Retrofitting Gravity Load Designed R.C Frames Using FRP

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Abstract. Many existing worldwide Reinforced Concrete (RC) structures, such as non-ductile RC frames, were designed for gravity loads only during the 1950s through 1970s or earlier. Due to variations in the identification of seismic active zones by national codes, such structures may not satisfy the current design requirements, especially when lying in a recently identified seismic active zone. This is because such structures, as a result of poorer reinforcement detailing, may generally do not possess the adequate ductility and strength needed to withstand an expected earthquake. Consequently, older RC frames may undergo substantial damage during earthquakes. One of the main damage aspects in such case is clear cracks around and within the beam-column connections. This is the case where the failure of beam-column joints is governed by bond and shear failure mechanisms which are usually brittle. This may be attributed to inadequate shear reinforcement in the beam-column joints region., This paper presents the first results of an experimental campaign performed – at the Laboratory of Materials & Structures of the Arab Academy And Technology (EGYPT) – with the aim to investigate the seismic performance of RC beam-columns joints strengthened with FRP. The experimental program includes testing specimens realized to be representative of existing exterior beam-column subassemblies with inadequate seismic details. A technical solution was selected in order to improve the joint seismic behaviour, and the performance of the proposed strengthening system is investigated in this paper. To this aim, two as built beam-column joints have been tested, one strengthened specimen and a reference unstrengthened one. Test results provide useful information for the adopted strengthening systems in terms of strength, ductility and energy dissipation capacity. Results indicate that the proposed strengthening technique was successful in adding up to 50% of the beam column joint capacity. The results are encaging to apply this technique on existing gravity load designed buildings.

1 Introduction

Old buildings have many factors that can affect their integrity such as being subjected to earthquakes, or not being designed in the first place to endure lateral loads. This could lead to structural failures. This the case with knowing that the cost of

© Springer Nature Switzerland AG 2019
H. Rodrigues and A. Elnashai (Eds.): GeoMEast 2018, SUCI, pp. 1–13, 2019.
https://doi.org/10.1007/978-3-030-01932-7_1

demolishing and rebuilding is very high. Nevertheless, the economic costs become measure due to delaying works and projects for individuals, companies and the government. Due to all what have been mentioned, it would be preferable to reinforce the building instead of demolishing it. However, to repair a building, one needs first to figure out the weak parts that need to be strengthened in a way that doesn't require the building to be evacuated if possible (Anagnostopoulos *et al*. 1996).

Beam-column connections have been diagnosed as potentially vulnerable components when Reinforced Concrete (R.C.) frame buildings are subjected to seismic loads, Generally, older buildings are normally designed only for gravity loads. Such Buildings when subjected to seismic loading may be subjected to damage, and the most affected parts are the structural beam- column joints, and particularly, the corner joints or the exterior joints (Wernli 2004). The interior joints are also affected due to seismic loads, but the damage is relatively smaller in magnitude. In addition, the accurate seismic assessment of beam-column subassemblies has been an important objective for many research groups over the years. Experimental and analytical research on different aspects of these members by various research groups have provided numerous design and assessment techniques with little consensus amongst these research groups.

In this paper, the feasibility of a novel strengthening solution using Fiber Reinforced Polymers (FRP) in increasing the seismic performance of exterior RC beam-column joints is investigated. An experimental program was organized at the Arab Academy For Science and Technology which includes several as-built specimens representative of existing beam-column joint subassemblies with inadequate seismic details that may exist in gravity load designed buildings. Of these specimens, the first one was strengthened by using FRP, while the second one was not strengthened. The two as-built specimens where loaded till failure in a step by step manner to identify the gain in the beam- column joint capacity after strengthening while anther specimen was used as a reference benchmark.

2 Problem Definition and Research Objectives

Prior to modern codes that include detailed information for designing structures under seismic loads, older RC frame structures were designed only for gravity loads. This is even the case when considering that the seismic active zones varied in the national codes by time, such that some older structures are presently lying in active seismic zones, though this was not the case in the past. Such existing RC frame structures, though performing well under conventional gravity load case, could lead to questionable structural performance under earthquakes. In most cases, those structures are vulnerable to any moderate or major earthquake, and thus need immediate assessment and retrofitting to avoid a sudden full or partial collapse mechanism bringing considerable losses in human lives and economic assets (Elmasry *et al*. 2016).

