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Seismic behavior of a strengthened full scale reinforced concrete building using the finite element modelling approach

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ABSTRACT

In Iraq, the increase in earthquake activity was observed, but most of the existing buildings can still suffer from severe injury or destruction, and therefore can cause major issues. In this paper, we performed numerically analyses by experimental modeling to demonstrate efficiency using final element analysis (FEA) in the development of modern solutions (FEA) in the development of modern solutions to maintain existing structures from the risk of earthquakes. Using ABAQUS software that supports dynamic analysis, and uses this model to use models for several ways to enhance the earthquake center. This model was a large-scale 4 building tested using a doctor dynamic test (PSD). Experimental models were performed by extending RC walls with various connectivity details in existing buildings to comply with gravity design only for this building. The goal of this study was to determine the impact of adding an above RC wall as a way of modernization, including the design of Dowels and their contribution to the new mouse wall's connection to the existing RC buildings. These enhancements are performed by converting the selected compartment to the new inlet wall RC [2]. The result of analysis modeling is 4.11% of the proportion of differences in the X direction in the upper layer displacement of Abaqus software and the experimental test of Elsa results, and 2.15% of the negative direction X is 4.11%. an accurate similarity and exact building modeling. After verification process, three earthquake enhancement methods are used Next analysis.

Keywords: Numerical simulations, Retrofitting technique, Infill RC walls, Steel tube, Steel Plate shear walls, Abaqus software

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1. Introduction

A useful tool for solving civil engineering issues is finite element analysis (FEA). It is essentially a method in which a continuous with infinite degrees of freedom correlates to a collection of members (or sub-areas), each with unknown variables of finite quantities. [1, 2]. Buildings designed so according to seismic code criteria can withstand earthquake without collapsing, and earthquake loading calculations are critical aspect of the construction design process. At earthquakes, the sections of the structure must be able to endure laterally loads and hence comply effectively when stresses grow, thereby boosting life safety. Usually strengthening is currently done using strengthening techniques [2], and lateral movement can be reduced by reinforcing structures. [3]. For seismic upgrading objectives, rapidly increasing stiffness and lowering the expected seismic displacements of a building could possibly be more cost than locally intervention of components. [4]. In the matter, Chrysostomou C. Z et al in 2013 conducted an experimental Seismic Retrofitted Study by PSD techniques on a full-scale, A four-story RC structure with RC Infill wall was built at the ELSA site in Ispraa, Italy, by converting particular bays into contemporary RC infill walls utilizing RC materials. It was designed according to the BS-8110 (1983) [5] and Euro code2 [6]. The pseudo-dynamic technique was used to analyze a 12 metre high, three-bay (8.500-meter-long) structure with parallel frames connected by 0.150-meter-thick RC slabs and a middle bay with an infilled RC wall (2.50 m). The current frames were identical to frames built in Cyprus in the 19701s and were detailed and designed for solely gravity load resistance. For the 2 infilled frames, different reinforcement percentages and connection details were chosen with the goal of examining their effects on building reaction. A 0.250g seismic load was able to pass through the structure without causing substantial damage, and an infill wall placed in the chosen bay may be utilized to improve standing strength and correct structural flaws. The structure's locally and globally performance gives data for numerical modeling development; as a result, design recommendations for this retrofitting technique have been presented [7]. Moreover, Elpida G, et al. In 2015 carried out a numerical model of the experimental seismic findings, which were utilized to reinforce existing structures. DIANA - finite element analysis (FEA) technology was utilizing to model and analyses an empirical result that looked at the efficiency of seismic reuse of standing structures. The structure was put to the test at the ELSA facility in Ispraa, Italy, at the Joints Research Centre. The pseudo-dynamic (PSD) approach was used to evaluate a full-scale four-story model. This may be accomplished by using unique details for connecting the walls and the bounding frame. The existence frames are created and developed for solely gravity load resistance. The goal of the testing was to see how effective the proposed retrofitting method was, and the building of new infill wells and the role of dowels in connecting the existing RC frame to the new buildings wall. In order to simulate the experimental data, nonlinear transient analysis was done in addition to FEA frame modeling [8].

It was discovered that the numerical results of the two-dimensional numerical model can accurately reproduce the behavior of the test specimen. As a result, the experimental data may be supplemented, and the interactions between the frame and its surroundings can be explored at both the globally and locally levels. These findings will aid in the investigation of the general model's application as well as the design of RC infills for current RC frames. [8,2]

The goal of this research is to use Abaqus /CAE 2019 to model and verification of an experimental evaluation of a building that was experimentally tested at the ELSA Lab. in Ispraa, Spain, to explore the influence of placing walls in mid-frame (a retrofit approach) under dynamic load. [2] software. Details can be found in [9], [10], [7] and [11]. Second to Study the performance of the structure and it is free of any kind of seismic reinforcement under the influence of a real earthquake. Third to Study the effect of using steel plate shear walls with two thicknesses (5, 10) mm instead of infilling RC walls to illustrate another type of strengthening and seismic modification. Finally, to use of steel tubes for ground floor columns as a kind of seismic strengthening

2. Description of the geometrical experimental model

There were four floors and two exterior frames in the model (southern and northern) each containing three bays as described in the SERFIN Project. [12, 13,14]. Two frames are 6.00 m apart and are joined by a 0.150 m Floor slab and four 0.250 m by 0.500 m beams perpendicular on the plane of the 2 three-bay frames. As illustrated in Figure 1, The building was 8. 50m in total length (Central Bay 2.50m and two 3.00m outside bays), with a 3.00m floor height and a 12.0m overall building height. Columns are spaced 0.250m apart from 0.40m to 0.250m. The structure is supported by an 11.00 by 8.00 meter foundation slab with a 0.400 meter thickness and a 0.40 meter high by 0.60 meter wide beam. Seismic Project SERFIN. Furthermore, the CFRP interconnection in the north frame is located at the lower part of a ground shear wall column. For further information, see the SERFIN Seismic Project. [2,13].

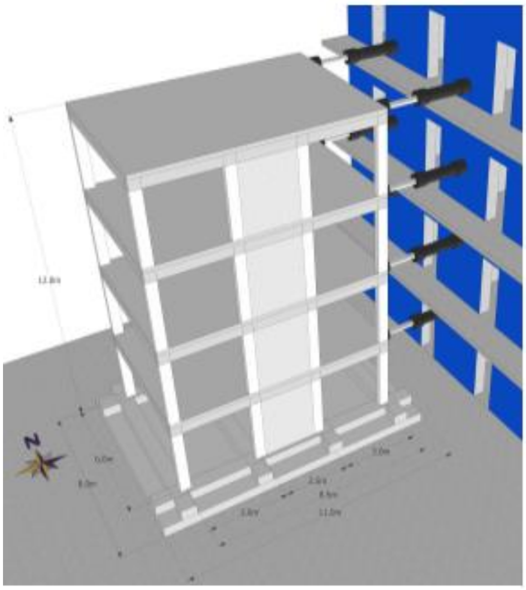


Figure 1. The building

3. Experimental study and simulation techniques assumptions

Assumptions that were regarded in this research in the basic design that was accepted are listed below [2]:
1- The building was designed in accordance with the BS8110 (1983) revision code.
2- Due to the fact that the structure was intended to endure just gravity stresses, it exhibits more or fewer features that distinguish it from normal buildings meant to handle earthquake loads. These features provide information on how buildings react to seismic loadings.
3- There is no consideration of the friction between the earth and the RC (the base was considered).
4- The X-direction earthquake accelerations were selected because of the actuators' placement in the test.
5- The effect of the pressure of pore waters was taken into account.
6- The impact of the CFRP considered in order to minimize a seismic risk.
7- The wind load effect was ignored.

