SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

COMPARISON OF A REINFORCED CONCRETE BUILDING STRENGTHRND WITH VARIOUS METHODS

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ABSTRACT

The earthquake performance of a school building having three stories which has been retrofitted afterwards by two approaches, are investigated herein this study. The school building that constructed in 1970, in city of Zanjan (Iran), is studied to investigate earthquake performance. The building has six and three spans at x and y directions, respectively. The story heights from first to third floors are 4.00m, 3.75m and 3.75m, respectively. The structural system of the building consists of reinforced concrete frames. The material tests are carried out by using destructive and non- destructive testing techniques on the columns. Compressive strength of concrete is evaluated by means of statistical procedures which yield the lower and the upper concrete strength is obtained to be 20.0MPa and 28.3MPa. Numerical analysis of the building is carried out by adopting a three dimensional modeling in SAP2000 software, under vertical and lateral loads according to Iranian Earthquake Resistant Design Code (IERDC 2007). The pushover analysis is carried out for each of x and y directions and capacity spectrum method, which is based on static pushover analysis, is used to obtain the performance levels of the existing structural system. Numerical results reveal that the existing structural system is insufficient and it should be strengthened. Two different strengthening techniques, jacketing of columns and adding shear walls, are considered to strengthen the building. By use of steel braces and strengthening of infill walls between frames is not considered. The strengthened systems are analyzed similarly and performance evaluation is realized, based on the demand and capacity curves. Nonlinear elastic performance method assessment is accomplished according to FEMA-356 and Iranian Code-360. Immediate occupancy under the design earthquake and the life safety under the maximum earthquake are considered in design of the extent of the strengthening intervention. Numerical results are given in figures and tables, comparatively.

INTRODUCTION

The structure is modeled as 3D by using the SAP 2000 software. The lateral displacement of the structure is more than the limit defined. Design of members is supervised with regard to IERDC 2007. The structure has enough strength to bear gravity loads, but it does not have the required strength to support the lateral seismic loads.

According to the seismicity map included in the earthquake regulations IERDC 2007, Zanjan city is highly earthquake-prone.

Here, the design base acceleration is: A=0.3. In addition, the earth of this region is type III .The other associated parameters, which are also used in the structural analysis, are as follows: T_o=0.15, T_s=0.7, and B=2.75.

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Due to observance the presented results, low structural concrete compressive strength bound and low bound of tensile yield stress structural bars equal to 200 kg/cm^2 and 4000 kg/cm^2 respectively and expected compressive strength of structure concrete and expected foundation bar tensile yield stress equal to 283 kg/cm^2 and 4400 kg/cm^2, i.e. equal to 1.1 fold of low bound strength.

Based on the Regulation of building resultant loads in educational buildings, live load of classrooms and corridors is equal to 3.5 kN/m^2 and 5.0 kN/m^2 respectively. Dead load is including Shelter, Ceiling weight and weight of surrounding and internal walls. Finally we can calculate the structure' weight.

Table 1. Effective weight

Effective weight					
Story	Area (m^2)	Height from base (m)	Dead load (kN)	Live load (kN)	Effective weight D+0.4L (kN)
3	595.65	11.50	6440	890	6796
2	595.65	7.75	7580	2257.5	8483
1	595.65	4.00	7720	2257.5	8623
				Σ	W= 23902

The main oscillatory period is determined based on the building characteristics and its height in relation to the base level, using the following experimental equations:

-Buildings with moment resisting frames:

$T=0.07H^{3/4}=0.43$ (unreinforced concrete frames) (1)

Where H is building' height in relation to its base level. If the weight of the stair turret is 25% of the roof weight, its height is also take into account while calculating the total building height (H).

-The minimum base shear force or a total of seismic lateral forces for each lengths of a building:

V is base shear force = ASI W / R =5915,74 kN (2)

I is building' importance coefficient, the building that researched is school and according Iranian earthquake regulations I=1.4 .

W is building total weight, including the dead loads and 40% of the live loads and R is behavior coefficient of building.

Structure' Analysis:

$V=C_1*C_2*C_3*C_m*S_a*W$ (3)

C_1 is the correction factor for applying non-resilient places of the system.

$C_1=1+[(T_s-T)/(2T_s-0.2)]=1.17 \quad 1<C_1<1.5$ (4)

C_2 includes effects of reduction of stiffness and resistance of the structural members for displacement due to rotational behavior (it equals to 1 for linear analysis)

C_3 Modification factor to represent increased displacements due to dynamic P_Δ effects which is considered to be equal to 1.

C_m is considered in order to apply the effect of higher modes and is equal to 0.9 for concrete moment frame.

S_a is Response spectrum acceleration =S*A=2.75*0.3=0.825

Finally for building, respectively: V= 21822.52 kN

In nonlinear static analysis, the lateral load due to earthquake is applied to the structure statically and gradually until the amount of displacement in an external point is reached a certain value under lateral load or the structure is collapsed.

Target displacement:

Target displacements of a structure with rigid diaphragms must be estimated with respect to non-linear behavior of that structure:

$\delta= C_0*C_1*C_2*C_3*S_a*T_e^2/4\pi^2*g$ (5)

C_0: correction coefficient of the ratio of spectral displacement with one-degree freedom system and roof displacement of a multi-degree freedom system which is equal to 1.2 based on the table.

