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Analysis Of Masonry Structures Retrofitted With Glass Fiber Reinforced Polymer Using Finite Element Method

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Abstract—*In this study, Analysis of masonry structures retrofitted with glass fiber reinforced polymer using finite element method. by using the same method & analyzing the existing building, dynamic parameters were compared. The building consists of two stories with wooden floors and stone walls. Stress, shear forces and moment of the structural members are calculated by ETABS v.16 program. Structural members of the masonry building are modeled as shell member after the material properties are determined. There's have been a decrease in the value of stress, moment, shear forces and periods of the modal when the building was retrofitted by unidirectional GFRP.*

Keywords*- GFRP; masonry structure; frequency; period; retrofitting*

I. INTRODUCTION

Most of the structures found in earthquake hazardous areas are subject to various destructive effects caused by seismic loads. When an earthquake occurs, the structural elements of the structures are damaged. On the other hand, especially considering the performance of structures in seismic load effect, it is very important to strengthen the columns without changing the mass of the building. It is clear that this technique needs to investigate the relationship between repair and retrofitting operations and column capacity. More work should be done to clarify the performance of structures under seismic loads. Recently, application of fiber reinforced plastic composite system by gluing them to external part of the reinforced concrete structures is gradually becoming popular for the aim of repairing and strengthening (Yang et al. 2017), Keykha (2017), (Smyrou et al. 2015), Elwan and Omar (2014). Fibers to be used, as they have required characteristics include: glass, aramid and carbon. 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. The experimental result shows that CFRP laminate can effectively be used to provide beams ductility performance. The effect of FRP wrapping number to the maximum axial capacity has been evaluated Kasimzade and Tuhta (2012), Kasimzade and Tuhta (2017), Kasimzade and Tuhta (2005).

II. BUILDING DESCRIPTION

The building consists of 2 stories with wooden floors and stone walls. The building was used as a school. The height of the 1st story is 3.9 meters, the 2nd story is 4.35 meters, and the total height of the building is 8.25 meters. The lower level's height is -0.9 meters, for that the total height of the building is 7.35 meters. The floor area of the building is 215.23 m^2. Building's inner and outer walls thickness are 40 cm. Floor thickness is 7cm. This floor was applied to secondary beams which had a diameter of 15 cm and 60 cm distant from one another.