4. The materials used in the experiment

Materials for the model were chosen depending on their availability in an Italian research lab. It was decided to utilize C20.0/25.0 concrete, which has a modulus of elasticity of Ec = 30.0GPa and a unit weight of 25.0kN/m3. The bar's yield strength was 400.0MPa. Whereas the yield strength of such infill wall reinforcement, which consisted of web bars and impeded rebars, was 450.0 MPa, this material was utilized in the 1980s in Cyprus structures. This structure was numerically analyzed utilizing a three-dimensional FE models with non-linear materials properties. Accurate modeling of the stress - strain performance of uniaxial materials could be used to achieve the response of RC structures. Thus, table (1), and (2) and figures (2) and (3) gives the results of the ELSA research lab materials test. [2,13,14,15]

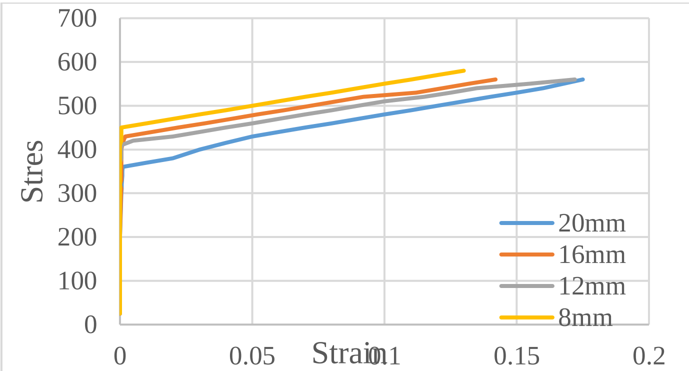


Figure 2. Relationship between stress- strain for steel

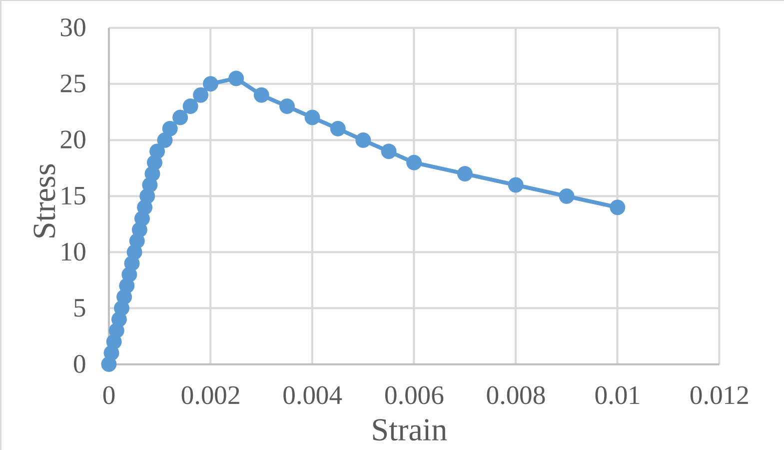


Figure 3. Relationship between stress- strain for concrete

Table 1. The features of the bars are based on data from the ELSA-laboratory [2]

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. The parameter of Concrete based on information on material from ELSAA- laboratory [2]

Poisson – Ratio	**0.2**
Elasticity Modulus	30000 MPa
Tensile Stresses Limit	2.75 MPa
Tensile Deformations Limit	0.00018
Stresses Limits	25 MPa
Deformations Limits	-0.0030

5. Experimental model setup

The model is a recreation of the structure that was common in 1980s Cyprus. Because there were no codes that included seismic loads at the time, the buildings have only been designed for primary loads. As a result, there was no specific standard for seismic design. As a result, the BS-8110 code was selected.

The self-weight has been determined and used the concrete unit weight indicated above. Each floor was considered to have a dead load of 3.0 k/m2 (including the load of the masonry walls) and a live load of 30% of 1.50 kN/m2. Consequently, each floor received (1.00 x 3.00 kN/m2 + 0.30 x 1.50 kN/m2) x 6.250 m x 8.900 m = 192.0 kN. 135.40kN was achieved with 15.0 barrels of water (Figure 4), with the remainder being the self-weight of the engine connection packages.

Figure 4. Barrels of water used within the structure

To simulate the real situation in which an old building is strengthened, the structure has been loaded with self-weight load prior to the casting of interior walls and live load beyond casting. The above loads have been combined using limited safety factors of 1.400 for total dead-load, and 1.600 for the live loads. Table 3 and plates (5. to 9) illustrate all the specific information of building strengthening. The test building was reinforced in a variety of ways and locations, with the north wall being the most difficult., to apply the test case for more numerous factors. To link the walls to the frame, a complicated and uneven description of dowels and starting bars was being used, as seen in figure (9). It is worth mentioning that the examined model was constructed with two separate details between the walls and surround frame in order to test the role of dowels in connecting the newer wall to the older RC frame (see Figure 10). the many types of dowels.

Table 3. Dimensions of Structure model

Type of models		**Dimensions**	**Reinforcement; (mm)**
Beams	Transversal	500*250.0mm	Top:2ø20.0 mm, Bottom:5 ø 20.0, Stirrup: ø 10 @150.0
	Longitudinal	500*250.0mm	Top:4ϕ12, Bottom:4ϕ12, Stirrup: ϕ 8 @200.0
Slabs		8900*6250.0*150 mm	ø 10@150.0mm for top and bottom reinfor.
Columns		400*250mm	4 ø 20.0, Stirrup: ø 8 @200.0
Foundation		11000*8000.0*400mm	ø 16@250.0mm for top and bottom reinfor.
Tie beams		600*800.0*800	7 ø 16 for top rein, 4 ø 16 bottom rein and Stirrup: ø 12 @175.0

