Special Issue: AESMT-3

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Finite element analysis and retrofit of the existing reinforced concrete columns in Iraqi schools by using CFRP as confining technique

https://doi.org/10.1515/eng-2022-0461
received January 13, 2023; accepted May 04, 2023

Abstract: There are many studies about the use of carbon fiber-reinforced polymer (CFRP) to strengthen concrete members such as columns, beams, and slabs. The effectiveness of these strengthening techniques has been proved by enhancing the mechanical properties of concrete structures. So, CFRP has been used to strengthen and repair existing concrete structures in Iraq. For example, in Al-Mosul city, the strengthening and repairing system is done for concrete members such as beams, columns, and slabs using the Near Surface Mounted or confinement technique. Therefore, the research aim is to use CFRP for maintenance as an alternative material to strengthen and repair concrete members in Iraqi schools. This article employs methods to enhance and repairing of some of concrete columns at Al-Abeer school in Najaf city by using modern materials as an alternative method of maintenance. In addition, finite element analysis was carried out using Abaqus software to verify the effectiveness of strengthening. The reinforced concrete (RC) column strengthened by using fiber-reinforced polymer as a confining technique increased compressive strength by about 91% compared to the control column. In addition, the value of strains increased to nearly 100% in the longitudinal direction with the stability of the value of the lateral strains, despite the occurrence of a significant increase in the compressive strength capacity. So, the values of vertical displacement at stress 4 MPa were 22.3 mm for the strengthened RC column and 5 mm for the control RC column. Thus, the strengthened RC column increases the values of compressive strength with a decrease in displacement to approximately 22%. Four years ago, the strength of the school building was assessed, thus the success of the strengthening.

Keywords: strengthening reinforced concrete, columns, CFRP material, finite element analysis

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1 Introduction

In the last century and more than 40 years ago, fiber-reinforced polymer (FRP) was tried to strengthen and/or repair infrastructures such as bridges [1–7]. This is due to the fact that FRP is lightweight, has high tensile strength, is highly durable (correction-resistant), has good fatigue resistance, is resistant to chemical attack, and is highly versatile [8,9]. The tensile strength of FRP is around six times that of steel bars. Lately, the strengthening and repair of steel bridges by using FRP have been applied and developed worldwide [10–17].

In the mid-1980s, fully or partially wrapped columns with carbon FRP (CFRP) sheets were known applications and accepted for the strengthening and repair of concrete and steel structures in Japan [18]. This paper reviews the features of strengthening and repairing by using the Near Surface Mounted technique for concrete columns and slabs with CFRP sheets in Iraq. Many studies have been conducted in different ways to strengthen and repair concrete members, some of which were for the retrofitting of reinforced concrete (RC) columns using CFRP wrapping.

They found that CFRP jacketing reinforces and increases the ultimate load and ductility if it is used to strengthen the hollow concrete sections [19]. Some researchers made models of square-shaped RC columns, wrapped them with CFRP, and studied their effect on increasing the shear load [20–22]. It was found that the scheme of failure did not change exclusively, except that the buckling occurred after the column was subjected to greater stress than in the prior. In addition, the CFRP provided an improvement by increasing the bearing of the column (high load capacity) by no less than 15%, and it was also noted that there was an increase in the ductility [23]. Richard and Cheyrezy [24] produced an ultrahigh strength ductile concrete based on improving uniformity by removing coarse aggregate, improving microstructure by post-set heat treatment, and increasing tensile strength by inserting small, straight, high-tensile microfiber. RPC200 and RPC800 were two types of concrete designed with remarkable mechanical properties. Strengthening the RC columns in the longitudinal and transverse directions is very easy when wrapping the column with CFRP material for different column shapes, like circular, square, rectangular, and others [25]. Moreover, research on the effect of wrapping columns with CFRP material is still limited [26]. As previously mentioned, the study of the behavior of columns after confining with CFRP is very important because this technique has a significant impact on increasing the compressive strength of RC columns, and the confinement technique using CFRP has been used since approximately 18 years ago [27].

