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Use of FRP in Egypt, Research Overview and Applications

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Abstract

Advanced Composite Materials, (ACM), have been used in civil engineering applications in Egypt over the last two decades. Significant progress has been made in the use of ACM in the form of fibre reinforced polymers, (FRP), to repair, rehabilitate and upgrade aging or damaged structures. Egypt has released its national code for design and application of FRP in construction fields addressing both externally bonded and internal FRP reinforcement in concrete elements. As a result, the use of FRP for repair, strengthening and retrofitting of structures have become a very well accepted practice in Egypt. The code has been issued after a series of successful rehabilitation projects and extensive studies at different research institutions in Egypt. This paper presents a general overview on samples of the research activities in Egypt for using FRP in strengthening concrete structures. FRP laminates are applied for strengthening slabs or beams in flexure and shear as well as for confinement of reinforced concrete, (RC), columns. Different research programs carried out in Egypt in the field of FRP are presented. This research is an outcome of collaboration between different universities and research institutes in Egypt. The paper also presents field applications of FRP strengthening of special structures in Egypt. Selected projects utilizing ACM in the form of externally bonded FRP laminates to strengthen existing reinforced concrete structures are presented. Historical buildings such as the Egyptian Museum and Kaitbay Fence were rehabilitated after distress/deterioration caused by corrosion of steel reinforcement and lack of maintenance.. Design concepts and constructional details are presented for each project.

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Keywords: applications; code; composite materials; fibre reinforced polymers; historical buildings; laminates; research; strengthening.

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1. Introduction

Egypt is challenged by the rapid deterioration of concrete structures due to corrosion of steel reinforcement. The long coasts on the Mediterranean and the Red Sea cause an adverse environment that accelerates corrosion of steel. Use of advanced composite materials, (ACM), in the form of Fibre Reinforced Polymer, (FRP) in the construction fields has received a special attention in Egypt during the last two decades. This is attested to by the issuance of first formalized Egyptian FRP code (Housing and Building National Research Centre 2005), which is considered to be the second stand alone FRP code to be available worldwide. A large number of research projects was carried out and a series of international conferences under the title "Middle East Symposium on Structural Composites for Infrastructure Applications", were held regularly in Egypt every three years since 1996 (Egyptian Society of Engineers 1996, 1999, 2002, 2005, 2008). As a result, the use of FRP for repair, strengthening and retrofitting of structures have become a very well accepted practice in Egypt.

This paper addresses recent applications of ACM in different projects in Egypt presenting the design concepts and constructional details for use of FRP laminates to strengthen RC structures. Historical buildings such as the Egyptian Museum in Cairo and Kaitbay Fence were rehabilitated after distress/deterioration caused by corrosion of steel reinforcement and lack of maintenance. Strengthening of special projects such as the dolphin piles in Abou-Kier harbour is also reported after cracking occurred due to ship hit.

2. The Egyptian FRP Code

In April 2002, the Egyptian Minister of Housing, Utilities and Development, established the first Egyptian FRP Standing Code Committee. The code was approved by the Egyptian Authorities in December 2005 and became the first formalized design code addressing FRP in Egypt (Housing and Building National Research Centre 2005). It is pointed out that with the exception of both the Canadian (CAN/CSA-S806-02 2002; CAN/CSA-S6-00 2000) and the Egyptian FRP codes, all other available FRP documents are intended to provide guidance for the use of FRP materials and do not carry the weight of design standards (ACI 440R-07 2007). In this regard, Egypt has taken a leading role in utilizing FRP technology in the construction fields not only in the middle east but also worldwide.

In the development of the Egyptian FRP Code (Housing and Building National Research Centre 2005), the most up-to-date versions of Canadian code (CAN/CSA-S806-02 2002) and a number of guidelines, including ACI440 and Fib and other guidelines were considered (ACI 440-02 F Guidelines 2002; ACI 440-06 H Guidelines 2006; ACI 440-04 K Guidelines 2004; Fib (CEB-FIB) 2001; JSCE 2002; ISIS Canada 2001). Accordingly, the Egyptian FRP code reflects the state-of-the-art of the FRP technology currently available worldwide. The formalized Egyptian FRP code is based on the principles and philosophies of the limit states design method of the formalized Egyptian Code for the design and construction of Concrete Structures (Housing and Building National Research Centre 2007). However, since the mechanical properties of the commercially available FRP materials are different from those of steel, it is expected that the design principles and the resulting safety requirements of the FRP code will be different from those of the reinforced concrete code in a number of applications.

