Study of effect of shear wall in the seismic response of the existing buildings

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ABSTRACT

In Iraq, it has been observed that an increase in seismic activity, and that most existing buildings are not seismically designed and that can suffer serious damage or collapse, thus causing loss of life. In this paper, a numerical simulation of the experimental laboratory sample on the subject of non-seismically designed buildings and methods of strengthening them was performed using a seismic strengthening technique using an infill RC wall in order to maintain the risk of earthquakes. This study was carried out through the work of verifying the numerical and practical model by matching the results of laboratory work with the results of numerical analysis using the analysis finite element analysis method (FEAM) by Abaqus CAE 2019 software and then using the model to study the effect of openings in the infill RC walls and the extent of its impact on the response of the building. The practical model is a full four-story building tested laboratory in Elsa, Italy using pseudo dynamic test (PSD). The experimental model is a sample of not seismically design buildings (gravity design only) and ways to improve them by adding new RC walls with different contact details to the existing building. The goal of the experimental test was to study the effectiveness of adding RC infill walls with two types (North and South) infill RC walls, including designing it and the contribution of two types of dowels that connect the new infill walls to the existing RC building. In other words, it's a way of strengthening by converting selected bays into RC walls with two types of reinforcement and connection between new infill RC walls and existing builders called (north and south) frames. The results of analytical modeling show that the percentage of differences in X- Direction of top story displacement between Abaqus software and Experimental tested at ELSA results are 2.47% in positive and 3.12% for negative X direction, which refer to a very good similarity and accurate building simulation.

Keywords: Numerical Simulations, Strengthening techniques, Infill RC Walls, North Frame, South Frame, RC Infill Wall, Abaqus CAE2019 software.

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1. Introduction

FEA is a helpful tool for finding solutions to many engineering problems. It is fundamentally a process where a continuum with finite degrees of freedom in which corresponds to be a congregation of elements (or sub-regions) each with unknowns specified finite numbers [1]. Design building according to the specifications of the seismic codes provides capabilities to resist earthquakes without collapsing, the seismic loading calculation is an important part of the structure designing procedure. During earthquakes, the structural parts of the building must have sufficient capacity to withstand lateral loads and thus comply adequately when increasing pressures and being able to increase life safety. Two types of seismic retrofitting, are known as a global and local modification [1]. Fig.1 shows types of retrofitting techniques.
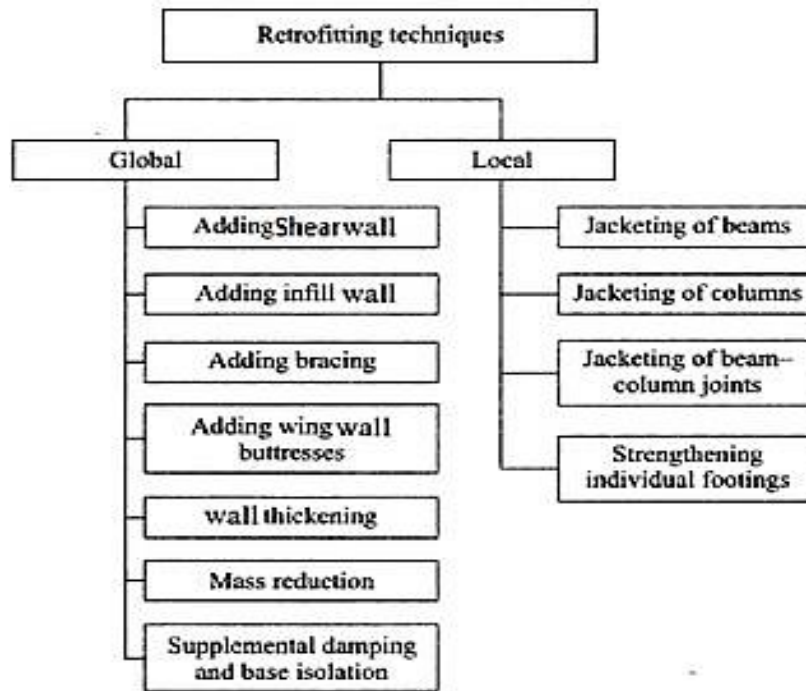
Figure 1. Seismic strengthening techniques, Pankaj and Manish 2006

At present, most strengthening techniques are based on global strengthening schemes [2] and structures are usually strengthened to reduce lateral displacement [3]. Increasing global stiffness and reducing the expectations of seismic deformation of a building may be more cost-effective than local strengthening of existing components for buildings [4]. In this investigation, the verification study depended on an experimental study on a full-scale of four-Story RC Frames with two types of RC Infill walls connection by converting central bays into new RC infill walls at the ELSA facility in Ispra-Italy. It was designed based on the BS8110 [5] and Euro code2 [6] for only gravity load resistance. The experimental test was done by the pseudo-dynamic method, the pseudo-dynamic test technique defined as an on-line computer-controlled testing method used to the evaluating of a structure subjected to dynamic loading. The results of the experiment test show that, the building managed to tolerate a seismic load of 0. 25g with no significant damage, also it was proven that adding an infill wall into the selected bay can be used to increase strength, ductility and reduce structural deficiencies. The main objectives are as follows:

1- A Numerical Study based on an experimental work done at the ELSA laboratory in Ispra, Italy, by verifying model for more studies.
2- To study the seismic behavior of the building which is free of RC infill walls.
3- To study the effect of openings in two types, window and door in RC infill walls on the seismic response of the building.

2. Experimental model description

The model consisted of four stories with two external frames named (north and south) frame. These frames were spaced at 6.0 m and are connected by 15cm RC slab and four beams (0.25m by 0.50m) perpendicular to the plane of the two frames three-bay. building total length was 8. 5m (Central Bay 2.5m and two 3.0m outer bays) with 3.0m floor height and 12m total building height as shown in Fig.2. The columns were 0.25m from 0.4m. The building was constructed on an 11.0 by 8.0 m foundation slab with a 0.40m thickness, with 0.4m high and 0. 6m wide beam. The RC infill walls were placed in the central bays of the building with the same thickness as 0. 25m as columns and beams surrounding them, it was designed and were similar to buildings constructed in the 1980s in Cyprus. For more details, described in SERFIN Seismic Project [12,13,14] and in [7,8,9,11].
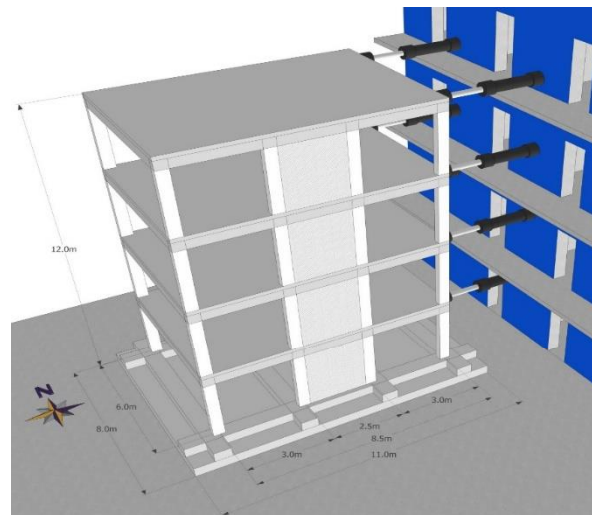
Figure 2. Full-scale of the building

3. Assumption in the experimental work and numerical simulation

As follows, some assumptions, which were considered in this investigation in the original design that was adopted [12]:

1- The Building design was based on the BS8110 revision code.

