

Response of Seismically Detailed RC BEAM-Column Joints Strengthened With FRP

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ABSTRACT: Traditional types of strengthening of R.C. beam-column connections using FRP give a limited increase in strength. This paper presents an experimental and analytical program to study the behavior of exterior RC beam-column connections. The main objectives of this paper is focused on upgrading an ordinary exterior beam-column joint to withstand the lateral load expected in moderate earthquake zones using nontraditional methods of retrofitting (FRP) wraps. The experimental program included five (5) medium scale reinforced concrete beam-column joints. Specimens were tested under cyclic reversed loading up to failure. In the analytical study, the specimens were modeled using (Straus7) computer program based on finite element analysis method. Test results showed that, strengthening of RC beam-column joints with traditional methods of wrapping using CFRP improved their lateral load carrying capacity, flexural and shear capacity as well as overall ductility of the strengthened specimens.

KEYWORDS: Beam-Column Joints, GFRP, Reinforced Concrete, CFRP, strengthened, specimens.

I INTRODUCTION

During the past few decades, it was a common practice in Egypt to design and analysis of low to medium high rise buildings to resist gravity loads only, without any consideration to any lateral loads caused by earthquakes or wind. In fact, the majority of residential and public buildings were designed as gravity dominated R.C. frames. However, the amount of damage observed in reinforced concrete structures during the October 12th 1992 earthquake pointed out the urgent need to consider these forces in designing and detailing. This was reflected in the Egyptian Code of Practice ECP – 89 [1], and the subsequent edition ECP-95 [3], where regulations for lateral loads caused by earthquakes and wind are included. Although lateral loads are now explicitly specified in a special code for loads and forces ECP- 93 [12] the important issue of detailing the structure to fulfill these design requirements is still not fully addressed.

According to the observations of many consultants after the October 12th earthquake, hundreds of buildings were totally collapsed or severely cracked only due to poor reinforcement details. In many of these cases the initial failure initiated at the beam - column joints.

The rapid increase in the cost of construction has forced the engineers to look for economical and better methods for building and/or repair of distressed structures. Among the materials used for construction and repair, Fiber Reinforced Plastics (FRP) is comparatively new approach. It is considered as a composite material made of laminates of reinforcing by embedded in a matrix.

II RELATED WORK

In the last decade, the effect of external application of fiber reinforced polymers (FRP) plates and wraps to reinforced concrete beam-column joints to increase their performance has been investigated theoretically and experimentally. External application of FRP material provides a practical solution to improve the overall performance of an R.C. frame structure without the necessity of a radical alteration to the original structure. Externally bonded FRP may be used in a repair capacity for structure that has undergone moderate earthquakes damage or to reinforce structure that are

considered to be vulnerable or substandard.

Analytical work on beam-column joint behaviour was first developed by Mehta who proposed a formulation on compatibility of strain and stress equilibrium within the core. This model showed that shear strength of a joint depends on usable capacity of concrete as well as the presence of shear hoops increased vertical load.

III TEST PROGRAM

The experimental program included testing of five typical space exterior RC beam-column joints as shown in Fig. (1). The shown subassembly represented a beam-column joint between the mid height of two successive stories at the inflection points.

Also the reinforcement details of the tested specimens are shown in Fig. (1). the details of specimens' reinforcement were according to Egyptian code [12]. The longitudinal reinforcement ratio for beams was about 0.8%. While the ratio of longitudinal reinforcement for columns was about 1.2%. The compressive strength of the used concrete was about 30 N/mm². The steel used was grade 52 deformed bars for longitudinal reinforcement and grade 37 normal mild bars for stirrups which spaced at 80mm. Two specimens were retrofitted by using (GFRP) and another two specimens were retrofitted by (CFRP) using two different techniques, and the fifth was a control specimen. And then they had been cracked under cyclic loading, as will be explained later.

