Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 70 (1993)

Artikel: The study of an old palace structure and its repair

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DOI: https://doi.org/10.5169/seals-53361

The Study of an Old Palace Structure and its Repair

Etude de la structure d'un vieux palais et sa réparation

Studie eines alten Palastes und seine Reparatur

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SUMMARY

This is a comprehensive study carried out to diagnose and assess the reinforced concrete quality and structural safety of an old historic palace in Alexandria. The study covered different in-situ non-destructive tests carried out on concrete as well as mechanical tests carried out on steel bars to assess the materials quality and performance. Wooden trusses which represent the structural system on one of the main palace halls were structurally checked. Repair recommendations and techniques for the reinforced concrete elements and the wooden trusses have been brought up based on the corresponding study and analysis.

RÉSUMÉ

Cette étude vise à analyser et à évaluer la qualité du béton armé et la sécurité de la structure d'un palais historique à Alexandrie. Elle couvre différents essais, non destructifs, effectués en chantier sur le béton ainsi que des essais mécaniques sur les barres en acier afin d'en évaluer la qualité et la performance. Les poutres en bois, qui représentent le système structural d'une des principales salles du palais, furent examinées du point de vue structural. Les réparations et les techniques recommandées pour les éléments en béton armé ainsi que les poutres en bois, sont le résultat de cette étude.

ZUSAMMENFASSUNG

Der Artikel bewertete die Qualität armierter Betonelemente und die Tragfähigkeit eines historischen Palastes in Alexandria. Es wurden zerstörungsfreie In-situ-Versuche am Beton sowie mechanische Versuche an Bewehrungsstählen durchgeführt. Das Ziel war die Bewertung der Baumaterialien und ihrer mechanischen Beschaffenheit. Die Holzbalken, als wichtigste tragenden Elemente in einer der Haupthallen des Palastes, wurden strukturell untersucht. Aufgrund der gemachten Analysen und Versuche wurden Empfehlungen für die Reparatur des armierten Betons und der hölzernen Tragbalken abgegeben.

1. INTRODUCTION

In many countries engineers are confronted with problems of architectural heritage (such as historical buildings, monuments, bridges, etc.) needing structural repairs of retrofitting. The recent collapse of monumental buildings has shown that their vulnerability may not only be a risk of loss of a precious masterpiece but also a risk of human life. An important task for structural engineers is growing, and the corresponding knowledge and professional tools need to be developed. Extensive research work has been carried out in that field, Ref.[1-3]. The place under study is located in Alexandria and overlooks the Mediterranean Sea. It consists of two parts, the main building (the old structure) which was built more than one hundred and twenty years ago and the extension building (the new structure) which was built about fifty years ago.

2. DESCRIPTION OF PALACE STRUCTURE

2.1 The Main Building (the old structure)

This building was well maintained and in a good condition. Nevertheless, there was water leakage in one of its major halls. Figure (1) shows the layout of the hall under study. This hall is one of the most luxurious halls in the palace. The ceiling and walls contain precious masterpiece decorations. The main hall was 18 meters long and 11 meters wide. Connected to this hall from one side was an entrance hall (9 m x 7 m) and from the other side to a hall (9 m x 4.3 m) connecting it to the main throne hall.

The structural system consists of load-bearing masonry wall with a thickness of about 70 cm. The precious decorative false ceiling was hung by means of wooden trusses and beams resting on the bearing walls. The spacings between the trusses were 1.70 m, and between the trusses there was a wooden beam at the same level of the bottom chord of the trusses, as shown in Figure (1). Figure (4) shows the dimensions of a typical truss.

2.2 The Extension Building (the new structure)

The building consists of a basement, ground floor, first floor and a second floor. Figure (3) shows a general layout of the ground floor only. The area of each floor was 2000 m^2. The structural system consists of load-bearing walls and reinforced concrete slabs. Columns were sometimes used in lobbies and terraces but were not considered as a major supporting structural element.

3. VISUAL INSPECTION

From inspecting the hall false ceiling of the main building, sagging of the decorated false ceiling was noticed as well as traces of water leakage. But nevertheless, from inspecting the hall from the space between the false decorated ceiling and the roof, longitudinal cracks were quite visible in beams and trusses.