2- The adopted building was designed to resist gravity loads only and consequently has more or fewer properties that be different from those in typical buildings constructed to sustain seismic loads. These properties source deficiencies in building response under seismic loadings.

3- Friction between soil and RC is not taken into account (the fixed base was considered).

4- Earthquake acceleration in x-direction has been adopted according to experimental work.

5- The influence of the pore water pressure was considered.

6- The effect of the CFRP has been taken as detailed in experimental work.

7- The effect of wind load was neglected.

4. Materials used in the experimental test

In this model, materials used based on their availability in the Italian market during the period 1980. It was decided to adopt C20/25 concrete for both RC infill walls and the building with a unit weight of 25kN/m³ and with 30GPa modulus of elasticity. The yield strength of reinforced was 400MPa While the yield strength of the reinforcement of the infill wall consisted starter web bar and impeded rebar was 450 MPa, this material used in construction practice in Cyprus in the 1980s. This building was numerical analysis using three-dimensional finite element model by adopting non-linear material behavior. The response of RC structures can be achieved by accurately modeling the stress- strain curve behavior of uniaxial materials as shown in Tables (1), and (2) and Figs. 3 and 4 show results of the ELSA laboratory materials test [13,14,15].
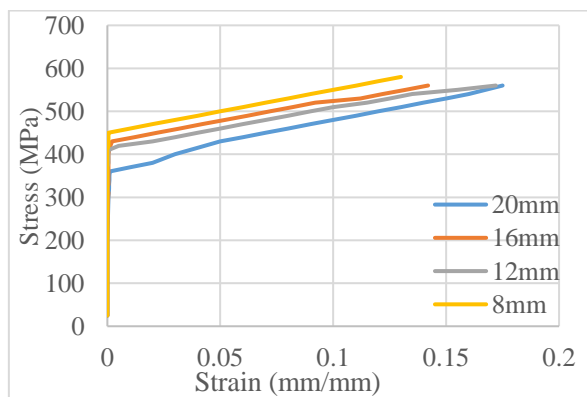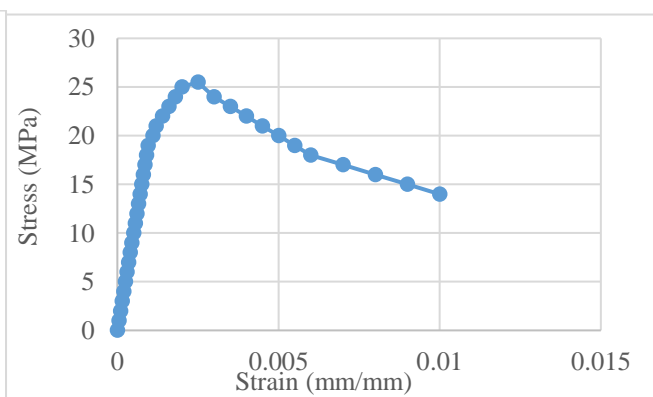

Figure 3. Stress- strain curve for steel

Figure 4. Stress- strain curve for concrete

Table 1. Rebar properties based on material data from ELSA laboratory

Bar dim. (mm)	Yield strength (MPa)	Yield strain	Ultimate strength (MPa)	Ultimate strain	Poisson Coefficient	Young's modulus
8.0	417.01	0.00226	583.68	0.132	0.3	206000
12.0	424.68	0.00222	570.32	0.173	0.3	206000
16.0	437.42	0.00213	546.69	0.141	0.3	206000
20.0	376.68	0.00182	567.32	0.167	0.3	206000

Table 2. Concrete properties based on data on material taken from ELSA laboratory

Poisson Coefficient	0.2
Young's Modulus	30000 MPa
Tension Stress Limit	2.75 MPa
Tension Deformation Limit	0.00018
Stress Limit	25 MPa
Deformation Limit	-0.003

5. Experimental model design

The model is an expression of the buildings that constructed in the 1980s in Cyprus. At that time, the structures were designed for gravity loads only because there were no codes that includes seismic effect. Accordingly, it was decided to use the BS8110 code. The self-weight was calculated using the unit weight of concrete specified above. Each floor was supposed to be loaded with 3 k/m2 of dead load (include the load of masonry infill walls) and 30% of 1.5 kN/m2 live loads. Thus, (1.0 x 3.0 kN/m2 + 0.3 x 1.5 kN/m2) x 6.25 m x 8.90 m = 192 kN that applied on each floor.135.4kN was applied with 15 barrels of water as shown in Fig. 5 and the rest was the self-weight of the engine attachment packages.

Figure 5. Barrels of water use in the building

These loads were combined using partial factors of safety of 1.40 for self-weight and imposed dead-load, and 1.60 for the live load. All details are shown in Table 3 and 4 and Fig.s (6 to 10).

To use the case study for more various parameters, the sample (test building consist of two frames north frame and south frame was strengthened in a different amount and location for reinforcements, the northern wall being the strongest. More specifically, a detailed and irregular system of dowels and starter bars was used to join the walls with the frame are shown in Fig.11. It is important to mention that, the tested model was designed using two different connection details between the new walls and the surrounding frame to evaluate the contribution of dowels that connect the new infill wall to the existing RC frame as Fig. 11 show the different types of dowels.

