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EFFECT OF CARBON FIBER REINFORCED POLYMER (CFRP) COMPOSITES APPLIED TO WALLS AND SLABS OF MASONRY BUILDING

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Abstract: *The use of fiber reinforced polymers (FRPs) has become popular because of their attractive behaviors such as high strength-to-weight and high stiffness-to-weight ratios, high mechanical performance and possibility to be produced in any shape, ease of installation and lesser requirements for supporting structure, corrosion resistance, light weight and high durability. It has been shown in the literature that the use of small sheets of CFRP composites improve structure's responses substantially. In this study, analysis of masonry building strengthened with CFRP on tension sides of slabs and walls is conducted. A commonly Finite Element Method by use of ETAPBS Software v.16 is used to analyze a 2 storey masonry building with brick walls and wooden slabs. Both walls and slabs are strengthened with CFRP, and comparison is done in terms of stresses and stiffness for buildings with and without CFRP. It is shown that there is around 48% increase in the stiffness of building with CFRP compared to one without CFRP. In addition, stresses resulted from building with CFRP are far smaller, indicating the effectiveness of using CFRP in strengthening and prevention of both invisible and visible cracks for Retrofitted structures.*

Keywords: *CFRP, masonry building, stiffness, stress, strengthening.*

I. INTRODUCTION

1.1. Background

Recently, application of fiber reinforced plastic composites system by gluing them to external part of the reinforced concrete structures is gradually becoming popular for the aim of repairing and strengthening [1, 2, 3, and 4]. FRP exhibit attractive properties such as high strength, stiffness and durability, light weight and easy installation. FRP have been commonly used in the renewal of constructed facilities such as buildings, bridges and pipelines. They have been used in rehabilitation of concrete structures because of their easy application and low life cycle costs. All these powerful behaviors of FRP have led to the development of the light weight structural concepts by utilizing FRP systems or new FRP/concrete composite systems [5]. Fibers which are currently being used include: carbon, glass, aramid and basalt. The production of these fibers is done in two ways: either as plates (covered by thin fibers) or as tissues (knitted in one and two directions). The behavior of the system that is covered with external FRP composite is related to the type of the element covered. Generally, FRPs have been separated into three categories: bending strengthening, shear strengthening and envelope scripts.

1.2. Previous Studies Related to Fiber Reinforced Polymers (FRP)

In recent years, a wide number of researches have been conducted on the use of FRP to investigate its efficiency through experimental tests, analytical and finite element numerical simulations. In some studies related to the use of CFRP, Evidence of their potential was clearly shown for various types of structures such as ones shown in [6, 7, 8, 9, 10, and 11]. Group of different slabs were tested to check their performance with and without FRP, where various types of FRP were tested, and it was shown that sheets of CFRP perform better compared to other tested types [11]. In [12] Authors tested RC frames strengthened with GFRP and CFRP. No severe cracks or excessive deflections were found and a moment redistribution of up to 30 % was observed at the mid-span frames. The effectiveness of using FRP as reinforcing bars was also demonstrated by a number of researchers, including [13, 14, and 15]. However, despite all these positive effects, there are some drawbacks such as the fact that FRP can be affected by the rate of loading, temperature and environmental conditions as shown in [16]. In the study [17], it was shown that CFRP exhibit a significant and direct influence on the mechanical behavior and ultimate strengths of the investigated samples, where it was shown that the higher the fiber content, the higher is the ultimate strength as well as higher elastic stiffness. In the study [18] Authors investigated behaviors of both GFRP and CFRP through numerical modelling of masonry structures, for the purpose of enhancing the in plane seismic performance for historical masonry walls with various and geometrically complex building systems, where the effectiveness of using these fibers was clearly discussed. Furthermore, the use of CFRP in masonry walls was investigated in [19], where Authors concluded that the improvement in lateral capacity of up to three times the capacity of unreinforced masonry rocking mode was achieved. More work should be done to clarify the performance of structures under seismic loads. In the latest research on the use of GFRP when applied to walls only, for retrofitting a school building, it was shown that stiffness of the retrofitted building is increased up to around 86% [20].

1.3. Building Description

The examined building is designed to be a historical masonry residence with two stories (see fig.1, 2). Its walls are made of bricks, and slabs are of wood type. The 1st floor height is 3.5m and the second floor height is 3.5 m. The Length of front and side facades are 14 and 10.5 m respectively. Slab and wall thicknesses are 70mm and 250mm, respectively. Live load is assumed to be 0.2t/m^2. The modulus of elasticity, weight per unit volume and Poisson' s ratio of structural elements of building are 7500 kg/cm2, 1.75 t/m3 and 0.2, respectively. Similar values are already present in literature [21].