Figure (2) shows the extension building and a sample of the damaged parts. The building was abandoned for sometime and badly maintained. Traces of water leakage could be seen from water piping system at the basement, at the bathroom and at ceiling walls of the top floor (due to rain). Cracks and spalling of concrete could be seen in reinforced concrete elements, while some uncovered corroded steel reinforcement bars were detected.

4. EXPERIMENTAL TESTS CARRIED OUT ON THE REINFORCED CONCRETE

It was taken in to consideration that the tested specimen and testing locations were representative to the different degrees of damage. Figure (3) shows a sample of types and locations of such tests. Core specimens were extracted from various locations, their equivalent cube strength and chemical analysis (percentage of chlorides) are presented in Table (1). Schmidt Hammer test applications were carried out, a sample of these tests are presented in Table (2), and mechanical testing of steel bars for concrete reinforcement are presented in Table (3).

5. ANALYSIS OF DATA

5.1 The hall of the main building

The dimensions and features of the supporting trusses as well as beams were all measured from the site condition. Loads acting on the truss due to the top roof and decorated false ceiling were calculated. Stresses were checked for all critical sections and were within the permissible values.

5.2 The extension building

In general concrete is known to be a porous material. Therefore, due to the presence of harmful amounts of chlorides in concrete and with the help of moisture gained (i.e. absorbed due to water leakage, the humid environment, etc..) it would slowly penetrate the concrete. When the chlorides reaches the reinforcing steel, the natural corrosion protection barrier on the steel surface breaks down, and the corrosion process begins. Corrosion generated rust that increases the volume of the original steel. The corroding steel stresses the surrounding concrete, eventually forming cracks around the reinforcing bars. Therefore more salt and water enter as cracks reach the surface and the process feeds on itself. Tests carried out on concrete specimen summarized the following:

- Equivalent cube strength obtained by means of Schmidt Hammer rebound numbers revealed that the compressive strength was within the permissible values for such structural elements. The lower values of compressive strength at level two was mainly due to water leakage that affected the surface hardness of the concrete in that area.
- Compressive strength results based on core tests reveals a fluctuation of the concrete strength from a value of = 164 kg/cm^2 to a value of = 375 kg/cm^2. Although an increase of about 20% to such results could be made for the difference between in-site conditions and standard cube strength in the laboratory. Yet it reflects a lack of quality control applied to the concrete at the times as a whole.
- The chlorides content obtained for the different specimen representing the different floor ranged from the permissible values of = 0.205% to values of as high as 0.645% of cement weight which greatly exceeds the permissible values of 0.30% of cement weight. Hence steel bars embedded in such a concrete would be prone to corrosion attack.
- Concrete cover was removed in several locations to verify visually the effect of rust. Tests were carried out on samples of such bars. Table (3) shows some examples of poor results obtained by such tests on the reinforced bars. Reduction of steel

Core Test I.D.	Floor No.	Structural Element	Compressive Strength kg/cm²	% of Chloride	Steel Bars Remarks
C	Basement	Cont. footing	298	0.226	
D	Basement	Cont. footing	282	0.368	
E	Basement	Slab	346	0.468	Pitting Corrosion
F	Basement	Slab	369	0.357	
G	Ground	Slab	236	0.645	
H	Ground	Slab	210	0.567	
I	Ist Floor	Slab	164	0.230	Corrosion of Steel Bars with a Visible Reduction of Diameter
J	Ist Floor	Slab	375	0.205	
A	2nd Floor	Slab	262	0.444	
B	2nd Floor	Slab	189	0.210	

Table (1) Results of Core Tests

Sample Identification	Basement Slab	Ist Floor Bathroom	2nd Floor Terrace	2nd Floor Lobby
Nominal Diameter mm	9.4	9	10.5	10.8
Measured Diameter mm	9.31	8.95	10.17	9.45
Yield Strength kg/cm²	2653	3680	2542	2119
Tensile Strength kg/cm²	3575	4246	3281	2796
Elongation %	9.5	14.5	10	29
Remarks	Minor Corrosion	Corrosion & Reduction in Area	Severe Corrosion	Minor Corrosion

Table (3) Mechanical testing of steel bars

Test No.	Floor No.	Structural Element	Average Rebound Number R.N.	Equivalent Cube Strength kg/cm²
32	Basement	Slab	41.9	397
33	"	Beam	33.1	311
6	Ground	"	41.0	380
2	Ist Floor	"	36.9	299
9	2nd Floor	"	27.7	143

Table (2) A sample of the Schmidt Hammer (R.N.) tests diameters were quite visible especially in parts where pitting corrosion was observed. In general, pitting corrosion was obtained in bars embedded in concrete of the basement and ground floors where a large amount of CI% was obtained by means of the chemical tests. While uniform corrosion on bars was detected in the first and second floors where leaking water was observed as could be seen from Table (1).