The behavior of RC columns that are strengthened by confining technique varies according to the design of the column in a structure that is normal or subject to seismic loads [28,29]. The main objective of strengthening the columns using the confining technique is to increase the resistance to compression, especially when the column needs to be re-designed due to an increase in live loads or the addition of new elements to the concrete structure (a change in the use of buildings) [30]. Utilizing the method of confinement with CFRP offers numerous benefits in terms of ease of implementation, speed in processing, a relatively acceptable cost and does not require many labors [31]. Iraq is one of the countries that are most vulnerable to fires resulting from wars in the world. Due to these fires, many structures were damaged entirely and some partially damaged. Many of these partially damaged structures were RC structures [32]. Most of the Iraqi population and the companies executing the projects do not have sufficient information and experience to use modern technologies in the treatment of concrete structures, as many of them are compelled to demolish buildings or use primitive methods to treat the damaged facilities, which leads to a large financial loss in the end. These structures could have been spared if correct retrofitting procedures had been used. In order to increase the capacity of such structures, a variety of strengthening/retrofitting procedures can be used. FRP is one of the newest materials for retrofitting that has several advantages and is utilized worldwide. FRP materials have been widely used in jacketing to improve shear and flexural strength and have proven to be quite successful [33]. Many studies on RPC have been conducted in recent years to analyze its features and behavior. The following are some of the projects that were completed: the main objective of this research is to evaluate the effectiveness of using CFRP material through the confinement technique, as scientific quantifiable evaluation of the different properties of structures strengthened by using CFRP is still insignificant in Iraq.

2 Significance of study

The importance of the research is the implementation of the reinforcement technique using FRP for the constructed building (school Iraqi) that was exposed to collapse as a result of rusting of some RC columns. A numerical study was done using finite element analysis (FEA) to simulate the strengthening before practical implementation. Then, the practical strengthening was carried out on the RC columns using two layers of FRP. The follow-up of the constructed building was more than 5 years without any observation being recorded, indicating the success of the strengthening process. It is worth noting that the cost of rehabilitating the RC columns is approximately $2,000, but the demolition and rebuilding of the concrete structure exceeds $30,000.

3 Experimental program

The experimental work consists of four-square RC columns with a full-scale cross-section of about 0.6 m by 0.4 m and 5 m in height. These columns were wrapped in CFRP sheets according to the Hand lay-up system (Figure 1), a typical wrap system.

The same technique was also used in Al-Mosul city of Iraq in 2017. Figure 2 shows the steps involved in repairing and strengthening these columns. First, the damaged concrete is removed, and the column is cleaned of dust. Then, special cement materials were used to repair the affected areas. Finally, epoxy was added to perfect the bond between FRP sheets around RC columns.

So, in this research, the same procedure is used to strengthen the RC columns of school buildings in Al-Mosul city. The wet lay-up method was used for the CFRP wrapping of four plain square columns from each specimen [35]. The first step was cleaning the face of the columns to remove damaged concrete and dust. Then, the

Figure 1: Strengthening of RC columns by FRP sheet in Sweden, photo by Täljsten [34].

Figure 2: Steps involved in repairing and strengthening RC columns in Al-Mosul city.

outer surface was coated by using weberep 331 TX, as shown in Figure 3. Weberep 331 TX is a ready mortar mainly made of sand (reconstituted grain size range), special cement, fibers, and special additives. So, it provides special properties such as non-shrinking, thixotropic, high strength, high adhesion, and compactness. Thus, its closed porosity slows down carbonation [36].

Then, the specimens were sandblasted to provide better adhesion between columns with the CFRP laminates. A thin coat of the Weberep epo 412 Primer was applied, and it was permitted a maximum of 1 h for curing. The primer layer of the column received an application of Weber EPO 412 epoxy at perfect bonding with CFRP laminates. The CFRP laminates were attached to the concrete surface and provided an overlap of not less than 100 mm when the column was wrapped because the normal width of the laminates available in Iraq was 1 m. Then, the column was wrapped with two layers of CFRP laminates interspersed with epoxy, as shown in Figure 4.

Figure 3: Cleaning and coating concrete surface.

Figure 4: Wrapping columns by using CFRP sheet.