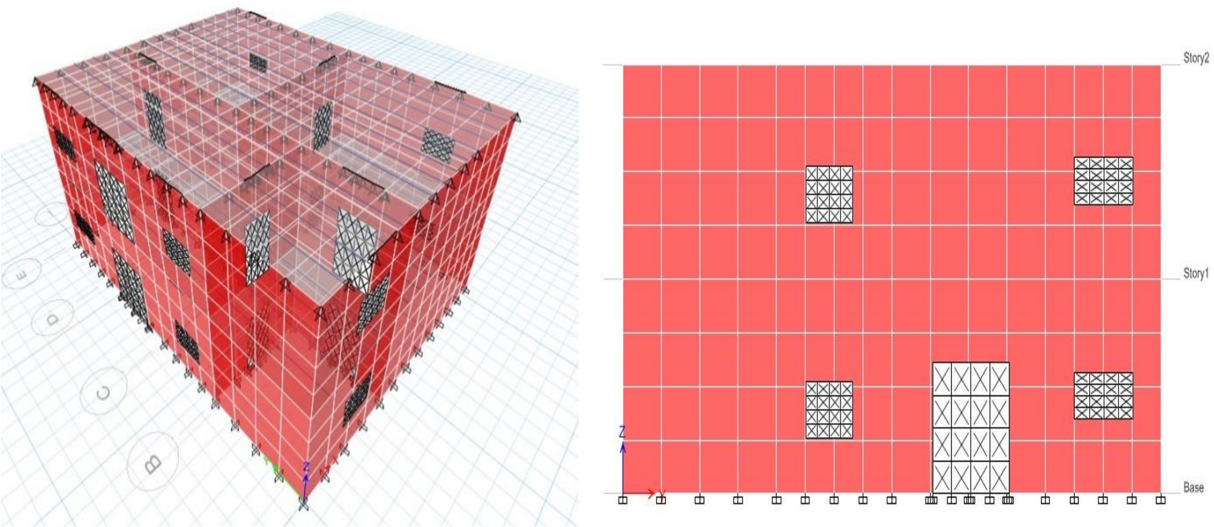

Figure 1. Model of the building (Left) and its front view (right)

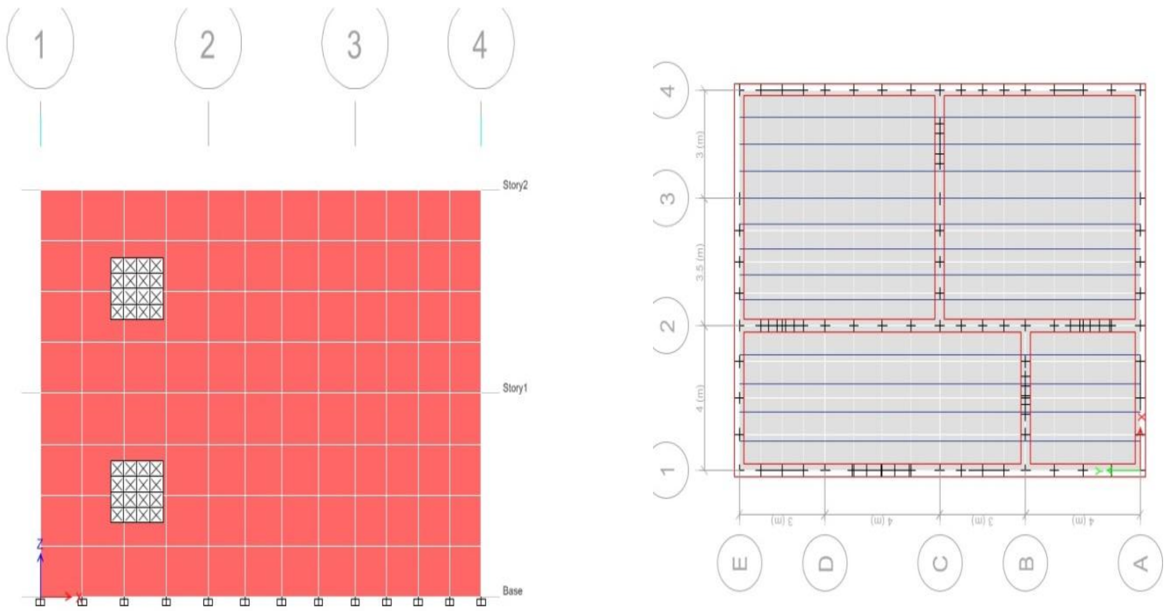

Figure 2. Side view (left) and Floor plan (right)

I. STRUCTURAL ANALYSIS OF THE SHOWN BUILDING

In this part, the above building is analyzed in two different cases: In the 1st case, the building without CFRP is investigated for its responses (frequencies and periods, stiffness and stresses). In the 2nd case, the same building is analyzed when CFRP is used to strengthen both the walls and slabs. Then responses from both cases are compared.