Number of Stories	Shear Buildings		Other Buildings
	Triangular Load Pattern (1.1, 1.2, 1.3)	Uniform Load Pattern (2.1)	Any Load Pattern
1	1.0	1.0	1.0
1	1.0	1.0	1.0
2	1.2	1.15	1.2
3	1.2	1.2	1.3
5	1.3	1.2	1.4
10 and more	1.3	1.2	1.5

Table 2. Values for Modification Factor C_0

$C_1 = 0.858$ is calculated based on the below equation:
: [(1+ (R-1)(T_s/T_e)]/ R for Te≤Ts (6)

S_a: spectral acceleration in accordance with effective main cycle

R= (S_a/ (V_y/W)) C_m =0.8159 (7)

C_2 represents the effects of stiffness reduction which is selected equal to 1 based on the regulations for a frame of type 2 and lateral safety level and $T>T_0$.(from table 3)

	$T \leq 0.1$ second	T>Ts second	$T \leq 0.1$ second	T>Ts second
Structural Performance Level	Framing Type 1[1]	Framing Type 2[2]	Framing Type 1[1]	Framing Type 2[2]
Immediate Occupancy	1.0	1.0	1.0	1.0
Life Safety	1.3	1.0	1.0	1.0
Collapse Prevention	1.5	1.0	1.2	1.0

Table 3. Values for Modification Factor C_2

C_3 is equal to 1 for those structures that have positive stiffness after yield.

Regarding this fact that determination of the target displacement is as a try and error process, hence firstly based on

$\delta_{t}=1.2*0.858*1*1*0.825*0.43^2/4\pi^2*9.81=40.07$cm

With giving this target displacement to program, we can find Te=1.08

C_1 =1 Te≥Ts
S_a=B*A=1.36*0.3=0.409

$\delta_{t}=1.2*0.858*1*1*0.825*1.08^2/4\pi^2*9.81=22.45$ cm

Then, the structure has been analyzed again based on the target displacement.

Hence, the final value of the target displacement must be selected to be equal to 22.45 cm.

1. Structures in which more than 30% of the story shear at any level is resisted by any combination of the following components, elements, or frames: ordinary moment-resisting frames, concentrically-braced frames, frames with partially-restrained connections, tension-only braces, unreinforced masonry walls , shear-critical, piers, and spandrels of reinforced concrete or masonry.
2. All frames not assigned to framing Type 1.

Primary modeling of structure

After modeling of structure, assigning earthquake loading and assigning nonlinear hinges of structure's elements according to Fema 356 will be do. Then nonlinear static analyzing in direction X, give below results to us:

Evaluation of the performance levels of the structure members suggests that the columns suffer from weakness to a great extent. By increase the amount of the applied lateral load, plastic joints are created in the column posts in the first story. To ensure life safety in the structure earthquake risk level 1 is selected with regard to the rehabilitation goal. As it can be seen cannot ensure life safety and therefore require retrofitting.

A retrofitting method, concrete coverings and adding shear walls are employed to increase strength and rigidity of the structure.

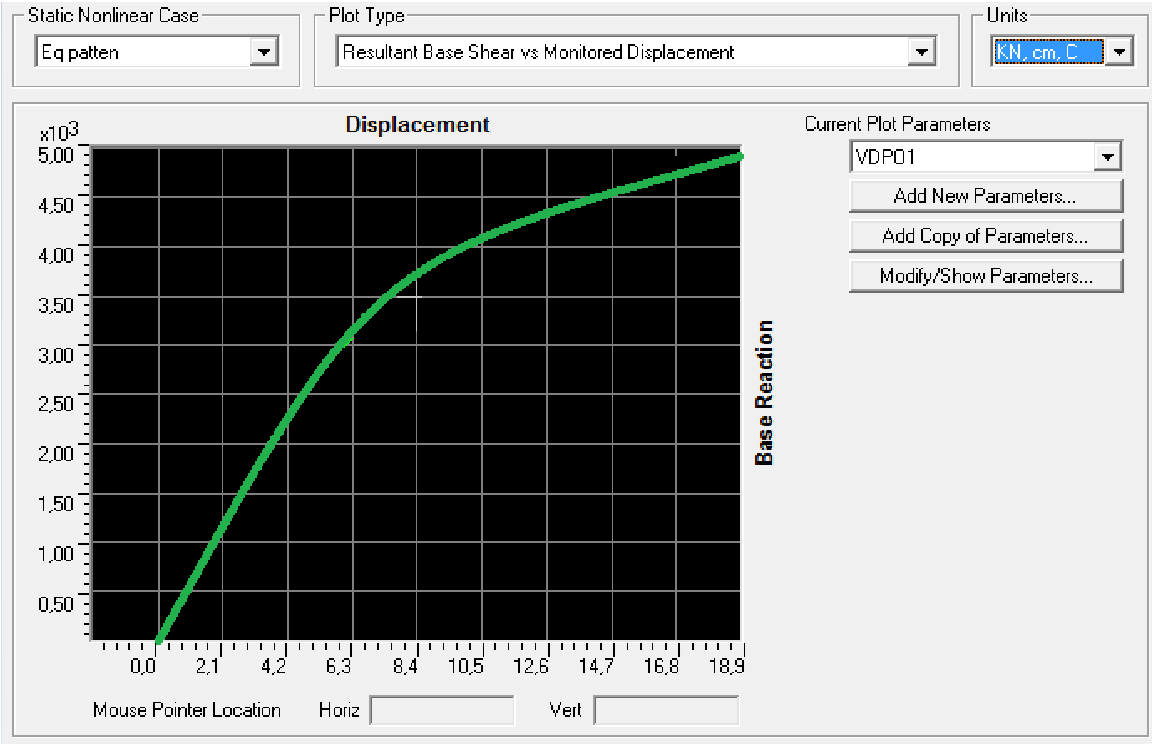

Figure 1. Push over curves Primary model' before rehabilitation.