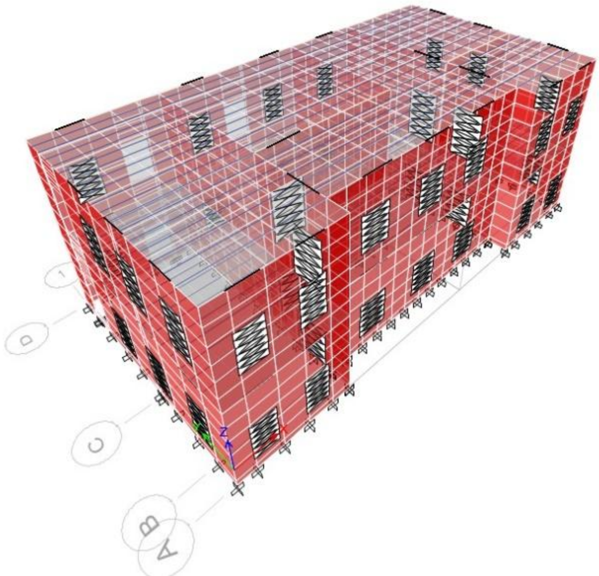


Figure 1. Model of masonry building

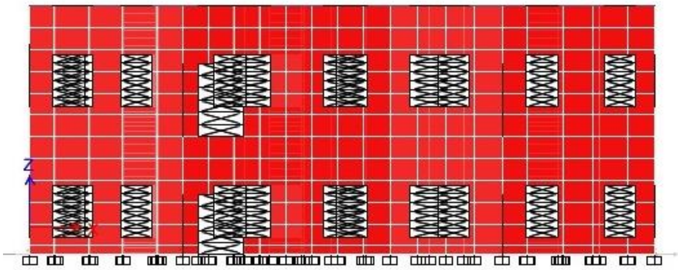


Figure 2. Front view of the model

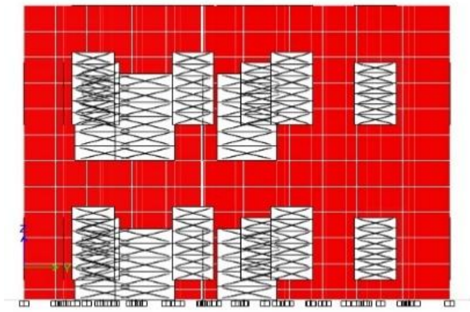


Figure 3. Side view of the model

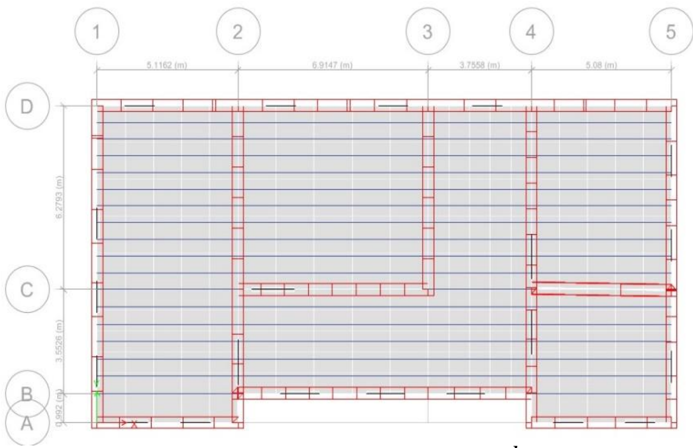


Figure 4. Plan view of the 1st and 2nd stories

III. ANALYSIS & COMPARISON

Using ETABS v.16 program Unidirectional GFRP's properties and existing Masonry building model's loads and materials properties were entered. In this study GFRP materials were applied to the Masonry structure's walls using ETABS v.16 program a (0.02mm) layer of unidirectional GFRP were added to a (400 mm) wall as shown in Table 1 and Figure 5.

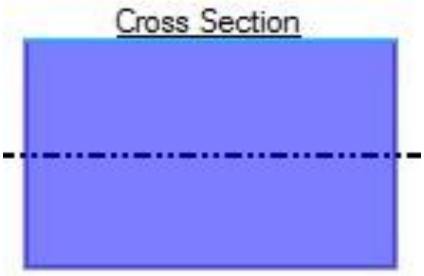


