main steps in the intervention in the balcony floor: a. dismantling of the decorative units; b. Removing the old tiles; c. Strengthening of the steel beams using longitudinal and transversal steel plates from bottom; d. Strengthening of the steel beams using longitudinal and transversal steel plates from top; e. Adding steel mesh from top; f. Pouring cement mortar above the steel mesh; g. Adding water insulation above the cement mortar; h. Adding the sand, cement mortar and the ceramic tiles

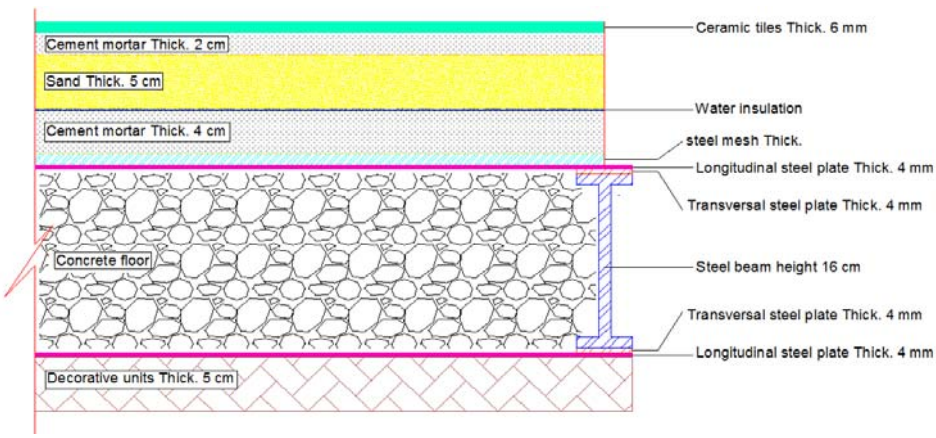

Fig. 16. Cross section in the balcony floor showing strengthening plates and flooring layers

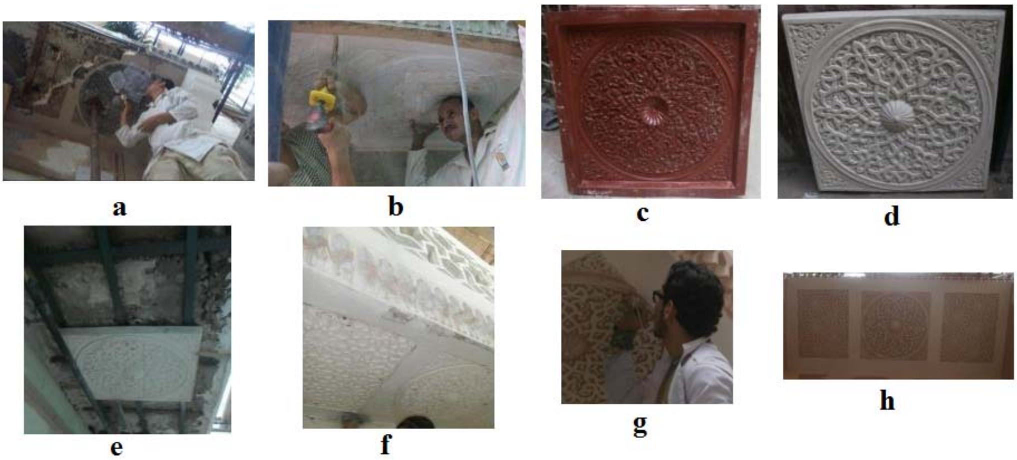

Fig. 17. Main steps of the restoration of the decorative units at the balcony bottom: a. Fixing gauze on the decorative units; b. Cutting the decorative units; **c.** Polyester mold. d. New cast decorative unit; e. Fixation using Fisher bolts; f. Finishing the fixation using gypsum mortar; g. Recoloring; h. After completion

Evaluation

In-situ static loading test

This test was carried out according to the provisions of the [8]. The testing load was calculated according to the following equation:

$$P = 0.85\ (1.4\ D + 1.6\ L) - D \qquad (1)$$

Where: P = testing load, D = Dead load = slab own weight + flooring = 300kg/m^2, L = Live load = 300kg/m^2 for balconies according to [9].

The testing load was applied incrementally. Each increment was equal to 25% P. After reaching 100% P, the load was left on the balcony for 24 hours. The deflection of the balcony was measured after each load increment using two dial gauges. Figure 18 shows the loading and the measured deflection during testing and Table 2 reports the deflection values after each load increment.