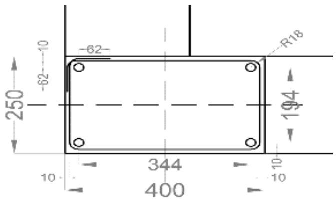


Figure 5. Columns cross section

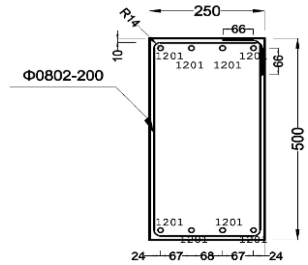


Figure 6. Longitudinal beams cross section

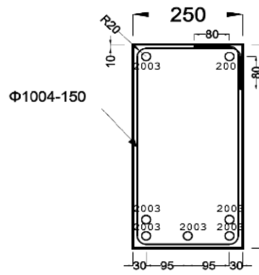


Figure 7. Transverse beams cross sec

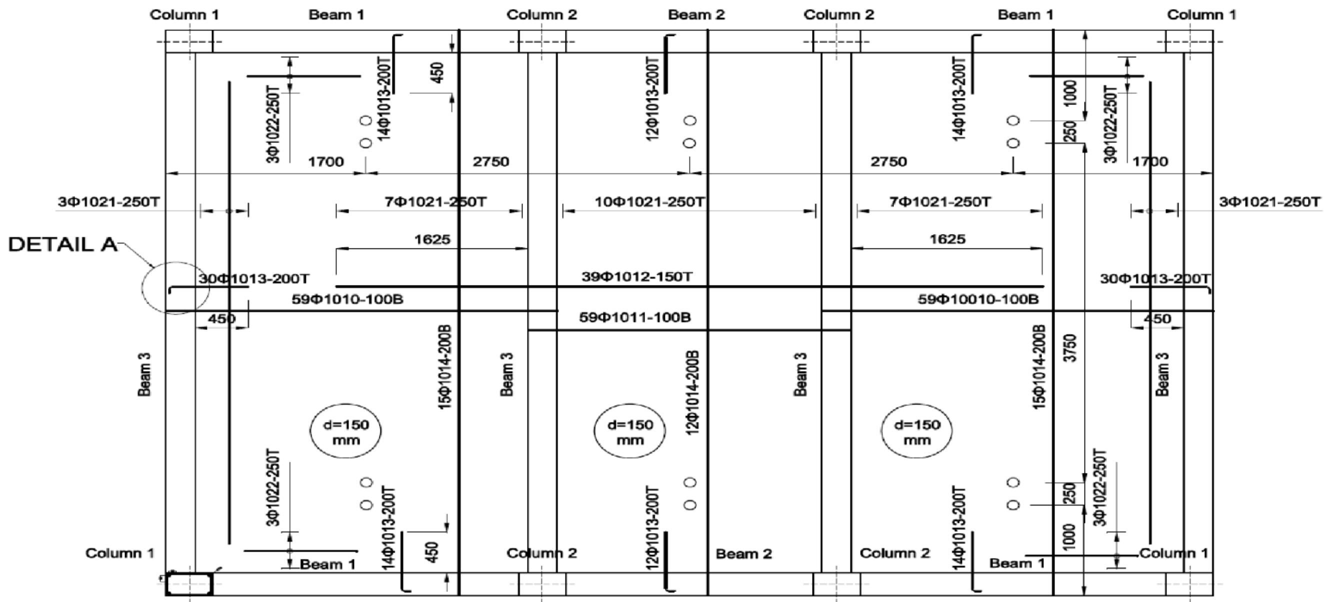
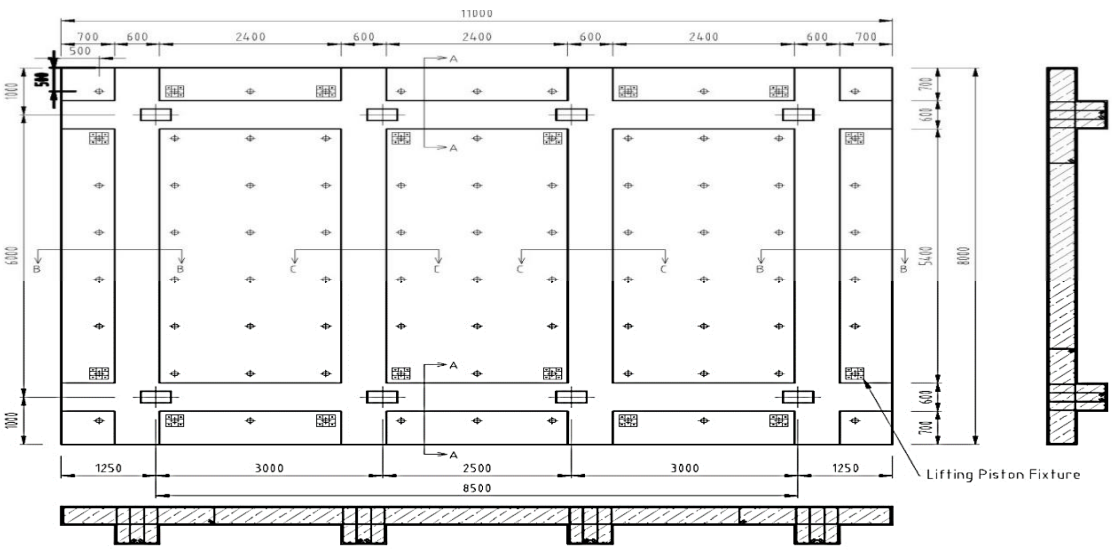


Figure 8. Reinforcement of slab, T implies to top, and B implies to the bottom [2]



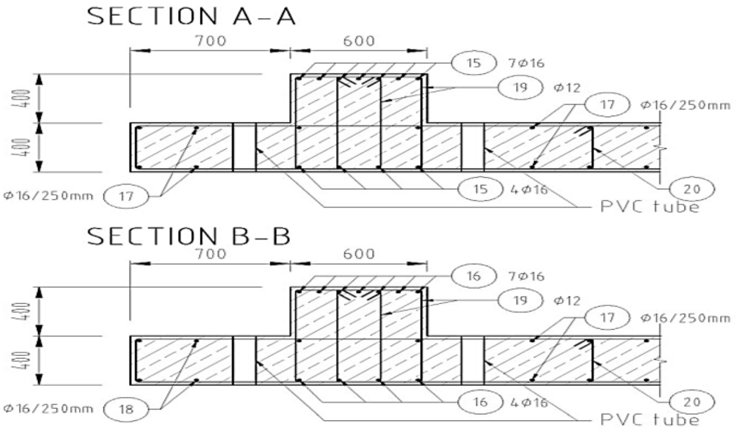


Figure 9. Foundation and sections

Figure 10. (a) Shorts dowels- (b) starter and dowel bars, (c) Starter, dowel and web bar

6. Representation of seismic loads in experimental test

The recorded of the Pseudo Dynamic Test (Psd) [16]. Utilizing one-direction loadings in accordance with a ground motion recorded at Montenegro's Herceg-Nove station during the 1979 earthquake, as seen in Fig (11).

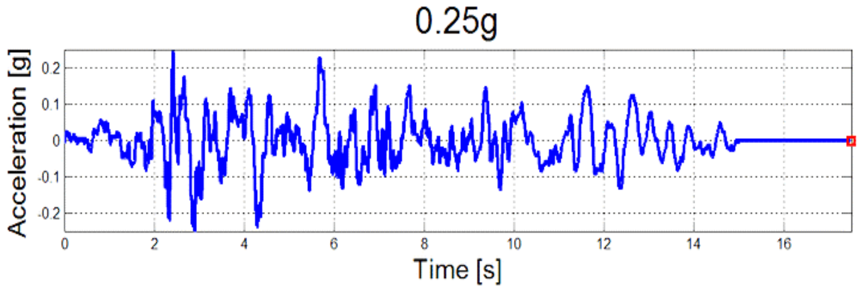


Figure 11. Accelerogram scaled to 0. 250 g of Herzeg Novi (Montenegro 1979)

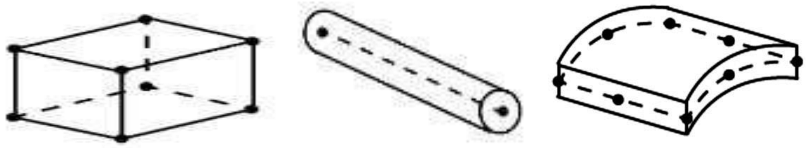
7. Case one: validation of the problem

The following subsections present the finite element modelling steps and validation process of the experimental works

7.1 Elements used in Abaqus software

It is critical to validate the formed simulation model. In this study of the effect of dynamic vibration, the application Abaqus/Cae 6.19 is used. When compared to the experimental findings of a four-story building, the numerical data obtained from this computer program, three various one bay RC structural.