Figure 5. Layers of masonry wall and GFRP

Table 1. Wall property layer definition data

Layer Name	Material	Distance (mm)	Thickness (mm)
1	Masonry	0	400
2	GFRP	200.1	0.2

A. Modal Periods and Frequencies Comparison

The modal frequency & periods before & after the application of unidirectional GFRP are given in table 2 and table 3.

Table 2. Modal periods and frequencies (existing building)

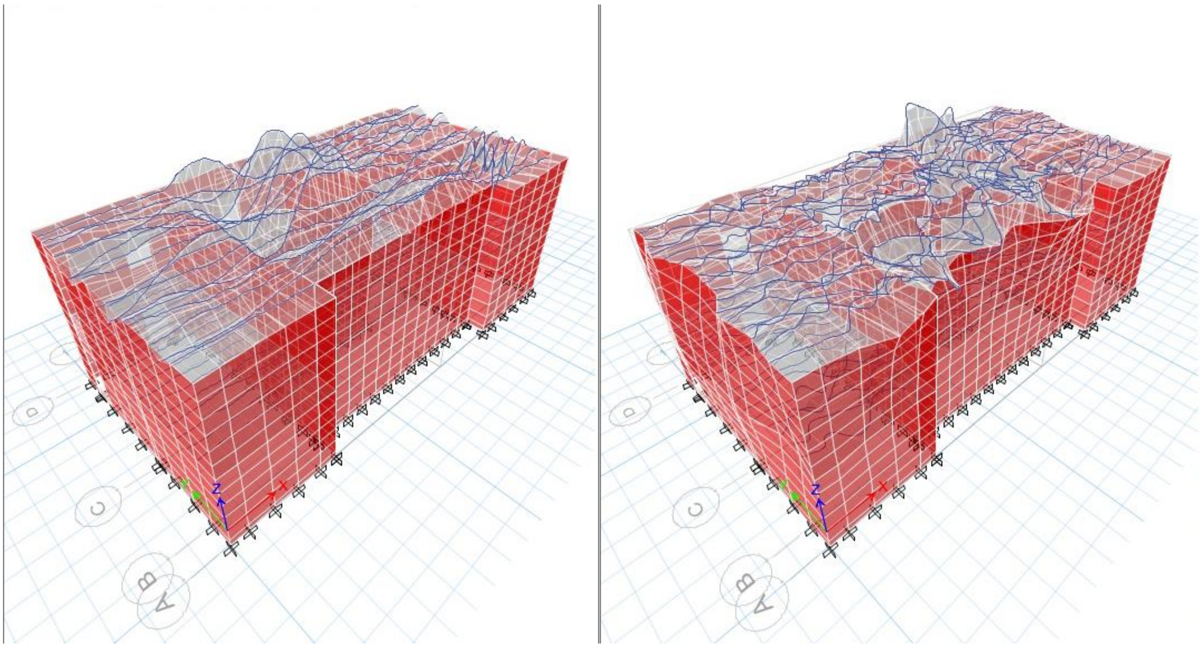
Case	Mode	Period (sec)	Frequency (cyc/sec)	Circular Frequency rad/sec	Eigenvalue (rad^2/sec^2)
Modal	1	0.417	2.396	15.0574	226.7253
Modal	2	0.334	2.992	18.7991	353.4068
Modal	3	0.124	8.059	50.6336	2563.7569
Modal	4	0.084	11.844	74.4188	5538.1568
Modal	5	0.073	13.653	85.7857	7359.1861