The Egyptian FRP Code comprises five chapters, as follows:

Chapter 1: *Scope and Design Fundamentals.*

Chapter 2: *Properties of FRP Constituent Materials and Systems*

Chapter 3: *Durability of FRP Systems*

Chapter 4: *The Use of FRP For Strengthening and Repair of Reinforced Concrete Structures*

Chapter 5: *Design of Concrete Reinforced with FRP Bars*

Appendix I: *Guide for Test Methods for FRP*

The first Chapter covers information pertaining to the scope of applications of FRP systems in the construction fields and the basic design philosophies and fundamentals of the code. The second and the third chapters provide information pertaining to the properties of FRP materials and the durability of FRP works, respectively. The scope of applications utilizing FRP in the Egyptian code is limited only to two types of applications, namely; (1) Strengthening and Repair of Concrete Structures and, (2) the use of FRP bars as Reinforcement for Reinforced Concrete Structures, as outlined in Chapters 4 and 5, respectively. The Egyptian FRP Code, consistent with the Egyptian Concrete Code , prescribe a material – resistance factors approach related to the ductility of failure mode considered, importance of the structural element, in addition to all durability-related criteria with the exception of fire resistance. The code is 212 pages and published in both Arabic and English languages.

3. Research Programs

The main objective of the coordinated program of research on strengthening structures using composite materials is to develop an understanding of the behaviour of concrete structures strengthened with FRP. This included development of a database of previous and pending research programs. The on-going research projects include strengthening of rectangular columns subjected to axial loading and eccentric loading under cyclic loading. The columns are strengthened with FRP from three and four sides to represent the case of an edge and interior columns. The research programs also include flexural behaviour of hollow core prestressed slabs strengthened with carbon FRP laminates. Research programs on two-span continuous beams and two-hinged frames strengthened with FRP subjected to short- and long-term loading are also discussed.

3.1. Rectangular Columns

Confinement of RC columns with circular or square cross section using FRP laminates in the transverse direction has been applied successfully for seismic rehabilitation. It is reported that FRP is much less efficient for case of rectangular columns (ACI 440-02 F Guidelines 2002). This is due to the out-of-plane deformation of the laminates induced by the axial loading. Rectangular columns, with aspect ratio up to one-to-five, are commonly used in residential buildings. This is because it meets the architectural requirements in cases where partitions are provided in the building. Therefore, there is an urgent need to upgrade these columns for seismic rehabilitation. Different research programs were carried out to enhance the axial as well as the flexural capacity of the columns.

Figure 1. Test Set-up of rectangular columns under axial loads

Figure 2. Failure of a rectangular column subjected to axial load

The first research program consists of three phases; the first phase investigates enhancement of the axial capacity and ductility of rectangular columns. An experimental program was conducted on rectangular RC columns strengthened with carbon FRP, (CFRP), laminates. A total of twelve columns with aspect ratio of one-to-three and overall dimensions of 150 x 450 mm and 2100-mm height were tested (Hosny et al. 2002). One and two layers of CFRP laminates were wrapped around the columns at different intervals between the wraps. Different types of anchorage systems were suggested to prevent the out-of-plane deformation of the laminates. The results show that the axial strength of the rectangular columns can be increased up to 90 percent. Anchoring the laminates is much more effective than increase of the number of FRP layers. Fig. 1 and 2 show one of the testing set-up and one of the tested columns after failure

An analytical model based on the stress-strain characteristics of concrete under triaxial state of stresses was proposed. The model could predict with a good agreement both the axial carrying capacity and ductility of the columns. Fig.3 shows a comparison between the predicted and measured maximum loads of the tested specimens.

The second phase of the first research program focuses on the flexural enhancement of rectangular columns under constant axial loading and cyclic lateral loading. The experimental program consists of twelve columns tested using different CFRP and glass FRP, (GFRP) ratios and different anchorage schemes (Shahin et al. 2002). The columns had a cross section similar to that used in the first phase of the program. The columns were tested using two reaction frames to apply the axial and cyclic lateral loads as shown in Fig.4. It is concluded that both CFRP and GFRP can be used successfully to enhance the seismic performance of rectangular columns. Unlike the conventional techniques for strengthening, the initial stiffness of the retrofitted columns is similar to that of the original one. It is also concluded that increasing the CFRP volumetric ratio improved the overall behavior of the column. However, it is recommended to increase the number of CFRP layers instead of reducing the spacing between the layers.

