Budapest University of Technology and Economics

Department of Structural Engineering

Evaluation the Seismic Retrofitting Methods of the Reinforced Concrete Frames

Prepared by

Hayyan Aldimashky

Supervised by

László Gergely Vigh, Associate Professor

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ABSTRACT

Four techniques of enhancing seismic capacity of an existing reinforced concrete building have been evaluated in this paper with respect of specific response spectrum. None-linear Static Analysis (Push Over) has been implemented in order to obtain capacity curves, then seismic evaluation of the building behavior has been carried out based on Equivalent Linearization Method in FEMA-440, by using ETABS software to estimate the effectiveness and eligibility of the implemented rehabilitation technique. First technique was strengthening the columns by jacketing and providing a cage of longitudinal and lateral tie reinforcement around the column and casting a concrete ring. Second one was mass reduction intention to modify the dynamic response of the structure. Third technique was bracing the R.C building by conventional steel braces. Fourth one was Bracing by the building Buckling Restrained Bracing. the results which this research concluded to, have compared at the conclusion.

Key words

Seismic Evaluation, Pushover Analysis, Equivalent Linearization, Seismic Retrofitting, Buckling Restrained Bracing

1. Introduction

Seismic design did not used to be considered in pre-building codes. Consequently, existing old buildings do not have a proper lateral resistant structural system. Due to the historical value of some of these buildings, the economic cost of their demolition and reconstruction and their location in a dangerous seismic zone, many researches have been carried out to retrofit it,

In Eurocode, the seismic retrofitting of existing building did not receive enough concern, for instance the behavior factor of the frames braced by Buckling Restrained Bracing is not mentioned, where bracing the frames with BRB is an effective and innovative way to improve the seismic capacity of structures.

2. Technical of seismic retrofitting

Several retrofitting techniques for mitigation seismic risk on structures have developed over the last three decades, going from more conventional techniques, such as bracing existing structures by adding new shear walls or structural steel bracing elements, to new and innovative technologies that involve energy dissipation systems, dampers and base isolation. These retrofit techniques are intended to reduce the overall seismic drift demand on the structure, while also enhancing its lateral load resistance (Molai, 2014).

2-2. Strengthening the columns by concrete jacketing

Columns jacketing technique can be carried out by adding concrete with longitudinal and transverse reinforcement around the existing columns. There are two main purposes of columns jacketing, first one is increasing shear capacity of columns to achieve a strong column-weak beam design and the second is improving the column's flexural strength by the longitudinal rebars of the jacket, which is achieved by passing this new longitudinal reinforcement through holes drilled in the slab and by placing new concrete in the beam column joints as shown in the figure2-1, consequently, the major advantage of this technique is that it improves the lateral load capacity of the building in a uniform distributed way, hence avoiding the concentration of stiffness as in the case of shear walls (Kumar and Nayak, 2016).

Figure 2-1: Total jacketing of concrete columns in practice (Dritsos, 2015)

2-3. Adding steel bracing system

Retrofitting buildings by adding steel braces might be an effective way where bracing system are placed in orthogonal directions in clear bays to provide supplemental lateral loads resisting capacity, besides keeping lateral drift in an accepted range. The lateral loads induced by wind or earthquake, is transferred through the diaphragm to the braced frames, and subsequently to the members of bracing system, these members are strong enough to resist loads in near elastic state often, but if the demand on the structure significantly high, it will cause severe loads which exceed elastic capacity of the bracing members, where tension ties may yield and compression brace may buckle (Molai, 2014).

2-4. Buckling-Restrained Braced Frames (BRBFs)

Buckling restrained brace (BRB) is an innovative technique using in upgrading the seismic resistance capacity of the structures, and a brilliant solution to the problem of the limited ductility of classical concentric bracing, it basically consists of a very slender steel plates restrained against buckling, forming the core of the brace component, which is allowed to yield both in tension and compression almost simultaneously (Mazzolani, 2008). This buckling restraining and the structural composition of BRB, produce symmetric hysteretic behavior of the brace element illustrated in figure2-2, consequently a significant capability of dissipating energy is achieved. As a result, an improving in ductility is provided to

the frames braced by BRB compared to traditional concentrically braced frame (CBF's) which are limited by poor post-buckling resistance to compressive loads (Inoue, et al., 2001).

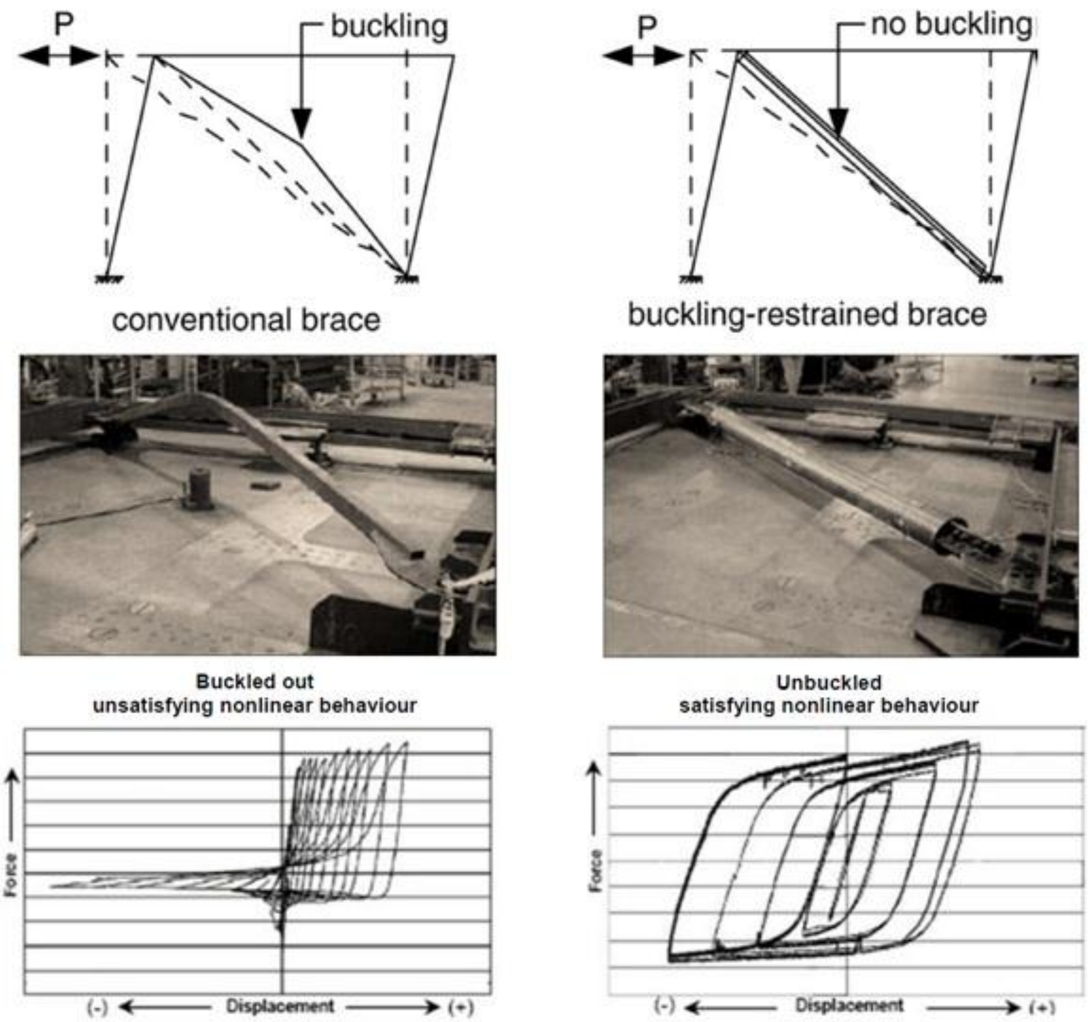

Figure 2-2: The difference between conventional brace member behavior and BRB member behavior. And Balanced Hysteresis of BRB's (Deulkar et al, 2010).

The most common and classical way for prohibiting the buckling of steel core is to install this core element confined in concrete mortar filled in steel outer tube as shown in the figure2-3 b), where the steel core is designed to axially resist the lateral forces, and both of the concrete confinement and the outer steel tube prevent the buckling of the core. Under the severe seismic loads, the buckling restrained braced frames (BRBFs) dissipate energy through axial yielding of the steel core of BRB component (Sahin, 2014).

An important characteristic for BRBs is the prevention of friction between the concrete filler and the internal yielding core, which has been implemented by a layer of special unbonding material able to prevent the transmission of shear stresses between the two components and it permits elongation and contraction of the steel internal core in order to dissipate the energy in tension and in compression (Cancellara and Angelis, 2012)

Three basic components of the whole core of BRB as it is illustrated in the figures2-3 a), the restrained non-yielding segment at the transition zone, unrestrained non-yielding segment at the terminal part and the restrained yielding core at the middle.