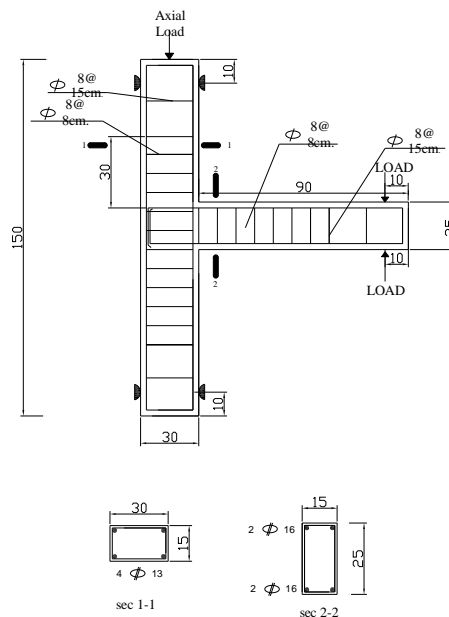


Fig. 1: Details of test specimens

IV RETROFITTING TECHNIQUES

The chosen retrofitting techniques are as follows:

First Specimen: without strengthening and it was considered as control specimen..

Second and third Specimen: The second specimen was wrapped with one layer of (GFRP). Three sheets of (GFRP) were placed as longitudinal reinforcement. The first one was placed on the top corner of the beam and the column. The second one was placed on the bottom corner of the beam and the column and the third one was placed on the column back. The third one wrapped as the same technique of the second specimen by using (CFRP), as shown in Fig. (2).

Forth and fifth Specimen: The forth specimen was wrapped with one layer of (GFRP). Four sheets of (GFRP) were placed as longitudinal reinforcement. The first one was placed on the beam and the column. The second one was wrapped the top part of the column above the beam. The third one was wrapped the bottom part of the column under the beam and the fourth one was wrapped the beam only. The fifth one wrapped as the same technique of the forth specimen using (CFRP), as shown in Fig.(3).

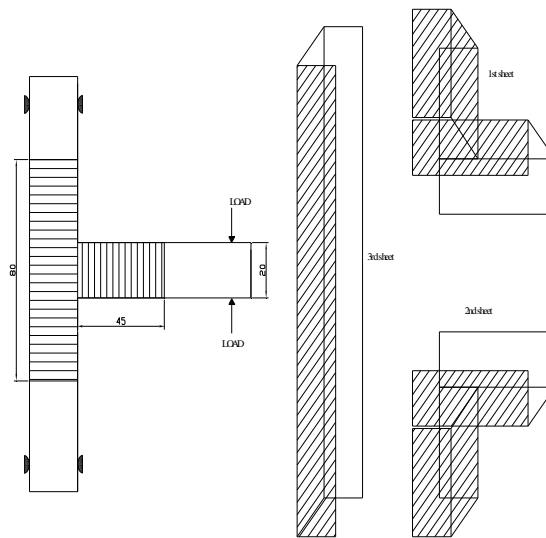


Fig. 2 : Details of the second and third specimens

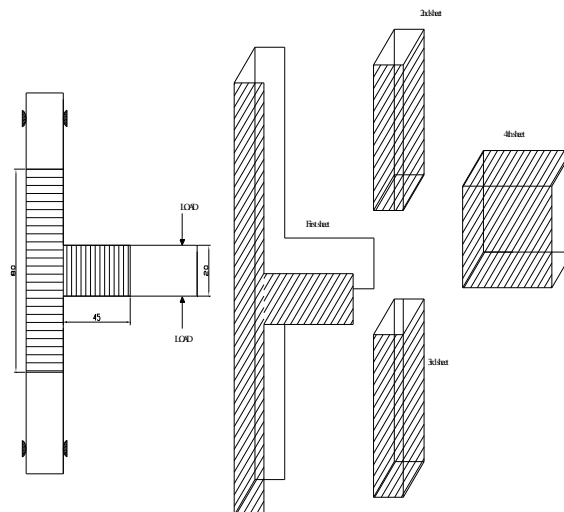


Fig. 3: Details of the forth and fifth specimens

V TEST SETUP

Three dial gauges 50 mms capacity and 0.01 mm accuracy were placed under the beam to measurer the vertical displacement and two dial gauges were placed behind the column to measurer the lateral displacement, as shown in Fig.(4) All data from dial gages were recorded. The load was applied by means of hydraulic jacks.