6. RECOMMENDATIONS AND METHODS OF REPAIR

6.1 The hall of the main building

Figure (4 and 5) illustrates the method used in repairing and strengthening the trusses of the hall. The following procedure was adopted:

- Collars were primarily loosely installed every about 50 cm to the truss members.
- The cracks were filled with a bonding material consisting of saw dust and an epoxy adhesive. Care was taken during filling to avoid any voids.
- The bolts of the collars were then tightened (during the initial drying period), thus forcing out any voids in the viscous epoxy and providing uniform bonding between the sides of the crack.
- Finally, the wooden structure was painted by an epoxy resin protecting it from humidity, decay and any environmental conditions.
- Leakage of water at the roof was fully checked and repair was carried out to ensure that no leakage would occur in the future.

6.2 The extension building

The following repair procedure was recommended:

- A full check and repair of the rain water drainage system, plumbing and maintenance of the building.
- Removal of all concrete cover for steel reinforcement where concrete has been affected and removal of all rust that might be found on the reinforcement bars by means of sand blasting.
- Areas where steel reinforcement was excessively corroded should be replaced by new bars.
- Steel bars should be covered by a protective layer against rust and bars should be covered by a bonding agent layer to ensure a good bonding between steel and newly placed concrete cover.
- Shot creeting with a dense mix ensuring that the mix fills in all the voids between steel bars and main concrete body.

7. CONCLUSION

1. The hall of the old building which is bearing wall with a false ceiling suspended by wooden trusses was proven safe. The deterioration of the ceiling was mainly due to water leakage while the cracks in the wooden truss members were mainly due to old age and lack of maintenance.
2. The method used in repairing the wooden trusses proved to be reliable on the grounds that the repair works has already been completed and no signs of cracks has appeared.

3. Deterioration of the extension building (reinforced concrete elements) as a whole was due to bad usage and poor maintenance. Corrosion of steel bars was mainly due to high chloride percent (>0.3%) and water penetration in concrete.
4. Old historical buildings based on old structural designs and methods of construction should be periodically checked and maintained as they are a symbol of national heritage and assets.

ACKNOWLEDGEMENTS

The author acknowledges the support of the Structural Engineering Department and its laboratories at Arab Consulting Engineers (Moharram-Bakoum).

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(3) Wood Design and Construction, Maurice J. Rhude, Standard Handbook for Civil Engineers, McGraw-Hill Company, 1976.