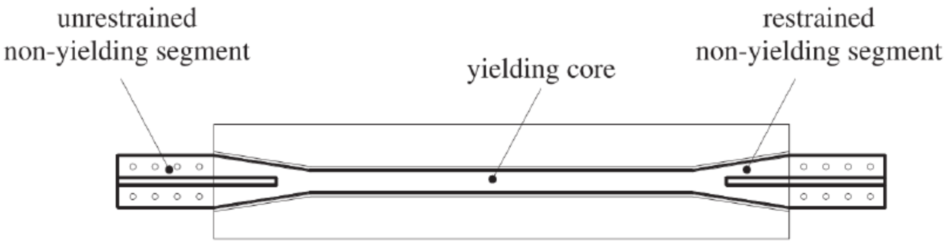

Figure2-3-a

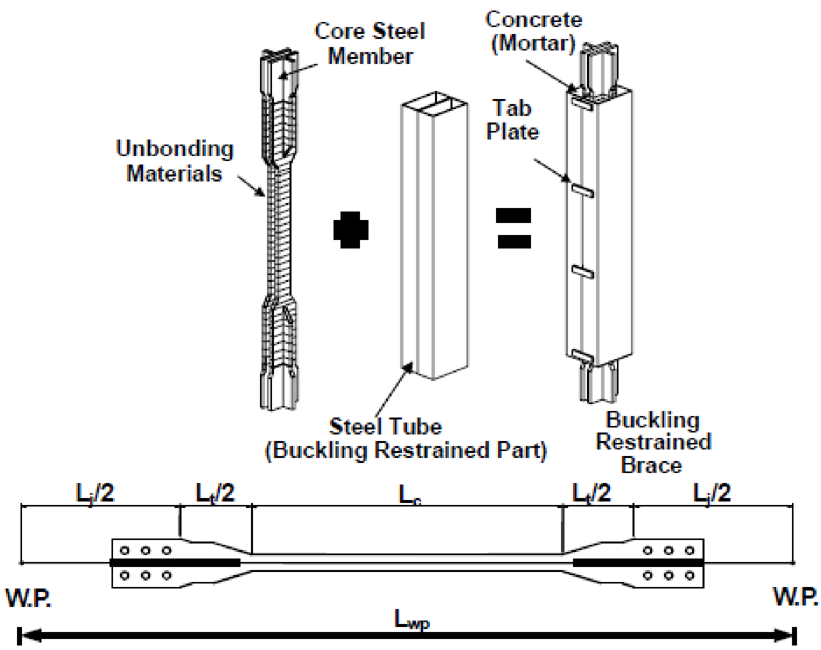

Figure2-3-b

Figure 2-2: a) Components of BRB (Bosco and Marino, 2012). b) Schematic of double-tubed buckling restrained brace (Tsai, Weng, Lin and Goel, 2004)

2-5. Reduce the mass

Mass of building can be reduced by removing several stories, which might be economical way and practical method of providing acceptable performance, but the disruption and noise might be an issue (Sahin, 2014). As shown in the figure2-4 it is clear that the removal of the mass will decrease period, from T_{nr} to T_r, which will cause an increase in the required strength, where the corresponded demand S_r in pseudo-acceleration terms for the new building will be larger than it is for the original one S_{nr}, as a result, the advantage gained by the mass reduction is partially cancelled by the increase in the demand because of the period shortening(Oliveto and Marletta, 2005).

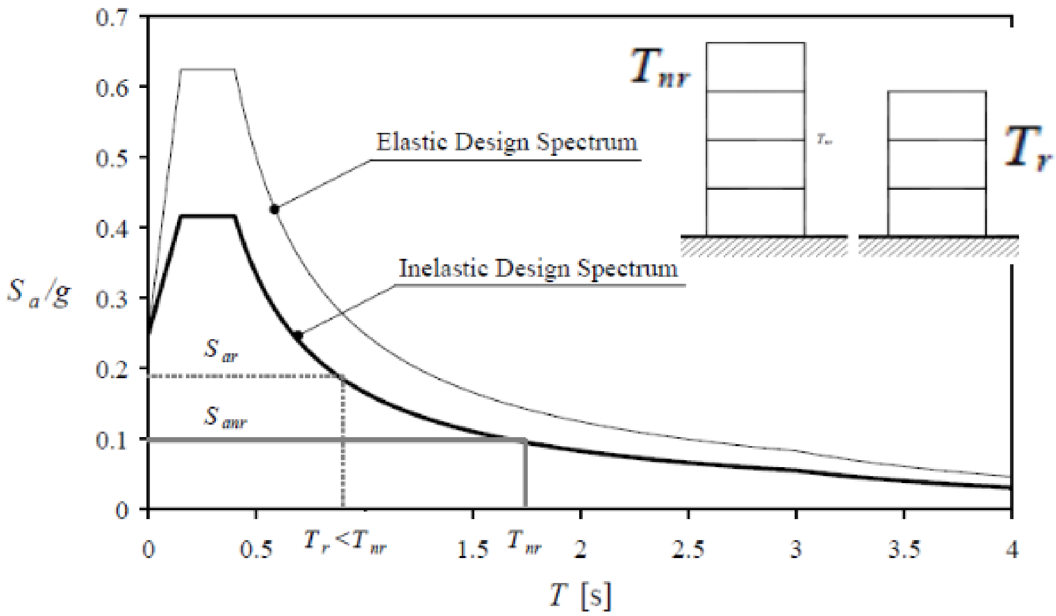

Figure 2-4: Increase of the seismic demand following an increase of seismic resistance (Oliveto and Marletta, 2005).

3. Seismic Evaluation using Improved Equivalent Linearization Method in FEMA 440

The basic assumption in equivalent linearization techniques is that the maximum inelastic displacement of a nonlinear SDOF system can be estimated approximately from the maximum displacement of a linear elastic SDOF system that has a period and a damping ratio that are larger than the initial values of those for the nonlinear system. This method recognizes that when the structure is shaken

beyond of its yield point, its effective damping and its effective period will increase. The maximum structural response is estimated to be the point where the capacity curve crosses the demand spectrum. (FEMA-440, 2005), therefore the essential intent of this evaluation method is to determine the most possible exact location of the performance point showed in the figure3-1, which is defined where the capacity spectrum of the structure intersect the imposed seismic demand spectrum by the earthquake on the same structure. The performance of the structure is being evaluated at that performance point, where response of the building should be compared to the certain acceptance criteria. These responses should be examined and checked to know if they can satisfy acceptability limits on both global levels such as the lateral load stability and the inter-story drift, and local levels including the element strength and the mechanism of forming plastic hinges in the section of the element (ATC-40, 1996).

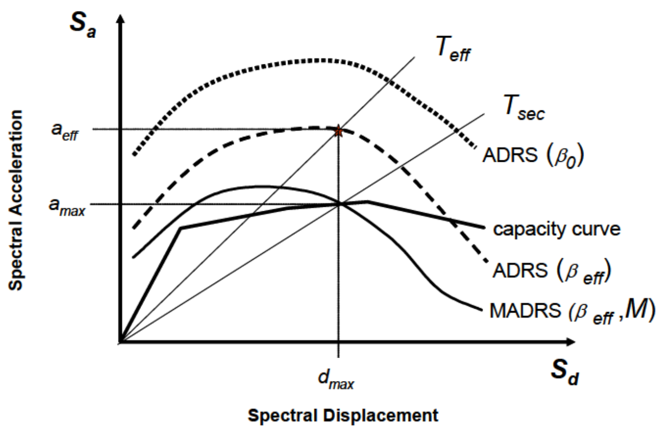

Figure 3-1: The performance point where the Modified Acceleration Displacement Response Spectrum (MADRS) intersect the capacity curve which is plotted in the Acceleration-Displacement coordinates (FEMA-440, 2005).

Performance levels and performance requirements according to Eurocode

The fundamental requirements refer to the state of damage in the structure

- **LS of Damage Limitation (DL) or Immediately Occupancy (IO), which referred as level A in the figure3-2.**
- **LS of Significant Damage (SD) or Life Safety (LS), which referred as level B in the figure3-2.**
- **LS of Near Collapse (NC) or Collapse Prevention (CP), which referred as level C in the figure3-2. (Eurocode 8).**

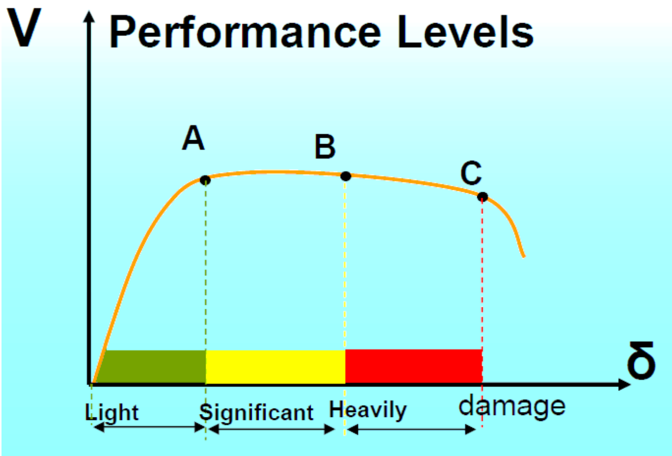

Figure 3-2: Performance levels on capacity curve (Dritsos, 2015).