Table 3. Structure model dimensions

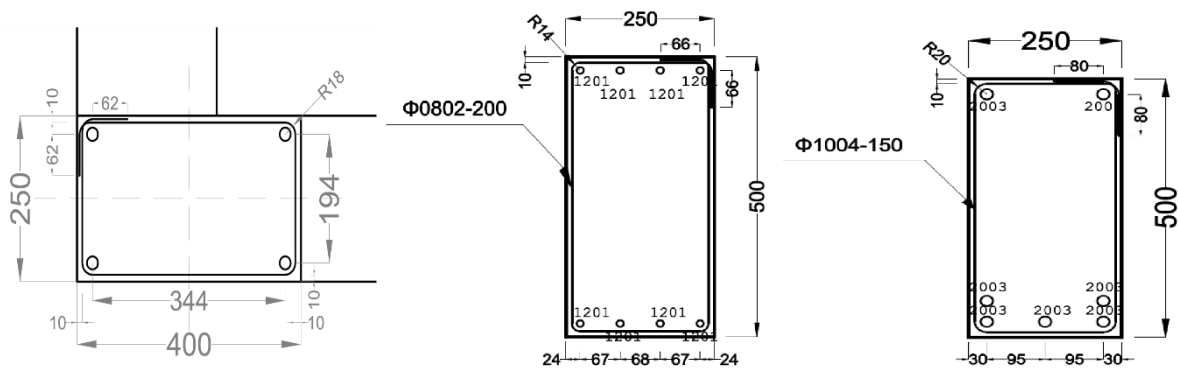| Type of model		Dimension	Reinforcement (mm)
Beams	Transversal	500*250mm	Top:2ϕ20, Bottom:5ϕ20, Stirrups: ϕ 10 @150
	Longitudinal	500*250mm	Top:4ϕ14, Bottom:4ϕ14, Stirrups: ϕ 8 @200
Slabs		8900*6250*150 mm	ϕ10@150mm for top and bottom reinforcement
Columns		400*250mm	4ϕ20,Stirrups:ϕ8 @200
Foundation		11000*8000*400mm	ϕ16@250mm for top and bottom reinforcement
Tie beams		600*800*800	7ϕ16 for top rein, 4ϕ16 bottom rein and Stirrups:ϕ12 @175

Figure 6. Column cross section   Figure 7. Longitudinal beam cross section   Figure 8. Transverse beam cross
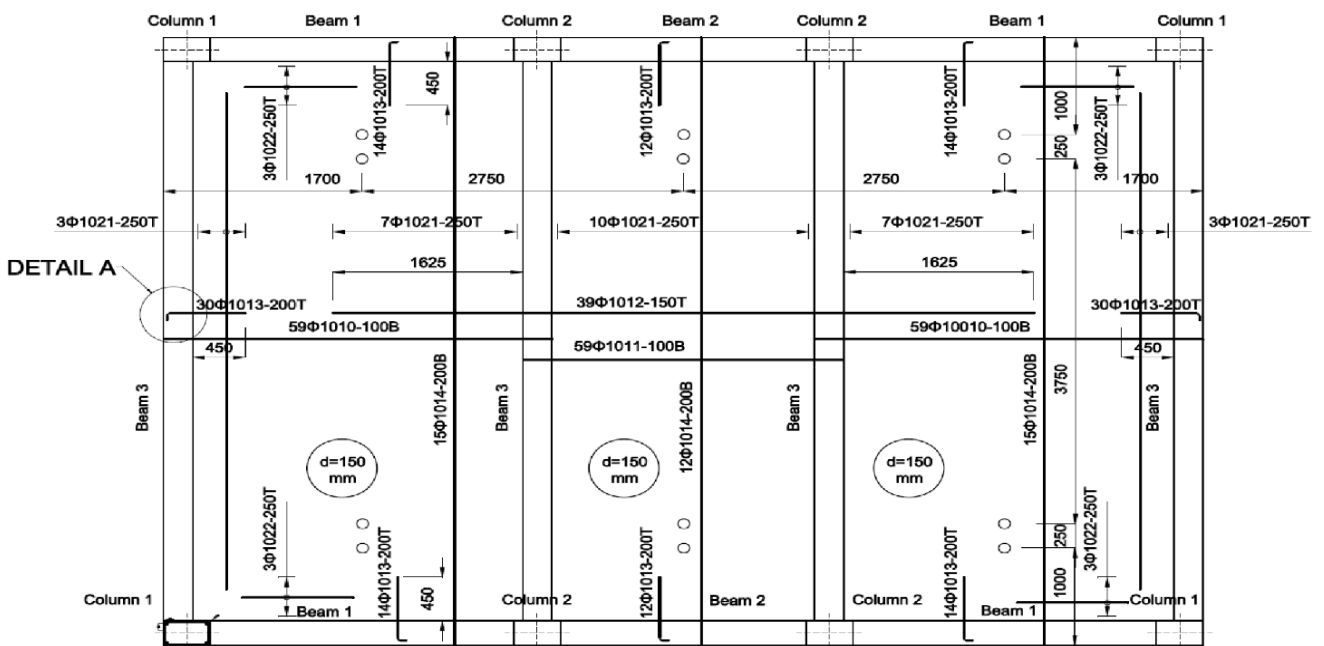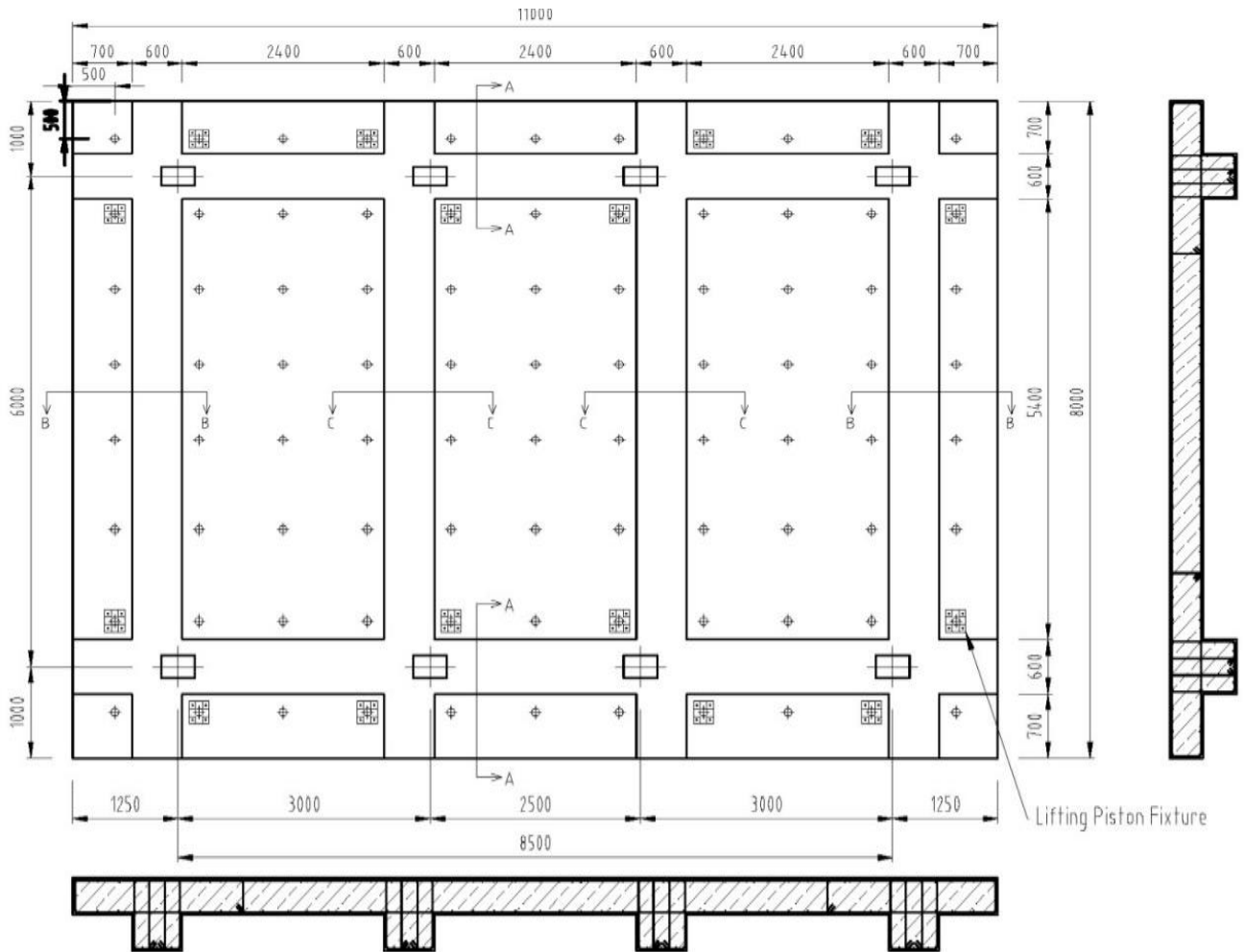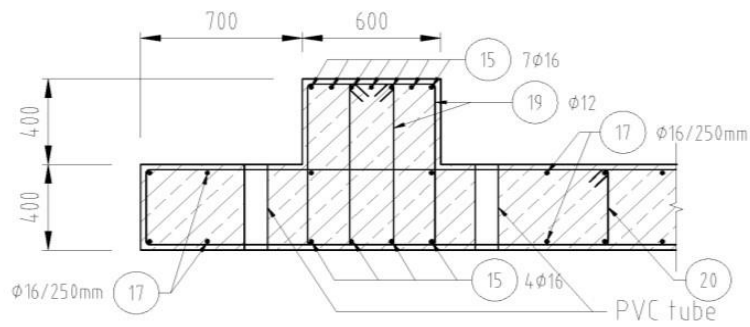