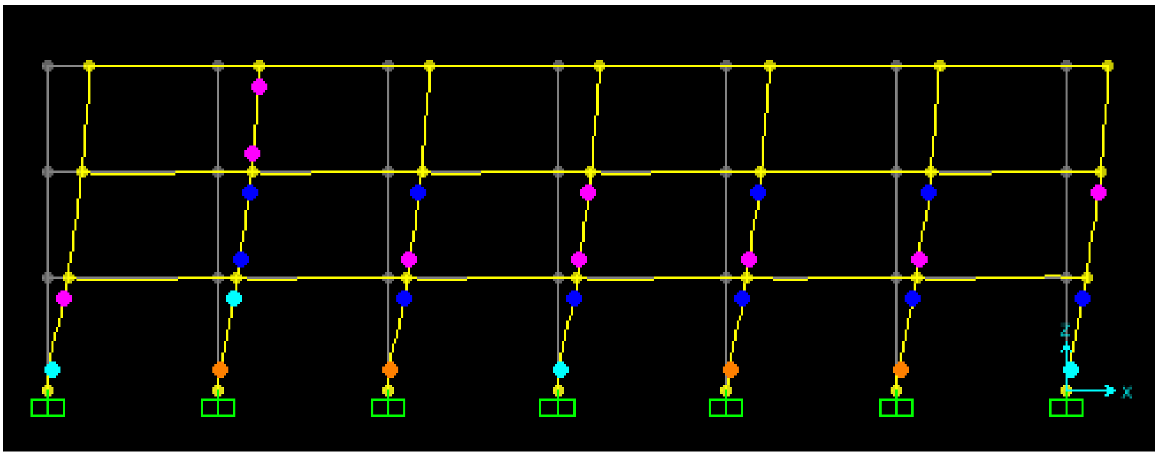

Figure 2. Plastic hinge patterns at last step of push over and last displacement after before strengthening (X-direction).

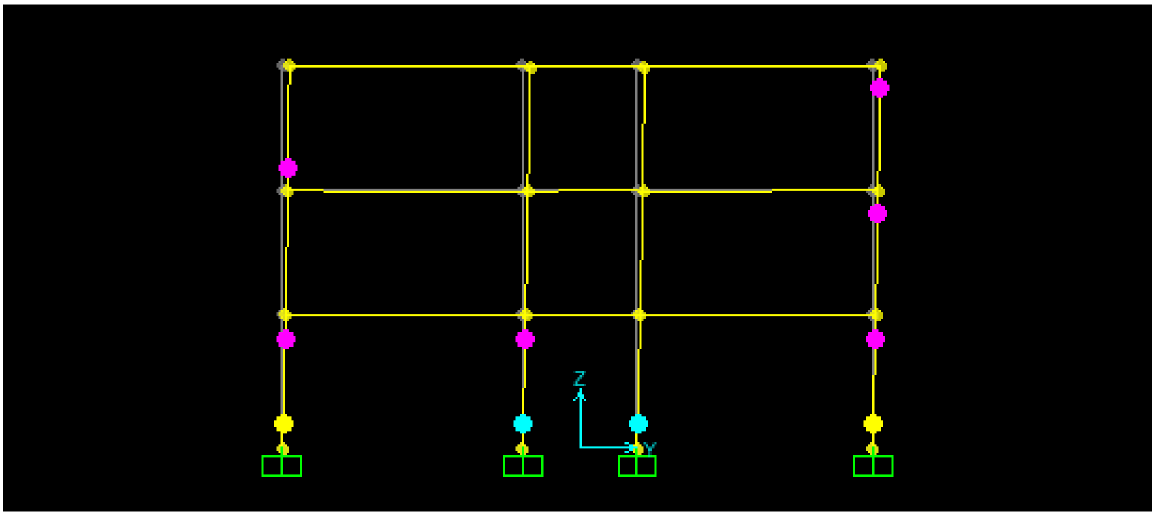

Figure 3. Plastic hinge patterns at last step of push over and last displacement after before strengthening (Y-direction).

Secondary Model (Strengthening Methods)

Concrete jacketing:

Covering can be used as a method for enhancing the bending strength ductility, shearing strength, and reinforcement development or a combination of all. The results of rehabilitation using concrete armors suggest that the bending strength of the reinforced members grows drastically. This occurs when the old and new concrete are connected to each other fully and properly.

If the column concrete armor is only limited one story, the compressive and shearing strength of that column is enhanced. In order to increase the bending strength of the column the concrete armor (covering) should pass through the ceiling of that story.

According to the weakness level of the columns several types of concrete coverings are employed to reinforce the members. Based on the concrete covering that surrounds the reinforced columns the non-linear behavior of these members is assumed to be similar to that of non-reinforced columns.

Therefore, in calculating the expected strength of the reinforced members the ductility parameters of non-linear joints used in the members are assumed to be similar to those of non-reinforced members.

In this project tried to cover and strengthening only elements that they passed safety factor' step, by using the concrete jacketing rehabilitation method tried to strengthening the building.