In this paper, objectives include developing an effective rehabilitation to strengthen beam-column joints in older structures to improve their seismic performance in terms of lateral strength and serviceability. Accordingly, An experimental program is prepared for validating the suggested technique. By interpreting results and studying the resulting advantages versus disadvantages, it is clearly shown that the proposed technique improves considerably the strength of the beam-column joints by using CFRP sheets (Elmasry *et al*. 2016).

3 Literature Review

3.1 Beam Column Joints

The functional requirement of a joint, which is the zone of intersection of beams and columns, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members. The beam-column joint in a frame is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified. an interior joint, an exterior joint and a corner joint as shown in Fig. 1. When four beams frame into the vertical faces of a column, the joint is called an interior joint. In contrast, when one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When two beams frame, into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behaviour. These forces develop complex mechanisms involving bond and shear within the joint (ACI 2002).

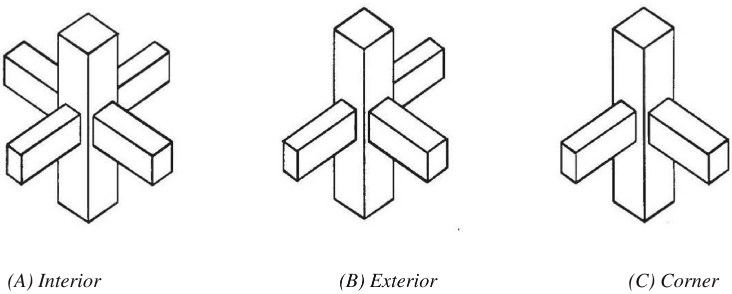
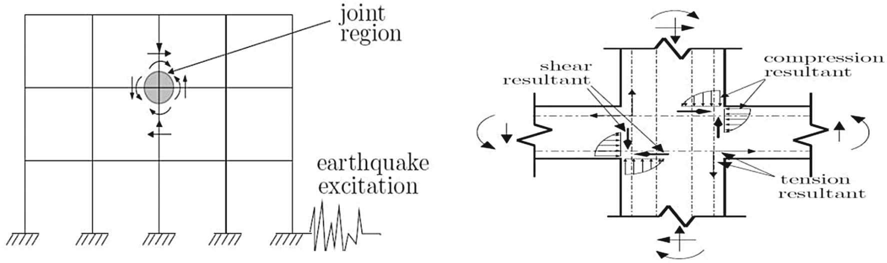


Fig. 1. Beam column joint connections types

3.1.1 Joints Behavior Under Seismic Loading

In two-dimensional (2D) frame joints subjected to earthquake loadings, beams and columns experience flexure and shear loadings. Figure 2 shows the forces that could be expected to develop in a 2D frame joint subjected to earthquake and gravity loading. Moreover, when recent seismically designed frames are subjected to moderate and severe earthquake loading, it is expected that the beams will develop flexural strength at the joint while columns will develop moments that approach the yield moment. Meanwhile, in older frames, shear failure of beams and columns or flexural yielding of columns may preclude beams achieving yielding flexural strength. Figure 2(A) shows the expected loads and resultants at the perimeter of the joint region. The load distribution, as shown in Fig. 2(B), can result in severe loading within the joint region. In addition, the moment reversal in the beams and columns results in large shear forces within the joint (Nilanjan 2007).