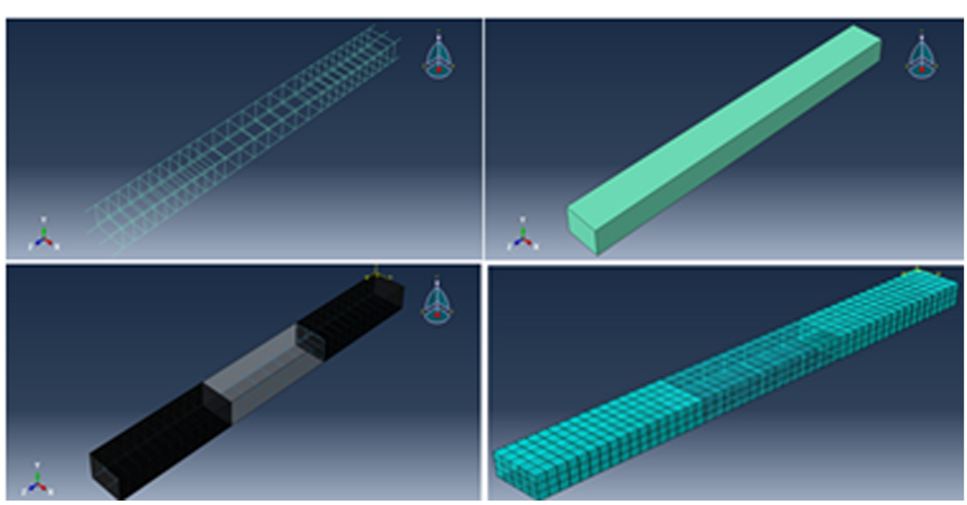

Figure 5: Model and mesh concrete, steel rebar, and CFRP confinement.

Table 1: Define concrete, steel rebar, and CFRP materials

Item	Element type	Element no.	Elastic	Isotropic	Hashin damage	Young's modulus	Poisson's ratio	Type of analysis	Longitudinal compression strength	Plastic	Yield stress	Plastic strain
Concrete	C3D8R	750	Done	Done	—	31,220	0.2	Dynamic, explicit	—	—	—	—
Steel	S4R	544	—	Done	—	200,000	0.2	Dynamic, explicit	—	Done	280, 370	0, 0.1
CFRP	T3D2	734	—	—	Done	—	—	Dynamic, explicit	1,200	—	—	—

4 Numerical and result analysis

4.1 Mechanical properties

Theoretical analysis programs have evolved in terms of their ability to predict the mechanical properties of concrete, including cracks and their theoretical appearance over the past decades. The impact parameters of concrete in the Abaqus program, including elastic modulus, Poisson's ratio, plastic degradation, tensile and compressive stresses, and the ratio of initial compressive yield stress to initial compressive yield stress, are mainly included in the analysis of

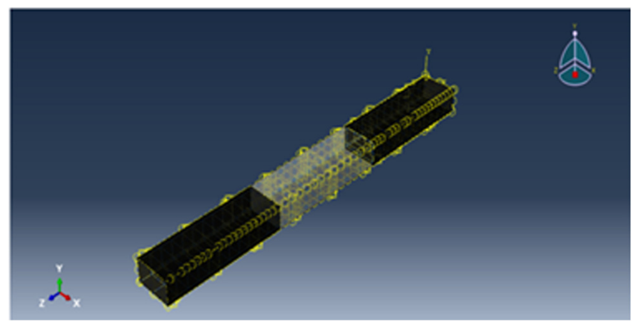

Figure 6: Interaction between the elements.

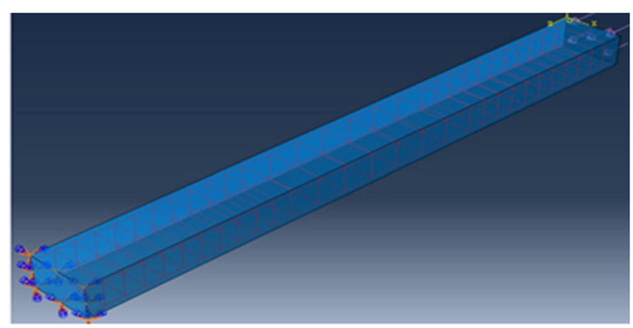

Figure 7: Loading and fixing of supports.

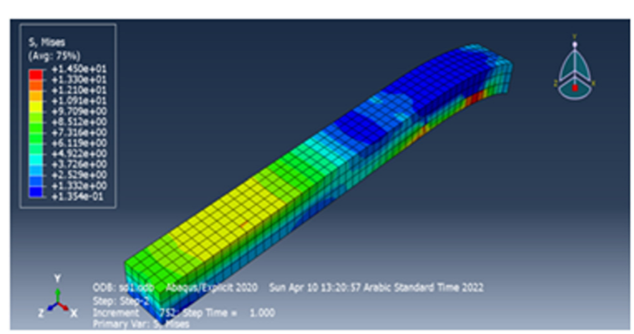

Figure 8: The stress of the control column.