Table 3. Modal periods and frequencies (retrofitted building)

Case	Mode	Period (sec)	Frequency (cyc/sec)	Circular Frequency rad/sec	Eigenvalue (rad^2/sec^2)
Modal	1	0.169	5.9150	37.1637	1381.1390
Modal	2	0.091	11.042	69.3806	4813.6661
Modal	3	0.121	8.2360	51.7459	2677.6340
Modal	4	0.081	12.397	77.8914	6067.0660
Modal	5	0.065	15.278	95.9962	9215.2687

The first five mode shapes are given in Figure (6-10).

Μοδε 1;



Ρετροφιττεδ βυιλδινγ　　　　Εξιστινγ βυιλδινγ

Figure 6. 3-D view mode shape (modal) – mode 1

Μοδε 2;

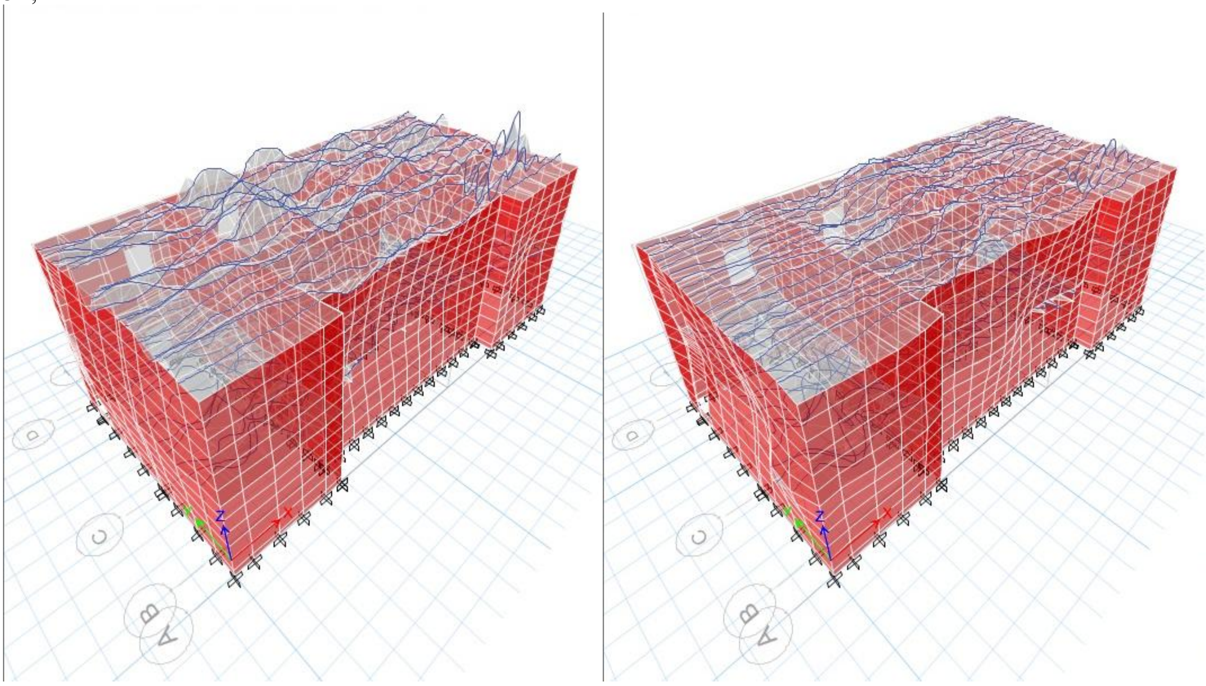


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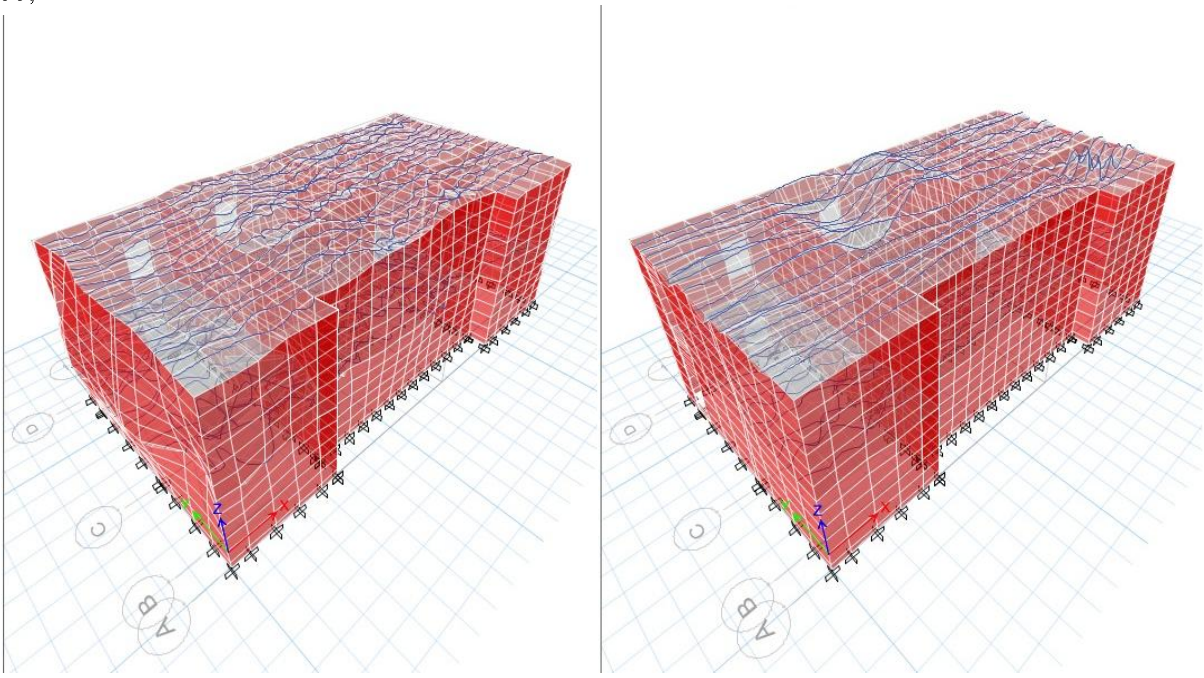
Figure 7. 3-D view mode shape (modal) – mode 2