Jacketing do to 10 columns, axis A and G in middle axis and axis 1 and 4 between axis CD and DE. Column 80x40 cm with 16ф20 and columns 80x40, were converted to 120x80 by adding 28ф20 in the jacketing area.

Central columns with 40x40 cm dimension, with the same method, converted to column 90x90 with 24ф20 in the jacketing area.

Concrete Jacketing at least 5MPa should be more strengthen than the old one. In this modeling because of the insufficiency of Sap 2000 program to define different concrete with different strengthen, equivalent method was used. Columns should be strengthening with the most economical way.

Concrete jacketing contributes to increase the seismic capacity of the structure and decrease the lateral displacements.

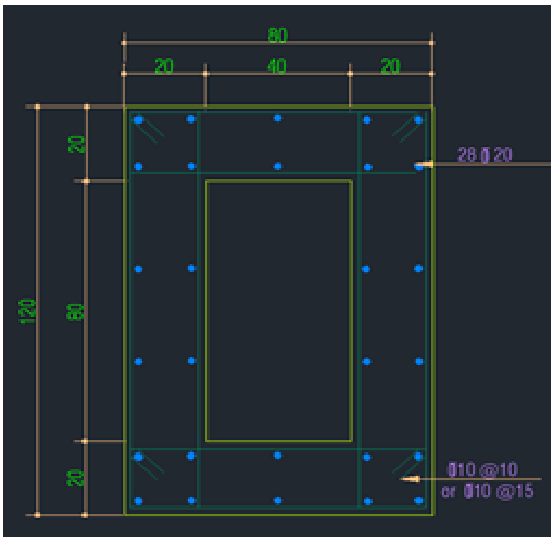

Figure 4. Shape of columns' 40x40after jacketing.

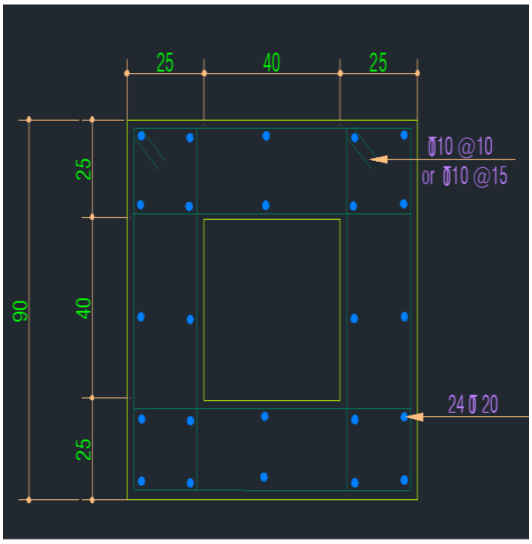

Figure 5. Shape of columns' 40x80 after jacketing.

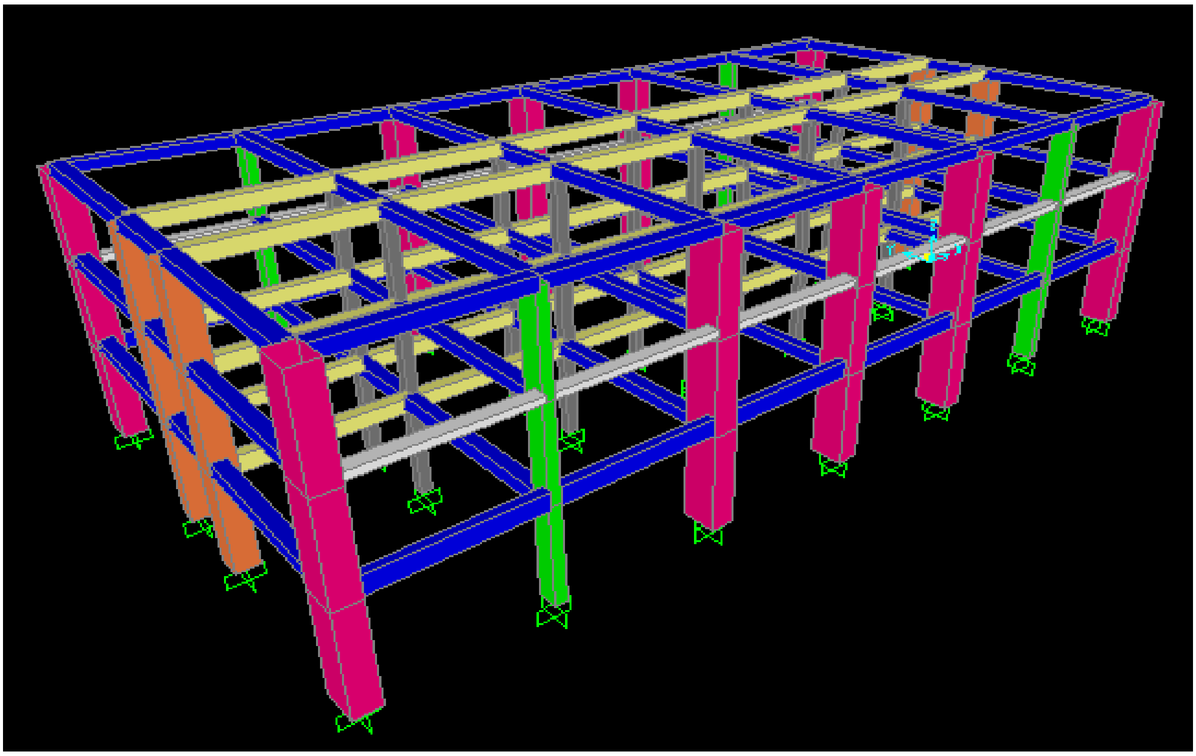

Figure 6. School building' 3D model after strengthening by concrete jacketing.