4. Research Problem

Studying the seismic behavior of R.C frames retrofitted by many retrofitting techniques.

5. Research aim

Investigate the effect of each retrofit technique on seismic behavior and performance level of the structure.

6. Research strategy

Modeling an existing building consists of R.C frames which designed only on gravity loads. apply Pushover analysis to obtain the capacity curve of the structure. Evaluate its seismic behavior by Capacity Spectrum Method or what so-called Equivalent Linearization method in FEMA-440. retrofitting the structure by using different seismic retrofitting technique and repeat the seismic evaluation procedures.

7. Literature review

In 2004, Kim and Choi carried out a non-linear static analysis of a steel frames building braced by BRBs to investigate the ability of this system to dissipate energy and its seismic response. The results of this analysis showed that the buckling restrained bracing system has increased the structure lateral rigidity and reduced the maximal story drift significantly.

In 2007, Youssef et al tested the efficiency of the metal bracing of the reinforced concrete frames in rising the seismic capacity. He performed two cyclic loading tests, first was done on a moment resistance frames and the second on a braced frame. The results showed that the braced frames were more able to resist lateral load than the moment resistance frames, and it provided adequate ductility.

In 2008, Mazzolani carried out a full-scale experimental test on different innovative seismic upgrading techniques, where cyclic tests have been conducted on real RC structures equipped with the many types of braces and shear walls, which were steel eccentric braces, steel buckling restrained braces and steel and aluminum shear panel. the results illustrated the different effectiveness of these various seismic upgrading techniques, in improving strength, stiffness and ductility capacity of the retrofitted RC structure.

In 2009, Kaliyaperumal and Sengupta investigated the effect of concrete jacketing on the flexural strength and performance of columns. Beam-column-joint sub-assemblage specimens were examined to study the ductility and energy dissipation, and incremental nonlinear analysis was adopted to predict the lateral load versus displacement behavior for a retrofitted sub-assemblage specimen. The results showed that the retrofitted specimens did not show any visible delamination between the existing concrete and the concrete in the jacket, and increasing in lateral strength, ductility (i.e., energy absorption) and energy dissipation in the retrofitted beam-column-joint sub-assemblage specimens.

In 2010, Hadigheh and Foroughi investigated the seismic behavior of an ordinary moment resisting RC frame strengthened by concentric steel braces. Nonlinear static analysis (pushover) was carried out on three frames with different height, in this study performance levels of frames are obtained using the capacity spectrum method of ATC-40, and the results indicated that strengthening RC buildings with steel braces can upgrade the seismic resistance capacity and increase the performance point of RC frames.

In 2012, Ozcelik et al carried out a seismic retrofitting for non-ductile reinforced concrete frames by bracing it with inverted V steel braces, and this technique was verified through experimental and numerical studies. Reverse cyclic load was implemented, and the results conclude to enhancing in stiffness and lateral

strength around 3.5 times the un-retrofitted frame, the results showed significant energy dissipation capability.

In 2017, Vig et al propose a Eurocode design procedure for Buckling Restrained Braced Frames, seismic design parameters and capacity design rules in order to improve Eurocode 8 specifications on steel Concentrically Braced Frames, the authors clarified the design procedures through an example of designing six-story BRBF, also probabilistic seismic performance evaluation environment have been developed on the basis of the methodology in FEMA P-695 and been used to assessment the performance of previous proposed design procedure and the results affirmed that it is applicable in Europe and it fits in Eurocode 8 among the specifications for steel Concentrically Braced Frames.

8. Evaluation the Existing building

An existing 4-story R.C frames building does not have proper seismic resistance system, and designed to withstand the gravity loads only has been modeled as a 3D model on ETABS software.

8-1. The model

- **Geometry: 4-story R.C frames building, three 4m-span on both X and Y direction, with 3.5m high story.**

Beams sections: Beams with 50cm depth and 25cm width.

Columns sections: 40cm-Squared columns for all stories reinforced by 16T14mm.

Slab sections:25cm-depth hordy slab.

- **Modeling the materials:**

All materials have been modeled taking non-linearity into account. 20Mpa-compresive strength concrete for all concrete members has been modeled as the Stress-Strain curve in figure8-1. 400Mpa-yielding strength reinforcing bars has been modeled as the Stress-Strain curve in figure8-2. Steel S235 and S355 steel bracing and BRB members have been modeled as the Stress-Strain curve in figure8-3.

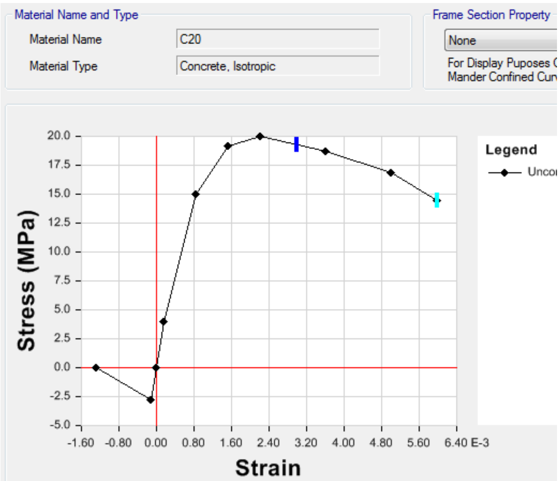

Figure 8-1 Stress-Strain curve of concrete

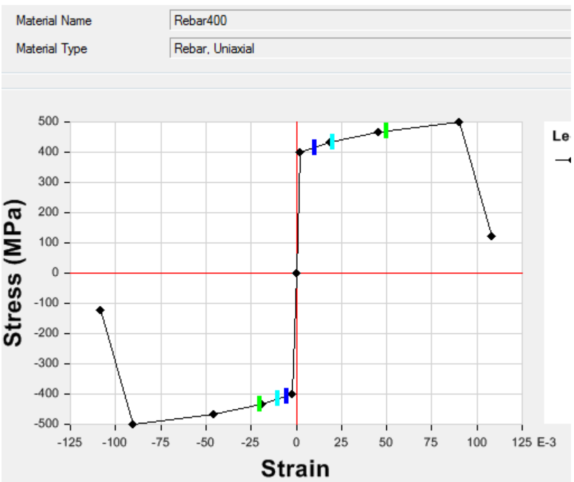

Figure 8-2: Stress-Strain curve of reinforcing

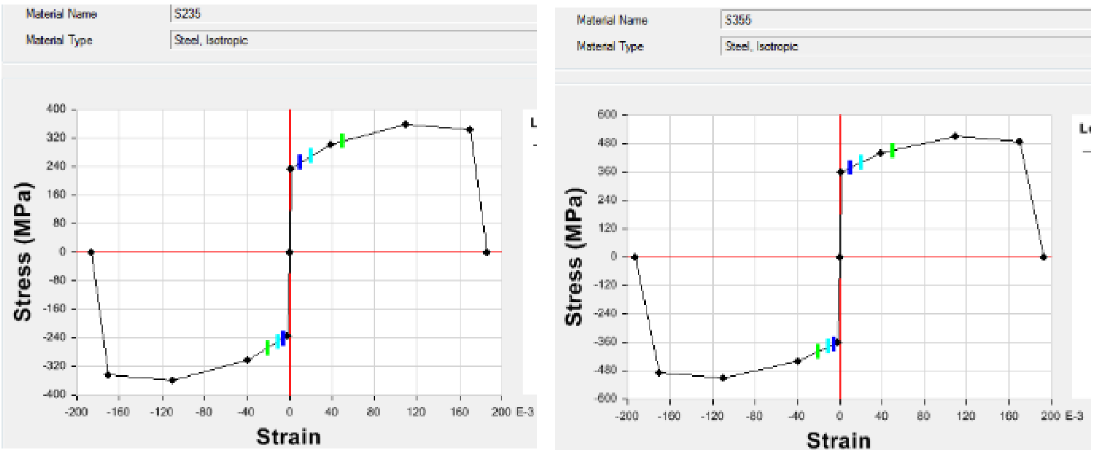

Figure 8-3: Stress-Strain curve of Steel S235 and S355

- **Modeling the plastic hinges**

The plastic hinges in beams and columns have been modeled according to ASCE 41-13 with Euro Code 8 2005, Part three Acceptance Criteria. Plastic hinge M3 for beams. Plastic hinge P-M3-M2 for columns.