To replicate concrete members, a solid (brick C3D8R-8-node) is utilized, although linear reinforcing bars (truss T3D2-2-node) and (CFRP) sheets are also employed (S4R - 4-nodal double curved). These components are versatile and may be utilized in models for straightforward linear or sophisticated non-linear analysis. such as property plasticity, big deflections, and contact. Figure 12 (a), (b), and (c) depict the typical solid members in Abaqus (c). Figure 13 depicts the RC building model.



(a) (b) (c)

Figure 12. Types of Elements a) Described of concrete utilizing Bricks Elements, (b) Described of steel

Reinforcement bars utilizing trusses elements, (c) Described of CFRP sheets utilizing Shell members

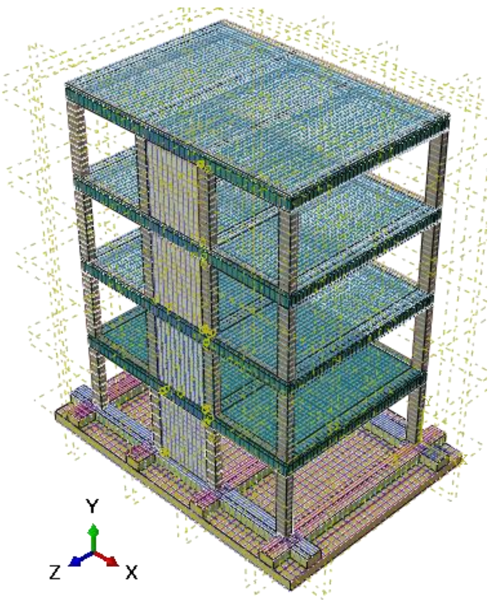


Figure 13. Infill RC walls addition [2]

7.2 Mesh systems and type of element

The concrete elements are simulated using first-order 3-dimensional lowered integration continuum members (C3D8R/8-nodes linear bricks), whereas the reinforcement bars are simulated utilizing (T3D2/2-node linear 3-D truss). In the Finite element analysis modeling, the footings, slabs, columns, and beams are approximated in terms of material and represented using solid (bricks) eight-node components., known as C3D8R elements in Abaqus. The C3D8R elements were chosen because they perfectly satisfy the constitutive rule with decreased integration and are hence well suited for nonlinear dynamic implicit analyses, as well as allowing for finite strain and rotation in larger - displacement calculations. 3-D-truss T3D2/2-node linear element was used to describe longitudinal and lateral steel reinforcing bars inserted in concrete block. The modestly fine mesh was selected for the model mesh because it offers a similar response to the experimental results. To obtain perfect results from the C3D8 component, the suggested rectangular mesh is used. For concrete simulation, the Concrete Damaged Plasticity Model (CDPM) was used. Figure 14 illustrates the finite element model of the reinforced concrete structure using the conventional mesh partitioning of the concrete and steel. [2].

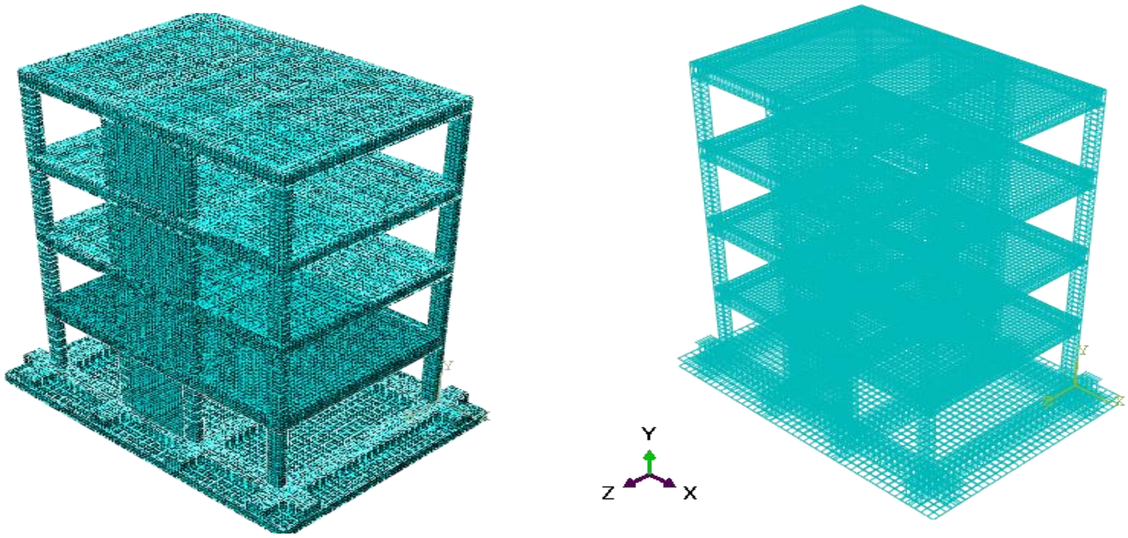


Figure 14. Abaqus program's finite element simulation of concrete and steel bars [2]

7.3 Validation results

The structure was pseudo-dynamically verified by evaluating the ground motion-basic acceleration at the Hercig—Novi station during the 1979 Montenegro earthquakes. In one linearly increasing intensity run of the 0.250 g test with the greatest peak ground acceleration, one directional documentation was implemented to the building. The same motion feedback was utilized to assess the appropriateness of the current analytical model. Table4, and figure 15 compare top floor displacement results from the Abaqus software system to experimental results from the ELSA research lab, allowing the very same model being used for future research papers with guarantee.

Table 4. Comparing the results of ABAQUS and ELSA in terms of top displacements.