(A) Building frame with joint region *(B) Detailed view of joint region*

Fig. 2. Loads in the beam-column joint region

4 Fibre Reinforced Polymer (FRP)

Fibre Reinforced Polymer (FRP) composites comprise fibres of high tensile strength within a polymer matrix such as epoxy. FRP composites are used in a lot of applications such as aircraft, helicopters, space-craft, satellites, ships, submarines, automobiles, chemical processing equipment, sporting goods and civil infrastructure (Liyoung *et al*. (2002); Abhishek (2012) and Sreelatha (2013)). In general, one of the advantages of using FRP products would be strengthening of the existing or new RC structures with the possibility of application without disturbing the existing functionality of the structure (Liyoung *et al*. (2002) and Sreelatha (2013)). In addition, FRP composites had proved to be extremely useful for strengthening of RC structures against both normal and seismic loads as stated in previous research as shown earlier. Moreover, most of the elements of a structure can be applicably strengthened with FRP composite materials. Currently, this method has been applied to strengthen structural elements as columns, beams, walls, slabs (Nikita *et al*. (2015), Sasmal *et al.* (2011) and Obaidat *et al*. (2010)). This means in fact that FRP composites can take up the majority of the forces developed in a structure as long as they are transmitted by the strengthened element to the composite one as tensile stresses. Furthermore, strengthening with externally bonded FRP fabric has shown to be applicable to many kinds of structures. The use of external FRP reinforcement may be classified in: (i) Flexural strengthening, (ii) Improving the ductility of compression members, and (iii) Shear strengthening. Furthermore, Carbon Fibre-Reinforced Polymer (CFRP), Carbon Fibre-Reinforced Plastic (CRP), or Carbon Fibre-Reinforced Thermoplastic (CFRTP) are extremely strong and light FRP which contain carbon fibres. This is the case where carbon fibres give CFRP its strength and rigidity in terms of increasing the ultimate stress and elastic modulus respectively. Unlike isotropic materials like steel and aluminium, CFRP has directional strength properties. The properties of CFRP depend on the layouts of the carbon fibre and the proposition of the carbon fibres relative to the polymer. Advantages for CFRP include high tensile strength, high strength to weight ratio, low weight to volume ratio, excellent fatigue behaviour, and quicker application (Naveeena and Ranjitham (2016)). Thus, CFRP composites are able to strengthen beam column joints in terms of the shear capacity and ductility.

5 Experimental Program

The ongoing experimental program includes several RC beam-column joints that are subjected to forces (variable load) applied by setting two opposite forces at the specimen beam tip by keeping the column fixed at the specimen top and bottom ends. Two as-built specimens where loaded till failure in a step by step manner to identify the gain in the beam-column joint capacity after strengthening while anther specimen was used as reference benchmark.

6 Design of Specimens

Exterior as-built beam-column joints were designed for the experimental campaign, characterized by the amounts of longitudinal steel reinforcement in the beams and columns. Figure 3 depicts the geometry and the rebar configuration of the strengthened and unstrengthened specimens. For the unstrengthened specimen, the structural dimensions of the studied beam-column joint, as shown in Fig. 3a, are summarized in having a vertical column with a cross section of 300 mm × 300 mm intersecting a horizontal beam with a 300 mm × 300 mm cross section. The height of the specimen is 1300 mm and the beams extend by 500 mm before and after the joint. The longitudinal reinforcement of the column is 8 T16 rebar as shown in Fig. 3, and the shear reinforcement is 8 mm diameter stirrups with a spacing of 75 mm to avoid beam shear failure and to direct the stresses concentrations to the connection zones. The beam steel reinforcement is 4 T16 rebar as shown in Fig. 3, and the shear reinforcement is 8 mm diameter stirrups with a spacing of 75 mm. The reason for having excessive shear reinforcement in the beam and the column is to enforce the shear cracks to be initiated within the beam-column joint zone rather than in the beam or the column. The cubic strength of concrete is 20 MPa which is typical in GLD older structures, while the yield strength of the steel reinforcement is 360 MPa.

In addition, the strengthened specimen is shown in Fig. 4. The concrete dimensions and reinforcement details of this retrofitted specimen are the same as the unstrengthened specimen. However, in this specimen, CFRP sheets diagonally reinforce the beam- column joint. In addition, webbed built up angles and covering plates, as shown in Fig. 5, are used as a bearing for the CFRP sheets to get wrapped around the columns at the beam-column connection. The thickness of the CFRP sheet is considered 0.13 mm. The modulus of elasticity (E) for CFRP is taken as 24000 MPa in the longitudinal direction and 18581 MPa in the transversal sides.