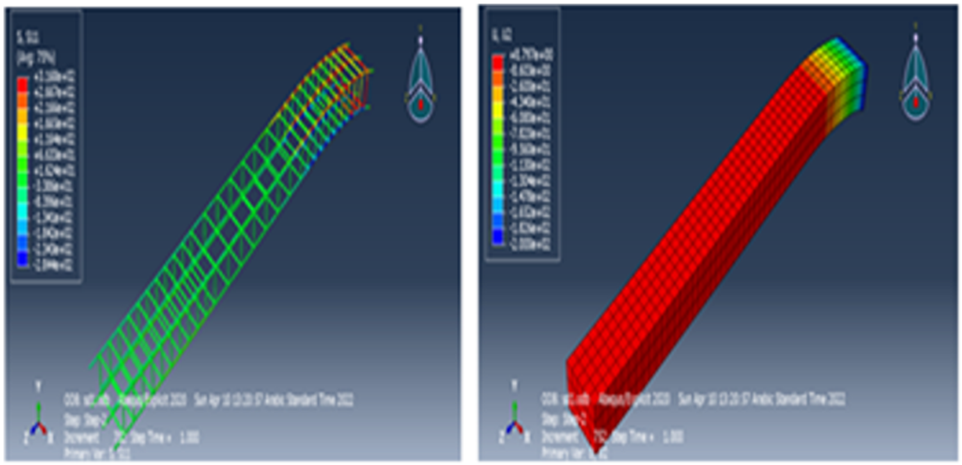

Figure 9: The displacement for each material in the control column.

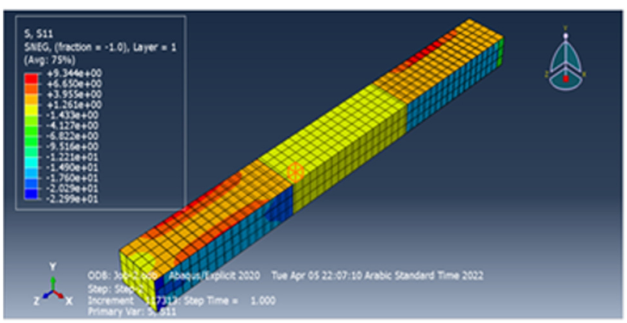

Figure 10: The stress of the strengthened column.

concrete. As for reinforcing steel, the model used was the metal-plastic model, where it is assumed that steel is a plastic material with perfect elasticity and identical through tensile strength. The modulus of elasticity, Es, and the yield stress, fy, were measured in the experimental study, and the obtained values were Es = 200 GPa, fy = 480 MPa, and the Poisson ratio was assumed to be 0.2. In addition, the used polymer fibers were considered a linear orthodontic material because the composite was unidirectional. The modulus of elasticity of `the CFRP material used in the pilot study was specified by the manufacturer as 170 GPa and the Poisson's ratio is 0.2. The utilization of the compound foundation, E11 = 225 GPa, E22 = 9.86 GPa, E33 = 9.86 GPa, ν12 = ν13 = 0.1, G12 = 0.1 GPa, G23 = 0.1 GPa, and G13 = 0.1 GPa use for the orthorhombic model.

4.2 Modeling

FEA (ABAQUS software) was used to analyze numerical simulation RC columns strengthened with FRP systems as a three-dimensional finite element [37]. The FEA model of strengthened RC columns improved their behavior in comparison to the non-strengthened control column. The concrete, steel rebar, and CFRP confinement were drawn as shown in Figure 5. Three types of material are used to make a model for concrete columns confined by CFRP, and these materials are defined as presented in Table 1.