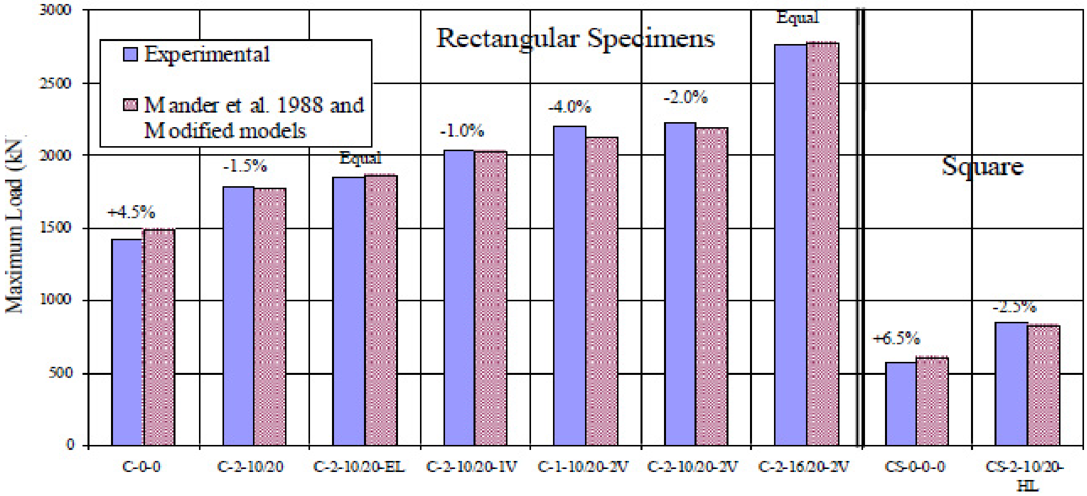


Figure 3. Predicted vs. measured ultimate loads of the columns

Figure 4. Test Set-up for rectangular columns tested under cyclic load

The third phase of the program investigates the efficiency of CFRP wrap when used for edge or corner columns. Five RC columns of dimensions 125 x 300 mm were wrapped from two and three sides with CFRP wraps. The wraps are anchored with CFRP anchors at the ends of each CFRP laminate. The tests are currently carried out at the RC Research Laboratory in Ain Shams University. The columns are subjected to a monotonic axial load up to failure.

3.2. Strengthening of Concrete Beams

Two series of beams were tested to investigate the flexural behavior of beams strengthened with CFRP strips. In the first series, rectangular beams were tested using four-point configuration (Bakhoum and Abdelrahman 1999). The beams were simply supported with 2.1 m span. The CFRP strips were placed at the bottom as well as on the sides of the beams as shown in Fig. 5. An increase in the flexural capacity of the beams up to 95 percent was observed. Analytical study was conducted to predict the flexural behavior of the beams. It is concluded that bond of CFRP strips controls the flexural behavior of the beams. Several attempts were taken to increase the bond characteristics of the strips by applying new concrete cover or by using mechanical anchors at the end of the strips.

In the second series, a group of eight two-span continuous beams strengthened with CFRP strips will be tested. The steel reinforcement ratio is varied from 0.5 to 0.8 percent in the sagging moment zone. The ratio between the steel reinforcement in the hogging and sagging moments was designed based on elastic analysis of the beam. CFRP strips were glued only on the bottom surface of two beams and on the top surface of another two beams.

Figure 5. Application of CFRP strips on the bottom and sides of concrete beams

3.3. Flexural Strengthening of Prestressed Slabs

Hollow core prestressed slabs is one of the commonly used systems to cover floors with long spans. This is particularly true for industrial building and multi-purpose halls. Flexural strengthening of these slabs was required recently due to either change in use or increase in the service load. A group of nine slabs strengthened with different schemes of CFRP strips and sheets was tested Hosny et al. 2003. The slabs were 5.0 m span, 1.2 m wide and 0.2 m thick. Fig. 6 shows the tested slabs during application of externally bonded CFRP. It is concluded that CFRP sheets are more effective in strengthening the slabs than the strips as shown in Fig. 7. The load-deflection curves show that an increase in the flexural capacity up to 25 and 40 % was achieved for slabs strengthened with CFRP strips and sheet, respectively. This is mainly to the better bond behaviour of the CFRP sheets.

3.4. Strengthening of Concrete Frames

A comprehensive two-phase experimental program is being carried out to study the behaviour of reinforced concrete frames strengthened with FRP (Okba et al. 2002). The first phase in the program consists of eleven two-hinged frames tested under short-term flexural loading. The frames have different reinforcement ratios at the mid-span and at the joints. Different strengthening schemes using CFRP and GFRP laminates were used. FRP laminates were bonded to the tension face for at the mid-span and/or at the joint section.

Figure 6. Prestressed slabs strengthened with FRP

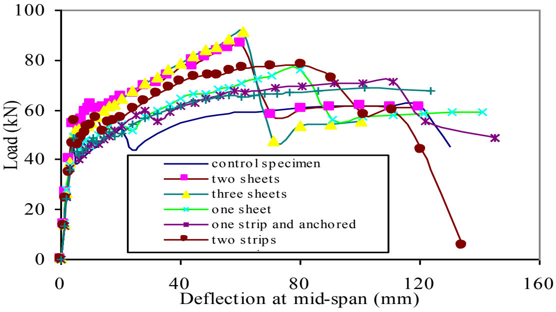
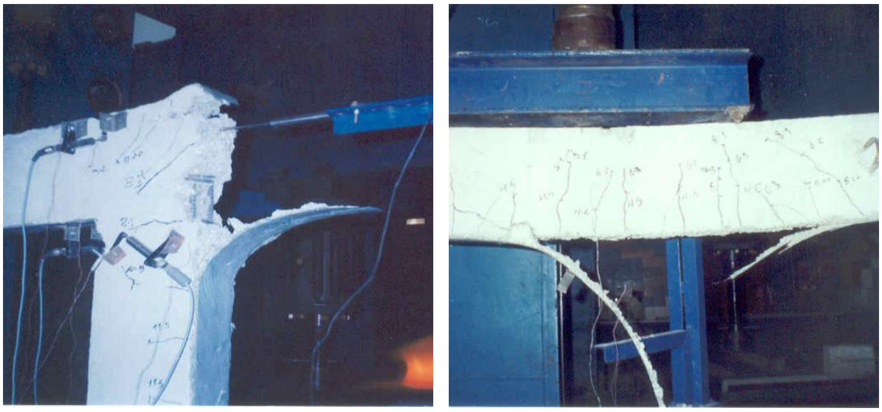