Figure 9. Reinforcement of slab, T refers to top and B refers to the bottom
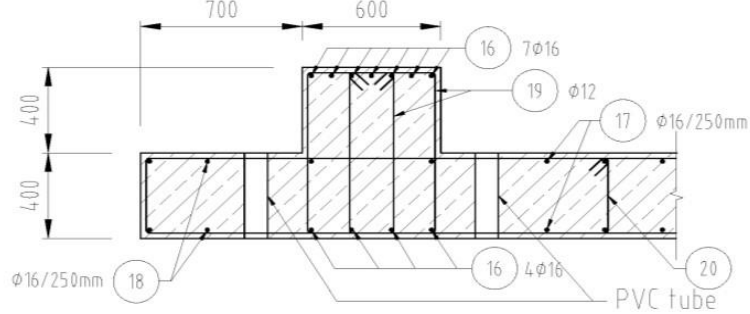
SECTION A-A

SECTION B-B

Figure 10. Foundation and sections

Figure 11. (a) Short dowels, (b) starter and dowels bar, (c) Starter, dowels and web bars

6. Representation of seismic loads in experimental work

One-directional (North- South) loading was using based on a ground motion recorded at Herceg-Novi station throughout Montenegro, earthquake happens in 1979 as shown in Fig. 12.
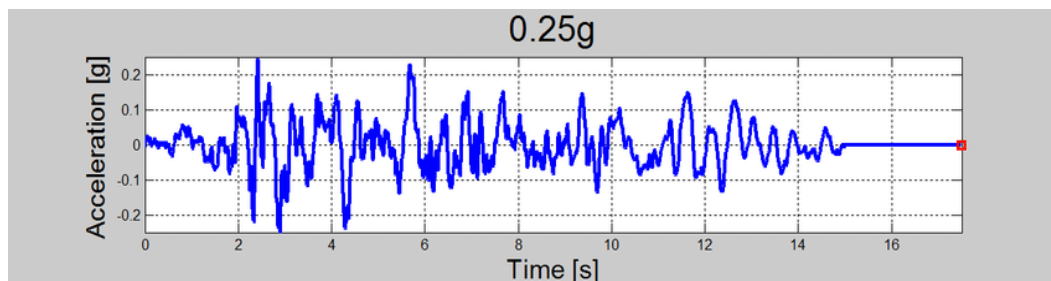

Figure 12. Accelerogram scaled to 0. 25g of Herzeg Novi (Montenegro 1979)

7. Case one: adding reinforced concrete infill walls

In this case, the building strengthening by adding reinforced concrete infill walls which can be able to display a big change in the seismic performance of the structure by increasing the system stiffness, reducing the displacement and drift for all story.

7.1. Verification of the problem

The purpose of the verification any model numerically is important for preparing a correct model that is developed to study other cases by developing the same model to conduct further investigations with high accuracy. Because of the difficulty of conducting these tests practically, moreover, no algorithm exists to select what procedures or techniques to be used. Each simulation project offers a unique and new challenge to developing the model. The problem of not seismically designing for the buildings has been selected. An example of this problem there is the experimental model represented by the SERFIN building is a model of construction between the period of the 1980s in Cyprus. This was designed only for sustaining gravity loads at that time, as there were no provisions for the payload of earthquakes. There is no specific standard design accepted by the criteria used in code countries such as DIN, BS8110. This model pseudo-dynamically tested with a ground motion based acceleration measured at Herceg-Novi station during the Montenegro earthquake in 1979 in One directional record applied to the building.

Abaqus/Cae 6.19 has been used in this verification for the dynamic load effect. The numerical results obtained from this software were compared with the experimental results of a full-scale with four-story, the test was conducted at the Joint Research Centre of the European Laboratory, specifically in ELSA, located in Ispra, Italy.