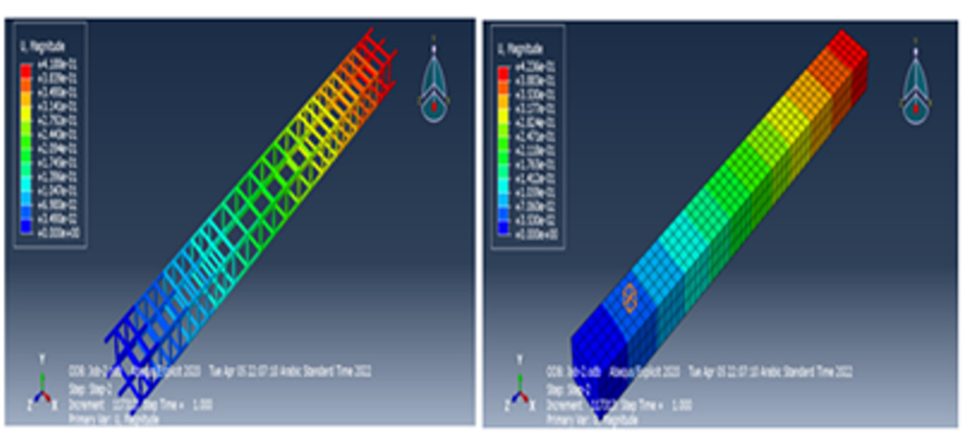

Figure 11: The displacement for each material in the strengthened column.

The interaction for these materials was done to make a good interaction between the elements, as shown in Figure 6.

Two types of support were applied for the column end; one of them was a fix for three dimensions, and a 3 N/mm uniform distribution load was applied at another end. These two supports can be seen in Figure 7.

In the next stage, the model was meshed with 0.5 mm for all materials. Finally, the job was made to analyze this model. This job was divided into two steps according to the type of load, support, and displacement. For the control specimen, the stress at the load point was very high and reached 1.4E01, as shown in Figure 8.

4.3 Performance of rehabilitation method

The displacements of steel rebar and concrete were 3.168×10^2 and 8.797, respectively. Figure 9 shows the displacement for each material in the control column.

For the confined column using CFRP material, the stress for this specimen was 9.344, as shown in Figure 10.

In addition, the maximum displacement for a confined column can be seen in Figure 11.

On the other hand, the longitudinal and lateral strains were calculated according to the points shown in Figure 12, where it was found that the highest value of the stress of the control column (RC column) reached 4.2 MPa, and the highest value of the strain was 0.0018, 0.001, 0.0015, and 0.0018 in the longitudinal and transverse directions, respectively, as shown in Figure 13.

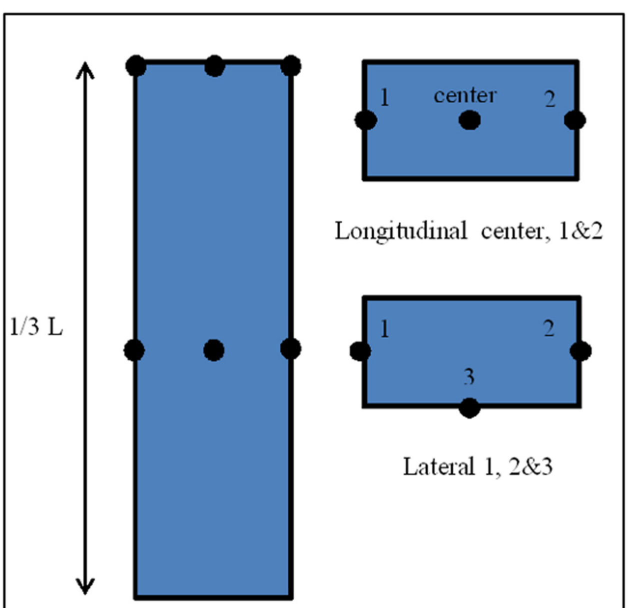

Figure 12: Strain results of the different nodes locations.

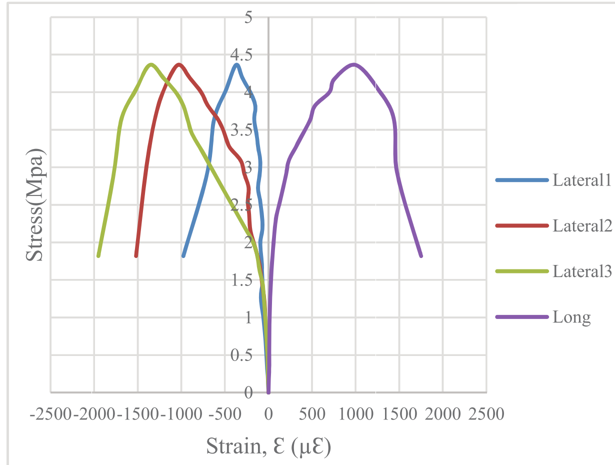

Figure 13: The stress–strain profile of the control column.