Case 1: Analysis of the building without CFRP

The behavior of the shown building when subjected to static and lateral load is analyzed by using finite element method through ETABS v.16 Software. Both walls and slabs are modelled as shell elements. In this study, 5 modes are considered and only 4 of them are demonstrated in fig.3, 4. Stresses in the shell elements are shown in fig.5, 6.

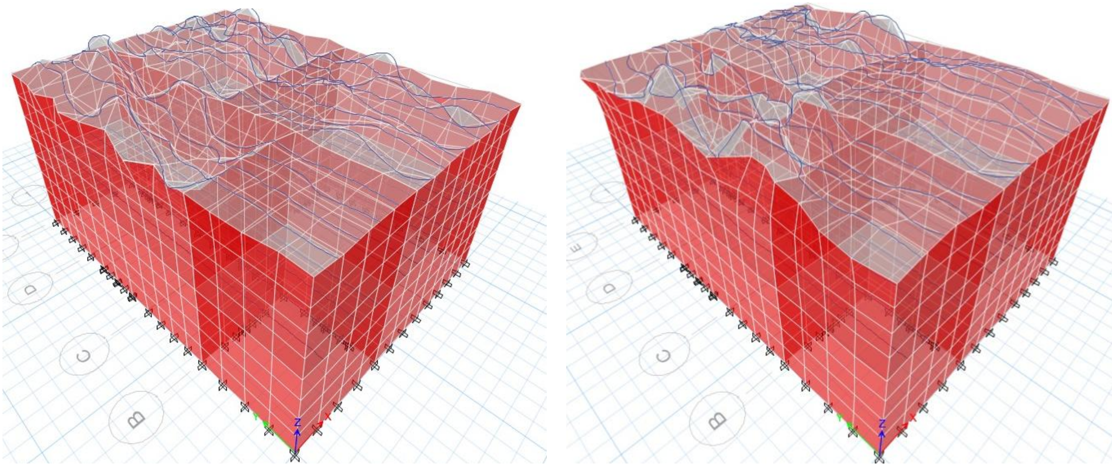

Figure 3. First mode shape (left) and second mode shape (right)

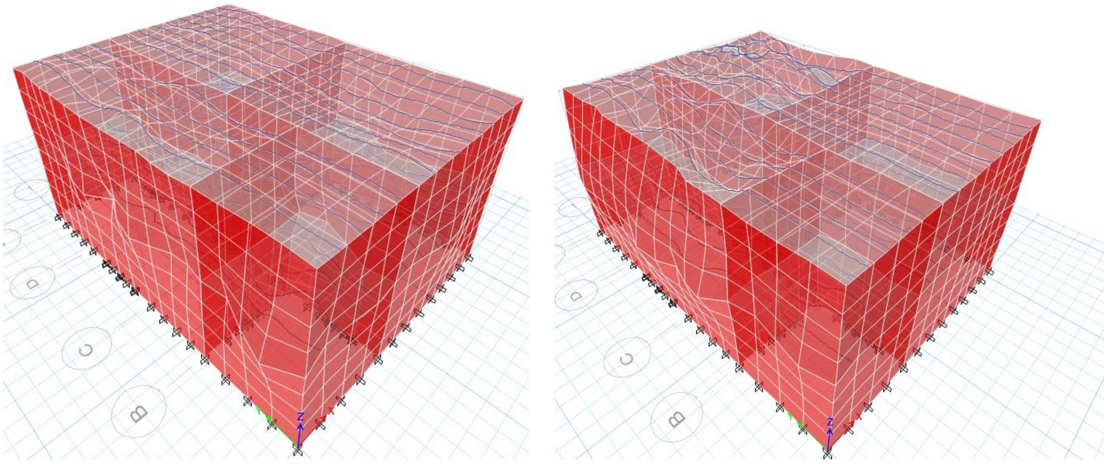

Figure 4. Third mode shape (left) and fourth mode shape (right)

The maximum stresses in the building without CFRP are demonstrated in the figure below.