Type	Max Top Positive Displacement (mm)	Max Top Negative Displacement (mm)	The Difference 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		

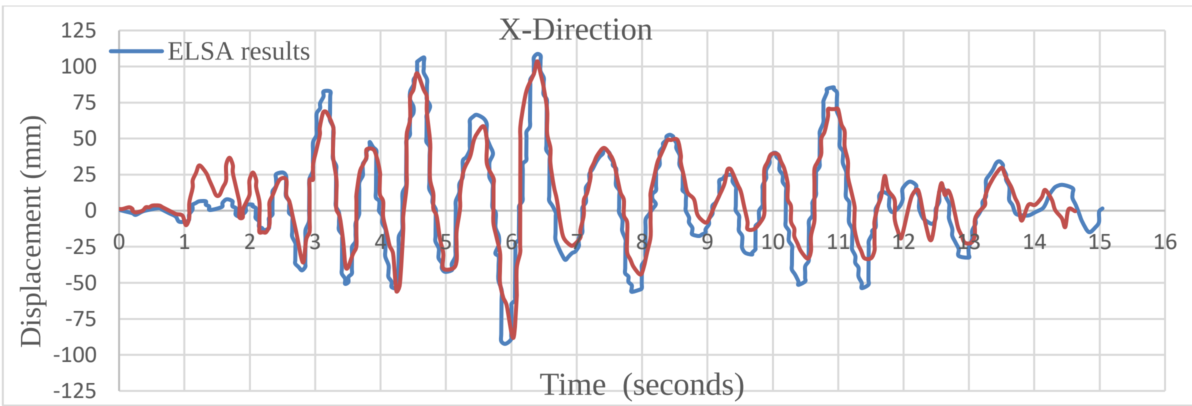


Figure 15. Correlation of ELSA 0. 250 g PGA-results to numerical FE findings for top floor X-displacement

In the development of a simulation model, typical verification is critical. Additionally, due to the difficulties of conducting these tests in a realistic situation, no strategy for selecting which steps must be followed appears to exist. Each modeling project presents a new and unique challenge to the model's development. According to Table 5, the percent of difference in upper story displacement in X-Directions between experimental ELSAA and FE software results is 2.470 percent in X for +ve top story displacement and 3.12 percent for -ve top story displacement, indicating a high degree of similarity and delicacy in building modeling

.8. Case two: control case (the structure without any addition)

The impact of earthquake loading on the construction of reinforced concrete are a major source of building damage. Additionally, the effects of this kind of building that lacks seismic reinforcement and was not seismically designed are vulnerable to failures [2,17]. This type of buildings is called soft floors buildings. The disposal of this type of building will be studied and made as a basis. Thus, knowing the need for his seismic modification. Figure 16 shows the form and makes it a control case.

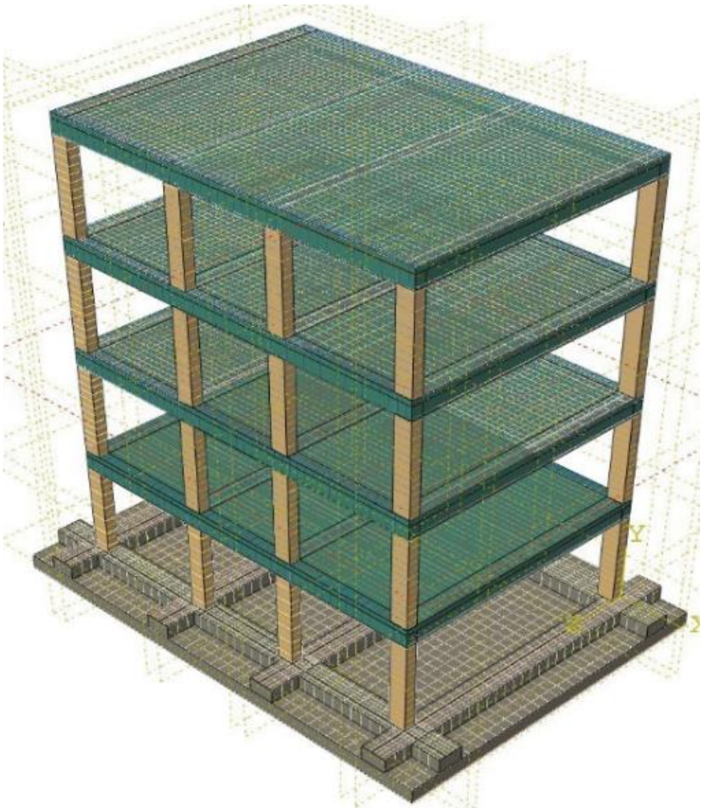


Figure 16. Control case (without any addition)

8.1 Analysis results and discussion

1. In this case study, we examine how the lateral storeys behave in the event of an earthquake. (Herzeg Novi, (Montenigro; 1979) , earthquake).
2. This study's findings showed that the maximum top-floor displacement was 827.970 millimetres, while the opposite direction's value was -982.380 millimetres.; [2].
3. There is a maximum first-story displacement of 548.0290 mm, and a minimum of -557.0990mm in this direction.; [2].
4. Based on the results, this structure appears to be in need of strengthening and modification in order to withstand earthquakes.
5. The figures 17 and 18 clarify the storeys behaviour in lateral X-displacement [2].

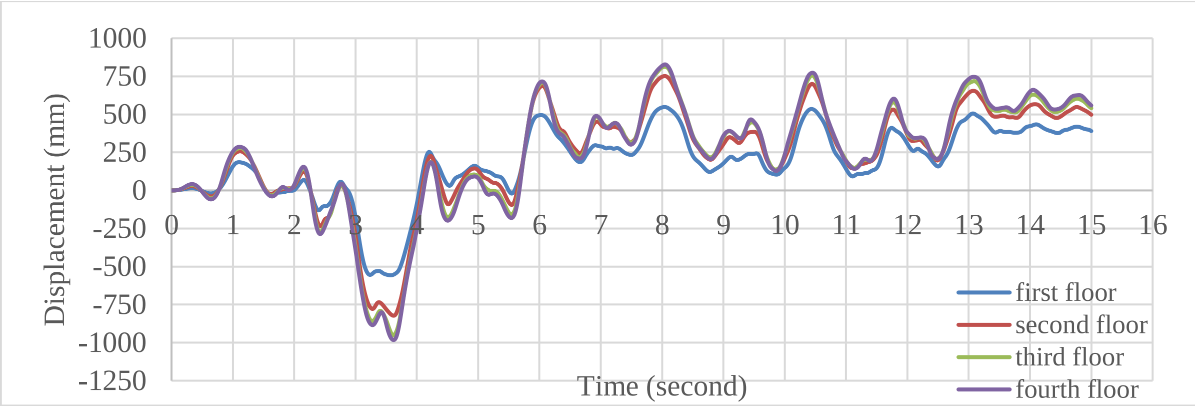


Figure 17. Relation between disp. Vs. time

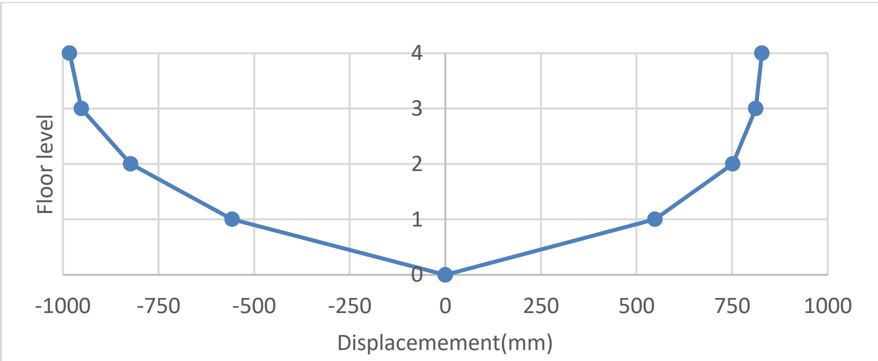


Figure 18. Maximum displacement at different floor levels in the control case

9. Case three: steel tube addition

The purpose of this strengthening method is to make the column and steel tube to act as a composite column and this construction work can be useful in a position where fire and explosions near the buildings can be expected in a way that, the surrounding steel protects the columns from different shocks [18].