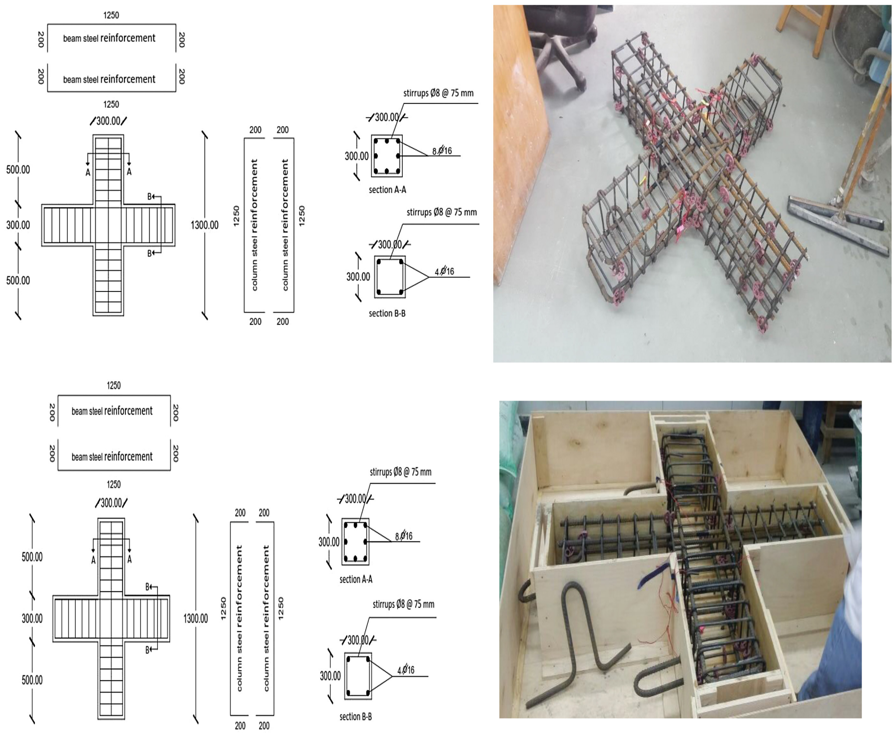


Fig. 3. The geometry and the rebar configuration of set of joints (a) The geometry and the rebars configuration of set of unstrengthened

7 Materials

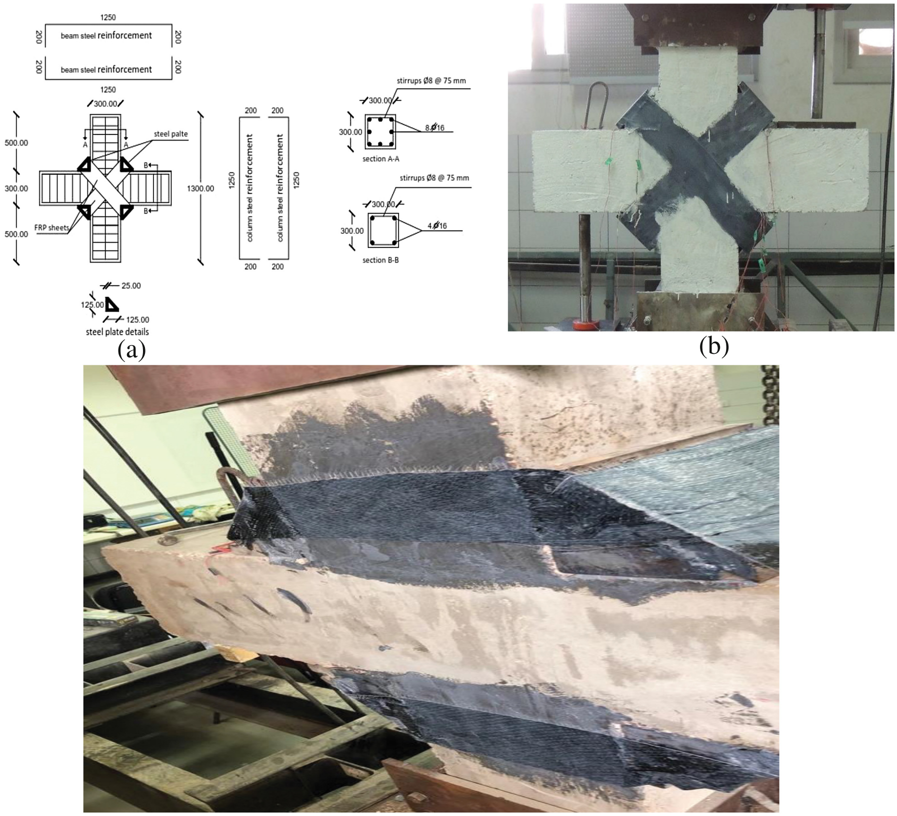
The Concrete cubic strength for all concrete specimens was evaluated after 28 day and reported in Table 1. In order to replicate the GLD buildings, the concrete cubic strength was assumed 20 MPa to infer the strength quality by the time of construction of such buildings.

Table 1. Mechanical properties of concrete for test specimens.