According to [8], the tested element is considered accepted if the following is satisfied:

$$\delta_{max} \leq L_t^2 / (20000 \cdot t) \qquad (2)$$

Where: δ_{max} is the maximum allowable deflection (mm), L_t is twice the balcony span (mm), and *t* is the balcony floor thickness (mm).

Substituting in the above equation δ_{max} was found as 0.288mm. This allowable deflection was higher than the maximum measured one 0.175mm. Therefore, the balcony after strengthening satisfied the code provisions.

Table 2. Loading and corresponding deflection during static loading test.

Loading value	Deflection (mm)		
	gauge (1)	gauge (2)	Average
0% P	0.00	0.00	0.00
25% P	0.04	0.02	0.03
50% P	0.07	0.09	0.08
75% P	0.10	0.13	0.115
100% P	0.15	0.16	0.155
100% P (after 24 hours)	0.17	0.18	0.175

Fig. 18. Static loading test: a. and b. Loading; c. and d. Measuring deflection

Numerical analysis

A Finite Element (FE) model of the balcony and the adjacent room was created using the software SAP 2000 version 15 [10]. This software has a friendly user interface and has been successfully used in the structural analysis of several historical structures such as [6, 11-16].

The aim of the numerical analysis was to exploit the results of the static loading test in updating the FE model. Afterwards, the updated FE model was used in assessing the deflection of the balcony under actual loads before and after strengthening. Doing so, it was possible to reveal the adequacy of the intervention. Numerical model updating based on experimental evidence is an efficient methodology in the study of historical structures. Several cases are found in the literature such as [17-19].

The case of the strengthened balcony was considered first. The concrete slab was modeled as shell elements. The steel beams and the steel plates used in strengthening were modeled as frame elements. The size of shell elements was about 0.09x0.09m. The model was composed of 2584 joints, 371 frame elements, and 2480 shell elements. The walls supporting the room floor were not modeled, instead, hinge supports were used (Fig. 19).

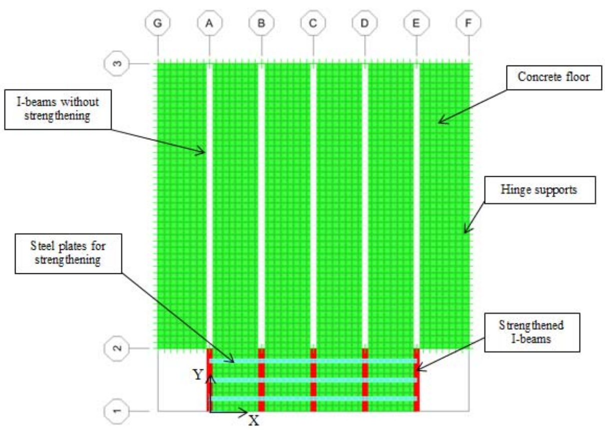

Fig. 19. FE model of the balcony and the adjacent room after strengthening

The model comprised the two materials of the concrete and the steel. Regarding the steel, the unit weight (γ) and the modulus of elasticity (E) were taken as 7800 kg/m^3 and 20 GPa, respectively. Regarding the concrete, as mentioned before, it is a historical concrete dating to the beginning of the 20th c. Its E and γ were not known. Initial values were assumed, and then, the FE model was loaded, similar to the static loading test, with 0%P, 25%P, 50%P and 100%P. The obtained numerical deflections were compared with the measured ones during the static loading test. Both of E and γ were updated until the numerical deflections were almost similar to the experimental ones.

The model updating was carried out manually according to the procedure summarized in Table 3. In phase I, E was taken similar to that one of the modern concrete 20 GPa, and γ was changed from 2500 kg/m^3 (similar to modern concrete) to 1000 kg/m^3 in four updating steps. It should be mentioned here that the detached parts of this concrete had a lightweight due to the usage of slag aggregate. Figure 20 shows the results of this phase of updating. In this figure, the positive deflection is upward and the negative one is downward. The unit weight value of 1250 kg/m^3 gave a good match between experimental and numerical deflections and was therefore selected to be used in phase II of the updating process.