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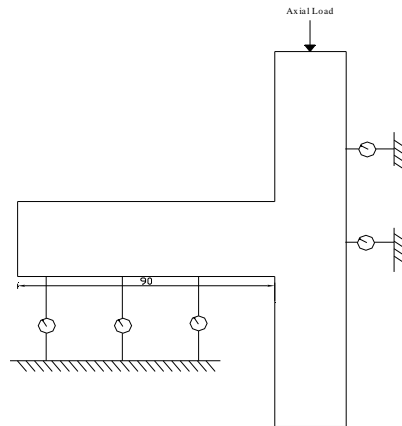


Fig.(4): Instrumentation and load arrangement

The loading was controlled by the displacement of the beam at the load point. The displacement controlled loading history used is shown in Fig. (5).

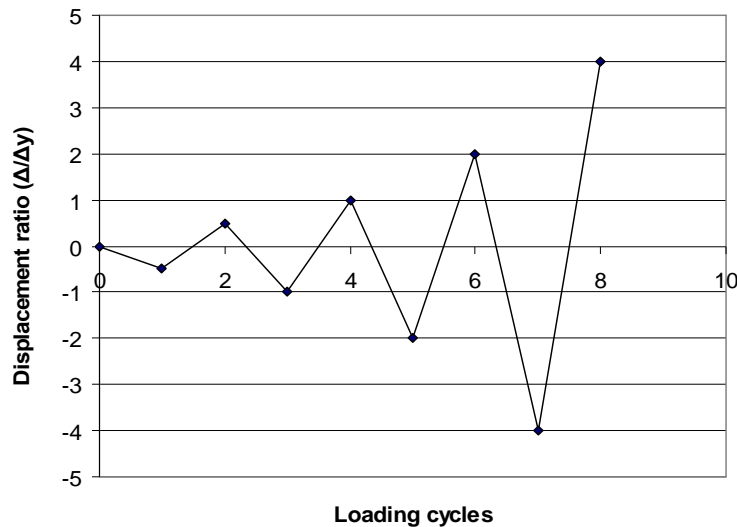


Fig.(5): Displacement time history (Load pattern)

The loading scheme provided information on strength as well as stiffness degradation of the specimens. The required axial load level was applied to the column and kept constant through out the test using 20 ton jack. Reversed cyclic displacements were applied to the free end of the beam simulating an earthquake type loading. The data acquisition controls the loading and the releasing of the test specimens. The loading process was controlled by the displacement with the load controls the releasing process. All the data gathered from load sensors and displacement transducers were recorded continuously during the test. Cracks were observed and traced for each load level.

VI EXPERIMENTAL RESULTS

- **Modes of failure**

After the peak of each cycle, the crack pattern was marked to provide necessary information required for defining the

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failure mechanism of each specimen.

The crack patterns of the tested specimens are shown in Figs (6) to (10). In the control specimen flexural vertical cracks were observed along the beam in the top and the bottom sides at the early cycles (2,3), then a major flexure cracks started at beam top fiber just after the bent bars and continued diagonally parallel to its direction. In the latest cycle (6) this crack was the predominant failure crack and caused degradation in specimen strength during downward displacement. The specimen was crushed at 3.3 ton.

In the other specimens strengthened by GFRP and CFRP sheets only the vertical cracks adjacent to the end of the FRP during cyclic loading. Wrapping the beam with FRP prevent the spread of elastic hinge even at large displacement cycles. All the specimens showed a ductile flexure behavior up to failure. Table (1) show the ultimate load of all specimens and the load which FRP started to separate or cut form concrete.