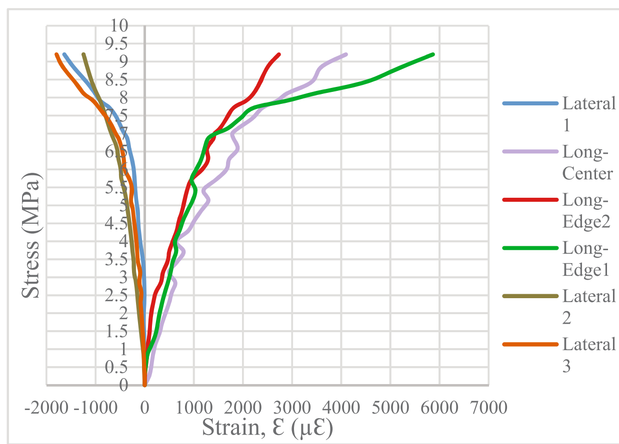

Figure 14: The stress–strain profile of a strengthened column.

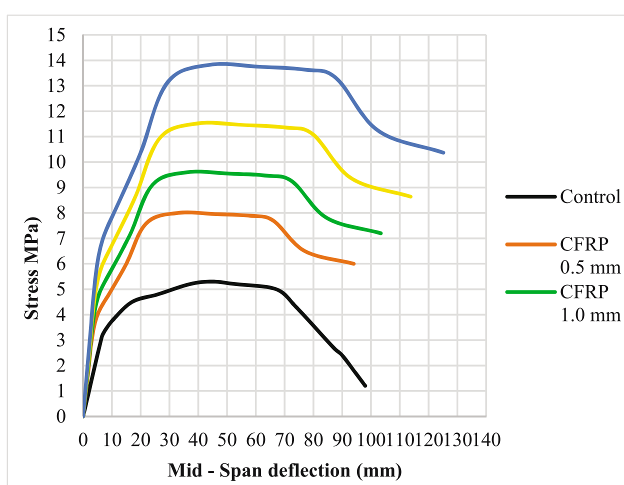

Figure 15: The displacement of CFRP and the control column profile.