Figure 7. Load-deflection of slabs

The specimens in the first phase consisted of three groups. Both the first and second groups consisted of four frames while the third group consisted of three frames. Steel reinforcement of frames in the first group was designed based on elastic analysis of the frames taking into consideration the stiffness of the columns and girders. Steel reinforcement of frames in the second and third groups was selected to be deficient at the joint and the mid-span sections, respectively. The first group had reinforcement ratio of 0.72 % as flexural reinforcement at both the mid-span and joint sections. The Second group had a reinforcement ratio of 0.72 and 0.5 % as flexural reinforcement at the mid-span and joint sections, respectively. While the steel ratio was 0.5 and 0.72 % at the mid-span and joint sections, respectively, for the third group. Fig.8 shows the testing set-up of the frames in phase (1). Figs.9 and 10 show two tested frames, failed by rupture of FRP laminates at the joint and mid-span sections, respectively.

Figure 8. Test set-up of RC frames



Figures 9 and 10. Failure modes of FRP-strengthened-RC frames

In the second phase of the program, four RC frames were subjected to long-term loading and the deflection was monitored with time. Moment redistribution of the tested frames is evaluated and compared to the permissible values according to different codes. Frames strengthened with FRP laminates at the mid-span section only had moment redistribution up to 30 %. No severe cracking or excessive deflections were observed under service loads.

4. Field Application of FRP Strengthening in Egypt

Application of ACM in Egypt so far is limited to strengthening of existing structures using externally bonded FRP reinforcement. This could be attributed to the high cost of other products such as reinforcing and prestressing FRP bars or pultruded sections. In this respect, it should be mentioned that internationally most of the FRP applications are related to strengthening of existing structures. The first FRP strengthened project in Egypt was completed in 1998 (Abdelrahman 2003). The following projects have been selected to demonstrate different applications of FRP in strengthening and retrofitting of existing structures in Egypt.

4.1. Strengthening of Historical Buildings

This section addresses the strengthening techniques of several historical buildings in Egypt including the Egyptian museum and Kaitbay fence. CFRP laminates were used in the two projects after performing a through structural analysis of the buildings and a detailed study of the problem.

4.1.1. The Egyptian Museum

The Egyptian museum was established in 1900 and celebrated the year 100 of having the first permanent Egyptian museum. It is by far the most valuable museum of Egyptian antiquities, which are the treasures of the greatest civilization in the world. The building (shown in Fig.11) contains a series of reinforced concrete arches of 17 meters span and 13.0 meters clear height. The concrete arches are supported on brick masonry walls, as shown in Figs. 11b and 12. The arches are reinforced by longitudinal steel reinforcing bars at the bottom soffit and steel stirrups of rectangular cross section as shear reinforcement. Concrete deterioration due to corrosion of both the longitudinal and transverse steel reinforcement was observed, as shown in Fig. 13.

a **b**

Figure 11. Picture of the museum (left shows external, right shows internal)

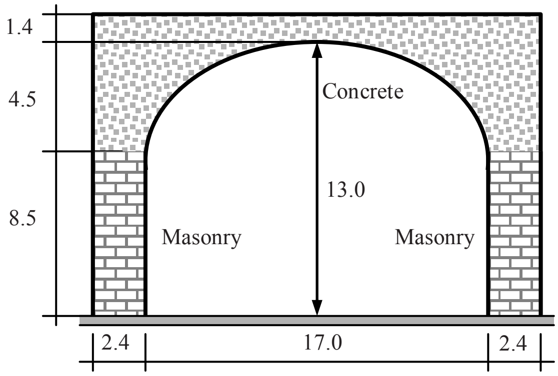


Figure 12. Schematic of the arch

Figure 13. Corrosion of the steel reinforcement

It was decided to strengthen the arches using carbon fibre reinforced polymer, (CFRP), laminates after treating the corrosion of the steel reinforcement. The construction was challenged by the very limited time allowed for applying the strengthening scheme in order to avoid closing the museum for the visitors. The strengthening scheme included flexural CFRP strips with 1.2 mm thickness attached to the bottom face of the arch and CFRP sheets with 0.13 mm dry fibre thickness attached to the sides, as shown in Fig.14. The transverse CFRP sheets were applied at close spacing to provide anchorage for the flexural CFRP strips and prevent possible peeling resulting from the curvature of the bottom soffit of the arch, in addition to its contribution in the shear capacity enhancement. Special detail was used to anchor the transverse sheets using CFRP anchors to enhance its bond capacity, as shown in Fig.14. The anchors were tested experimentally at the Reinforced Concrete Research Laboratory, Ain Shams University to ensure its efficiency in preventing the bond failure of short CFRP laminates. The project was completed and the museum was never closed to the visitors during construction. More design details and construction aspects can be found in the design report by the consultants (Abdelrahman and El-Ghandour 2004).