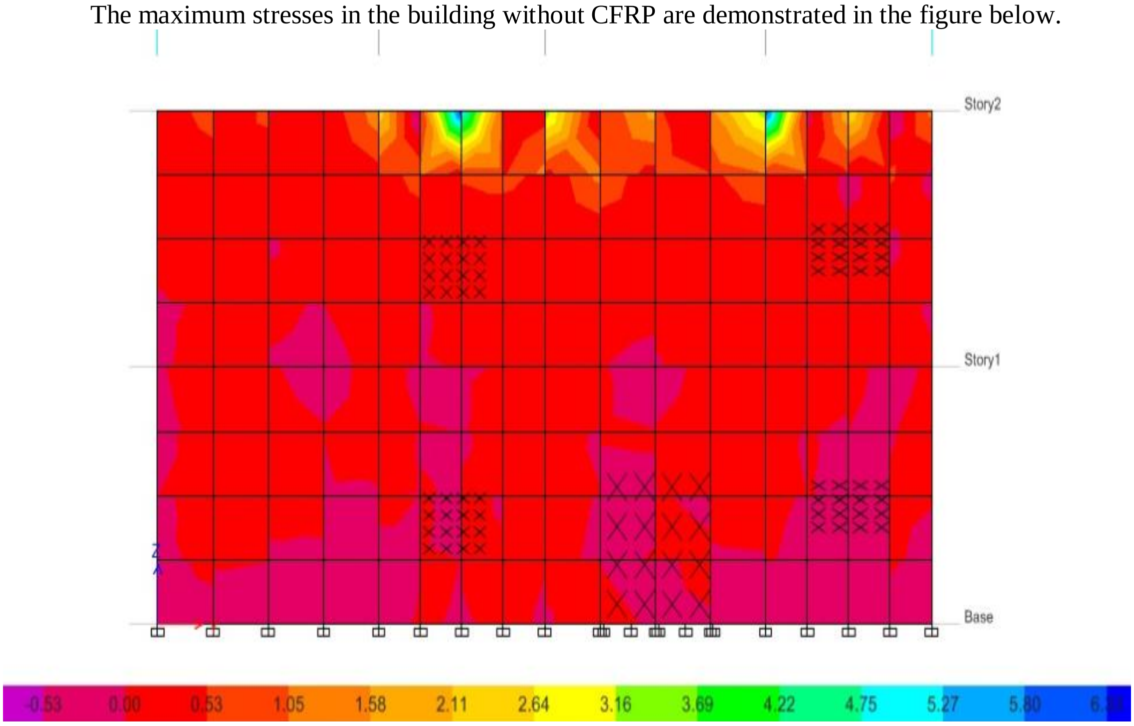

Figure 5. Maximum wall stresses for the building without CFRP (side elevation view)