- **The loads**

Dead load 4 KN/m2 + self-weight
Live load 2 KN/m2
Response Spectrum RS1: according to EC8, Ground Accelerations 0.4g. Type1. Ground Type D as shown in the figure8-4

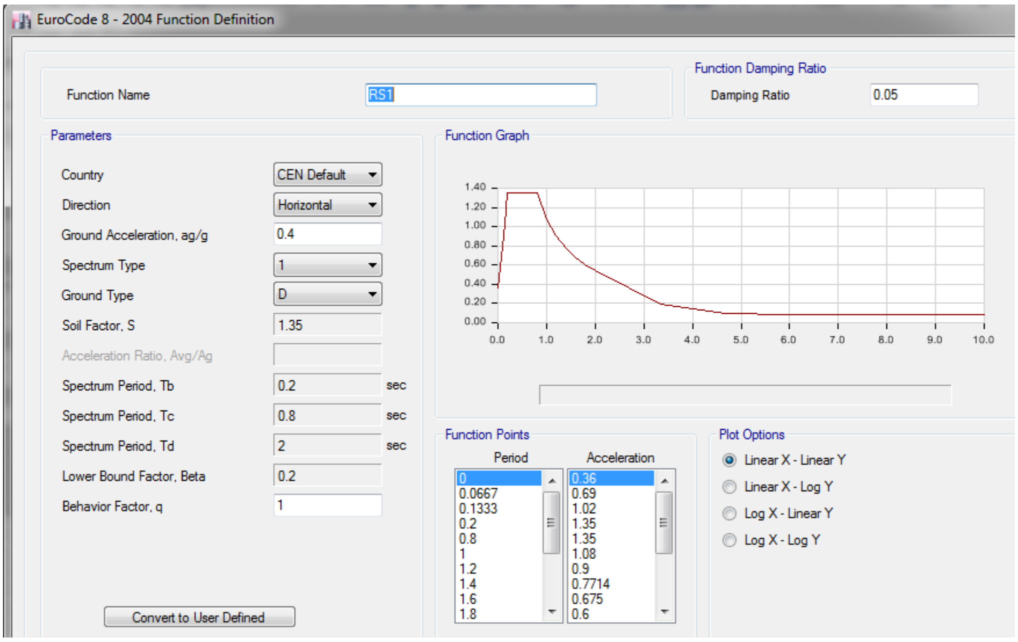

Figure 8-4: Response Spectrum 1

8-2. The results

The obtained PushOver curve (capacity curve) is illustrated in the figure8-5, where the building collapse at max base shear 1879.59KN with 245.68mm corresponding roof displacement.

Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure8-6, where it is evident that the building does not have performance point, consequently labeled as insufficient.

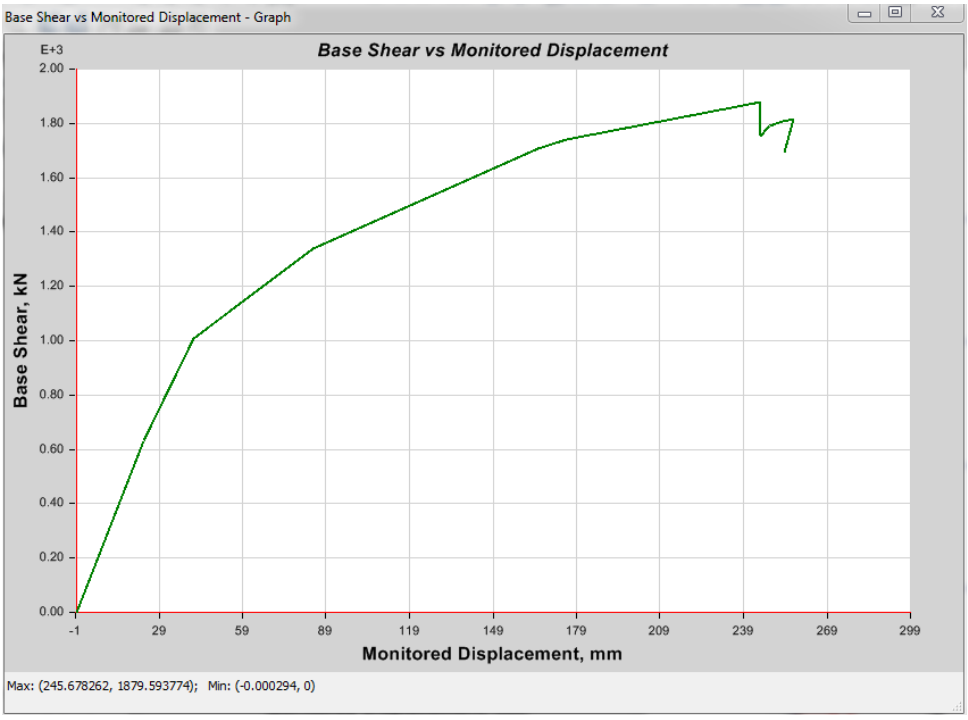

Figure 8-5: Capacity curve of bare R.C frames

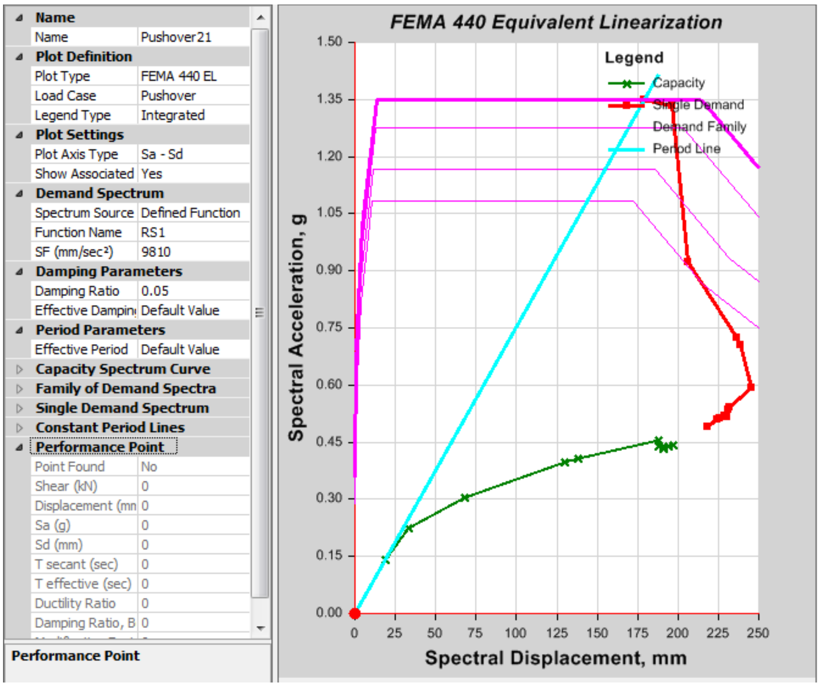

Figure 8-6: Evaluation the behavior of bare R.C frames under the demand of RS1

9. Evaluation the Retrofitted building

9-1. Retrofitting the building by Jacketing the columns

The Building retrofitted by columns R.C-jacketing 1

The structure has been retrofitted by jacketing all columns at all stories by 50mm-concrete layer with 8T14mm longitudinal reinforcement bars for each side of the column, and Ø8mm/100mm for confinement reinforcing.

- **The results**

The obtained PushOver curve (capacity curve) is illustrated in the figure9-1, where the building collapse at max base shear 2410.13KN with 246.36mm corresponding roof displacement. Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure9-2, where it is evident that the building does not have performance point, consequently labeled as insufficient.

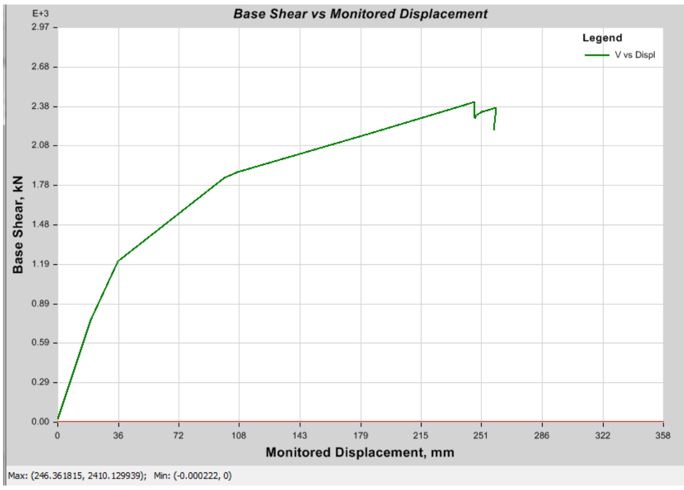

Figure 9-1: Capacity curve of the building retrofitted by column-R.C jacketed 1

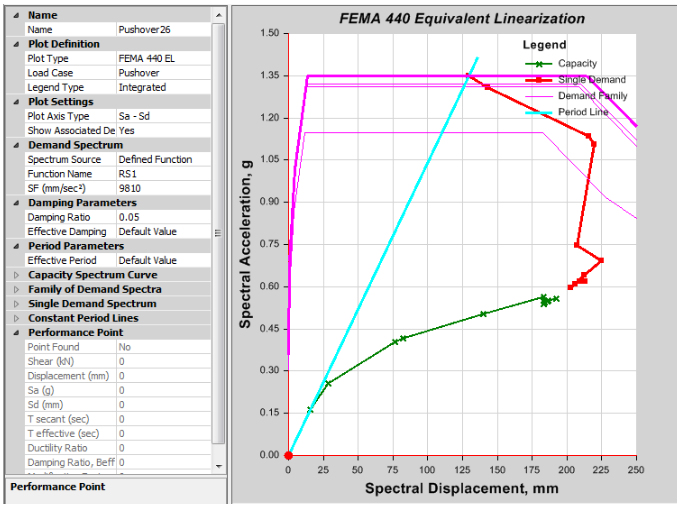

Figure 9-2: Evaluation the behavior of the building retrofitted by column-R.C jacketed 1 under the demand of RS1

9-1-2. The Building retrofitted by columns-R.C-jacketing2

The structure has been retrofitted by jacketing columns at all stories by 75mm-concrete layer with 8T18mm longitudinal reinforcement bars for each side of the column, and Ø8mm/100mm for confinement reinforcing.