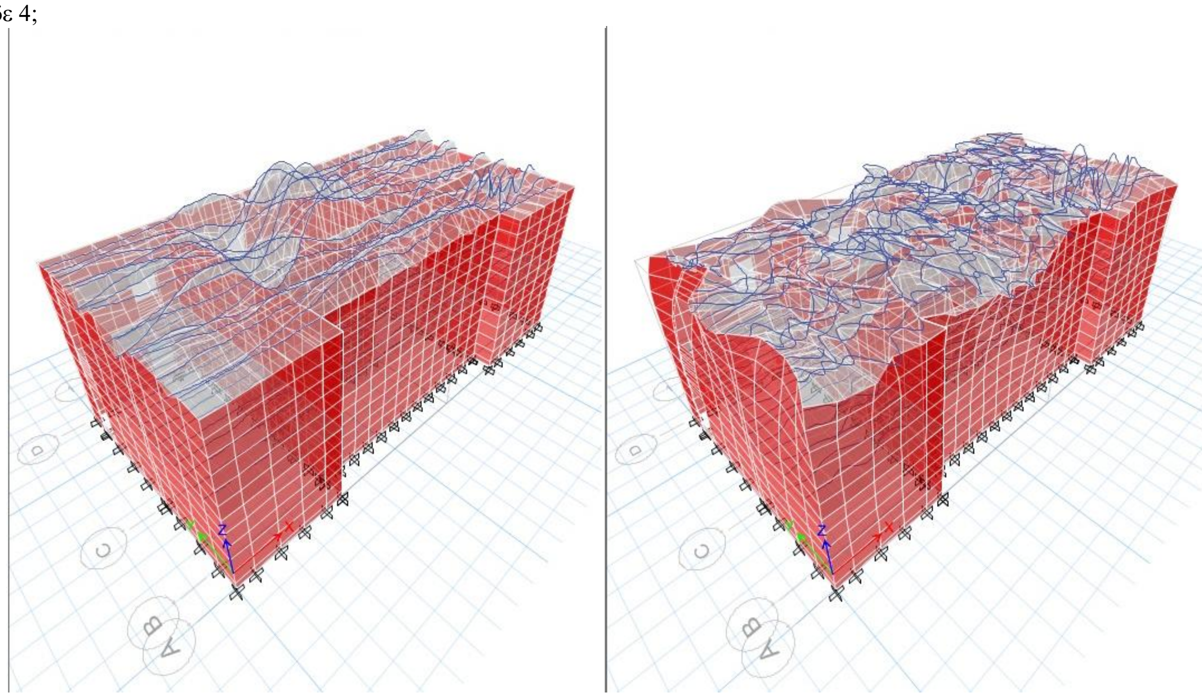
Μοδε 3;



Ρετροφιττεδ βυιλδινγ Εξιστινγ βυιλδινγ

Figure 8. 3-D view mode shape (modal) – mode 3

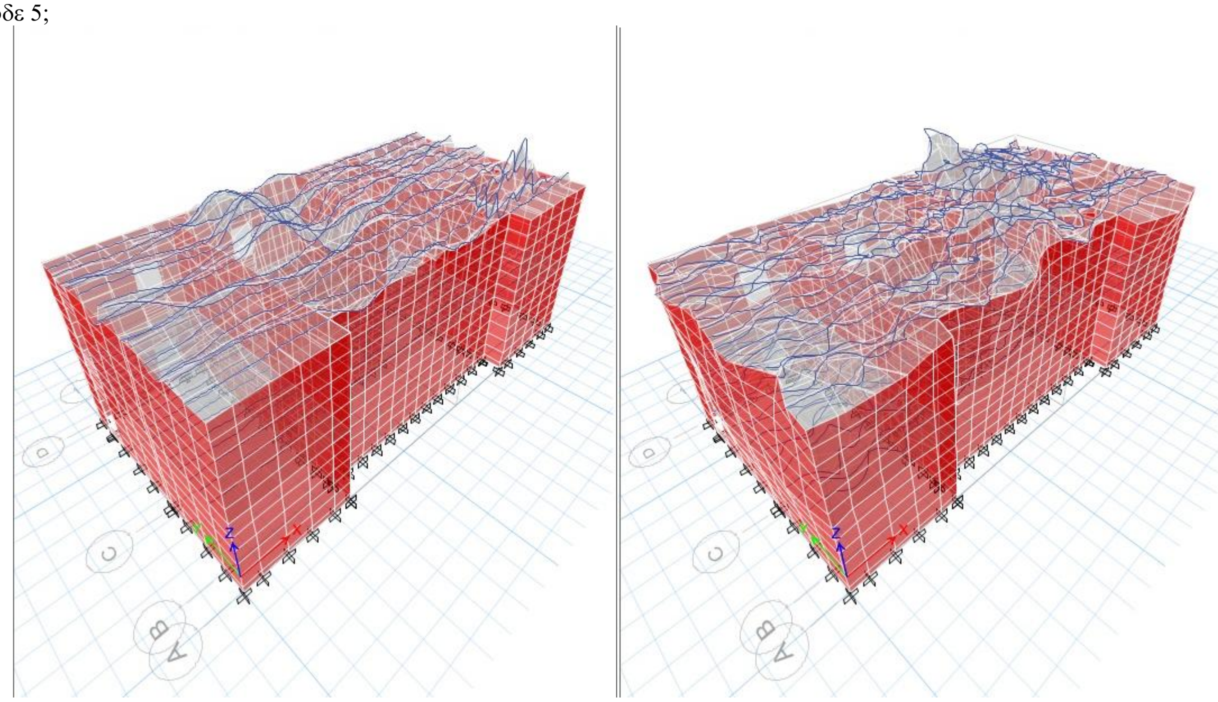
Μοδε 4;