Expansion of the dimensions of a column leads to a growth in the bending strength and shearing force of that column. Since the longitudinal reinforcements installed in the columns slide in the junctions, plastic joints are created. In the case of the beams, bending and shearing factures are mostly common. After expanding the dimensions of the elements in the SAP 2000 software in relation to the initial model of the structure, the structure takes the following figure.

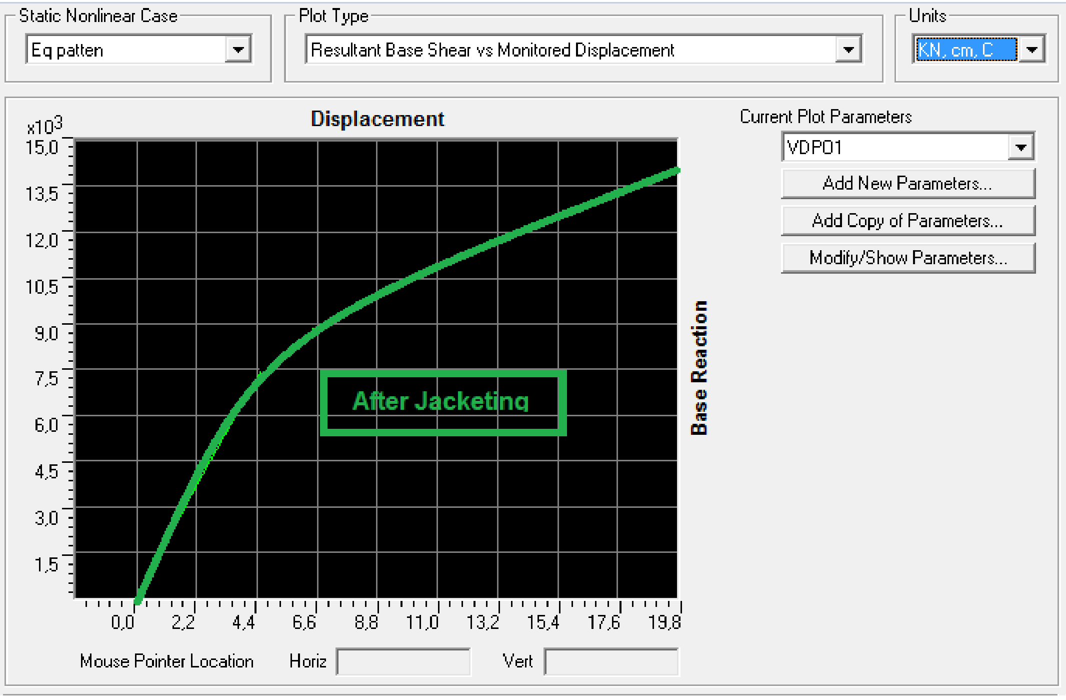

Figure 7. Push over curves secondary model after strengthening by jacketing.

In the structure under study, after concrete jacketing we can receive to performance point with:

(V , D) = (10868171, 0.205)

(T_{eff}, B_{eff}) = (1.158, 0.128)

(S_a,S_d)=(0.451, 0.150)

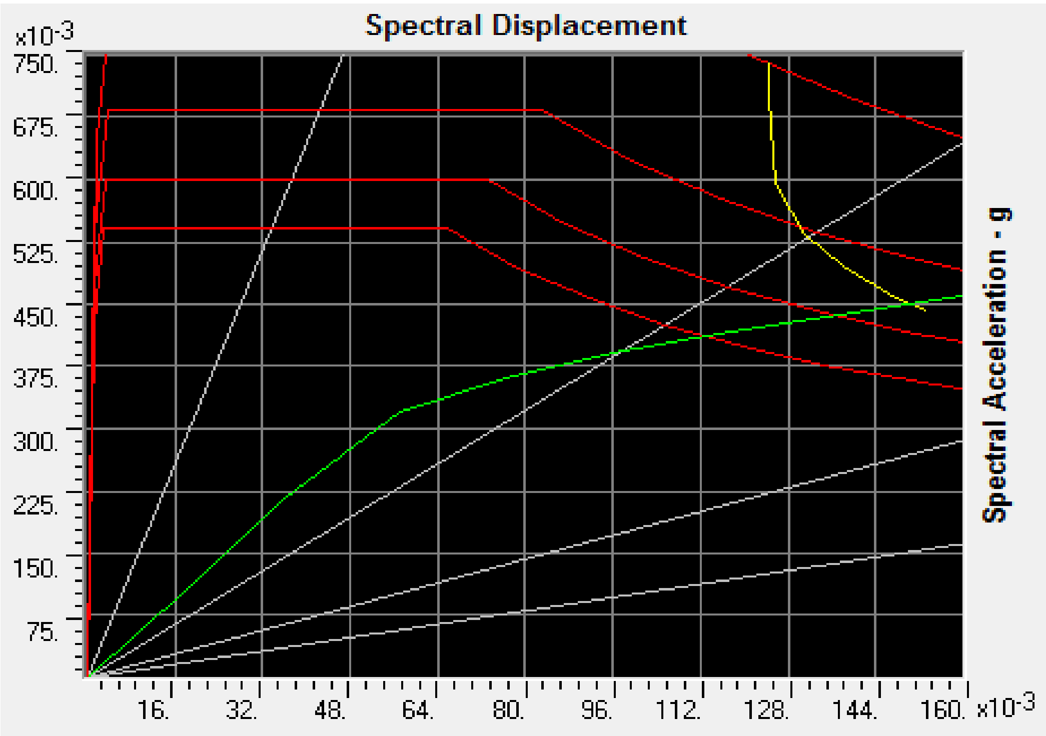

Figure 8. Performance point after strengthening by jacketing (ATC-40).