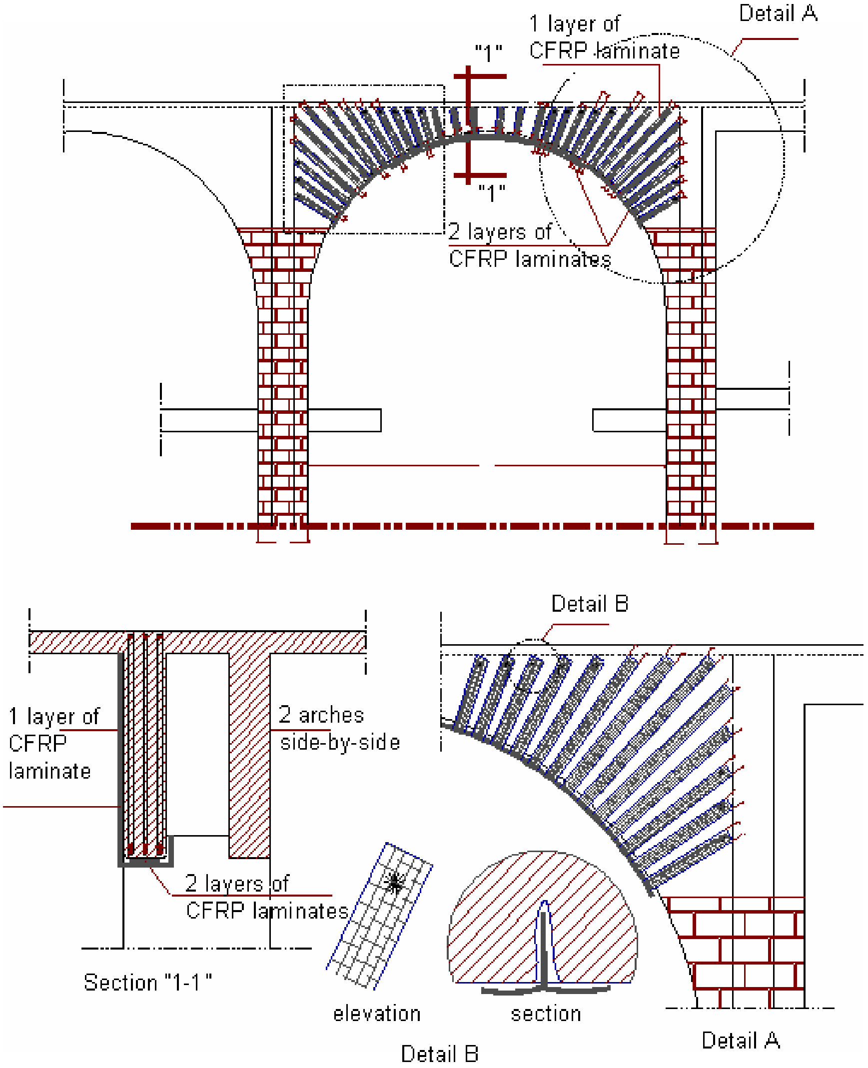


Figure 14. Details of strengthening scheme of the concrete arch

4.1.2. Kaitbay Fence

Kaitbay fence is one of the oldest places in Cairo built from stones and used as small shops, as shown in Fig. 15. The lintels used in the front entrances of the shops were made of stones with shear keys and without mortar, as shown in Fig.16. Deterioration of the joints between the stones and excessive deflection of the lintels was observed and as a result one of the stones fell off. It was decided to restore the historic fence with 70 meters total length, as shown schematically in Fig.17.