9.1 Description of the steel tube

In this case, steel plate tube with 5 mm thicknesses was added around the ground floor columns in (X) direction. Fig. 19 shows the steel tube strengthening.

9.2 Steel tube property

The parameters of steel tube summarize in table (5) and the model of Using (Steel Tube) is illustrated in Fig. 19. The property use of steel tube has received extensive research attention [18].

Table 5. Properties of steel tube

Material	Thickness	Definition	Value
Hollow rectangular section	5mm	Density (Ton/mm3) Tensile strength (MPa) Tensile modulus (MPa)	7.85E-9 410 206000

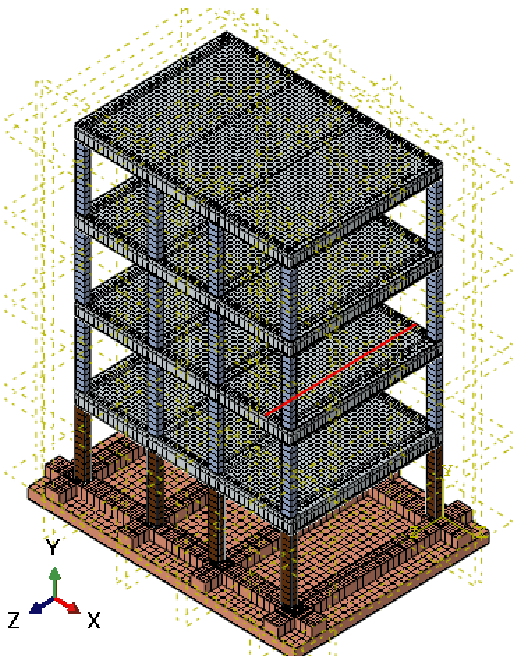


Figure 19. Steel tube addition for ground floor columns [2]

9.3 Analysis results and discussion

By looking at the data obtained from the analysis, the conclusion could be as follows [2]:

1. The significant effect occurs when using Steel Tube as it reduces lateral displacement on the floor that has been added in.
2. The max. top displacements in a +ve direction is 673.085 mm and in the -ve direction is -753.83 mm.
3. The maximum first story displacements in a +ve direction is 32.99 mm and in the -ve direction is -23.15 mm.

The results evaluated by comparing with the control case are as follows [2]:

1. The results of the analysis illustrated that when this technique was used for strengthening, the lateral displacement and the drift for all floors were reduced.
2. The max. +ve top story displacement decreases by 18.700 % compared with the control case, while, the -ve displacement decreases by 23.26% compared with the control case.
3. The maximum +ve first story for displacement decreases by 93.98 % compared with the control case, while, the -ve displacement decrease by 95.84% compared with the control case.

Fig.s (20) to (23) explain building behavior.

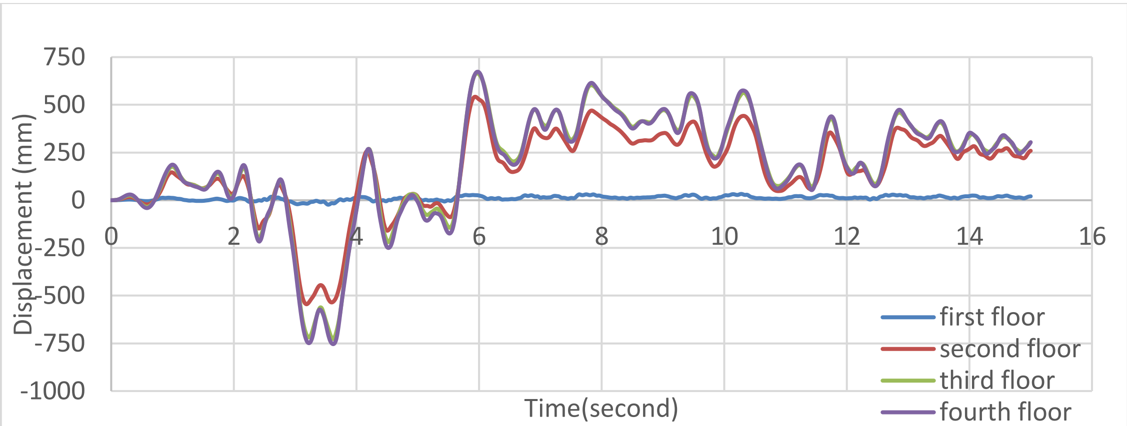


Figure 20. Displacements for all stories with the time

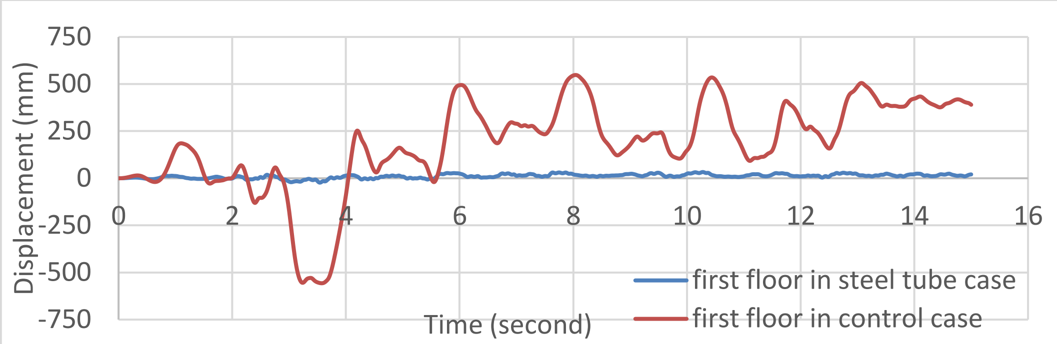


Figure 21. Comparison in first floor displacement with the time for Control case and steel tube case