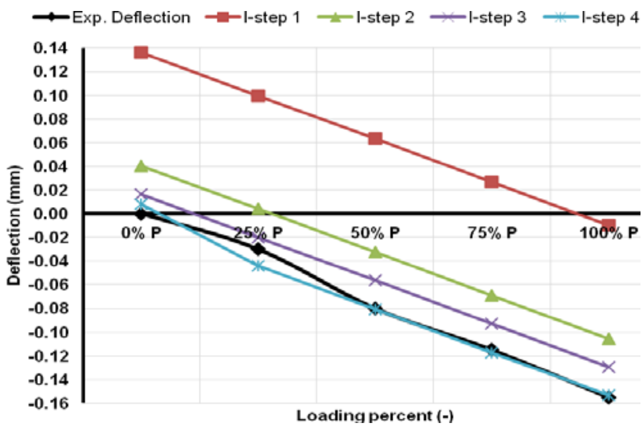

Fig. 20. Phase I of the numerical model updating

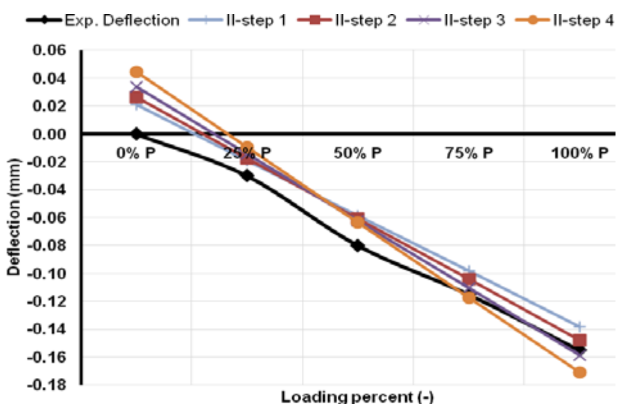

Fig. 21. Phase II of the numerical model updating

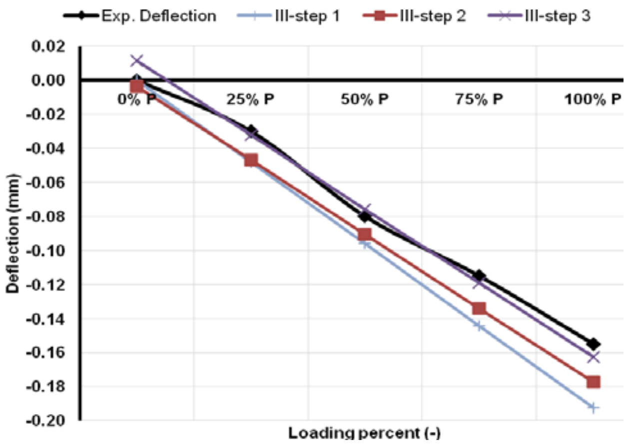

Fig. 22. Phase III of the numerical model updating

In phase II, the modulus of elasticity was changed gradually from 0.9 to 0.6 its initial value in four updating steps (Fig. 21). It was noticed that the two values of 0.8E and 0.7E resulted in numerical deflections near to the experimental ones.

In the last phase of updating, phase III, three steps were carried out. It was found that the best values for the modulus of elasticity and the unit weight of concrete were 1.6GPa (0.8E) and 1125kg/m^3, respectively. Using these values the experimental and numerical deflections were almost the same (Fig. 22).

Table 3. Phases of numerical model updating and corresponding E (GPa) and γ (kg/m^3) for concrete

Updating phase	Properties of concrete			
I	E = constant = 20GPa			
	γ (kg/m^3) = variable			
	I-step 1	I-step 2	I-step 3	I-step 4
	2500	1500	1250	1000
II	γ = constant = 1250kg/m^3			
	E = variable			
	II-step 1	II-step 2	II-step 3	II-step 4
	0.9 E	0.8 E	0.7 E	0.6 E
III	III-step 1	III-step 2		III-step 3
	0.7 E and γ = 1000	0.8 E and γ = 1000		0.8 E and γ = 1125

To reveal the efficiency of the intervention carried out, the model with strengthening was compared with that without strengthening. The applied loads were the slab own weight, the flooring, the parapet weight and the live load. In Figure 23, a comparison between the deflections of the two cases is shown, it can be noticed easily that the intervention resulted in a reduction in the deflection values. To show clearly the difference, the deflections of the points on the axis 1 (refer to Fig. 19) are plotted in figure 24 before and after strengthening. As observed, the maximum deflection value was reduced from about 0.24mm to 0.025mm. As well, the deflection of the points on three lines in the balcony shorter direction was plotted before and after strengthening (Fig. 25). These lines were on axes C, B and between the two axes (refer to Fig. 19). Again here, the maximum deflection value was reduced from about 0.24mm to 0.03mm.