Ρετροφιττεδ βυιλδινγ Εξιστινγ βυιλδινγ

Figure 9. 3-D view mode shape (modal) – mode 4

Μοδε 5;



Ρετροφιττεδ βυιλδινγ Εξιστινγ βυιλδινγ

Figure 10. 3-D view mode shape (modal) – mode 5

By examining table 4, the differences in frequency is clear.

Table 4. The differences in frequencies

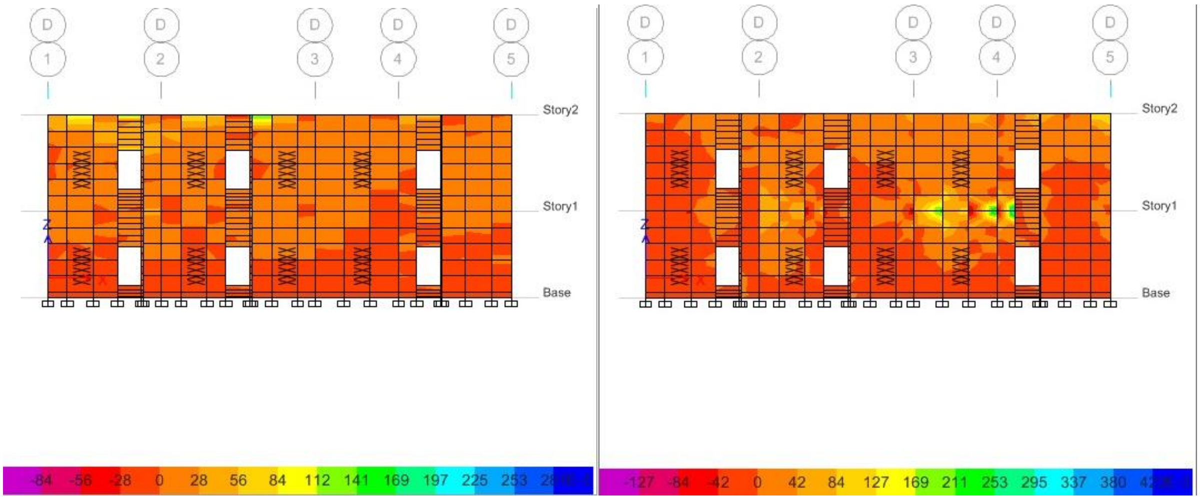
Mode	**Frequency (cyc/sec) E**	**Frequency (cyc/sec) R**	**Frequency Difference (%)**
1	2.396	5.915	147
2	2.992	11.042	269
3	8.059	8.236	2
4	11.844	12.397	5
5	13.653	15.278	12
Mean change percentage			86.45