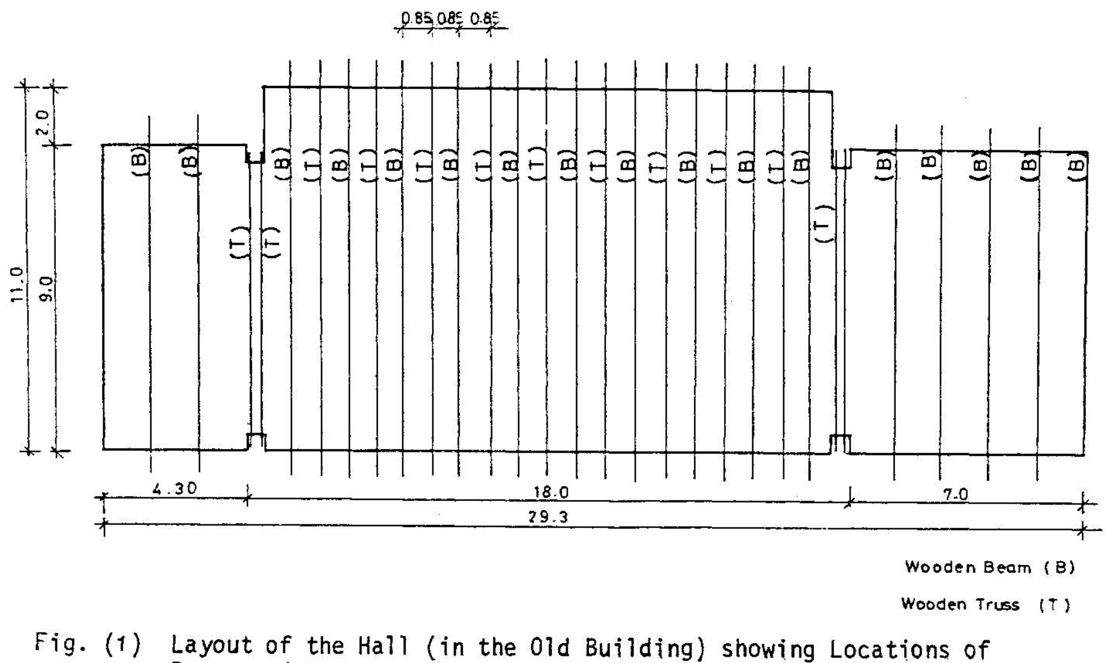
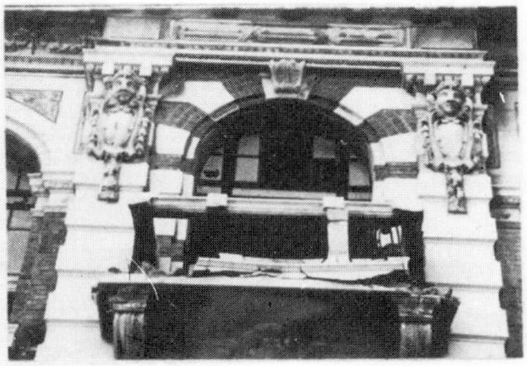
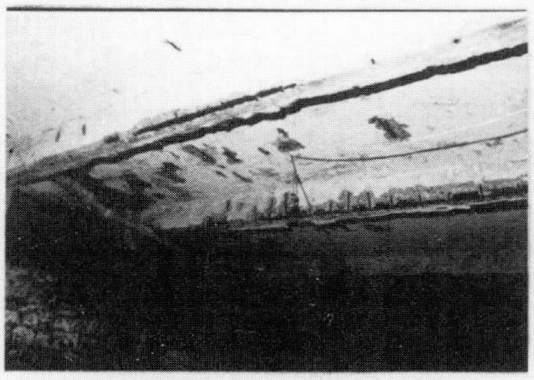


Fig. (1) Layout of the Hall (in the Old Building) showing Locations of Beams and Trusses

(a) Part of the Extension Building

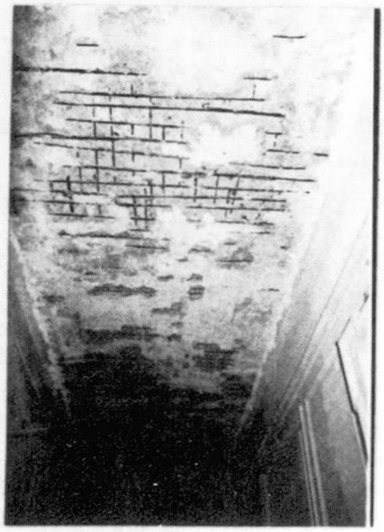


(b) A Balcony

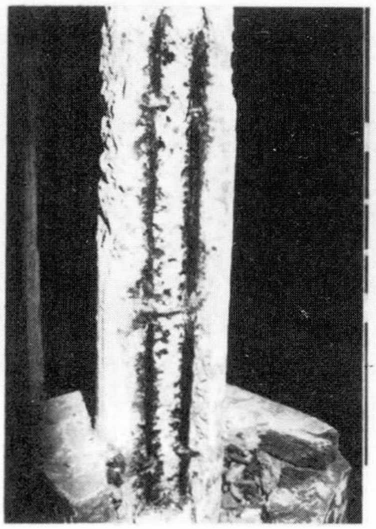


(c) The Basement

(d) The Terrace



(e) A Slab



(f) A Column

Fig. (2) Photos taken to the Extension Building showing a sample of the damaged parts