7.1.1. Geometrical elements used in Abaqus software

In Abaqus 6.19 CAE, there are different available types of 3D geometry elements. In this simulation, three types of elements (solid brick, wire truss, shell element) have been applied to model various parts. First-order 3D reduced integration continuum elements solid brick eight-node elements (C3D8R/8-node) are used to model the

concrete parts while the rebars are modeled by using (T3D2/2-node linear 3-D truss) element and to model the (CFRP) sheets, (S4R - 4-node) doubly curved are used. These elements are multipurpose and can be applied in models for direct linear or complex nonlinear analyses, including plasticity of properties, large deformations, and contact. The typical of Abaqus elements are shown in Fig. 13 (a), (b) & (c). The modeling of the reinforced concrete building is shown in Figure 14.
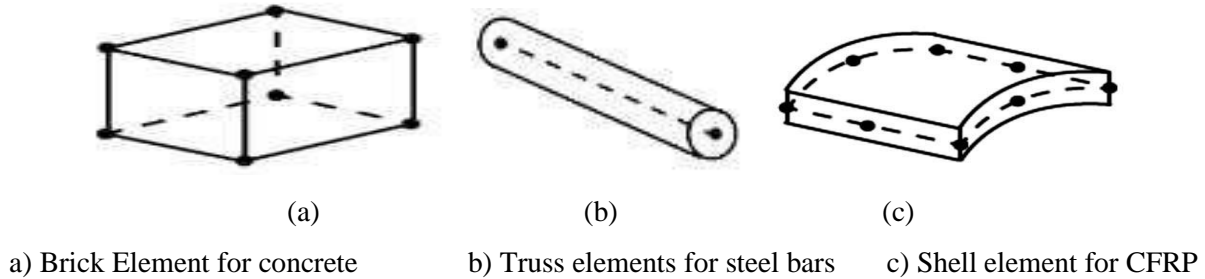

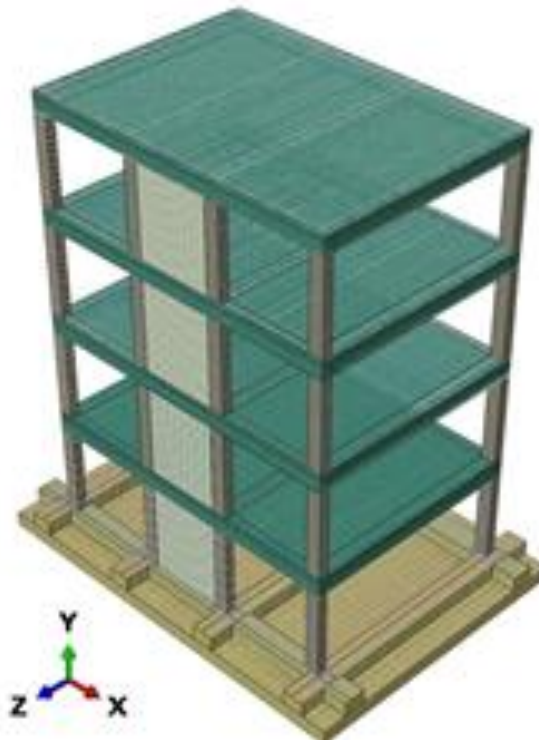| (a)	(b)	(c)
a) Brick Element for concrete	b) Truss elements for steel bars	c) Shell element for CFRP

Figure 13. a, b, and c are types of elements

Figure 14. Infill RC walls addition

7.1.2. Materials modeling in Abaqus

Material modelling is an important part of Finite Element Analysis. The Abaqus software, with its emphasis on nonlinear FEA and large deformation analysis, has provided advanced material models since its inception. For example, the Concrete Damaged plasticity model (CDPM) offers the tool to accurately simulate the (reinforced or plain) concrete element's behavior under dynamic load. The CDPM allows for the stiffness recovering during reversals of the load.

7.1.3. Concrete damage plasticity parameters

Performance can be described by other parameters measured for uniaxial stress. Table 4. Illustrated the parameters of the model that describe its performance to sustain compound stress.

Table 4. Concrete damage plasticity Parameters.

Property	value
Dilation angle	34
Viscosity	0.000050
Plastic strain ratio (Biaxial/Uniaxial compression)	1.160
Flow potential eccentricity	0.10
Invariant stress ration (Kc)	0.6670

7.1.4. Mesh system

Adopting appropriate mesh size is an important procedure. Large mesh sizes may lead to unacceptable results. Whereas, small mesh size can produce satisfactory results but in turn consumes too much time to run full analysis. Depending on how small the mesh is, completing full analysis can take up several days. A model mesh discretization of the concrete and reinforcement concrete is given in Fig. 15. The fine mesh was chosen for constructing the model mesh, provide a similar response to the results of the experimental work. It should be mentioned that the mesh was prepared and rectangular or square elements were shaped in a way that, the length and width of the element in the plates must be consistent with the nodes and elements in the model's concrete portions. Finally, a mesh size of 125mm was adopted for all models. The values for mesh size presented in Table 5.

Table 5. Selecting Optimal Mesh Size.

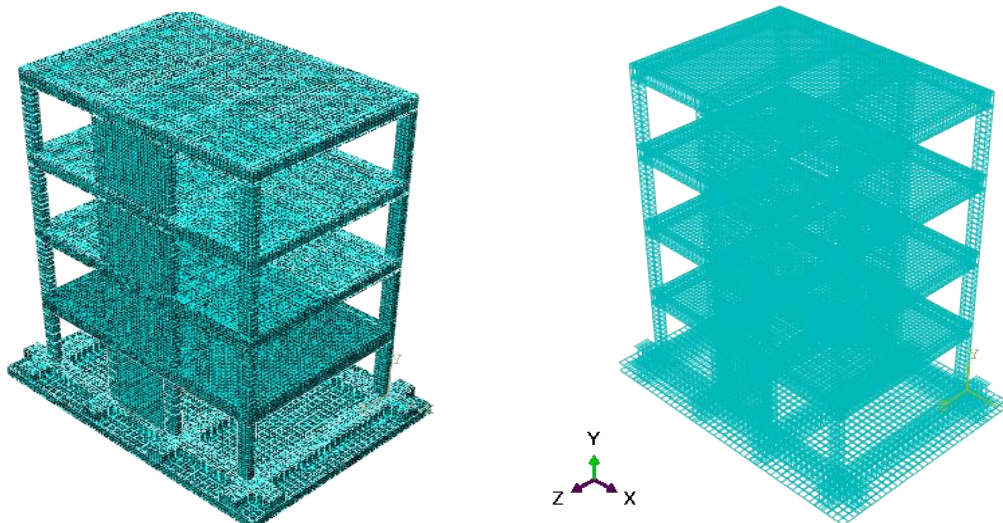| Mesh Size mm	No. of Nodes	No. of Elements	Max Top Positive Displacement (mm)
500	33194	38806	136.8
250	79065	67522	111.4
125	206046	169113	106.3

Figure 15. Finite Element Model for concrete and steel reinforcement in Abaqus program

7.1.5. Analysis results and discussion

The results of the analysis indicated that when using RC infill walls, the lateral displacement for all floors was decreased. The maximum top story displacement in a positive direction is 106.3mm and in the negative direction is –90.1mm.

7.1.6. Verification results

The identical same data input was applied to verify the current analytical model adequacy. Table 6 and Figs. 16 and 17 Show that, the percentage of differences in top story displacement in X- Direction between Experimental in ELSA and Abaqus software results are 2.47% in X for positive and 3.12% for negative top story displacement which refer to a very good similarity and accurate building simulation to use the same model for further case studies with assurance.

Table 6. Comparison in Top Displacement between Abaqus and ELSA test results.