E: Εξιστινγ βυιλδινγ
P: Ρετροφιττεδ βυιλδινγ

B. Maximum Stress, Moment and Maximum Shear Force Comparison

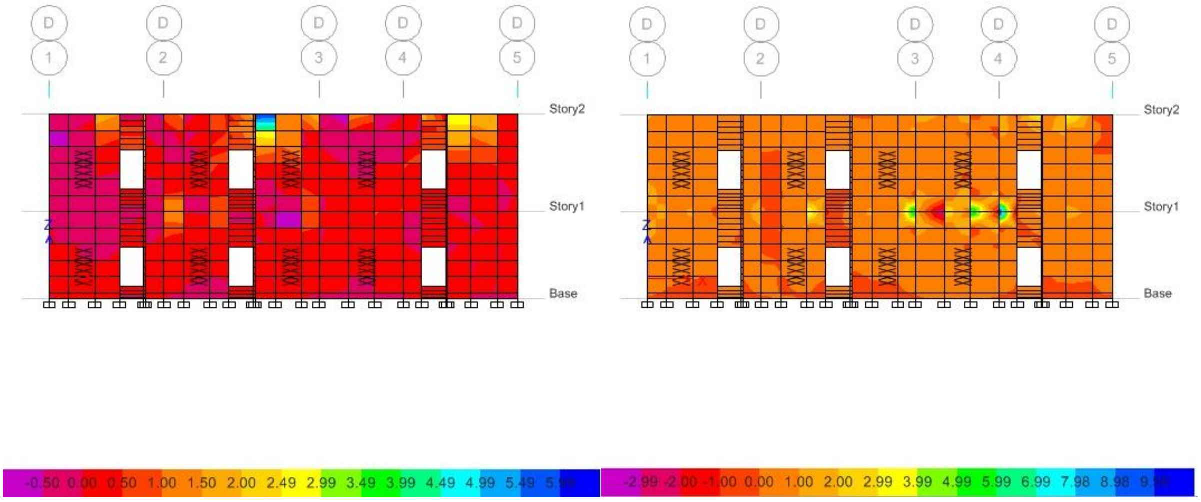
Using ETABS v.16 program maximum stress, moment and maximum shear force impacts were shown when GFRP materials were added to the walls of the Masonry structure and the effect was visually illustrated in the left side of the underlying shapes.

Maximum stress, moment and maximum shear force effect before the application of GFRP materials to the walls of the Masonry structure are visually illustrated in the right side of the underlying shapes. By looking at these illustrations, the differences can be seen clearly. Figure (11-13).



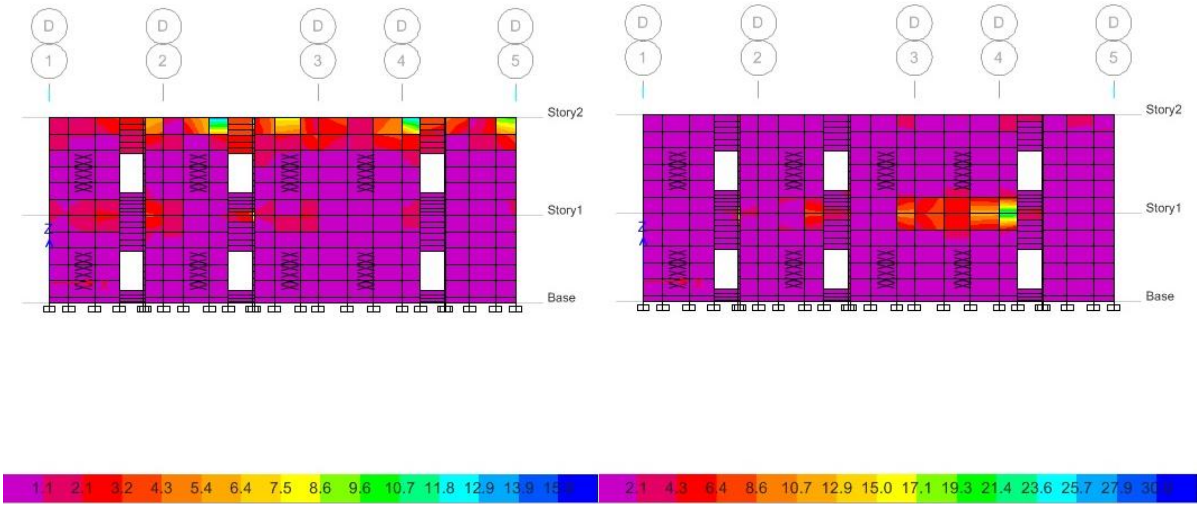
Ρετροφιττεδ βυιλδινγ (κγφ/μμ2)(E–03) | Εξιστινγ βυιλδινγ (κγφ/μμ2)(E–03)

Figure* 11. *Stress s max diagram (elevation view – d)



Ρετροφιττεδ βυιλδινγ (τονφ–μ/μ) | Εξιστινγ βυιλδινγ (τονφ–μ/μ)

Figure* 12. *Resultant m max diagram (elevation view – d)



Ρετροφιττεδ βυιλδινγ (τονφ/μ) | Εξιστινγ βυιλδινγ (τονφ/μ)

Figure 13. Resultant v max diagram (elevation view – d)

The SMAX, MMAX and VMAX values for all Elevations which received GFRP and the ones which had not received GFRP reinforcement were given in the tables below. the differences in frequency and periods are shown in Table (5-7).