- **The results**

The obtained PushOver curve (capacity curve) is illustrated in the figure9-3, where the building collapse at max base shear 2871.09KN with 245.23mm corresponding roof displacement. Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure9-4, where it is evident that the building does not have performance point, consequently labeled as insufficient.

Figure 9-3: Capacity curve of the building retrofitted by column-R.C jacketed 2

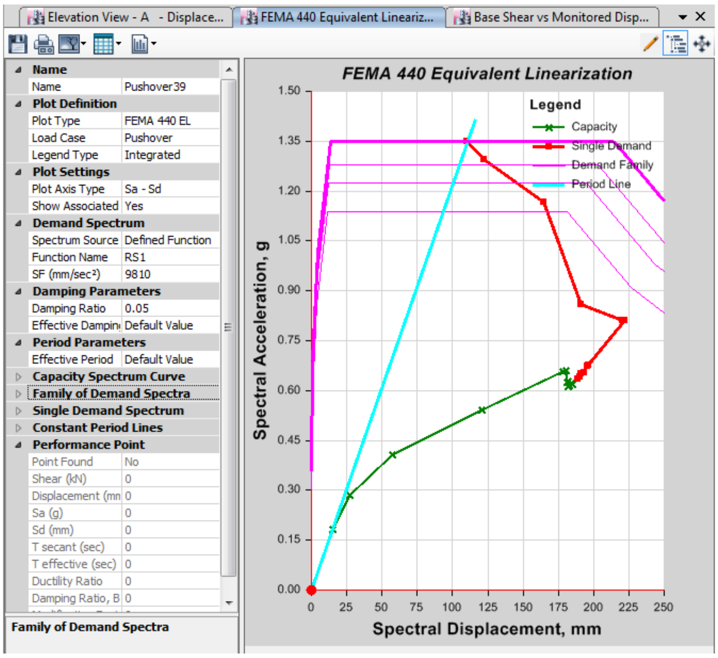

Figure 9-4: Evaluation the behavior of the building retrofitted by column-R.C jacketed 2 under the demand of RS1

- **Comparison**

The figure9-5 compares the capacity curves of existing building, the retrofitted building by columns R.C-jacketing.

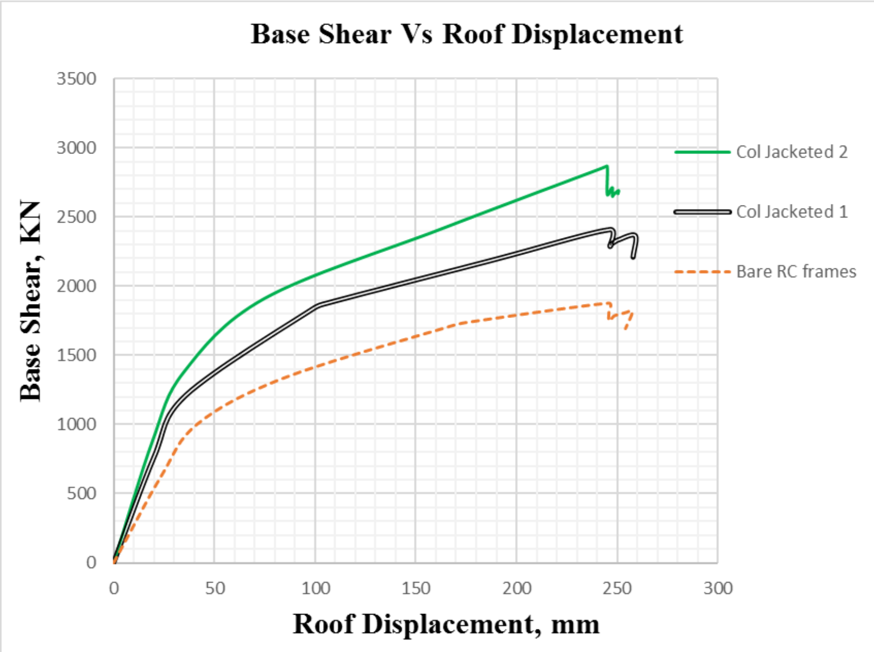

Figure 9-5: The capacity curves of the existing and retrofitted buildings

9-2. Retrofitting the building by reducing the mass

The mass of the building has been reduced by removing the last story.

- **The results**

The obtained PushOver curve (capacity curve) is illustrated in the figure9-6, where the building collapse at max base shear 2196.24KN with 196.17mm corresponding roof displacement.

Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure9-7, where it is evident that the building does not have performance point, consequently labeled as insufficient.

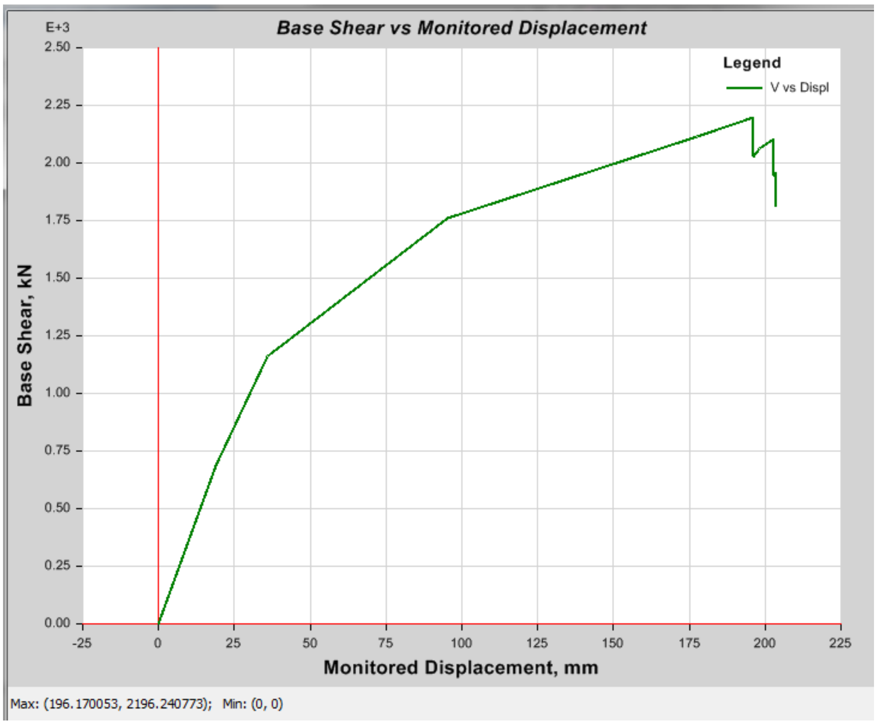

Figure 9-6: Capacity curve of the mass-reduced building

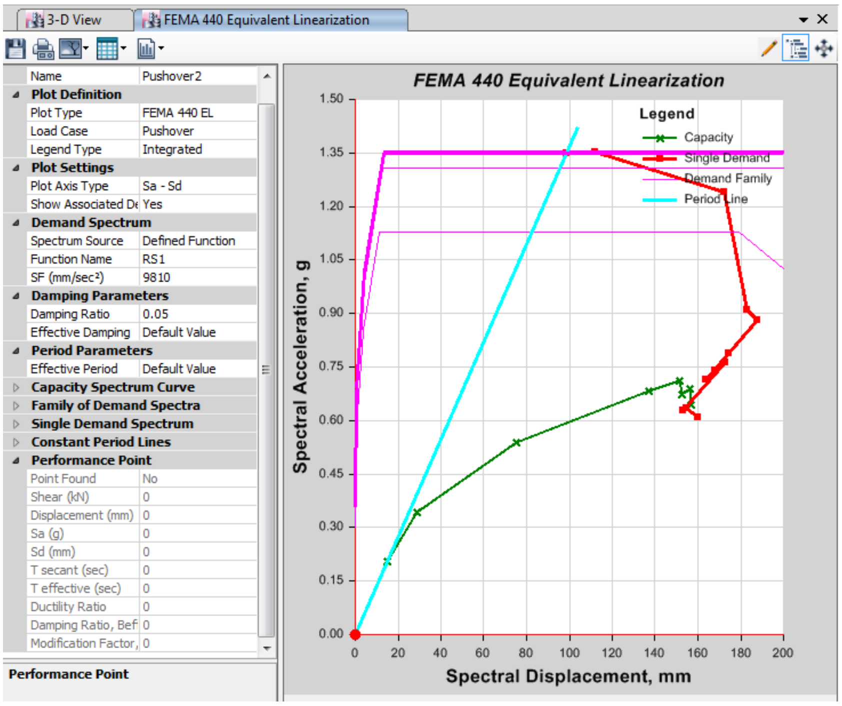

Figure 9-7: Evaluation the behavior of the mass-reduced building under the demand of RS1

9-2-1. Jacketing the columns of the mass-reduced building

The columns of the mass-reduced building have been jacketing, where R.C-jacketing2 were assigned to the columns of first story and R.C-jacketing1 were assigned to the columns of second and third stories

- **The results**

The obtained PushOver curve (capacity curve) is illustrated in the figure9-8, where the building collapse at max base shear 3634.522KN with 177.20mm corresponding roof displacement.