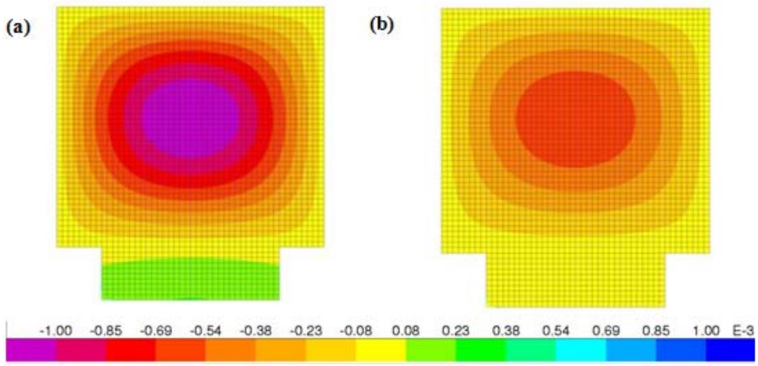

Fig. 23. Contours of the deflection (m) of the balcony:
a. Before strengthening; b. After strengthening

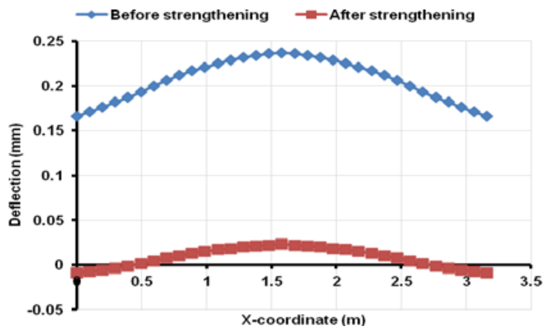

Fig. 24. Reduction of the deflection in the longer direction of the balcony after strengthening (points on axis 1 in Fig. 19).

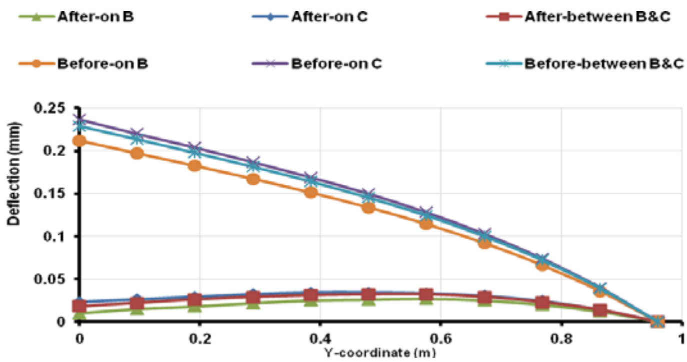

Fig. 25. Reduction of the deflection in the shorter direction of the balcony after strengthening (refer to Fig. 19 for locations of axes B and C).

Conclusions

The article reported the intervention carried out to restore a historic balcony in one the 20th c. architectural heritage buildings widely found in Cairo Down-Town. The balcony was made from cantilever steel beams supporting in-between lightweight concrete. The balcony suffered from the corrosion of the steel beams due to the infiltrated water from air-conditioning installed on the balcony. This in turn resulted in a heavy damage in the decorative units attached to the balcony bottom. Samples were taken from the balcony construction materials and tested using XRD and SEM-EDX. It was found that the concrete aggregates were mainly composed of hematite and quartz and the binding material was Calcite and Gypsum. Clear interference was found between the concrete components and the corrosion products from the steel corrosion.

The structural intervention was carried out by cleaning the corroded beams and then adding steel plates to the top and bottom flanges. Additionally, to increase the balcony rigidity, steel plates were added perpendicular to the top and the bottom flanges. The static loading test carried out to check this intervention showed that the balcony deflection satisfied the Egyptian code provisions. The FE model created for the balcony was updated using the measured experimental deflections. It was found that the best values for the modulus of elasticity and the unit weight of the concrete were $1.6 \times 10^6 t/m^2$ and $1.125 t/m^3$, respectively. The found lightweight of the concrete was due to the usage of slag as aggregate. The updated numerical model showed well the effectiveness of the intervention by reducing significantly the balcony deflection under the anticipated loads. A fine restoration was carried out to the decorative units found on the balcony bottom. A total dismantling and then re-attaching was carried out. The followed methodology reported in the article represents a good example that could be followed to safeguard many other 20th c. architectural heritage balconies composed of steel and concrete similar to the one discussed here.