Shear wall

When the structure reveals a general weakness while bearing the applied loads and for most of its members the ratio of the structural requirements to the available capacity is large, a lateral load bearing system is needed for the whole structure in order to provide the required capacity and strength. If the structural weakness is caused by the lateral rigidity of the structure and excessive displacements, adding number of shear have means of supplying the required lateral rigidity.

We cannot introduce the plastic hinges for shear walls, because of this define a section without any mass and weight with a big mount of moment and shear area is a good selection, with this situation we can define strength beam and it can play the role of imagine shear wall.

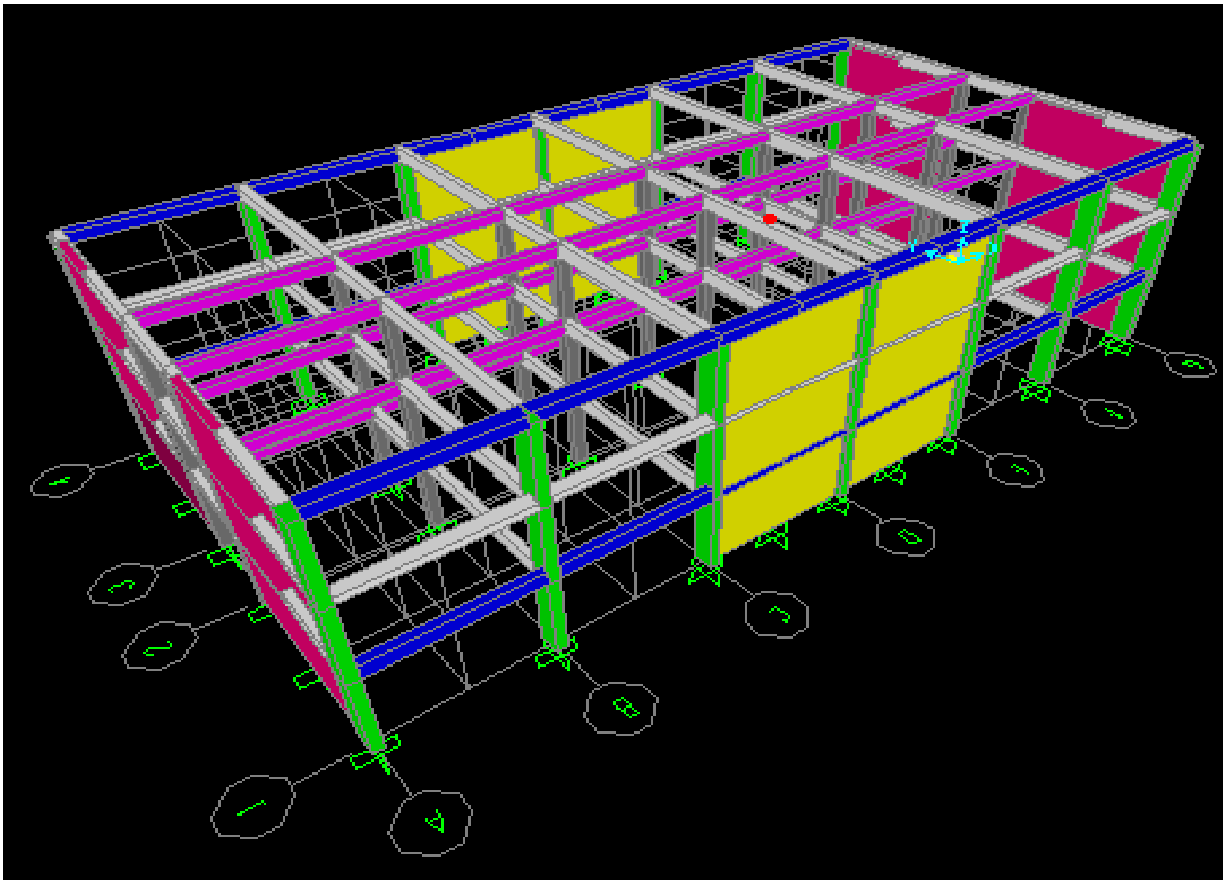

Figure 9. Situation of 3D model after strengthening by adding shear walls.

Figure below shows detail of shear walls that used in the strengthening of structure, shearwall designed by ф16@20cm (vertical and horizontal direction).