Figure 15. Picture of Kaitbay Fence

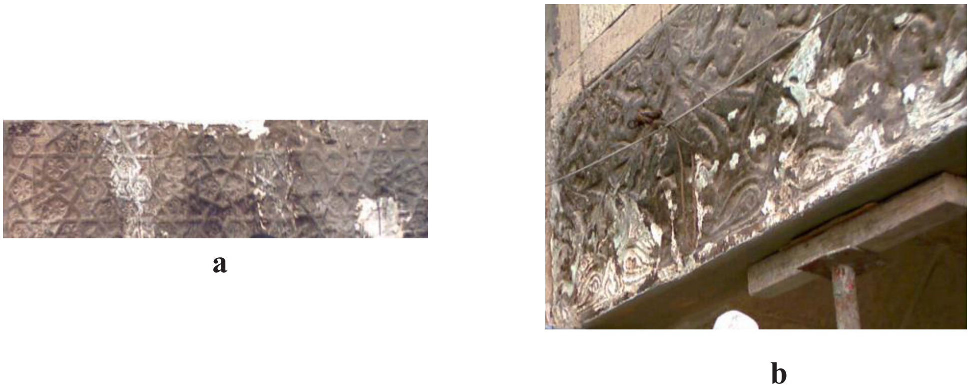


Figure 16. a, b Lintel of the shop entrance

CFRP laminates were used as tension reinforcement at the bottom surface of the lintels. Holes were drilled at the two ends of the lintel, as shown in Figs. 18 and 19. The CFRP laminates were stretched using a revolving device at the drilled holes, while attached to the bottom face of the lintel, as shown in Figs.18 and 20. Area of CFRP laminates was designed to maintain the self weight of the stone lintels. The design was carried out by Dr. Amr Abdelrahman and executed by Scad for Construction (Eng. Mostafa Saad).

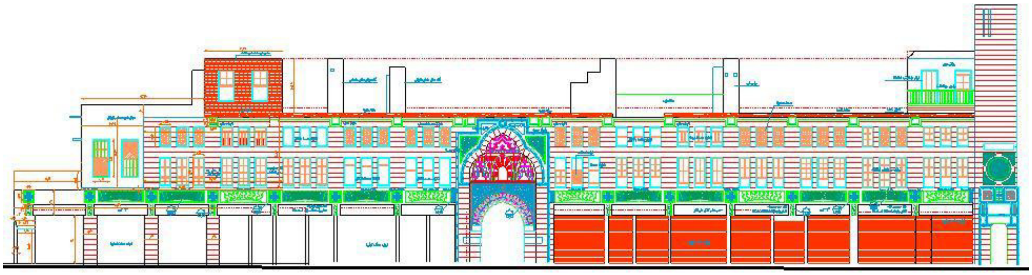


Figure 17. Schematic of the fence

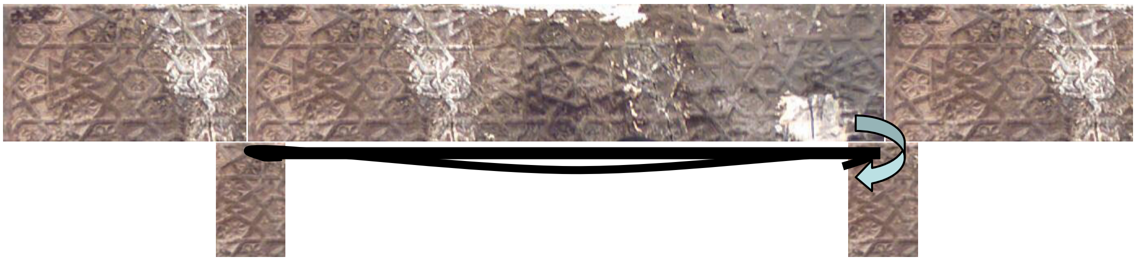


Figure 18. Schematic of the strengthening procedure

4.2 Strengthening of Special Projects

Several special projects were constructed in Egypt with the use of carbon FRP laminates for the purpose of strengthening concrete structures (Hosny et al. 2008). Strengthening of dolphin piles in Abu Qir harbour, Alexandria, suffered from flexural damage is addressed in this section.

Figure 19. Holes at the ends of the lintel

Figure 20. CFRP laminates at the bottom face

4.2.1. Dolphin Piles, Abu Qir Harbour, Alexandria, Egypt

Concrete dolphin in Abu Qir harbour were exposed to a ship hit resulted in various degrees of flexural damage in the top part of the concrete pile. The structure is 8.0 x 8.0 meters supported on 4 inclined piles, as shown in Fig.21. The piles were constructed with steel casing with its top level above the sea level and 600 mm below the bottom level of the pile cap. The horizontal component resulting from the impact force resulted in structural damage in the pat of the pile between the steel casing and the bottom surface of the pile caps, as shown in Figs. 22 to 24. Concerning the damaged piles, it was noted that two distinct levels of flexural damage occurred in the concrete piles, as follows:

High Level of Flexural Damage (Piles where Concrete Crushing Occurred) :

This category of flexural damage involved a few number of piles and was characterized by a large number of flexural cracks with large widths accompanied by concrete crushing in the opposite side, as shown in Fig. 13. This clearly reveals the occurrence of flexural failures in these regions, involving the yielding of some of the internal steel reinforcing bars and the associated loss of the initial flexural capacity under horizontal loads.

Figure 21. Overview of the dolphins

Figure 22. Concrete Crushing

Figure 23. Removed concrete

Figure 24. Large widths flexural cracks

Low Level of Flexural Damage (Piles where Only Concrete Cracking Occurred) :

This category of flexural damage involved the rest of the damaged piles and was characterised by a fewer number of flexural cracks with smaller widths. No concrete crushing was monitored in this category, hence, revealing that only a partial loss of the initial flexural capacity under horizontal loads is suspected in these regions.