References

[1] N. Rabbat, *Special problems in islamic and non Western architecture: Cairo, the history of a metropolis,* **Course Notes, Department of Architecture Massachusetts Institute of Technology**, 2011.

[2] M.A.S. Abou El-Ela, *Cultural globalization and changes in the urban form of metropolis cities. The case of Cairo*, **Proceedings of the 39th ISoCaRP Congress**, 17th-22nd October 2003, Cairo, Egypt, 2003.

[3] E. Abdel Sabour, S. Luoni, *Khedivial Cairo: An Evolved Metabolism,* **International Conference on Architectural Research**, 7th-10th June 2012, Mialno, Italy, 2012.

[4] J. Amedi, H. Nagler, C. Wessling, *Die Bedeutung der Erneuerung der Altstadt für die Entwicklung von Groß-Kairo,* **Megacities und Stadterneuerung** (Editor: Uwe Altrock), Universitätsverl der TU Berlin, 2009, pp. 307–326.

[5] S. Moustafa, S. Anwar, D. Ashraf, S. Ramadan, A. Elyamani, *The tomb of the High Priest of Aton in the regime of King Akhenaten: description, damage and restoration works,* **4th International Conference of Faculty of Archaeology, Cairo University, "Egypt and Mediterranean Countries through Ages"**, 14th-18th October 2015, Cairo, Egypt, 2015.

[6] A.A.O.D. El-Derby, A. Elyamani, *The adobe barrel vaulted structures in ancient Egypt: A study of two case studies for conservation purposes*, **Mediterranean Archaeology and Archaeometry, 16**(1), 2016, pp. 295-315.

[7] M.F. Awad, *Italian Influence on Alexandria's Architecture (1834-1985),* **Environmental Design,** Journal of the Islamic Environmental Design Research Centre, 1990, pp. 72-85.

[8] * * *, ECP-203, **Egyptian Code for Practice-203 for Design and Construction of Reinforced Concrete Structures**, Housing and Building National Research Center, Ministry of Housing, Utilities and Urban Development, 2007.

[9] * * *, ECP-201, **Egyptian Code for Practice-201 for Design Loads on Structures**, Housing and Building National Research Center, Ministry of Housing, Utilities and Urban Development, 2012.

[10] * * *, **SAP2000 v15 Integrated Finite Element Analysis and Design of Structures**, CSI (Computers and Structures Inc.), Berkeley, 2011.

[11] S.T. Beeson, J. Kubin, A.I. Unay, *Seismic vulnerability of historical masonry structures with irregular geometry*, **Gradevinar, 67**(2), 2015, pp. 151-158.
[12] H. Alexakis, N. Makris, *Structural stability and bearing capacity analysis of the tunnel-entrance to the stadium of ancient Nemea,* **International Journal of Architectural Heritage**, **7**(6), 2013, pp. 673-692.
[13] G. Brandonisio, A. De Luca, A. De Martino, G. Mautone, *Restoration through a traditional intervention of a historic unreinforced masonry building "Palazzo Scarpa" in Naples*, **International Journal of Architectural Heritage, 7**(4), 2013, pp. 479-508.
[14] F. Behnamfar, M. Afshari, *Collapse analysis and strengthening of stone arch bridges against earthquake*, **International Journal of Architectural Heritage**, **7**(1), 2013, pp. 1-25.
[15] Z.Y. Illerisoy, A. Soyluk, *Impact of shallow Earthquakes on the Sehzade Mehmet Mosque*, **Gradevinar, 64**(9), 2012, pp. 735-740.
[16] O.C. Celik, H. Sesigur, F. Cili, *Seismic evaluation and retrofit of a 16th century historic brick masonry dome in Istanbul using combined steel rings and CFRP sheets*, **14th World Conference on Earthquake Engineering**, 12th-17th October 2008, Beijing, China, 2008.
[17] O. Caselles, J. Clapes, P. Roca, A. Elyamani, *Approach to seismic behavior of Mallorca cathedral*, **15th World Conference of Earthquake Engineering**, 24th-28th September 2012, Lisbon, Portugal, 2012.
[18] A. Elyamani, *Integrated monitoring and structural analysis strategies for the study of large historical construction. Application to Mallorca cathedral*. **PhD Thesis**, Technical University of Catalonia, Barcelona, Spain, 2015.
[19] A. Elyamani, P. Roca, O. Caselles, J. Clapes, *Seismic safety assessment of historical structures using updated numerical models: The case of Mallorca cathedral in Spain*, **Engineering Failure Analysis, 74,** 2017, pp. 54-79.

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