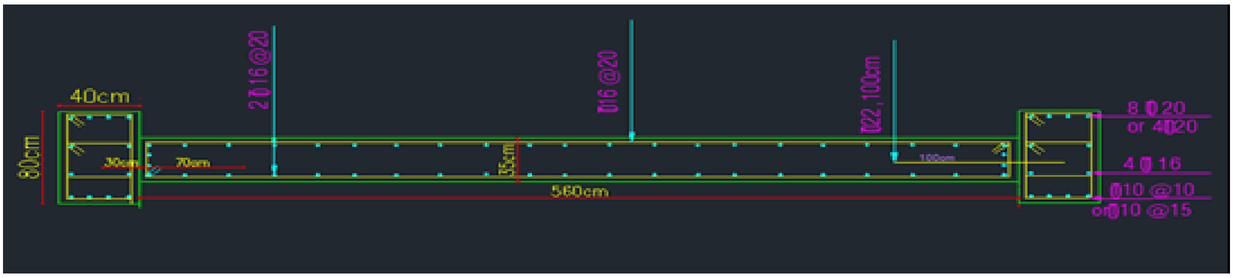

Figure 10. Shape of 3D model after strengthening by adding shear walls.

Using shear walls contributes to increase the seismic capacity of the structure and decrease the lateral displacements. In this way the strength and ductility of the structure are also enhanced. In any case the walls should be reinforced to control and bear both of the mentioned force types.
Analysis results show the conditions of the joints in the last displacement is bigger than the target displacement, so rehabilitation of the building has done successfully.

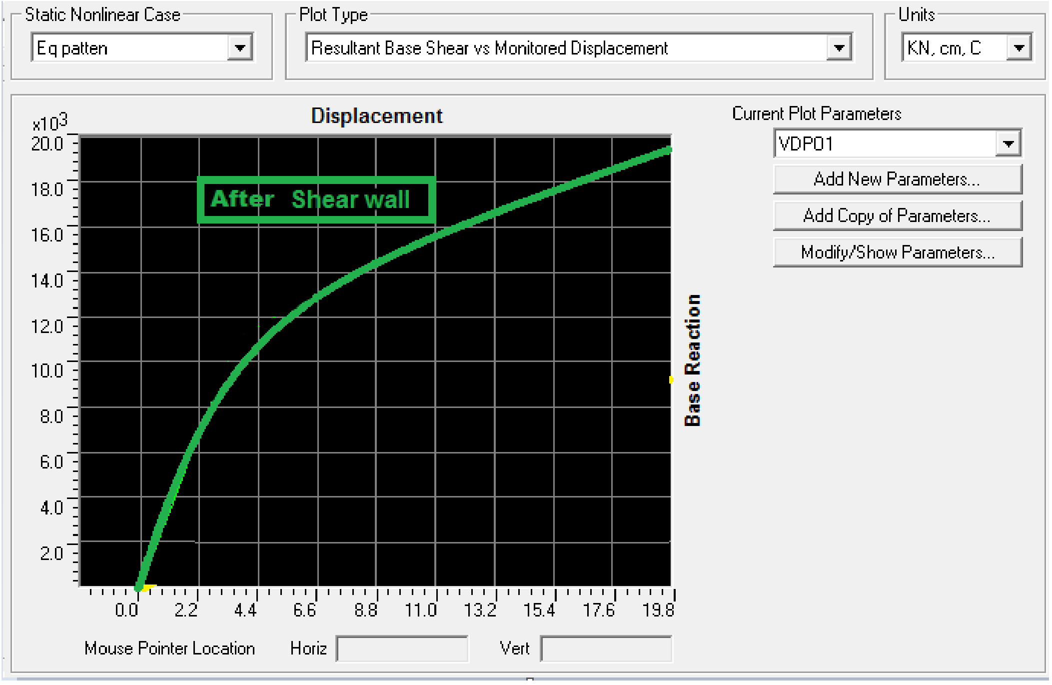

Figure 11. Push over curves secondary model after strengthening by adding shear walls.

Figure 12 show response spectrum curve after strengthening by adding shear walls (ATC 40). After adding shear wall we can receive to Performance point with:
(V , D) = (16198348, 0.059)
(T_{eff}, B_{eff}) = (0.521, 0.098)
(S_a , S_d) = (0.692, 0.047)

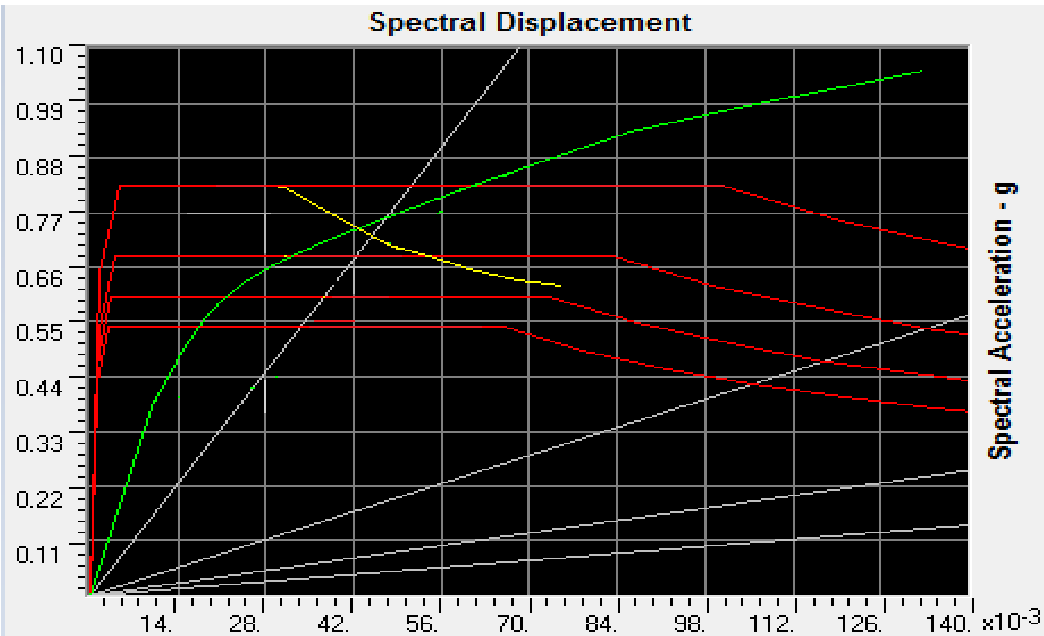

Figure 12. Response spectrum curve after strengthening by adding shear walls.