The strengthening scheme included application of GFRP and CFRP sheets as well as CFRP anchors, as shown schematically in Fig.25 and is given as follows:

1. Inject visible cracks with low viscosity epoxy resin using adequate pressure and pre-drilled holes or fixing nipples.
2. Round the intersection between the pile and the pile cap using the repair mortar with a minimum radius of 50 mm.
3. Apply one layer of GFRP sheets and the fibres oriented parallel to the centreline of the piles, as shown in Fig. 26. The GFRP was used to isolate the steel pipe from the CFRP sheets to avoid possible galvanic corrosion.
4. Apply one layer of CFRP sheets and the fibres oriented parallel to the centreline of the piles. The sheets should cover 600 mm from the top of the piles and to be applied partially on the repair mortar and on the steel casing. The sheets will be extended to the bottom of the pile cap with a length of 500 mm and width of 150 mm.
5. Apply 10 CFRP anchors of an equivalent diameter of 6 mm uniformly spaced around the circumference of the pile at the intersection with the pile cap. Another 10 CFRP anchors are applied and uniformly distributed around the circumference of the pile, as shown in Figs. 27 and 28. The anchors should be applied 75 mm away from the end of each CFRP sheet.
6. Apply two more layers of CFRP sheets with the fibres oriented parallel to the centrelines of the piles. The sheets should cover 600 mm from the top of the piles and extended to the bottom of the pile cap with a length of 500 mm and width of 150 mm.
7. Apply two layers of CFRP sheets with the fibres oriented perpendicular to the centrelines of the piles.

The project was jointly designed by Dr. Amr Abdelrahman and Dr. Abdel-Wahab El-Ghandour and executed by Scad for Construction (Eng. Mostafa Saad). Load test was carried out after rehabilitation of the piles to verify the strengthening scheme. Both the design and load tests were approved by the American Core of Engineers.

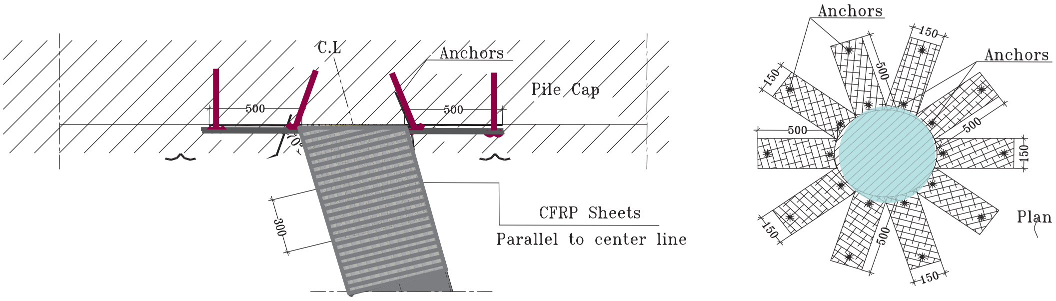


Figure 25. Schematic of the FRP Piles strengthening

Figure 26. GFRP application

Figure 27. Locations of CFRP anchors

Figure 28. Applications of CFRP anchors

4.2.2. The Panorama building, Sharm-El-Shaikh, Egypt

The Panorama building in one of the hotels in the city of Sharm-El-Shaikh, Egypt, is 11.0 m wide and 50.0 m long with a triangular shape, as shown in Fig. 29 The one story building is located close to the edge of a hill. Villas are located at the ground level, while the roof was not used. It was the owner's desire to use the roof as an open-air café having a view of the city from the top of the hill. The building consists of reinforced concrete slabs supported on rectangular beams and reinforced concrete columns.

After two years of construction, both the slabs and beams were severely cracked, as shown in Fig. 29 The crack width was up to 1.0 mm in some locations. The cracks were observed on the entire width of the slab, at the fourth bay away from the hill, crossing all beams and walls. Flexural and shear cracks were also observed at some of the beams. The Parapet of the roof, which is made of brick, was also cracked. The cracks were wide at the top of the parapet, reducing in width towards the bottom. The location of these cracks coincided with the cracks in the concrete slab. No cracks were observed in the columns.

The crack pattern indicated that differential settlement of the foundations of the building had occurred. The columns close to the edge of the hill settled more than the interior columns causing a rigid body movement of that part of the structure and cracks across the entire building. Soil pits were carried out to determine the properties of the soil. The investigations showed a layer of fine sand beneath the shallow foundations. The fine sand was washed out of the hill with the water drained from spraying plants close to the building. The washed sand found its way out from the side of the hill. A good soil stratum was located 10.0 meters below the ground level.