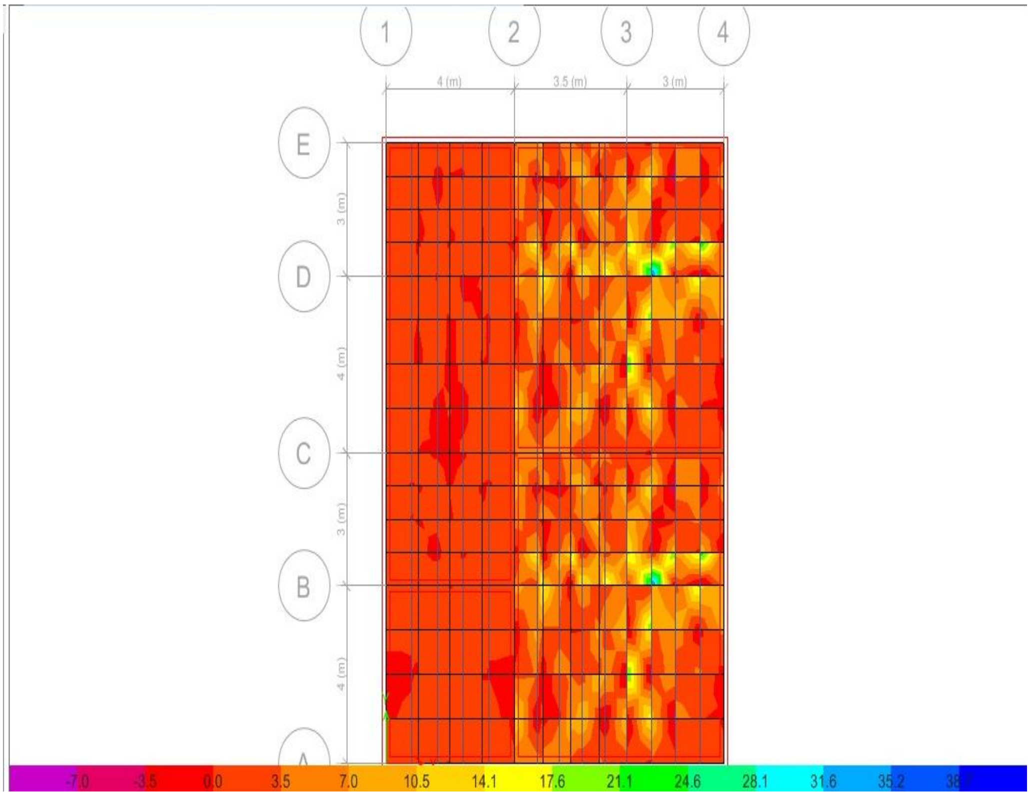

Figure 6. Maximum slab stresses of the 1st floor for building without CFRP

Case 2: Analysis of the building with CFRP

The behavior of the shown building when subjected to axial and lateral load is analyzed by using finite element method through ETABS v.16 Software. CFRP sheet with 0.2 mm thick is bonded to interior walls and tension side of slabs. Then, both walls and slabs are modelled as shell elements. 5 modes are considered and only 4 of them are demonstrated in fig.7, 8. Stresses in shell elements are shown in fig.9, 10.

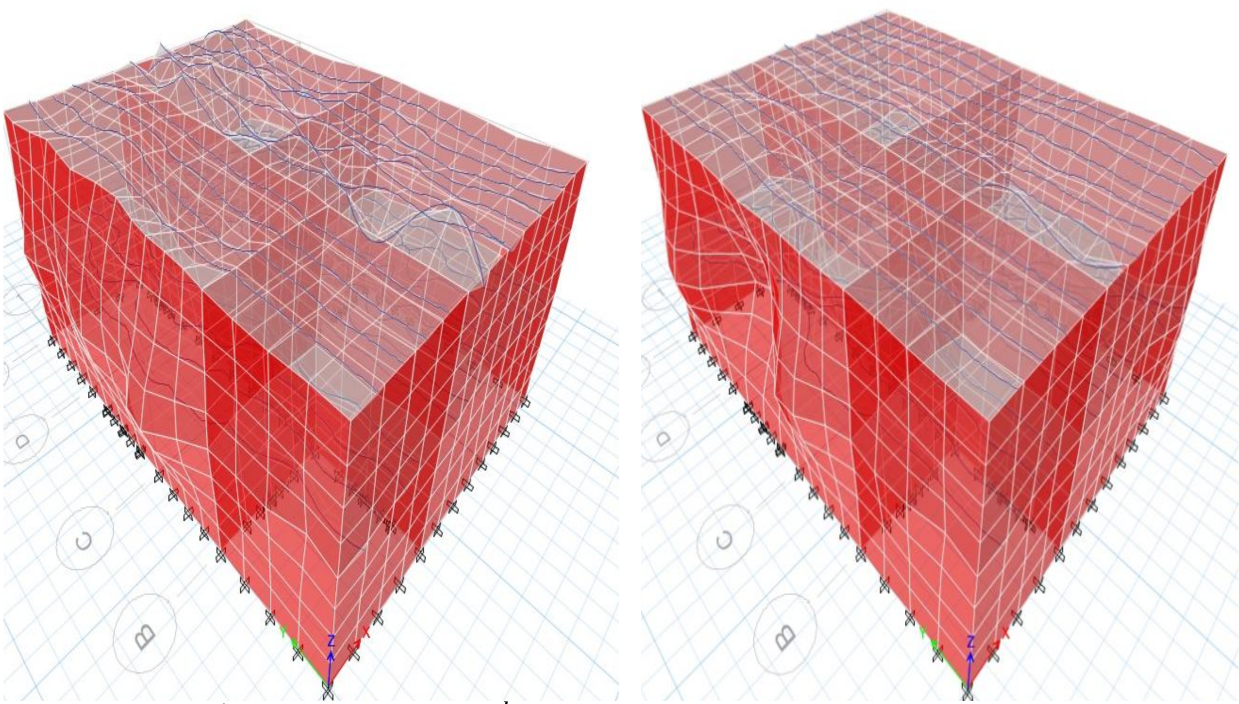

Figure 7. 1st mode shape (left) and 2nd mode shape (right) of the building strengthened by CFRP