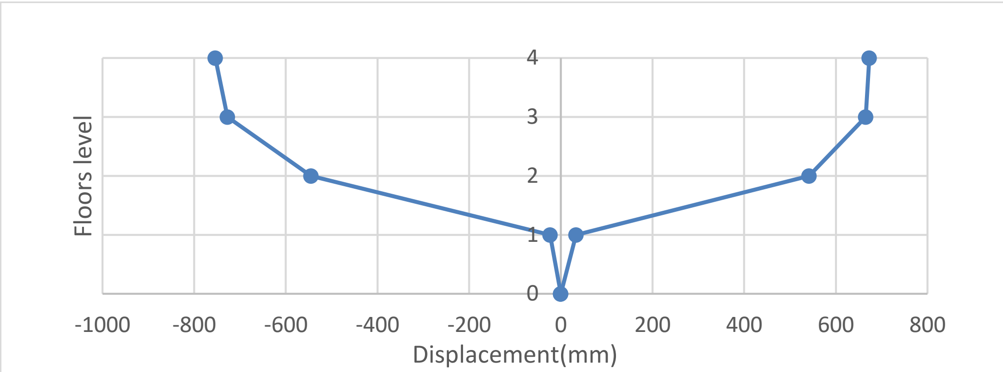


Figure 22. At various floor levels that max. displacement

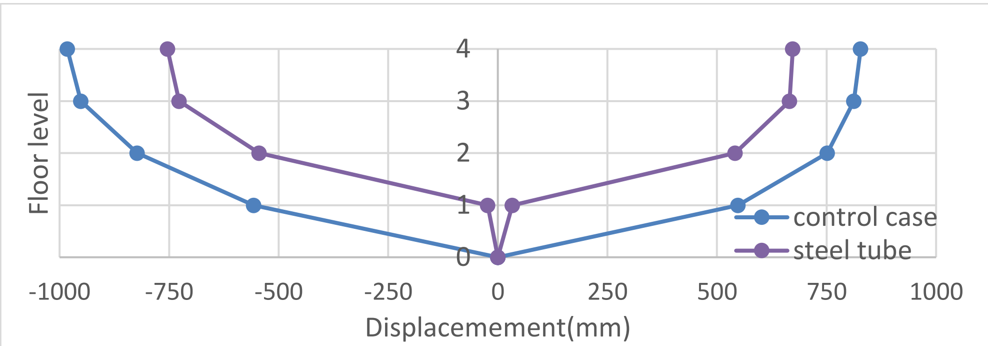


Figure 23. Comparison in Max. displacement at various floor level for Control case and steel tube addition

10. Case four: steel plate addition

In seismically active areas in recent years, steel plate shear wall systems have been used to resist lateral stresses. This method is economical in terms of cost, time of completion and saving of space because of its little thickness [19].

10.1 Description of the steel plate shear walls

In this scenario, steel plate shear wall systems with thicknesses of 5.0 mm and 10.0 mm were installed in the (X) direction together with the structure's height, because the infill RC walls were applied in the X-direction. Fig. 24 shows the steel plate strengthening of the structure [2].

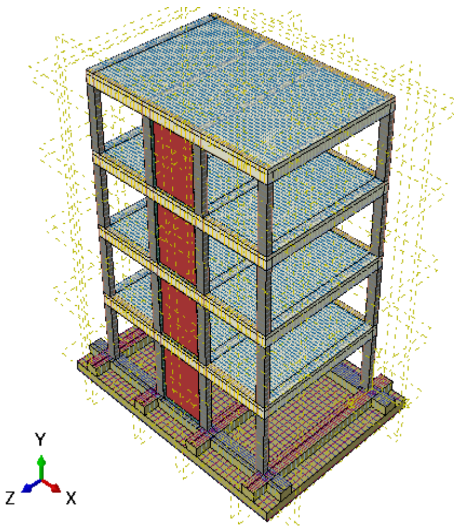


Figure 24. The steel plate shear walls retrofitting

10.2 Materials used in this case

Properties of using steel plate shear wall have received from a previous study [20], as Illustrated in table (6).

Table **6**. Properties of steel plate shear wall

Material	Thickness	Definition	Value
Steel plate	5,10mm	Density (Ton/mm3)	7.85E-9
		Tensile strength (MPa)	370
		Tensile modulus (MPa)	206000

10.3 For (5mm) steel plate thickness results

1. Maximum positive top story displacement with steel plate is 113.660mm and, in -ve displacement is –97.830mm. All behaviours illustrated in Figs. 25 and 26.

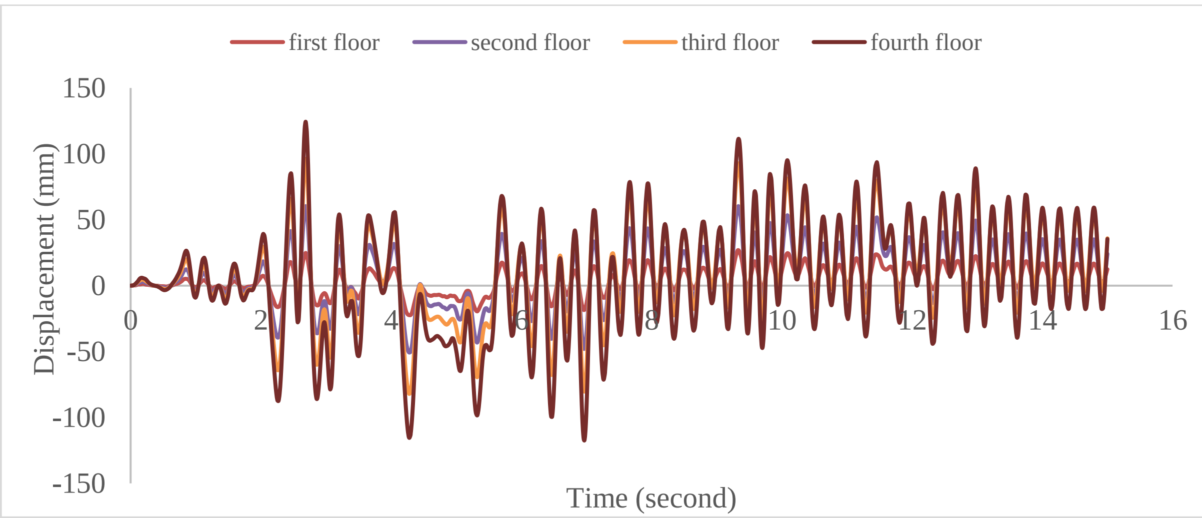


Figure 25. Relation between disp. for all stories vs. time

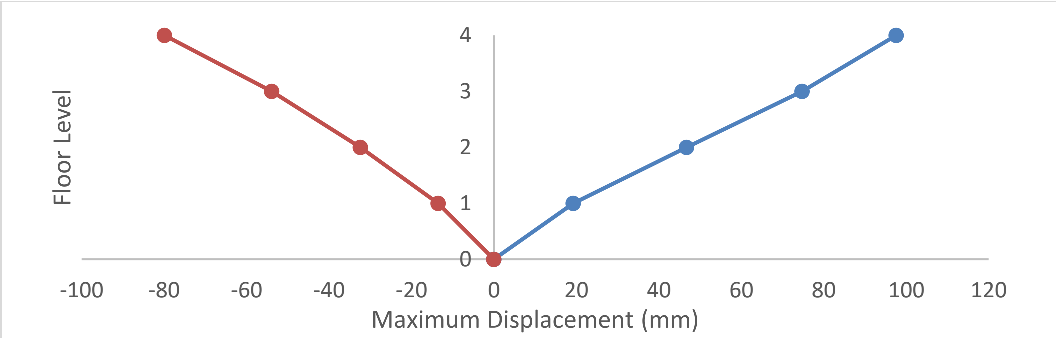


Figure 26. Max. displacements at various floor level

10.4 For case (10mm) steel plate thickness

1. Maximum positive top story displacement with steel plate is 97.6mm and in negative displacement is –79.6mm. All behaviors illustrated in Figures (27, 28).