Table (1): Recorded test results

Specimens	Strengthening technique	Ultimate Load (ton)	Separate (cut) Load (ton)
Sp. (G2-1)	Control	3.50	-----
Sp. (G2-2)	GFRP	4.00	3.50
Sp. (G2-3)	CFRP	5.50	4.50
Sp. (G2-4)	GFRP	6.00	5.00
Sp. (G2-5)	CFRP	8.00	6.50



Fig.(6): Crack pattern and mode of failure for Specimen (1)

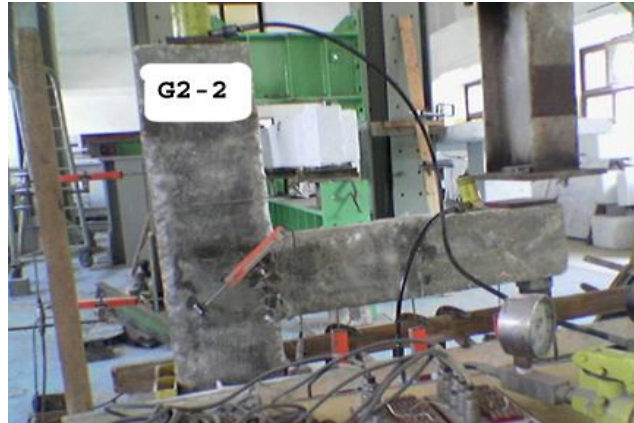


Fig.(7): Crack pattern and mode of failure for Specimen (2)



Fig.(8): Crack pattern and mode of failure for Specimen (3)



Fig.(9): Crack pattern and mode of failure for Specimen (4)

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Fig.(10): Crack pattern and mode of failure for Specimen (5)

- **Hysteresis Loops**

The measured loads were plotted against the associated applied beam tip displacement at different levels of loadings. Figure 11 to 15 presents the experimental load displacement hysteresis loops for all tested specimens. The load displacement hysteresis loops of all specimens displayed similar features. The figures revealed that all the specimens were able to retain wide stable hysteresis loops with large areas enclosed within the loops. For the initial small amplitude cycle, the response was almost elastic and only small residual displacement was observed. Upon reversal of displacement, cracks that were opened during the previous half cycle closed. After cracks closed, concrete resumed its previous role in resisting compressive stress.

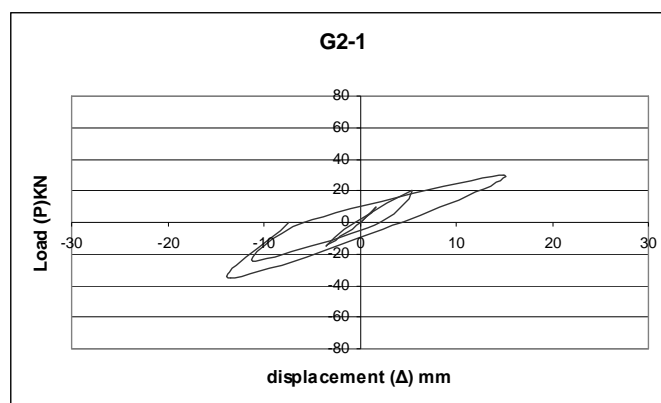


Fig.(11): Load versus displacement relationship for specimen (1)

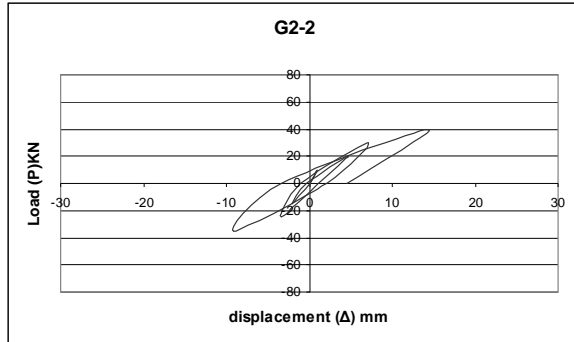


Fig.(12): Load versus displacement relationship for specimen (2)

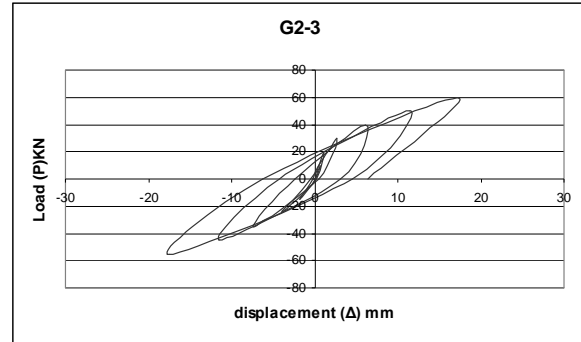


Fig.(13): Load versus displacement relationship for specimen (3)