	Max Top Positive Displacement (mm)	Max Top Negative Displacement (mm)	Differente between Top Positive Displacement	The Difference between Top Positive Displacement
Experimental results in (ELSA)	109	-93	2.47 %	3.12 %
Abaqus program results	106.3	-90.1		
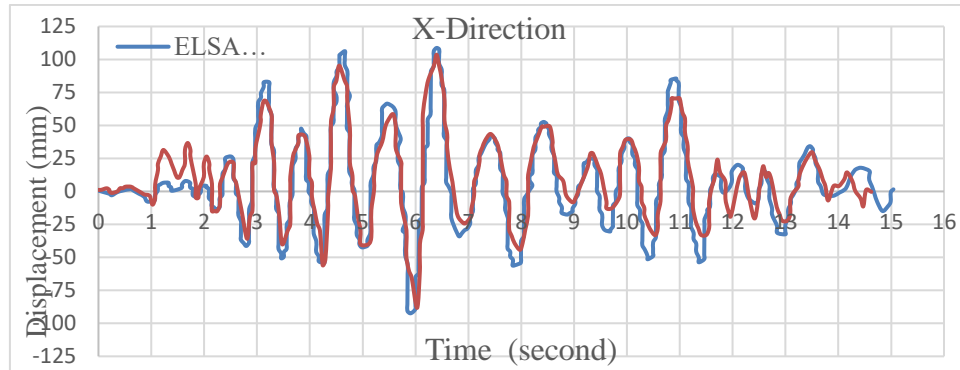
Figure 16. Experimental of ELSA 0. 25g PGA results vs. Numerical of Abaqus results for top floor X-displacement.
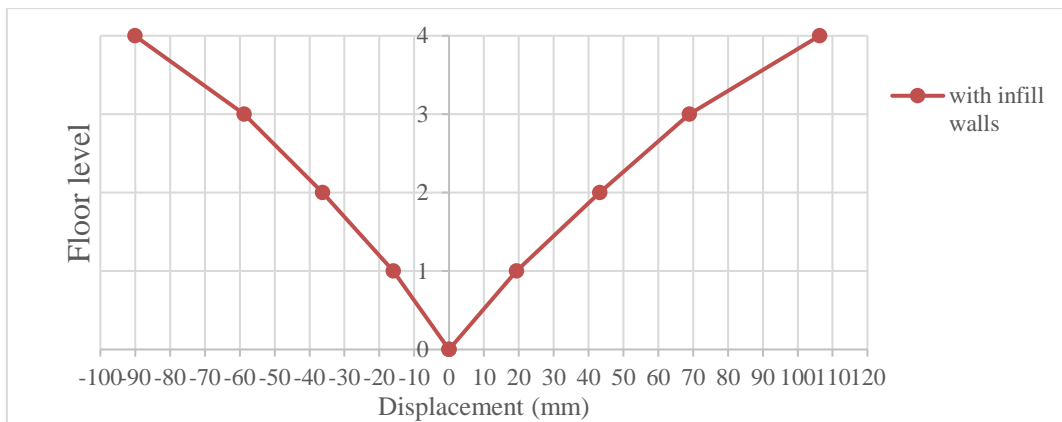

Figure 17. Abaqus results for different floor levels in X-displacement.

8. Case two: opening in reinforced concrete infill walls

Infill walls sometimes may have window and door openings in their planes. Accordingly, in this case, study the effect of openings in the infill reinforced concrete walls and show the influence of the presence of openings in the seismic response of the structure by studying the displacement and drift of all floors and comparing them with a no-opening model represented in case one.

8.1. Description of size openings

All the details of the building are the same in the first case but the change is the choice of two types of size openings: a window opening and a door opening in the reinforced concrete infill walls as investigative parameters. Holes are (1*1) m2 and (1*2) m2 as shown in Fig.18.
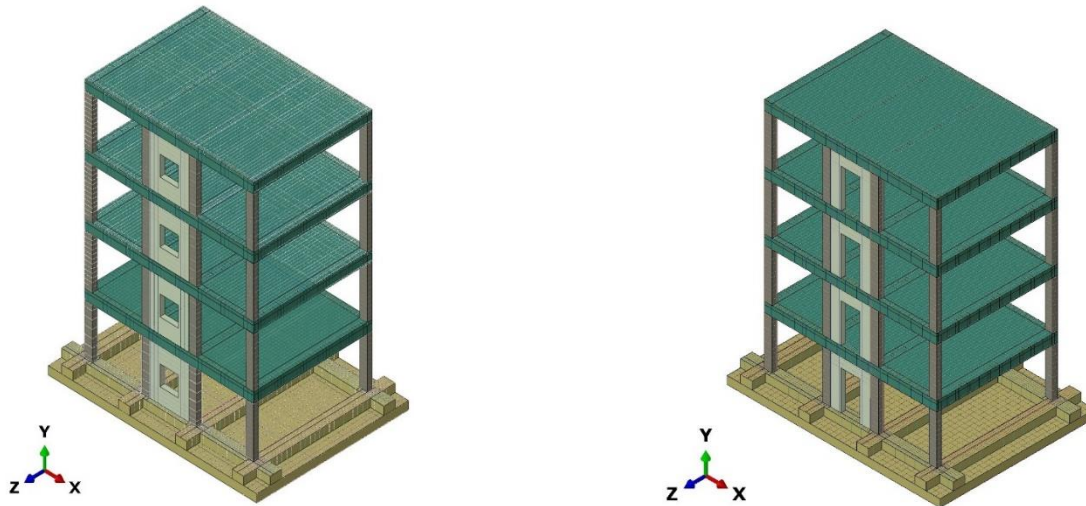
Figure 18. Openings (window and door) in the Infill RC walls addition

8.2. Results and conclusions

The results of the analysis indicated that when an increase in opening size the lateral displacement for all floors was increased.

A. In the case of using windows opening (1*1) m2, maximum top story displacement in a positive direction is 123.66mm and in the negative direction is –117.83mm.

B. In the case of using door opening (1*2) m2, maximum top displacement in a positive direction is 164.25mm and in the negative direction is -207.75mm.