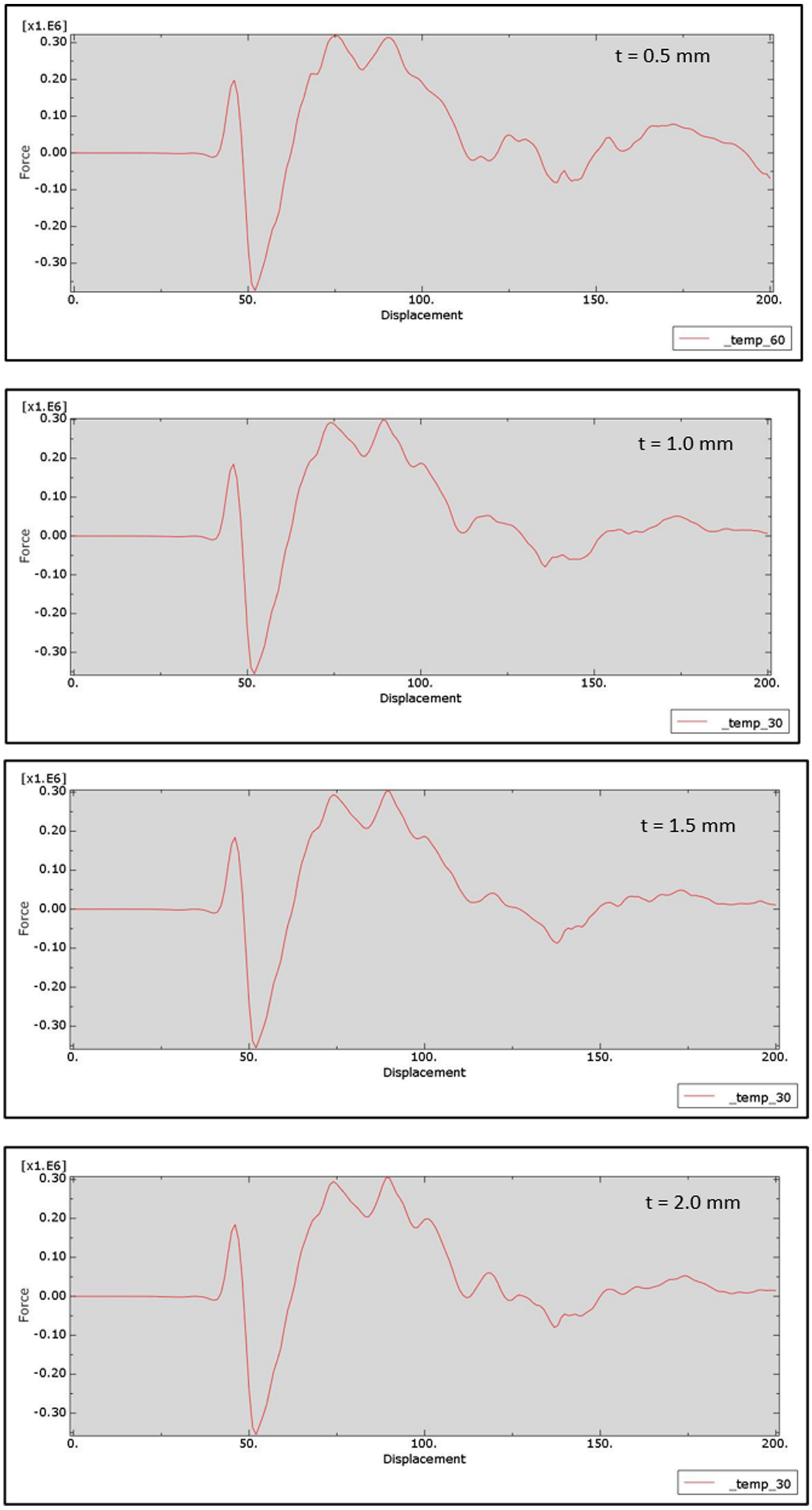

Figure 16: Load–displacement readings of CFRP.

Moreover, it was noted that the RC column using the confining technique gave an increase in compressive strength of about 91% compared to the control column. In addition, the value of strains increased to nearly 100% in the longitudinal direction with the stability of the value of the lateral strains, despite the occurrence of a significant increase in the compressive strength capacity. It was also noted that the shape of the curve between stress and strain has changed for the reinforced column and become almost linear, as shown in Figure 14.

In this article, the effect of confining on the vertical displacements in the concrete column was studied. From observing the results of strengthening using 0.5 mm CFRP columns, it was recorded an increase in the amount of compressive strength and a decrease in displacement to approximately 22%, as the amount of vertical displacement at stress 4 MPa was 22.3 and 5 mm for the strengthened and control columns, respectively, as shown in Figure 15. Similarly, the effectiveness of wraps according to different thicknesses of CFRP is shown in Figure 15. On the other hand, the variable readings of load–displacement results for 0.5, 1, 1.5, and 2 mm thickness of CFRP wraps recorded by Abaqus software are shown in Figure 16.

5 Conclusion

This study implemented a dual reinforcement approach for square-shaped RC columns were carried out, that it was studying the effect of static loads on these columns had low compressive strength. From these results, it can be concluded that the FRP jackets can increase the strength and ductility of the columns. The efficiency of FRP jackets increased the axial capacity of columns. The value of vertical displacement at stress 4 MPa was 22.3 and 5 mm for the strengthened and control columns, respectively. The strengthened RC column recorded an increase in the values of compressive strength with a decrease in displacement to approximately 22%. Through the results obtained, an increase in the bearing values of the RC columns of the applied loading leads to a decrease in the vertical and lateral displacements as a result of these strengthening. The strengthened RC column using FRP increased compressive strength by nearly 91% compared to the control column. Despite the occurrence of a significant increase in the compressive capacity, the value of strains increased to nearly 100% in the longitudinal direction, while the value of lateral strains remained stable. In addition, the absence of the need to evacuate the building during the treatment of columns, beams, and others in concrete facilities is one of the important advantages of using the confinement technique by CFRP. In general, FRP jackets have proven to be highly effective in strengthening, maintaining, and rehabilitating RC buildings in Iraqi schools.

Acknowledgements: The authors wish to extend their thanks to the Fourth Dimension Contracting Company for their support, guidance, and expertise that greatly assisted the research, especially in preparing the research materials and laboratory.

Conflict of interest: The authors state no conflict of interest.

Data availability statement: Most datasets generated and analyzed in this study are included in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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