Evaluation the seismic behavior results under the demand of response spectrum RS1 and the mechanism of failure are shown in the figure9-9, the building have performance point detailed in the table9-1, plastic hinges formed in all beams, where the plastic hinges formed in columns are only at the base, which is an acceptable deformation mechanism of the building at the performance point, based this location of the performance point on the capacity curve and according to performance requirements in Eurocode, the structure can be labeled in Limit State of Near Collapse (NC), consequently sufficient for level C.

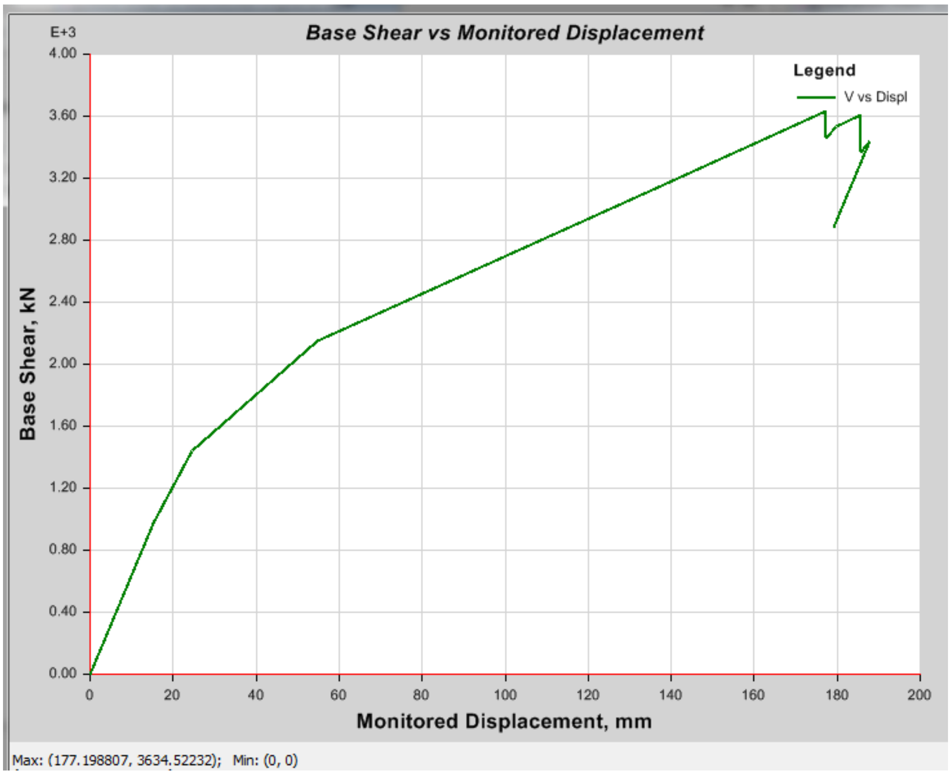

Figure 9-8: Capacity curve of the mass-reduced building after jacketing the columns

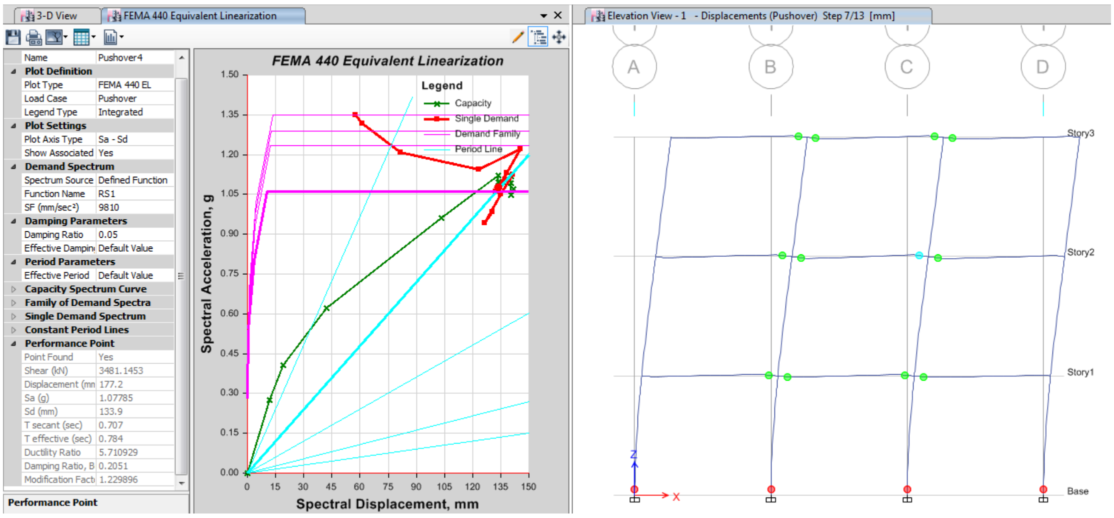

Figure 9-9: Evaluation the behavior of the mass-reduced building after jacketing the columns, under the demand of RS1

Performance Point

Point Found	Yes	T secant	0.707 sec
Shear	**3481.1453 kN**	**T effective**	**0.784 sec**
Displacement	**177.2 mm**	**Ductility Ratio**	**5.710929**
Sa	**1.07785**	**Effective Damping**	**0.2051**
Sd	**133.9 mm**	**Modification Factor**	**1.229896**

Table 9-1: The structure response at the performance point under the demand of RS1

9-2. Retrofitting the building by conventional steel bracing

Evaluation of the seismic behavior has been conducted considering two basic assumption, first one is that bracing members work both on compression and tension, and the second is that the bracing members work only on tension.

- **Modelling the bracing members**

Many steel bracing members have been used, where they were imported from the Euro database steel section which is included in ETABS software. The figure9-10 shows material assigned and geometry of the bracing member TUD108*3.6, and the figure9-11 shows modelling the plastic hinge of the that bracing member and the acceptance criteria. TUD 127*4, TUD 193.7*4.5 and TUD 244.5*5.4 also, have modeled at the same way