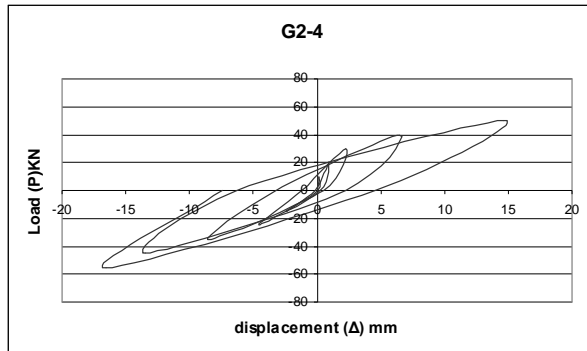


Fig.(14): Load versus displacement relationship for specimen (4)

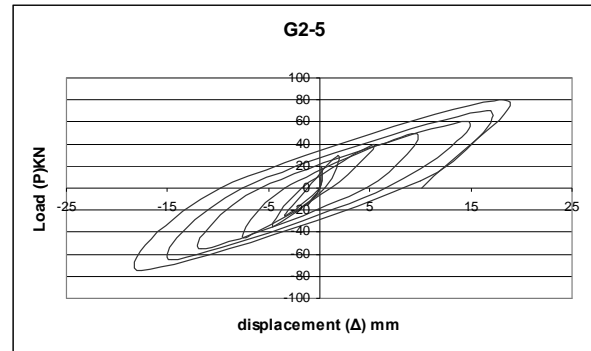


Fig.(15): Load versus displacement relationship for specimen (5)

VII.EVALUATION OF TEST RESULTS

Displacement ductility

The yield and failure displacements were determined for the tested specimens using the strength envelope. Table (2) presents the displacement ductility factor for the control and strengthened specimens. The control specimen produced poor ductility factor of (1.99). In the other hand, all strengthened specimens showed high displacement ductility factor. The displacement ductility factor reached (4.12) in specimen (5).

Table (2): Displacement ductility factor

Specimens	Average yield Displacement mm	Average failure Displacement mm	Displacement Ductility Factor	No. of Cycles
Sp. 1	3.89	9.12	1.99	7
Sp. 2	7.10	14.16	2.34	8
Sp. 3	8.64	17.32	2.00	12
Sp. 4	4.56	14.66	3.21	9
Sp. 5	12.0	17.90	4.12	14

Strength envelope

The strength envelope for all the tested specimens was presented in Fig. (16). It was noticed that the ultimate strength of the specimen NO. (5) were more than 2.2 times the ultimate strength of the control specimen.

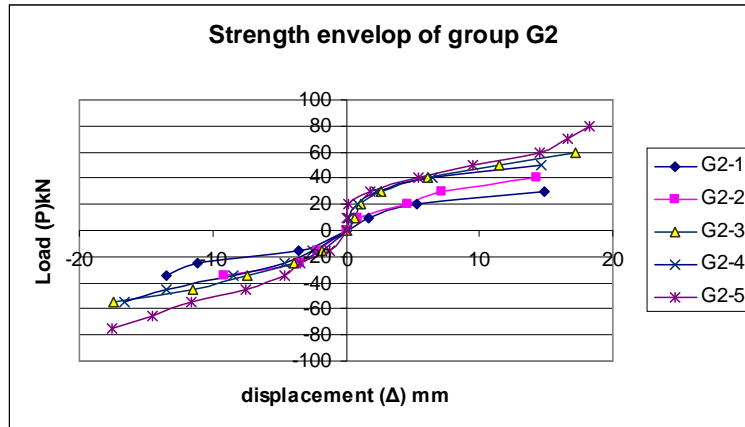


Fig.(16): Load-Displacement curves for tested specimens

Energy dissipation

All strengthened specimens produced close values of cumulated dissipated energy was large enough to guarantee ductile behavior of strengthened specimens. The cumulated energy dissipated curves are shown in Fig. (17).