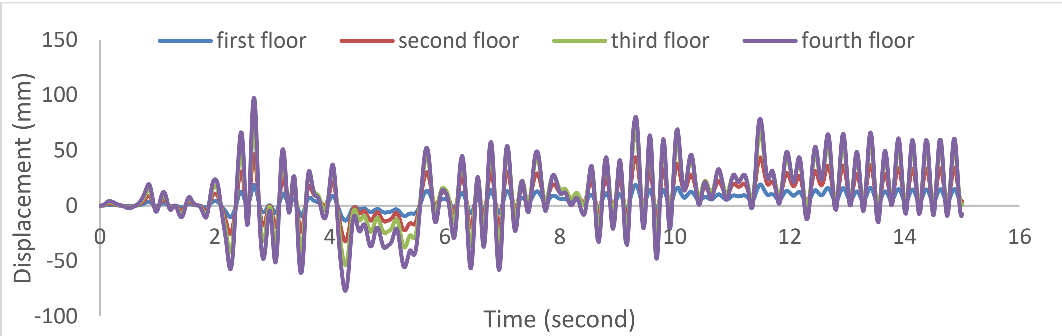


Figure 27. Relation between disp. for all stories vs. time

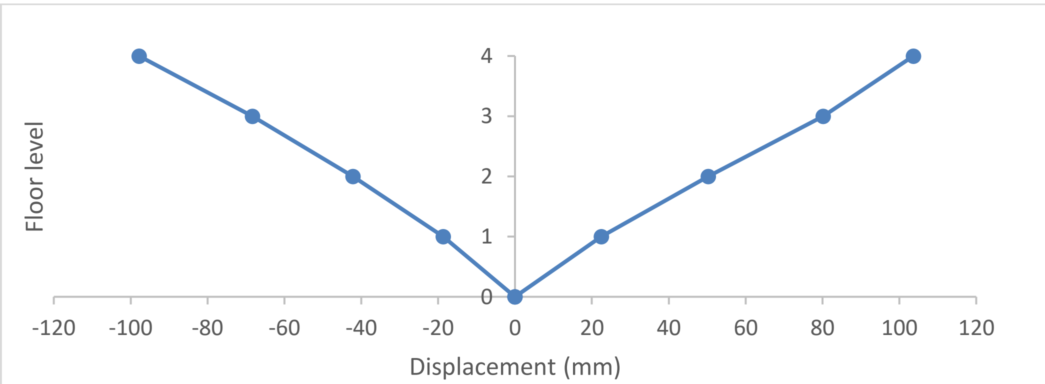


Figure 28. Max. displacement at various floor level

10.5 Results of analysis, and discussions

The following are the results when compared to the control case:

2. The major impact comes when the Steel plate shear wall is used to decrease the lateral displacement on all newly added floors.
3. The maximum positive top storey displacement is reduced by 86.27 percent in the 5mm thickness case, whereas the maximum negative top storey displacement is reduced by 90.04 percent in the 5mm thickness case.

4. In the case of 10mm thickness, the maximum positive top storey displacements decrease by 88.21 %, but, the negative displacements decrease by 91.87 % compared with the control case. Figures 29 and 30 explain the comparison with two cases.

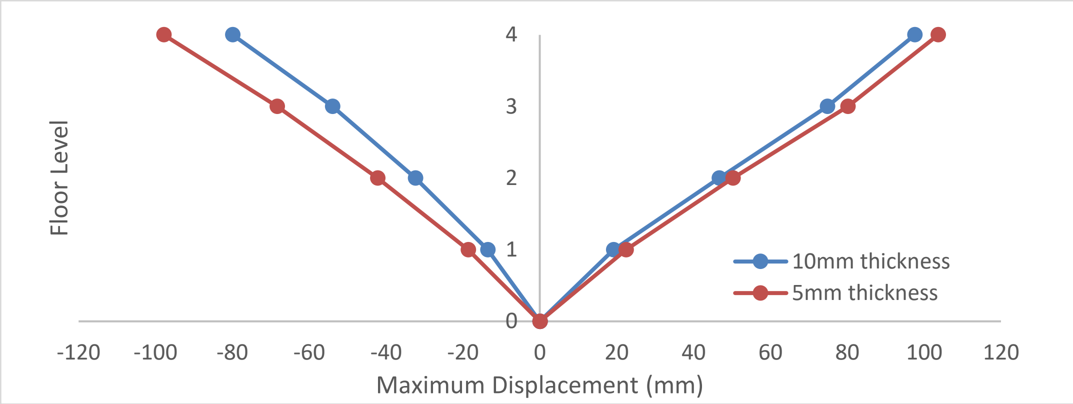


Figure 29. Comparison in max. displacement at different floor level for two thicknesses of steel plate addition

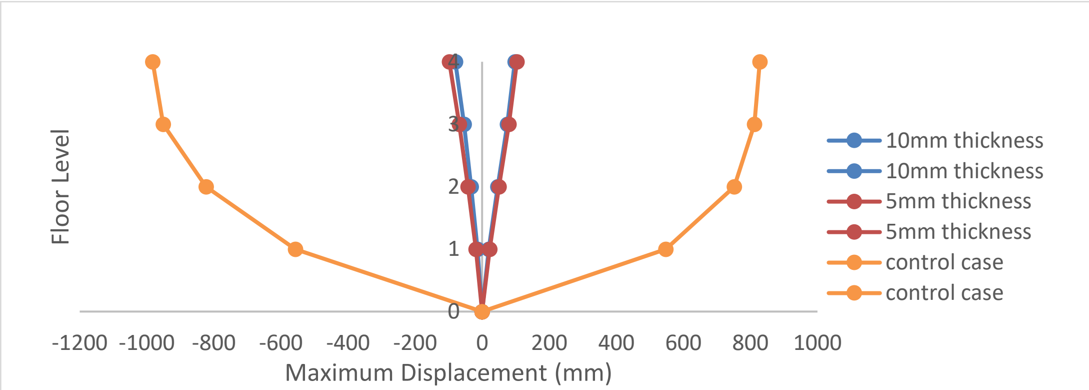


Figure 30. Comparison in max. displacements at different floor level for control case and two thicknesses of steel plate addition

The Maximum Displacement of the Top Floor in the Following Cases shown in Table (7).

Table 6.The result of max. top floor displacement for all cases

Control case		**827.97**	**-982.38**		
Case two: RC infill wall		106.3	-90.1	87.16%	90.83%
Case three: steel tube		673.1	-753.83	18.70%	23.26%
Case four: steel plate (mm)	5	113.66	-97.83	86.27%	90.04%
	10	97.6	-79.9	88.21%	91.87

11. Conclusions

1. Abaqus/cae2019 simulation of a full--scale reinforced concrete structure under dynamic load requires high computer power to obtain results in an acceptable time.

2. The successfully reproduced the RC high-rise building that was evaluated at the Elsa research center using the Abaqus functions, and the numerical findings were in good accord with the experimental data. There was a variation in concordance rates of less than 5%. It was able to simulate the RC building using several modernization strategies in this study.

3. When using a steel tube, it was even better with easy recovery in the upper layer and even improved the improvement in improvement in the bottom (in this case, adding it to the first-floor column). First, compared to the control system, the offset O (90,99_96) % reduces the reduction of offset O (88,98_99, 1) %. The maximum positive reduction of the upper floor displacement is about 28.4_23.26 (28.4_24.24) % in both directions compared to the control system.

4. When a steel wall shear wall is used, the result is that the reduction in the upper floor displacement was significant, and the reduction of the 5 mm thick X direction (89.99_96.64) % (78.2 -946.3) % thick It is 10 mm compared to the control case. However, the thickness change from 5mm to 10mm was only about 2.0% in both x directions.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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