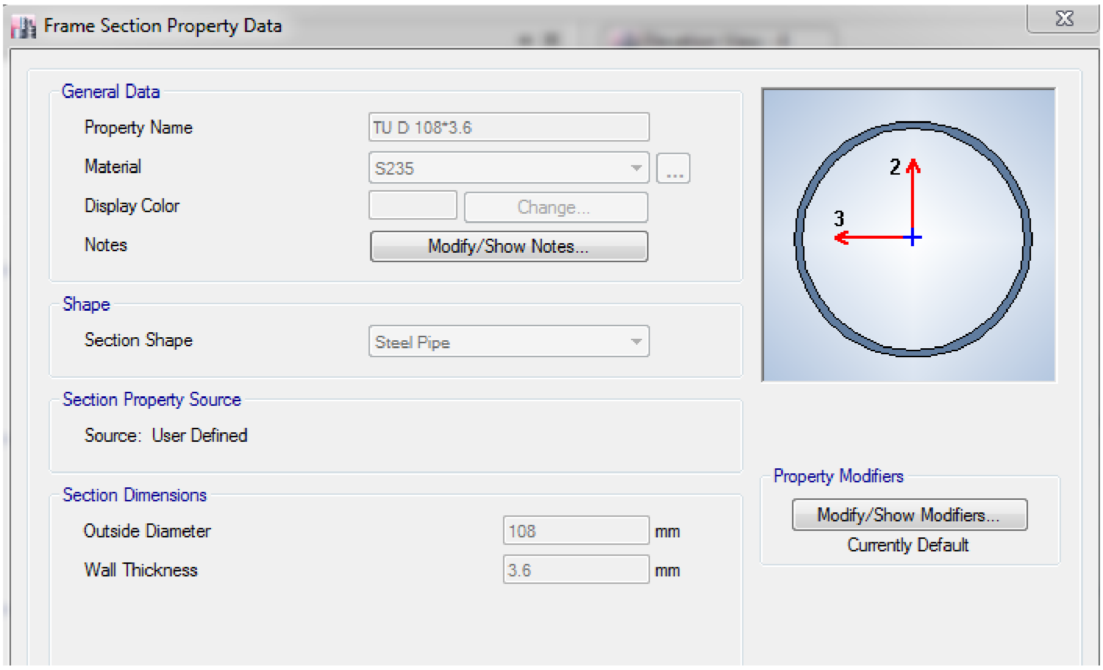

Figure 9-10: material assigned and geometry of the bracing member TUD108*3.6

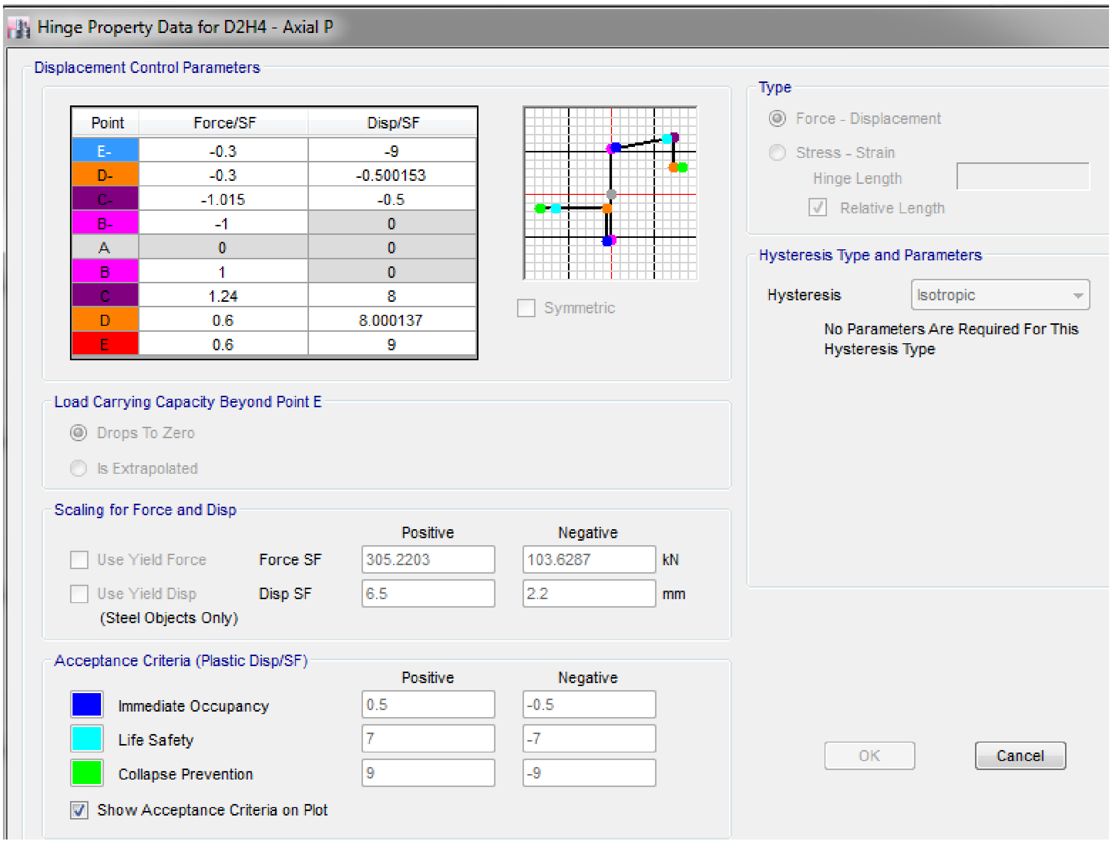

Figure 9-11: Plastic hinge property data for the bracing member TUD108*3.6

Steel bracing members work on tension and compression

- **The configuration1**

One diagonal steel bracing member was added in one span for one side of the building (Elevation1) for each story, and another one was added for the other side (Elevation4), but in opposite direction, as it is illustrated in the figure 9-12,

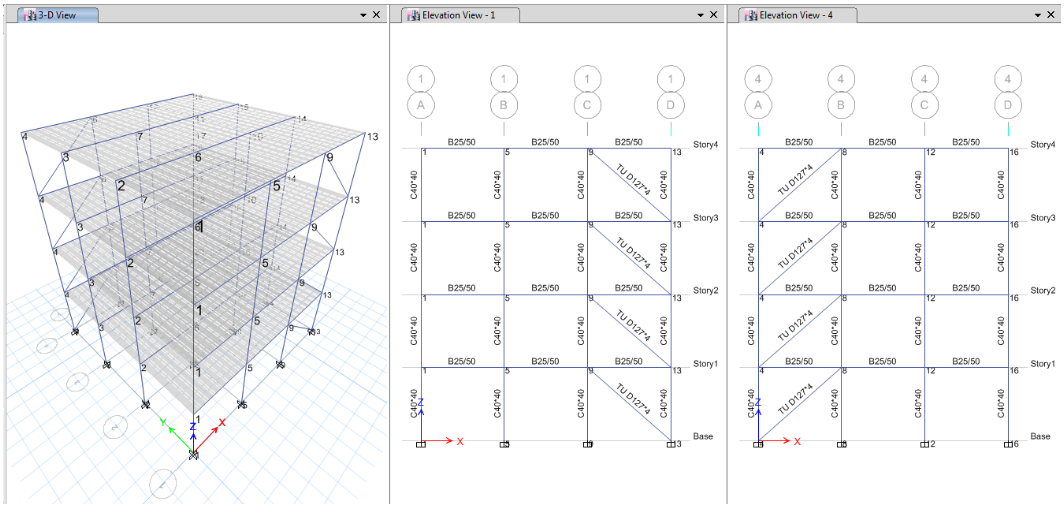

Figure 9-12: The configuration1 of braced frames

- **The results of configeration1**

Using the braces TUD127*4, the same section for all stories. The torsion mode is the dominator mode for deformation shape of the building because of the difference in compression and tension resistance of the steel bracing members, where the plastic hinges formed in the compressed braces before its formation in the tension, and due to the buckling of that compressed steel braces, drops and deterioration in the capacity curve can be seen, as in the figure9-13, which illustrates the torsional deformation of the building and the plastic hinges formed as well.

Consequently, its unacceptable configuration for this design.

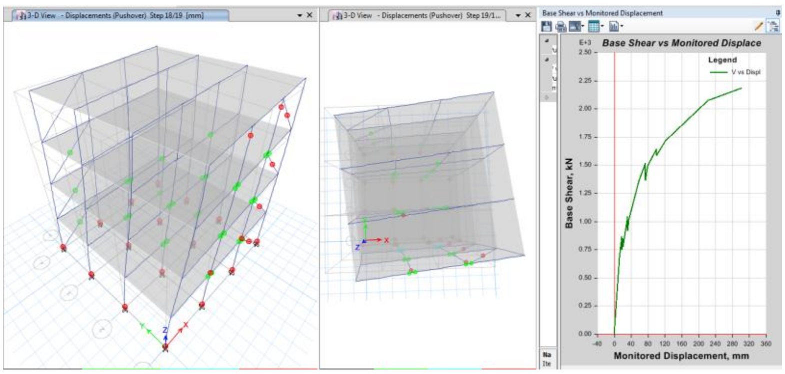

Figure 9-13: The deformation plastic hinges formed and the capacity curve of the building

- **The configuration2**

Two diagonal steel bracing members in two opposite directions were added in two spans of the building for the two sides, Elevation1 and Elevation2, in each story as in the figure9-14.

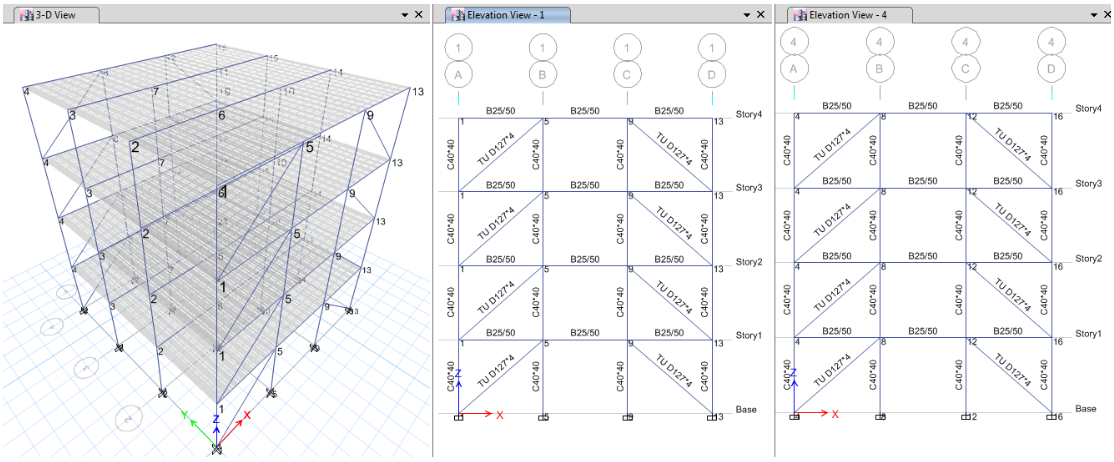

Figure 9-14: The configuration1 of braced frames

- **The results of configeration2**

The braces used as in the table9-2 below:

The story	Section of the brace
Story 1	**TUD 244.5*5.4**
Story 2	**TUD 193.7*4.5**
Story 3	**TUD 127*4**
Story 4	**TUD 108*3.6**

Table 9-2: Sections of braces according to story number

The PushOver curve (capacity curve) is illustrated in the figure9-15, where the building collapse at max base shear 3571.88KN with 167.82mm corresponding roof displacement. the plastic hinges formed in the compressed braces before its formation in the tension, and due to the sequential buckling of that compressed steel braces, drops and deterioration in the capacity curve can be seen, which is so-called "saw-tooth" effect.