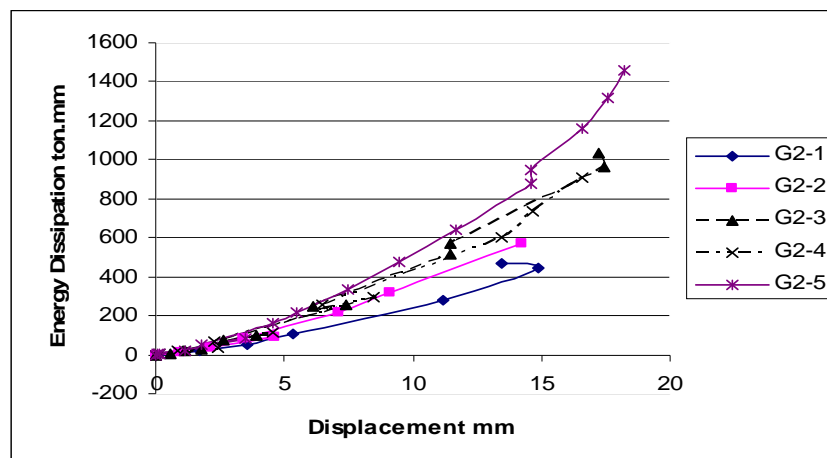


Fig.(17): Energy dissipation versus displacement relationship

VIII. ANALYTICAL STUDY

The control specimen and one of the strengthened specimens were analyzed theoretically using Straus7 program. The specimens were subjected to the same values of loading used in the experimental program. The Straus7 program was designed for the cyclic loading analysis.

The two specimens (G2-1) and (G2-5) were analyzed using the computer program in order to check its accuracy. The model of the specimens, boundary conditions and type of loading are presented as shown in Figs. (18) and (19) respectively.

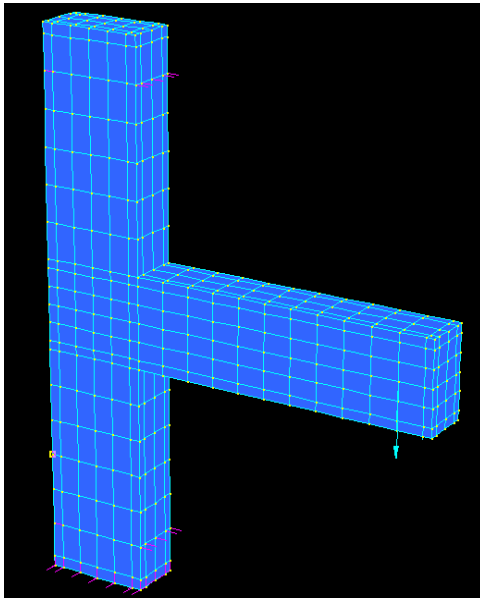


Fig.(18):Control specimen
(G2-1)

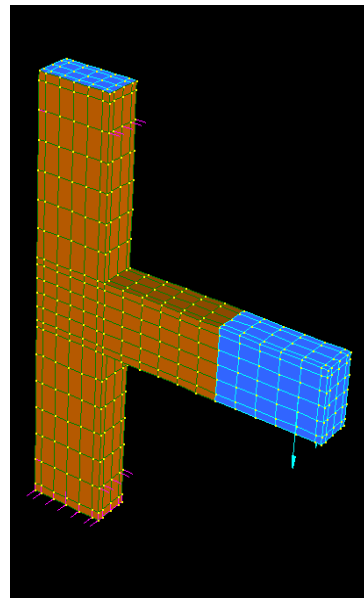


Fig.(19):Strengthened specimen
(G2-5)

IX. COMPARISON BETWEEN ANALYTICAL AND EXPERIMENTAL RESULTS

A comparing between the load displacement relationship (strength envelope) of tested specimens (G2-1) and (G2-5) as previously presented experimentally, and the theoretical results of the same specimens which calculated by the computer program straus7 are shown in the Fig.(20) and (21) respectively.