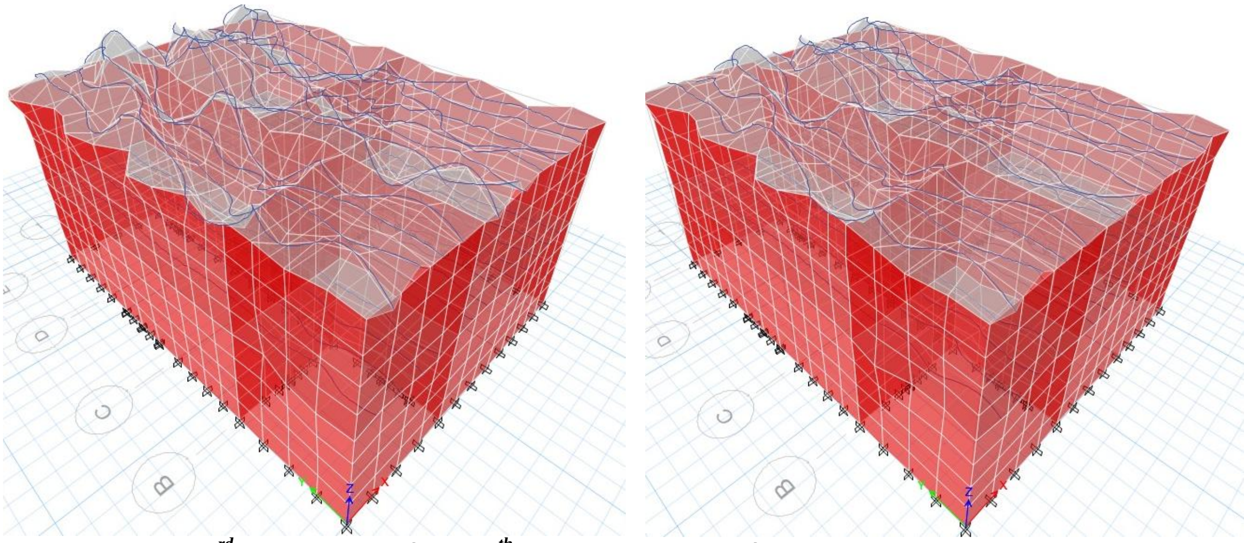

Figure 8. 3rd mode shape (left) and 4th mode shape (right) of the building strengthened by CFRP

The maximum stresses in the building strengthened with CFRP are demonstrated in the figure below.

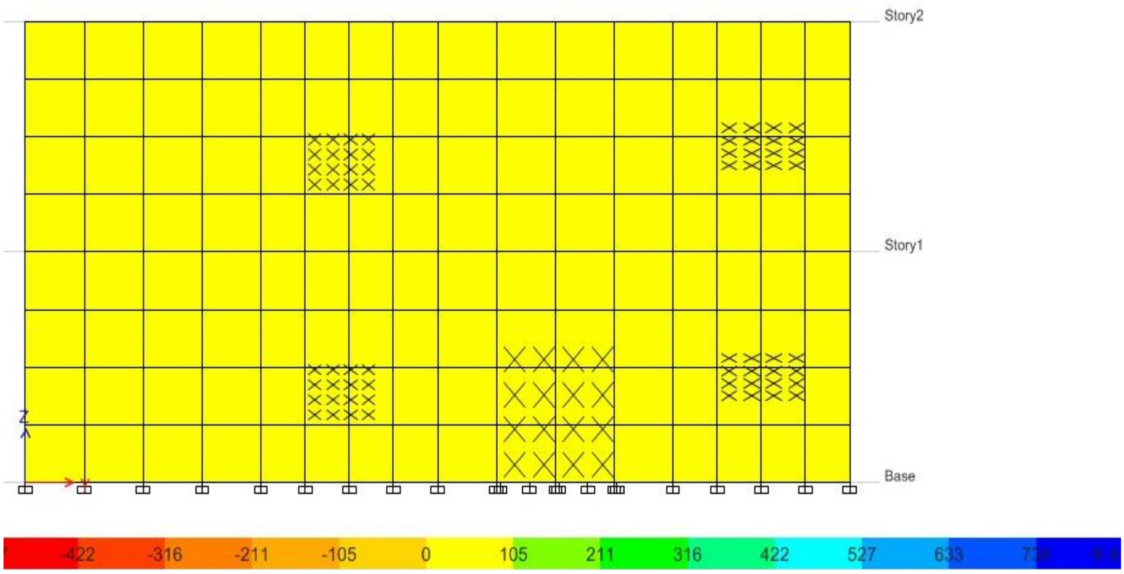

Figure 9. Maximum wall stresses for the building with CFRP (side elevation view)