Cubic sample	Compressive strength (fc) (MPa)
Unstrengthened	20
Strengthened	20

8 Test Set-up

The loading setup is shown in Fig. 6. The bottom and top of the column is considered constrained in three dimensions X, Y, Z using fixation steel jacket. Incrementally increasing concentrated loads are assumed to act on the specimen at the two cantilevering ends in opposite directions, to induce the resulting moments on the connection. A steel plate as shown in Fig. 7 is added at the expected loading location in order to avoid stress concentration problems. This provides a more even stress distribution over the loading area. There are ten strain gauges in the beam-column specimens that are distributed and fixed to the specimens as show in Fig. 8.



(c)

Fig. 4. The geometry and the rebars configuration of set of strengthened (a) The rebar in strengthened specimen (b) FRP fixation in front strengthened specimen (c) The back view of the strengthened specimen with FRP

9 Experimental Result

Crack patterns and failure modes of the unstrengthened specimen are shown in Fig. 9. Figure 10 shows the crack patterns in the strengthened specimen. The load & displacement curve for the unstrengthened cases shown in Fig. 11. Figure 12 shows the load & displacement curve for the strengthened specimen.

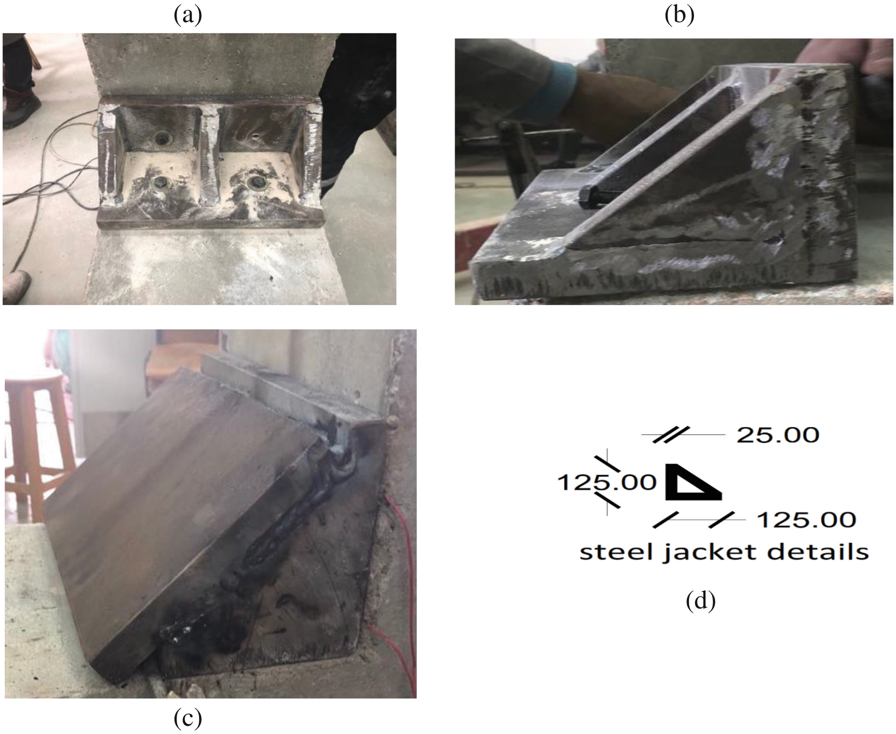
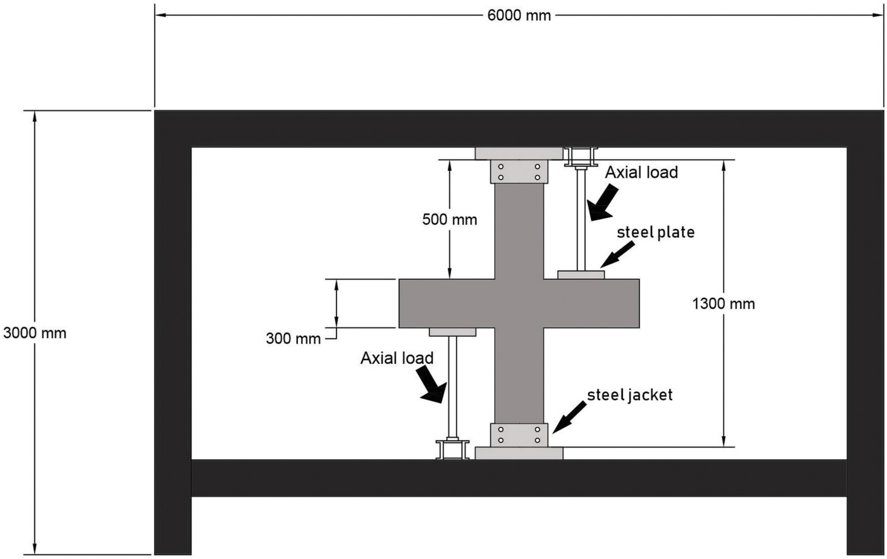
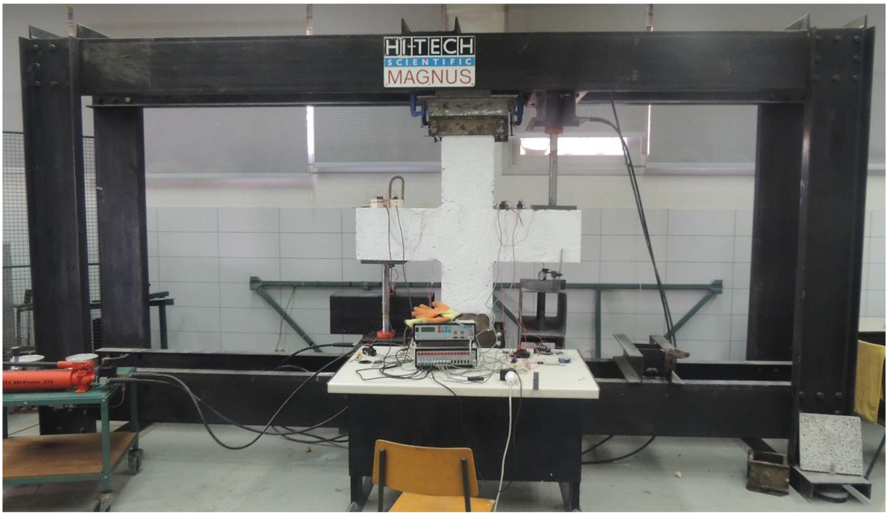