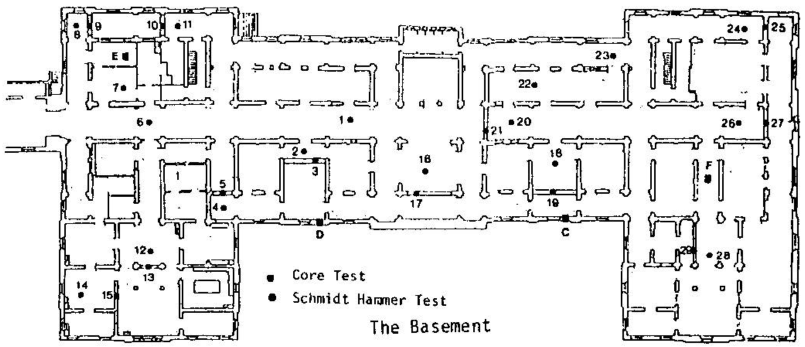


Fig. (3) Layout of the Extension Building (New Building) showing Locations of Tests

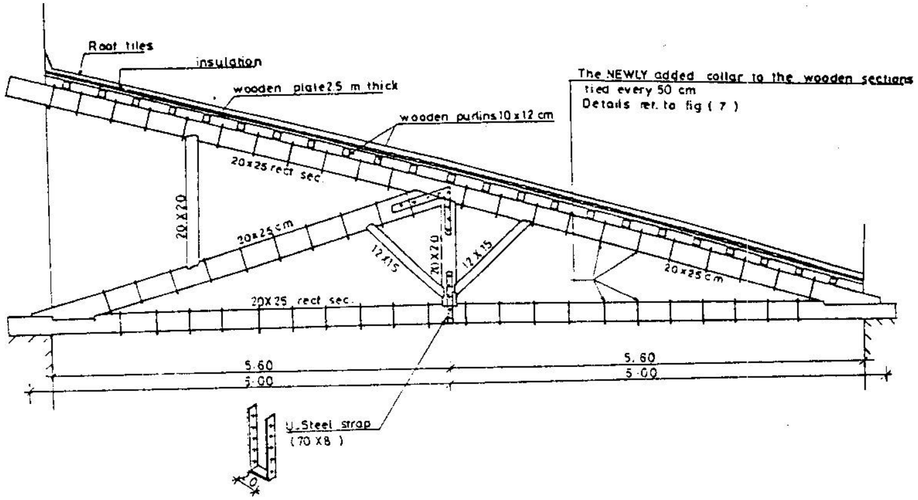


Fig. (4) A Typical Truss of the Old Building Hall (after repair).

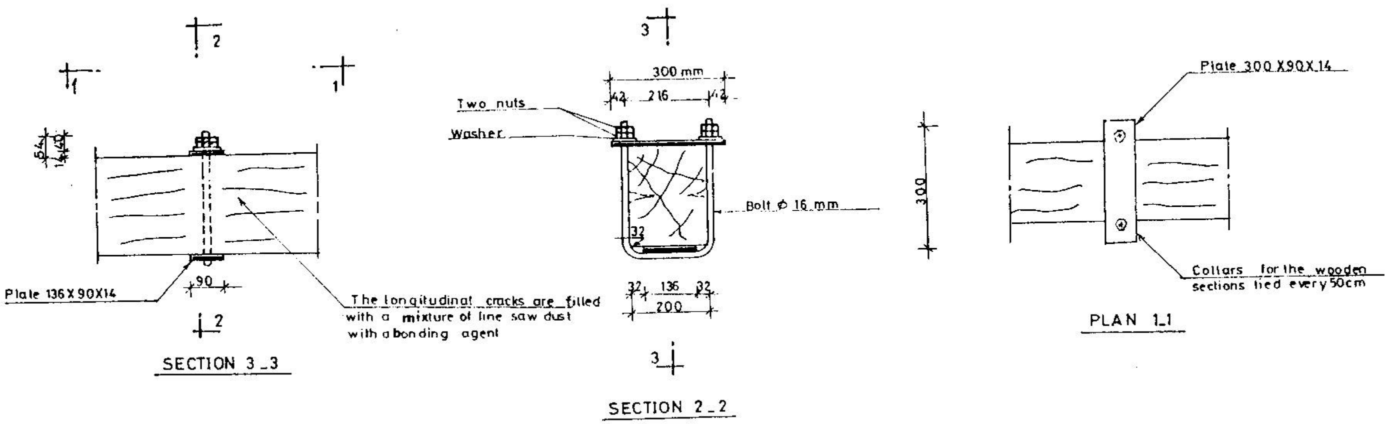


Fig. (5) Collar Details which were connected to the Truss Members