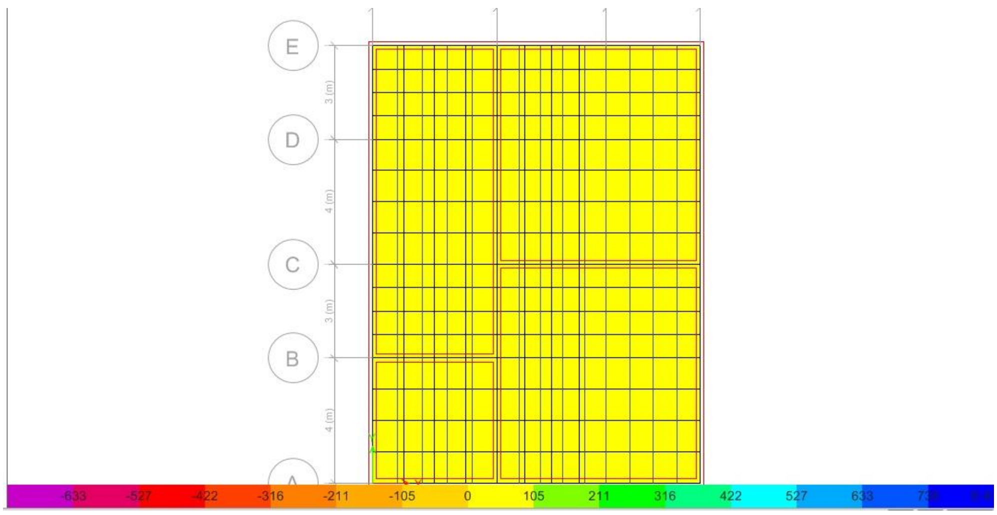

Figure.10. Maximum slab stresses of the 1st floor for building with CFRP

II. RESULTS AND DISCUSSION

***Case1*:** The study on a building without CFRP has shown that the maximum period occurred is 0.155s, corresponding to its minimum frequency of 6.449Hz for the first mode, and its lowest period of 0.039s corresponding to the highest frequency of 25.443Hz for the fifth mode as shown table1.

Case2: The study on a building with CFRP applied only to walls has shown that the maximum period occurred is 0.087s corresponding to its minimum frequency of 11.521Hz for the first mode, and its lowest period of 0.033s corresponding to the highest frequency of 30.735Hz for the fifth mode as shown table1. Similar comparisons can also be seen in table 4.

Table 1: Periods and frequencies for Building without CFRP (left) and with CFRP applied to walls only (right)

Mode number	Period	Frequency	Period	Frequency
	Without CFRP		With CFRP	
1	0.155	6.449	0.087	11.521
2	0.08	12.474	-0.076	-13.151
3	0.065	15.422	0.035	28.281
4	0.052	19.391	0.034	29.311
5	0.039	25.443	0.033	30.735

Comparison of Case 1 and case 2: Comparison of case 1 and 2 is shown in order to clearly analyse the effectiveness of using CFRP in masonry building, especially in terms of stiffness and stresses. However, other parameters like momennts and shears are not investigated in this research. In general, it is shown that frequencies are increased compared for building strengthened with CFRP (see table 1).

Table 2: Comparison of modal analysis results from Normal building and wall-strengthened building

Mode number	1	2	3	4	5
Frequency(Hz)-N	6.449	12.474	15.422	19.391	25.443
Frequency(Hz)-S	11.521	13.151	28.281	29.311	30.735
% age Difference	78.6479	5.42729	83.3809	51.1578	20.7994
Total increase in stiffness (in %age)					47.88264

Table 3: Comparison of modal analysis results from Normal building and strengthened building (both slab and walls)

Mode number	1	2	3	4	5
Frequency(Hz)-N	6.449	12.4	15.422	19.391	25.4
Frequency(Hz)-S	9.173	9.351	20	23.736	24.645
% age Difference	42.2391	-25	29.0364	22.4073	-3.136
Total increase in stiffness (in %age)					13.109

From table 2 and 3, it is shown that the use of CFRP increased the frequency of the building, leading to increase in stiffness of the structure up to around 48 % when CFRP is applied to walls only and 13% when it is applied to both walls and slabs. This indicates that the application of CFRP to walls only, provides greater stiffness compared to when applied to both walls and slabs. However, the use of CFRP on slabs can have great advantage in reducing stresses as shown in fig.10 and 12.

Table 4: Periods and frequencies for Building without CFRP (left) and with CFRP applied to both slab and walls (right)

Mode number	Period	Frequency	Period	Frequency
	Without CFRP		With CFRP	
1	0.155	6.449	-0.109	-9.173
2	0.08	12.474	0.107	9.351
3	0.065	15.422	-0.05	-19.941
4	0.052	19.391	0.042	23.736
5	0.039	25.443	0.041	24.645

N: Normal Building without CFRP, S: Building strengthened by CFRP.