Fig. 5. Webbed built up angles and covering plates

From the above mentioned figures, it is clear that the cracks were concentrated for the unstrengthened case that showed the lowest strength, while in unstrengthened specimen, a lot of cracks appeared, some in the beam, some in the column as well as cracks in joint. The cracks were concentrated in the joint horizontal cracks in the form of vertical and diagonal cracks. In the strengthened specimen when using the strengthening technique by CFRP sheets, the cracks appeared rather in the beam and the joint. The cracks in the strengthened joint are less than the case as the unstrengthened joint. In spite of the fact that the cracks propagation in the strengthened specimen are bigger, yet the ductility was in the unstrengthened specimen less than the case of the strengthened specimen, which showed higher deflections. It is clear that the strengthened specimen showed the highest strength. The unstrengthened specimen



(a)



(b)

Fig. 6. (a) The schematic Test setup (b) Reis contrast Test setup

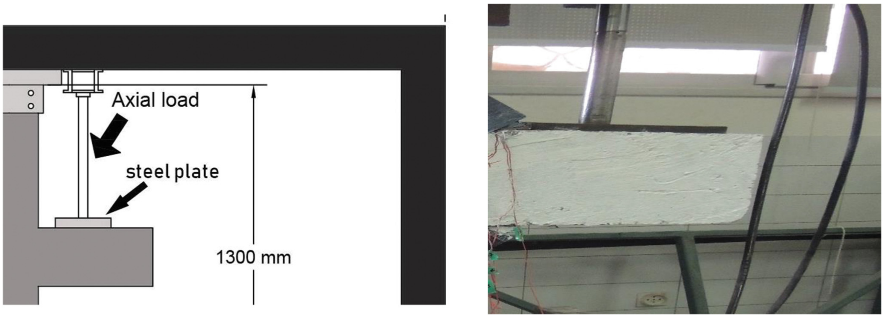
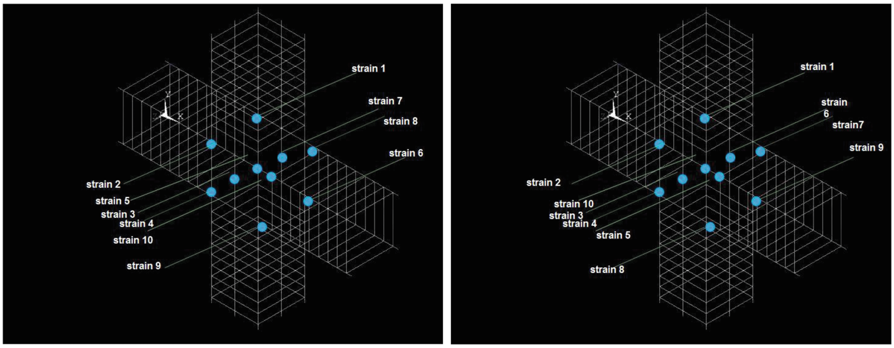