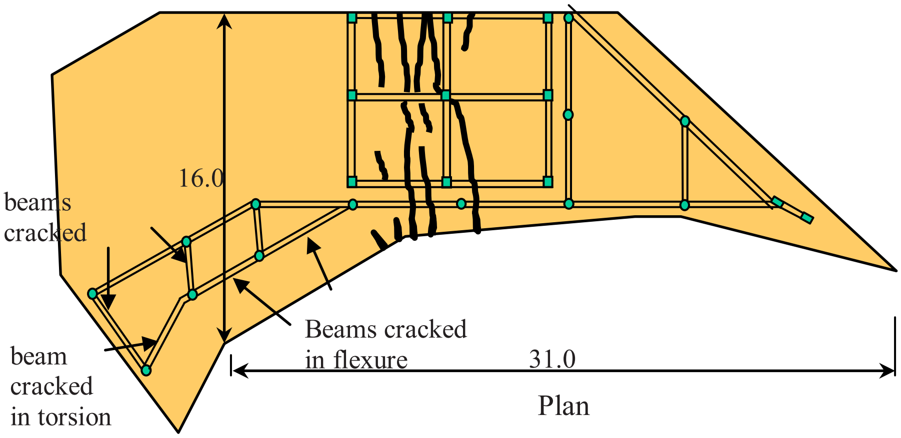


Figure 29. Crack pattern of the Panorama building

Before starting the strengthening scheme, it was decided to move the plants away from the building and eliminate any source of water close to the foundation of the building. In the first phase of the scheme, it was essential to eliminate the cause of the problem and stop the settlement of the foundations before remedy of the superstructure. A rigid reinforced concrete mat foundation supported on plain concrete caissons was cast to support the columns. The caissons were 1.0 meter diameter and 10 meters long, bearing on the good soil stratum. Two caissons were cast around each existing column. In order to ensure that the deformation of the structure was stopped after casting the new foundation, the cracks were monitored to record any changes. Several gypsum marks were made crossing the existing cracks in the slabs and beams. No further development of the cracks was observed.

The second phase of the strengthening scheme was to restore the building and increase the structural capacity of both the slabs and beams to resist higher live loads. It was the owner's demand to minimize the time and the working space during this phase of work. Two alternatives were studied to strengthen the superstructure; enlarging the concrete section of beams and slabs, and use of CFRP laminates. Based on cost benefit, it was decided to use the CFRP laminates to strengthen the slabs in flexure and the beams in flexure and shear.

CFRP strips of 1.2 mm thickness and 50 mm width were used to strengthen the slabs and beams in flexure, as shown in Fig. 30 The strips have a fiber volume content of 68% and epoxy resin. The tensile strength and modulus of the strips were 2800 MPa and 165 GPa, respectively. The strips were bonded to the concrete surface using epoxy-based two-component adhesive mortar. The adhesive strength of the mortar to the concrete surface was 4 MPa. CFRP laminates with a thickness of 0.13 mm were also used to strengthen the beams in shear as shown in Fig. 31 and 32. The tensile strength and modulus of the laminates were 3500 MPa and 230 GPa, respectively.

It was important to estimate the stress in the steel reinforcement caused by the additional straining actions resulting from the excessive settlement of the foundations. The measured crack width of the slabs and beams were used to estimate the tensile stress in the steel reinforcement. The required area of CFRP was calculated to allow for double the live load, accounting for the increase in the stress of the steel reinforcement. CFRP strips, 11.0 meters long and spaced every 500 mm were used on top of the slabs, as shown in Fig. 32 CFRP strips were used on the bottom surface of two cracked beams to increase its flexural capacity. One layer of CFRP laminates was applied on the sides of the beams in a "U" shape to strengthen the beams in shear, as shown in Fig. 32. The laminates were 300 mm wide and spaced every 50 mm.

Figure 30. Flexural strengthening of slabs

Figure 31. Surface preparation of beams

Figure 32. Shear strengthening of beams

Figure 33. The Panorama building after retrofit

The tensile strength of the concrete was measured and found to have an average value of 2.0 MPa. Before application of the laminates, the humidity of the concrete was measured to ensure the dryness of the concrete surface. Concrete surface of the beams was prepared and leveled to ensure that the unevenness of the surface did not exceed 10 mm in 2.0 meters length. The surface was cleaned and the blowholes were filled with epoxy mortar. The strips were cut to the specified length and the adhesive epoxy mortar was applied with a roof shaped spatula onto the strips to a thickness of 1 to 2 mm. The adhesive epoxy mortar was also applied with 1 mm thickness to the prepared surface of the concrete. The strips were carefully applied to the concrete surface and pressed with a rubber roller. CFRP laminates were also applied to the concrete surface in a similar fashion as the CFRP strips. The edges of the concrete beams were rounded to prevent any stress concentration at the corners. The Panorama building is shown in Fig. 33 after completion of the retrofit work.

5. Conclusions

Samples of research projects were presented including strengthening of rectangular columns subjected to axial loading and eccentric loading under cyclic loading. The research programs also included flexural behaviour of hollow core prestressed slabs strengthened with carbon FRP laminates. Research programs on two-span continuous beams and two-hinged frames strengthened with FRP subjected to short- and long-term loading were also discussed.

Several projects demonstrating the use of FRP in strengthening concrete structures had been successfully completed in Egypt. The paper highlighted design concepts and structural details for the application of FRP in two historical buildings and a marine structure. These projects were designed according to the Egyptian Code for the Use of Fibre Reinforced Polymers in the Construction Fields, which was published in 2005.

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