Table 5. Maximum stress (s max) comparison

Elevation Number	SMAX	Retrofitted building (kgf/mm^2)(E-03)	Existing building (kgf/mm^2)(E-03)	Difference (%)
1	Lower value	0	-193	-100.0
	Upper value	368	309	19.09
2	Lower value	-21.1	-211	-90.00
	Upper value	70.3	703	-90.00
3	Lower value	-14.1	-141	-90.00
	Upper value	77.3	316	-75.53
4	Lower value	-17	-337	-94.95
	Upper value	202	394	-48.73
5	Lower value	-7.7	-295	-97.39
	Upper value	92.6	345	-73.15
A	Lower value	-21.1	-127	-83.38
	Upper value	70.3	285	-75.33
B	Lower value	-15.5	-105	-85.23
	Upper value	85.1	352	-75.82
C	Lower value	-36.6	-127	-71.18
	Upper value	82.3	422	-80.50
D	Lower value	-84	-127	-33.86
	Upper value	281	422	-33.41
Mean change percentage				**-71.08 %**

Table 6. Maximum moment (m max) comparison

Elevation Number	M MAX	Retrofitted building (tonf-m/m)	Existing building (tonf-m/m)	Difference (%)
1	Lower value	-0.91	-4.99	-82
	Upper value	4.99	7.98	-37
2	Lower value	-3.86	-1.6	141
	Upper value	6.17	19.1	-68
3	Lower value	-0.64	-2.54	-75
	Upper value	7.62	5.72	33
4	Lower value	-3.2	-8.89	-64
	Upper value	17.5	7.62	130
5	Lower value	-3.6	-7.62	-53
	Upper value	20.0	6.53	206
A	Lower value	-1.3	-1.72	-24
	Upper value	2.18	9.49	-77
B	Lower value	-0.68	-2.59	-74
	Upper value	3.74	8.62	-57
C	Lower value	-0.59	-2.0	-71
	Upper value	7.08	11.0	-36
D	Lower value	-0.50	-2.99	-83
	Upper value	5.99	9.98	-40
Mean change percentage				**-18 %**

Table 7. Maximum shear force (v max) comparison

Elevation Number	V MAX	Retrofitted building (tonf/m)	Existing building (tonf/m)	Difference (%)
1	Lower value	1.8	9	-80.0
	Upper value	25.0	125	-80.0
2	Lower value	1.5	3.9	-61.54
	Upper value	21.3	55.0	-61.27
3	Lower value	0.7	1.1	-36.36
	Upper value	10.0	15.0	-33.33
4	Lower value	1.1	2.7	-59.26
	Upper value	15.0	37.5	-60.0
5	Lower value	1.6	1.5	6.67
	Upper value	22.5	21.3	5.63
A	Lower value	1.3	1.2	8.33
	Upper value	18.8	16.3	15.34
B	Lower value	0.63	1.2	-47.50
	Upper value	8.75	16.3	-46.32
C	Lower value	2.0	1.4	42.86
	Upper value	27.5	20.0	37.50
D	Lower value	1.1	2.1	-47.61
	Upper value	15.0	30.0	-50.0
Mean change percentage				**-30.38 %**

IV. CONCLUSION

- In this study in order to cover all visible & non-visible cracks in the walls of the building and to provide convenience to the workers, a unidirectional GFRP was used and all the building walls were covered. because the goal in this case was to cover a whole wall, a thin layer of GFRP was used. by this order the application's expenses were reduced.
- During this study when the building's walls were retrofitted the 1st story's floor stress, moment and shear forces values were increased, therefore when a similar study is attempted the building's floor should be analyzed and retrofitted.
- In this study the building's inner &outer walls were 400 mm in thickness, the building's walls were retrofitted by a 0.2mm layer of unidirectional GFRP. The estimated mean change percentage of the building's parameters were given below:
  1- MAX Stress mean change percentage: 71.08 % (Decrease)
  2- MAX Moment mean change percentage: -18 % (Decrease)
  3- MAX Shear force mean change percentage: -30.38 % (Decrease)
- The modal frequency difference lies in the interval of 2%-147% for Existing and retrofitted case and it provides increase of structure stiffness about 86.45%; for the retrofitted building, using GFRP applied to walls only.

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