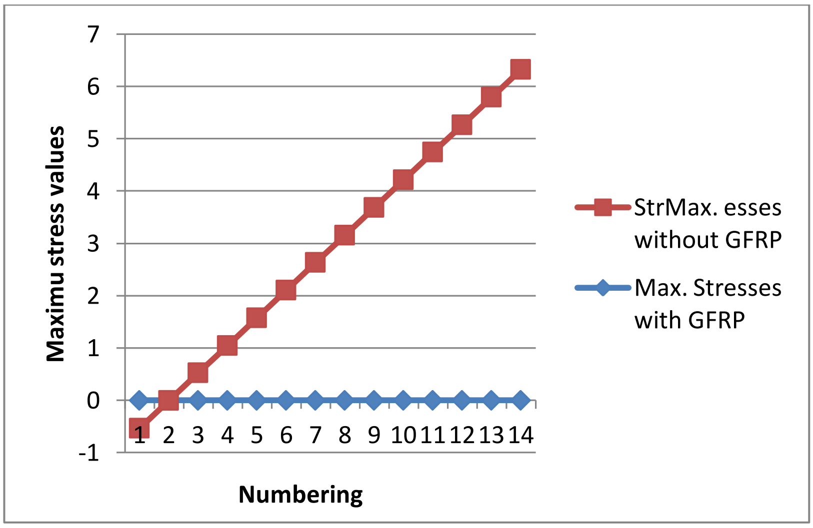

Figure 11. Comparison of stresses for building with CFRP (on walls) and without CFRP

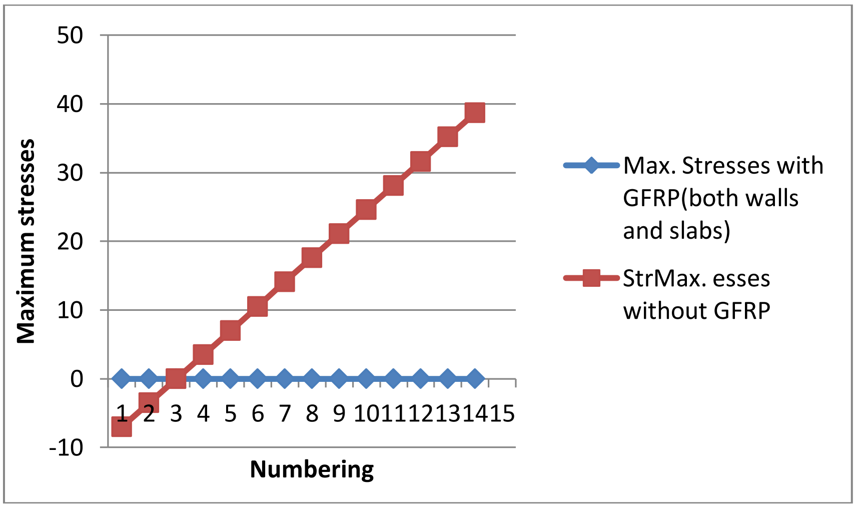

Figure 12. Comparison of stresses for building with CFRP (on both walls and slabs) and without CFRP

Looking at both figure 11 and figure 12, maximum Stresses in the strengthened building are much smaller compared to the ones resulted from building without CFRP. It is clearly shown that the use of CFRP is very effective in reduction of stresses, which are normally key parameters to cause development of cracks in the structure. Thus, it could be ensured that both visible and invisible cracks cannot develop easily when CFRP is bonded to interior walls and tension parts of slabs, while buildings which are not strengthened may result in cracks propagation time after time.

III. CONCLUSION

In this study, the effectiveness of using CFRP in masonry buildings for the sake of improving stiffness and reducing stresses has been investigated. A two storey building was analyzed to examine its responses with and without CFRP. When strengthened by CFRP bonded to its interior walls and tension side of its slabs, the studied building showed a remarkable effectiveness for the use of Carbon Fiber Reinforced Polymers, where its stiffness was increased by around 48 % (when applied to walls only) compared to the stiffness of the same building but without CFRP. Furthermore, when both walls and slabs are strenthened, there was a substantial reduction of stresses in walls and slabs, even if the increase in stifness reduced to 13%. Therefore, it was generally shown that the use of CFRP results in stresses which are much smaller than stresses resulted from non-strengthened building; whereas stiffness increase may depend on which part of the building CFRP is applied. The conclusion of this study strongly suggests that the strengthening of masonry building structures, especially in retrofitting and/or rehabilitation, should be very efficient in substantial reduction of stresses, increase in stiffness and natural frequencies, thus leading to a durable, crack free and sustainable structure.

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