By Comparing the results with the control case:

In case of (1*1) m2, maximum positive top story displacement increases by 14.04% while, negative displacement increases by 23.533% compared with the RC infill walls case. All results are explained in Figs. 19 and 20.
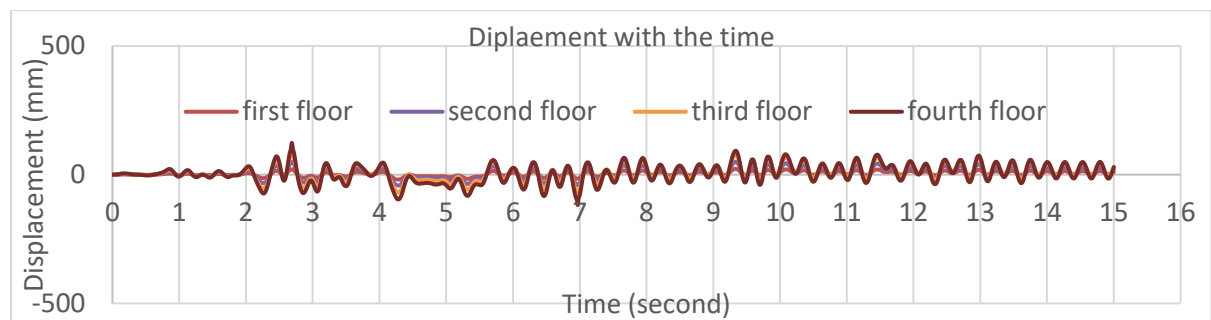

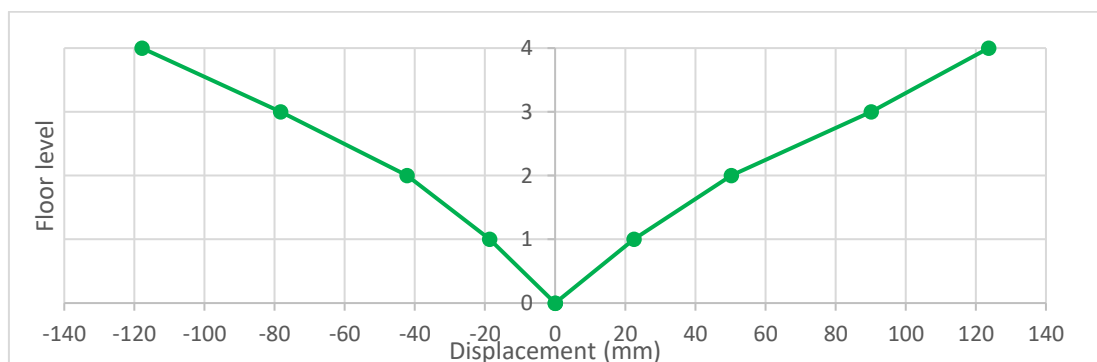Figure 19. Displacement with the time

Figure 20. Maximum displacement at different floor level

C. In case of (1*2) m2, the maximum positive top story displacement increases by 35.28% while, the negative displacement increases by 56.63% compared with the RC infill walls case. All results are explained in Figs. 21 and 22.
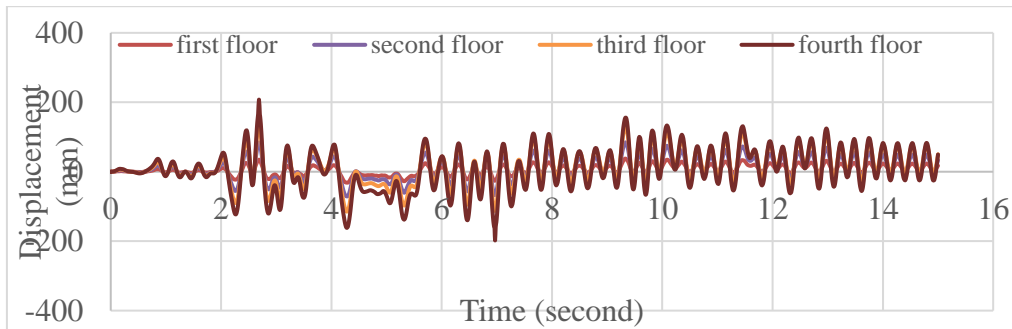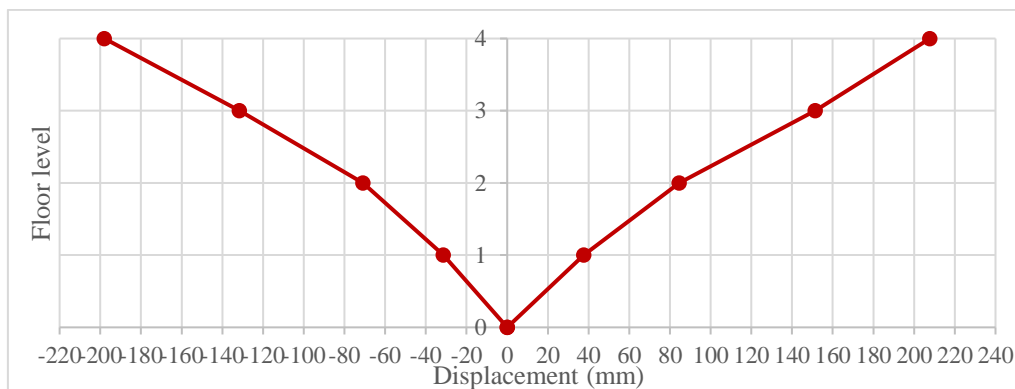

Figure 21. Displacements for all stories with the time

Figure 22. Maximum displacement at different floor level

9. Case three: without reinforced concrete infill walls

The effects of earthquake loading on the RC buildings are one of the main causes of construction damage furthermore, the effects of this type of building that are devoid of any seismic strengthening and were not seismically designed are prone to collapse [17]. In this study, buildings are selected from the type of soft floors and are made mainly for comparisons with the use of the technique of the infill RC walls.

9.1 DESCRIPTION OF SIZE OPENINGS

All the details of the building are the same in the case one but the change is to remove the RC infill walls in order to appreciate how it affects the building's response to earthquakes as shown in Fig. 23.
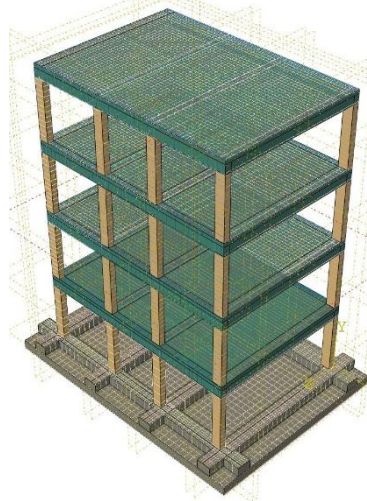

Figure 23. Without RC infill walls.

9.1. Analysis results and discussion

1. This case explains the lateral stories displacement behavior when subjected to a real earthquake (Herzeg Novi (Montenegro 1979) earthquake).
2. The results explained that, the maximum top story displacement is 627.97 mm while in the opposite direction was -782.38mm.

As a result, this building appears to have weak resistance to seismic loading. When the results of removing RC infill wall and compare it with the RC infill walls case it explains the following:

1. The results of the analysis indicated that when the RC shear wall was removed, the lateral displacement of all floors increased by about eight times.