Comparing of structure' modeling

In order to strengthening of the structure, different methods can be employed. The columns and the beams (of the moment resisting frame system) can be reinforced or increase the lateral rigidity of the system by jacketing of columns and adding shear walls. The structural weight can also be diminished by removing masonry walls and replacing them with light wall panels. After analyzing the structure depicted graphs show that the building has been undergone early-collapse due to insufficiency of the lateral load resisting system.

Hence, the building has collapsed much before than the reaching target displacement behaving non-ductile manner. At last we decided to strengthen by adding Shear wall and concrete Jacketing.

Linear elastic performance method assessment is accomplished according to FEMA-356 and Iranian Code-360. Immediate occupancy under the design earthquake and the life safety under the maximum considered earthquake are considered in design of the extent of the strengthening intervention. Numerical results on strengthening the structural system of the building are given in figures and tables, comparatively. Figure below can show the building' base shear' performance with target displacement during different types of strengthening methods.

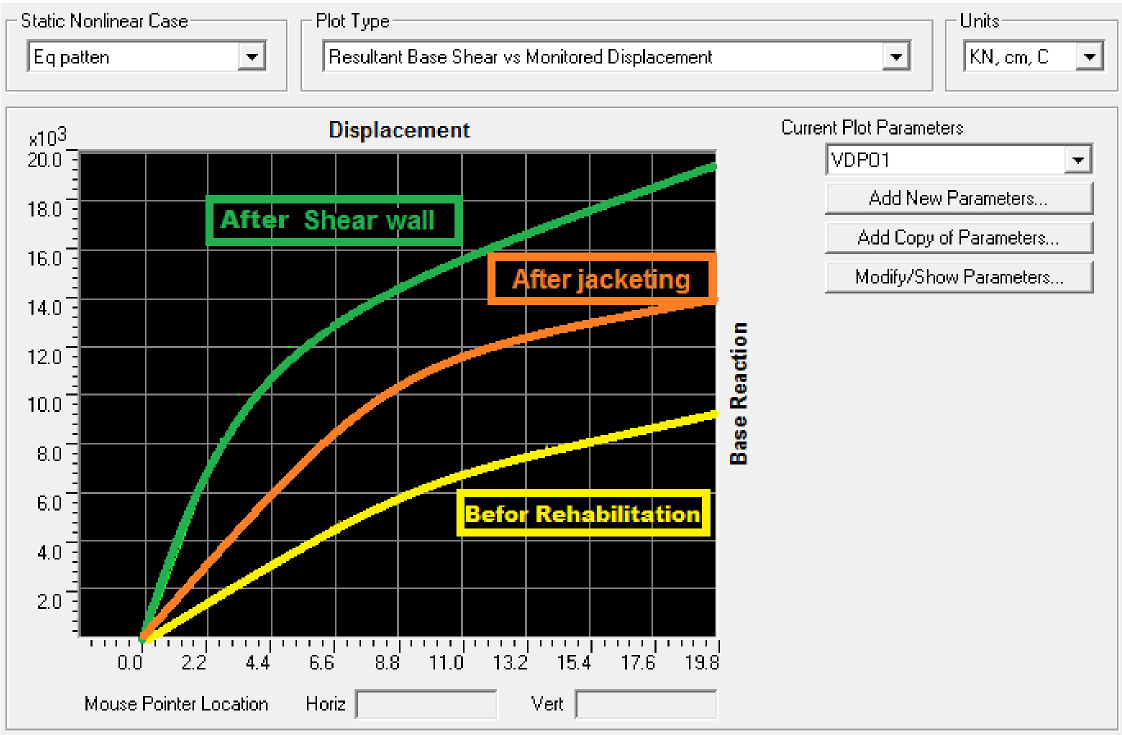

Figure 13. Compare Push over curves before rehabilitation and after jacketing and adding shear walls

CONCLUSION

According to the results obtained from the 3D non-linear analysis of the structure and the assumptions of the research the following results are obtained:

Retrofitting by using the concrete jacketing method enhances increases the strength of the structure and results in the proper performance of the structure during earthquake. Moreover, the structural components in the beams and columns should be extensively provided with jacketing, which adds to the costs of retrofitting.

Reinforcing the structure by installation of shear walls adds with increasing structure' stiffness, don't need to much more joint's attention, and doesn't provide strengthening extensively (like jacketing), it will be done with lower cost of retrofitting. At the same time adding shear wall make the highest contribution in increasing the rigidity and the lateral strength of the structure.

As a result of this study, it is strongly recommended to use shear walls for strengthening of the existing building. It shows the better base force reaction than the other type of strengthening technique (jacketing) Studied in the research.

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