Fig. 7. Steel plate.



(a) (b)

Fig. 8. Show the strain gauge in each specimen. (a) The strain gauge in specimen unstrengthened (b) The strain gauge in specimen strengthened

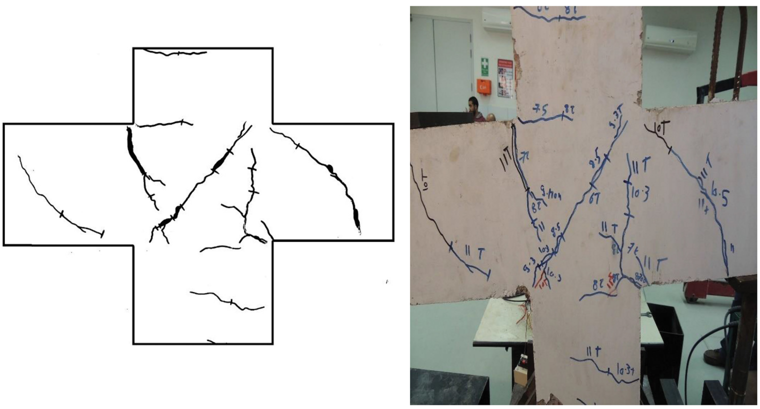


Fig. 9. The crack pattern of the unstrengthened specimen

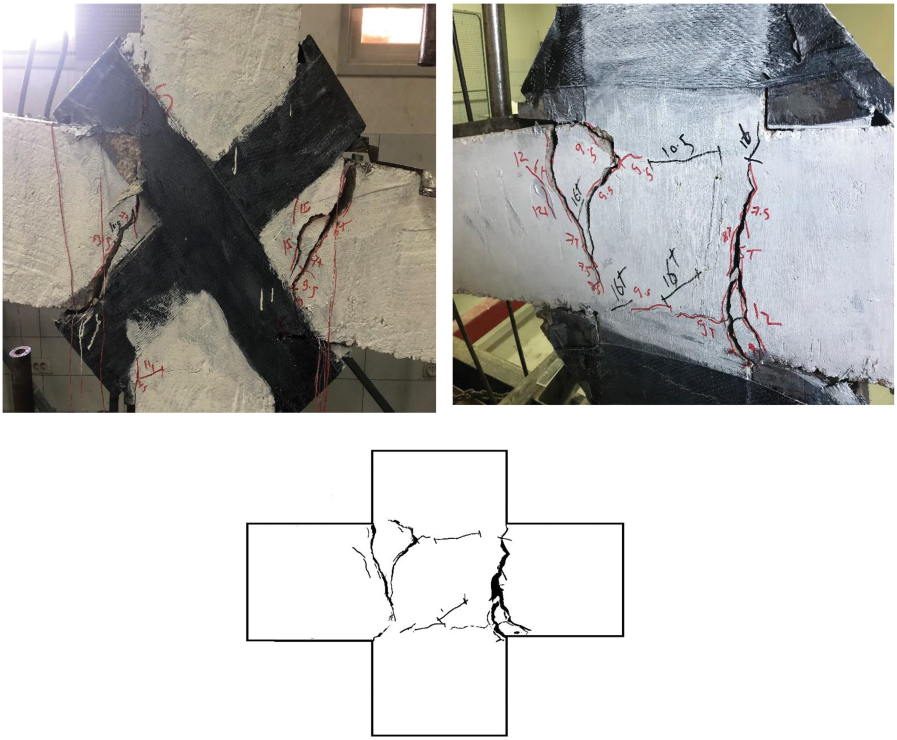


Fig. 10. The crack pattern of strengthened specimen

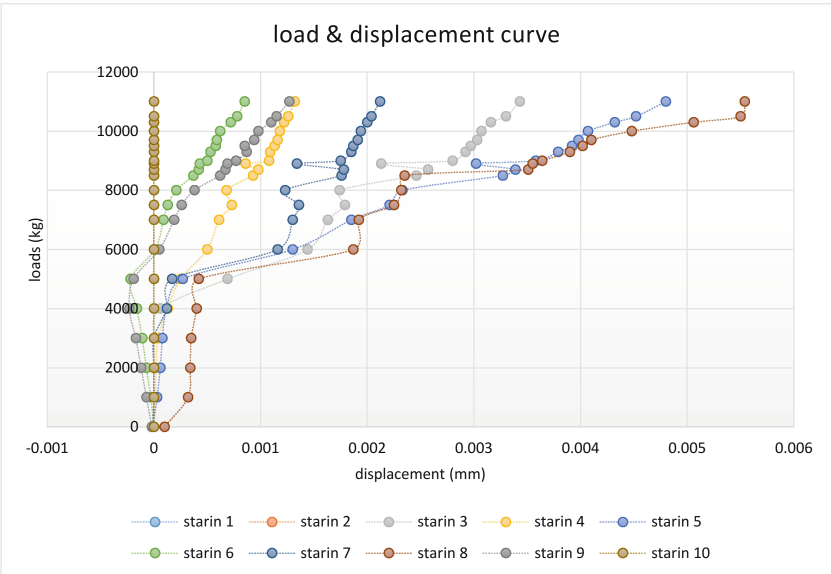


Fig. 11. The load & displacement curve for the unstrengthened specimen.

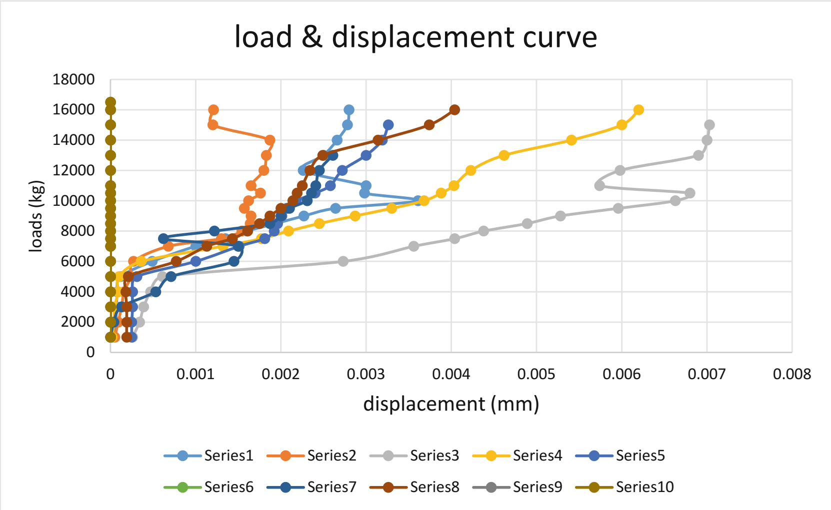


Fig. 12. Show the load & displacement curve for the strengthened specimen

failed when the axial load in both directions was equal to 110 KN (11 TON), and the strengthened specimen failed when the axial load in both directions was equal to 165 KN (16.5 TON).it is also noticed that the unstrengthened specimen failed in the beam-column joint, but the strengthened specimen failed rather in the beam. In summary, and as clear from this experimental study, it can be concluded that the proposed technique was successful in transferring the cracks from the beam-column joint to the beam through using diagonal wrapped CFRP sheets, this technique can be easily applied on older facades without varying or destroying the architecture layout.

10 Conclusions

An experimental study was undergone and shown in this paper to identify a suitable strengthening technique for the beam-column joints in GLD buildings. The results for the exterior RC beam-column joints were discussed. Two Specimens were tested, i.e., an unstrengthened specimen, and an upgraded specimen characterized by the strengthening of the beam -column joint. The performed tests have highlighted some critical aspects related to poor design of GLD structures. The beam-column joint strengthened with FRP showed only a 50% higher capacity for the joint than that of the unstrengthened case. The technique of wrapping CFRP sheets in a diagonal setup to be perpendicular to the expected shear cracks in the beam-column joint zone, proved to show better ductile response.

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