2. The maximum positive top story displacement increase by 83.07% and the maximum negative displacement increase by 88.48% compared with the control case. All results illustrated as shown in Figs. 24 and 25.
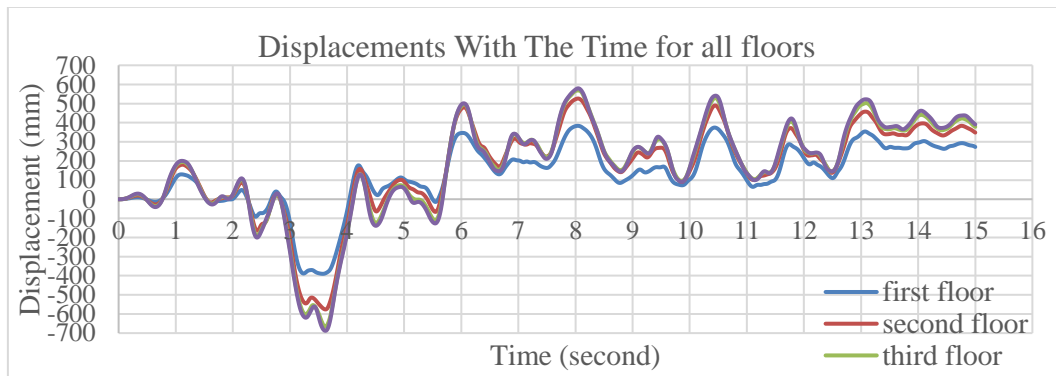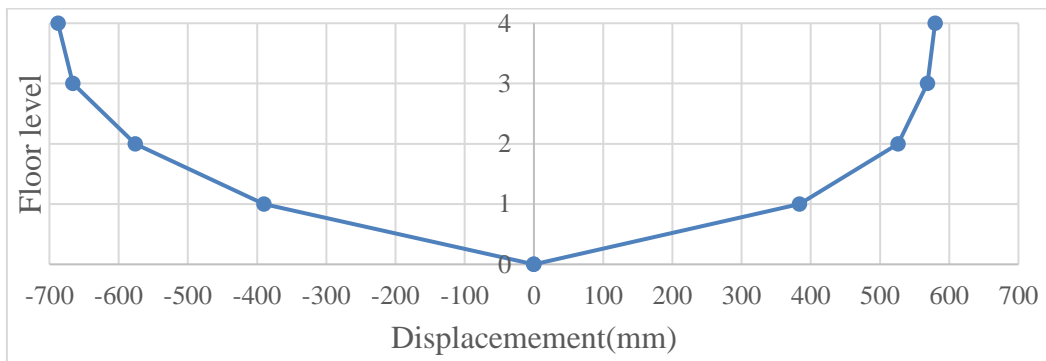

Figure 24. Displacement with the time

Figure 25. Maximum displacement at different floor levels

All results for all cases can be Summarized by a Table 7 and Fig. 26.

Table 7. All cases result for maximum top floor displacement

| Cases		Positive Maximum Top Story Lateral Displacement (mm)	Negative Maximum Top Story Lateral Displacement (mm)	Percentage of Positive Maximum Top Story Lateral Displacement (increase)	Percentage of Negative Maximum Top Story Lateral Displacement (increase)
Case One	RC Infill Wall	106.3	-90.1		
Case Two	Opening In RC Infill Wall (1*1)m2	123.66	-117.83	14.04%	23.533%
	Opening In RC Infill Wall (1*2)m2	164.25	-207.75	35.28%	56.63%
Case Three	Without RC Infill Wall	672.97	-782.28	83.07%	88.48%
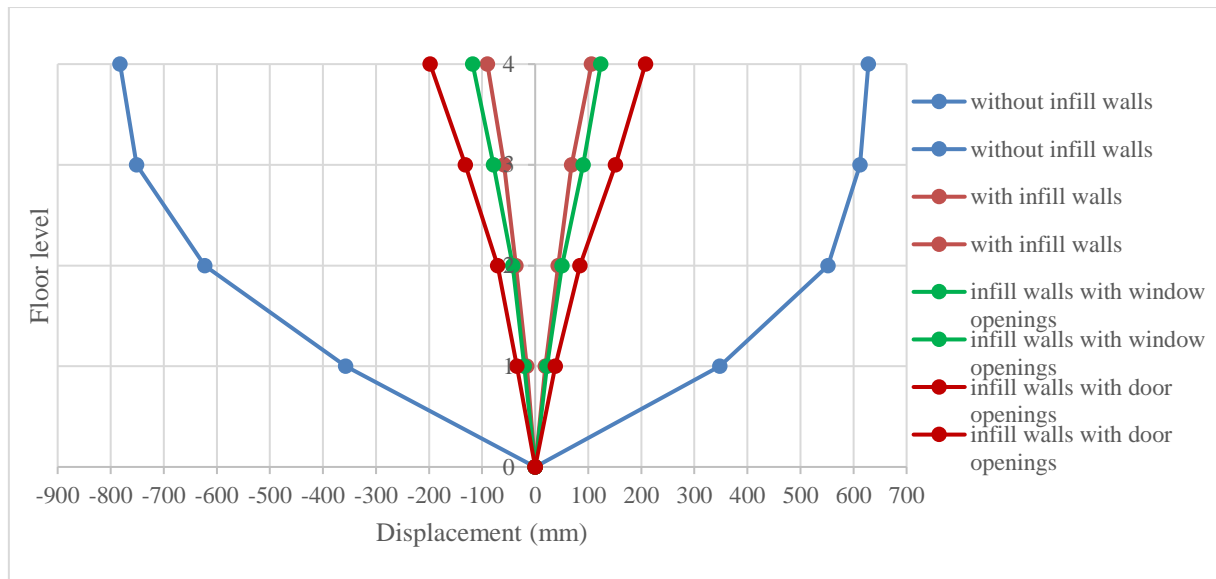
Figure 26. Results for maximum top floor displacement for all cases

10. Conclusions

1. To simulate full-scale reinforced concrete building exposed to dynamic loads in Abaqus/CAE 2019, its requires a high-specification of a computer to get results in a reasonable time.
2. With the possibility provided by Abaqus software, an RC multi-story building was successfully simulated, which was practically tested at the Elsa Research Center in Italy, and the results of the numerical analysis were satisfactorily consistent with the laboratory results, where the difference between the match rates was below 4%. In this study, it has become possible to simulate the RC building with different retrofitting techniques.
3. When there are openings in the RC infill walls, the results show a clear increase in the lateral displacement of all floors. Increase in openings size, rise in the lateral displacement. The lateral displacement of the top floor increased by 14.04%, 23.533%, respectively, in both X direction when the opening made up 15% of the area of the F-wall compared to the absence of openings and when the opening size was enlarged to 25%, the increase in lateral displacement increased by 35.28%, 56.63% in both X direction compared to the absence of openings.
4. When the RC infill walls of the building were removed to investigate the seismic response of the soft story building, the maximum displacement limit for the top floor increased about eight times in both X direction compared to the presence of the RC infill walls of the building

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