Figure (20) shows acceptable agreement when it compared with the experimental results from the load point of view. Also the figure shows a close behavior between theoretical and experimental hysteresis loops envelope. The theoretical ultimate positive load was approximately 16% lower than the experimental one and the displacement was approximately 21% lower than the experimental one. On the other hand, the negative load was lower than the experimental one by 25% and the displacement was approximately 8% lower than the experimental one.

At the same time the results showed in Figure (21) not acceptable when it compared with the experimental results. The theoretical ultimate positive load was approximately 105% higher than the experimental one and the displacement was approximately 8% lower than the experimental one. On the other hand, the negative load was higher than the experimental one by 108% and the displacement was approximately 5% lower than the experimental one. There was a high difference between the theoretical and experimental load at the last cycle of loading, and it took place approximately at the same displacement.

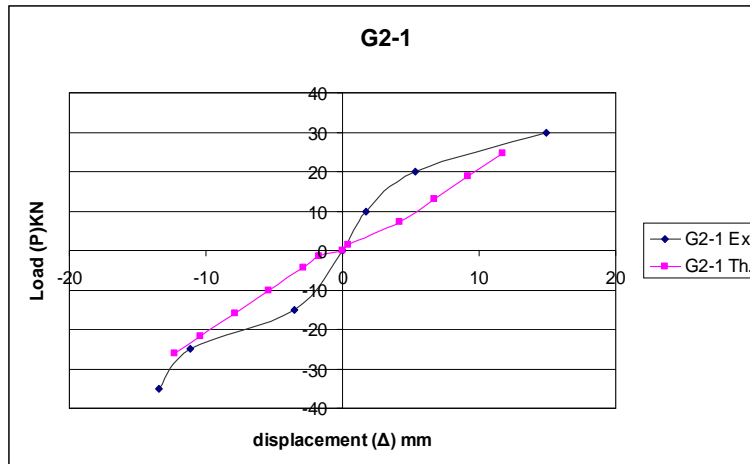


Fig.(20):Strength envelope for specimen (G2-1)

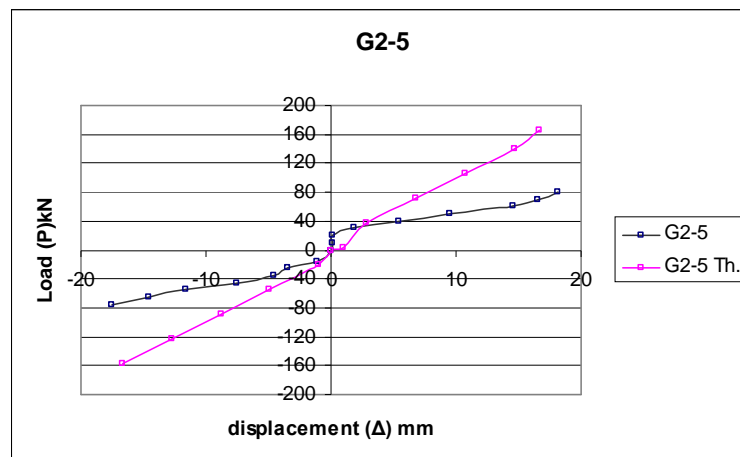


Fig.(21):Strength envelope for specimen (G2-5)

X. CONCLUSIONS

Based on the experimental and analytical results obtained from the study, the following conclusions can be drawn:

1. Strengthening of Beam-column joints using FRP wraps is quick and simple to implement.
2. Strengthening the beam-column joint using the second technique by GFRP delayed the failure and improved the joint properties. It also increased the moment carrying capacity of the original specimen by about 81 %.
3. Strengthening the beam-column joint using the second technique by CFRP delayed the failure and improved the joint properties. It also increased the moment carrying capacity of the original specimen by about 128 %.
4. The use of CFRP wrap resulted in a higher increase in the strength, the GFRP wrap can result in an appreciable increase in strength with the advantages of lower cost and higher chemical resistance. More than one layer of GFRP can be used to achieve high increase in the strength with lower cost compared to using CFRP.
5. The proposed modified Straus7 program used to predict the experimental load-displacement envelope for tested beam-Column by FRP needs more work to give satisfactory results for the new wrapping techniques suggested in this paper.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

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