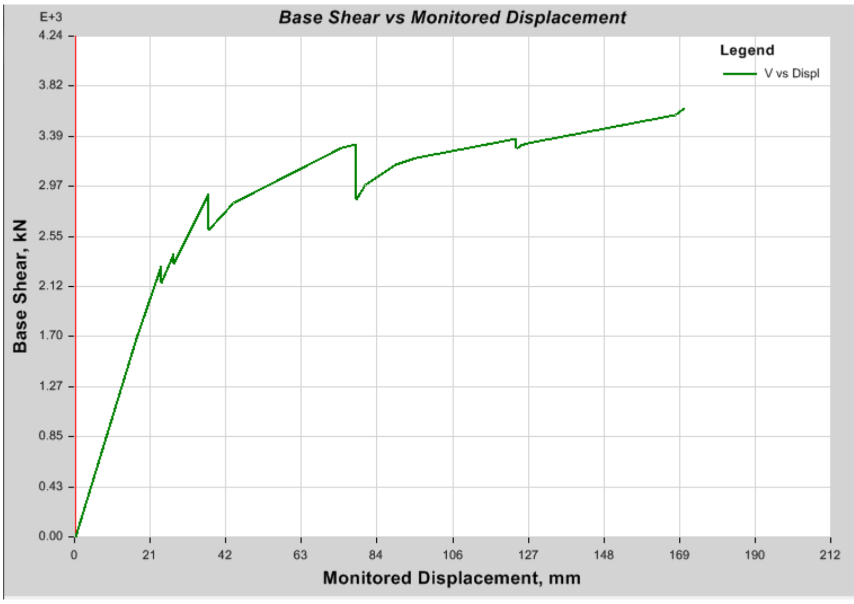

Figure9-15: Capacity curve of the braced building according to configuration2

Steel bracing members work only on tension

The bracing members have been modelled to resist only tension force, considering the configuration2 and the braces used as in the previous table9-2.

- **The results**

The PushOver curve (capacity curve) is illustrated in the figure9-16, where it is that the building collapse at max base shear 3600.14KN with 235.15mm corresponding roof displacement.

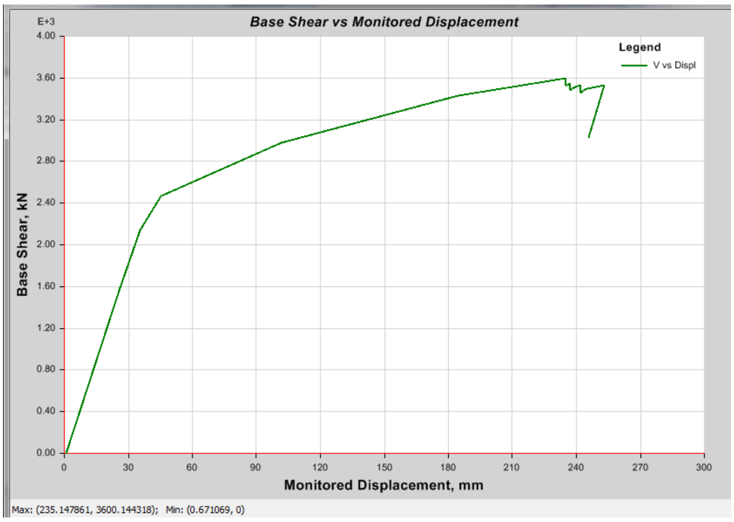

Figure 9-16: Capacity curve of the braced building according to configuration2

Evaluation the seismic behavior results under the demand of response spectrum RS1 and the mechanism of failure are shown in the figure9-17, the building have performance point detailed in the table9-3, but an unfavorable plastic hinges formed in many column at different stories, which is unfavorable deformation mechanism of the building at the performance point, based on this location of the performance point on the capacity curve and according to performance requirements in Eurocode it can be labeled in Limit State of Significant Damage(SD), consequently sufficient for level B

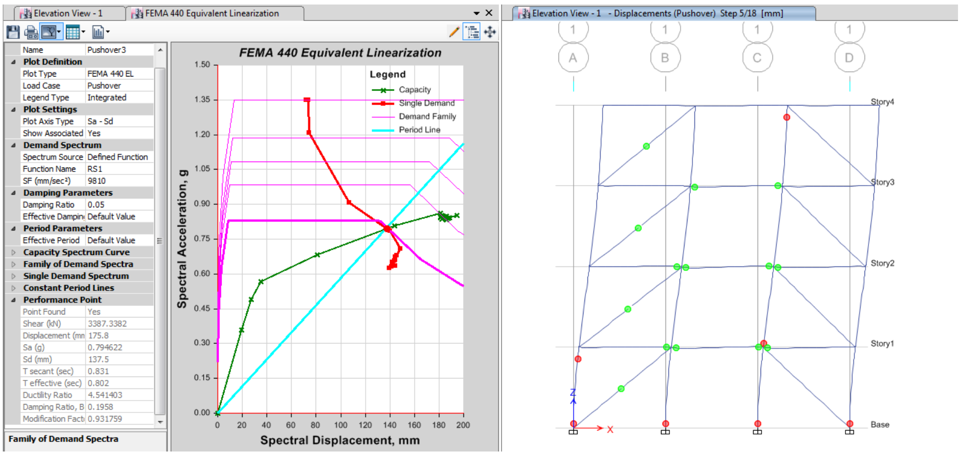

Figure 9-17: Evaluation the behavior of the Steel-braced building under the demand of RS1

Performance Point

Point Found	Yes	T secant	0.831 sec
Shear	**3387.3382 kN**	**T effective**	**0.802 sec**
Displacement	**175.8 mm**	**Ductility Ratio**	**4.541403**
Sa	**0.794622**	**Effective Damping**	**0.1958**
Sd	**137.5 mm**	**Modification Factor**	**0.931759**

Table 9-3: The structure response at the performance point under the demand of RS1

9-3. Retrofitting the building by Buckling Restrained Bracing

Modelling the Buckling Restrained Bracing (BRB) members

Many BRB members have been used, where they were imported from the StarseismicBRB database which is included in ETABS software.

- **Modelling the BRB member: StarBRB_1.0**

The figure9-18 depicts the section property data of the BRB member StarBRB_1.0, such as material assigned, geometry and the stiffnesses of yielding core and elastic segment which are calculated based on Starseismic,

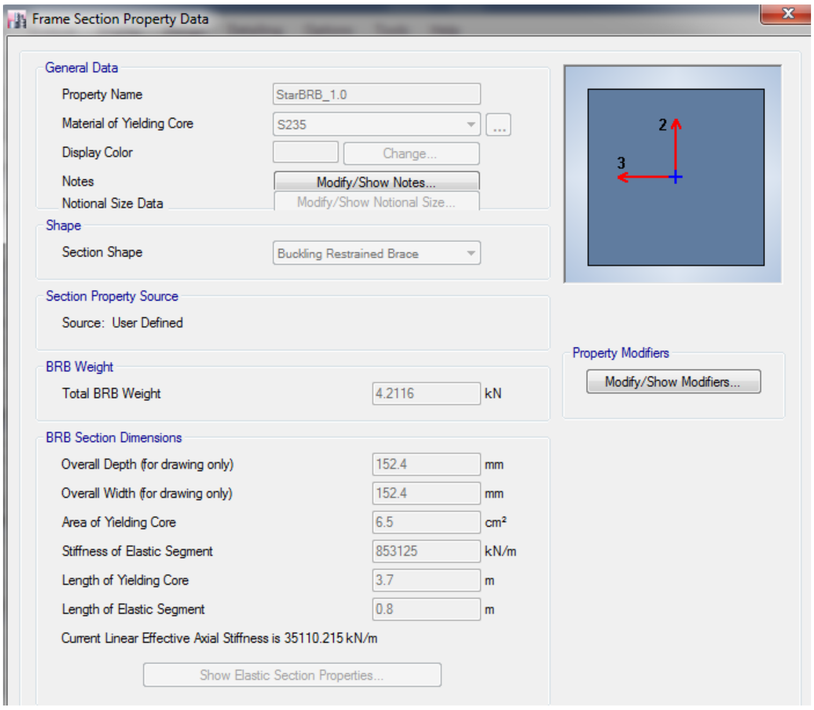

Figure 9-18: The section property data of the BRB member StarBRB_1.0

The figure9-19 shows modelling the plastic hinge of the BRB member StarBRB_1.0

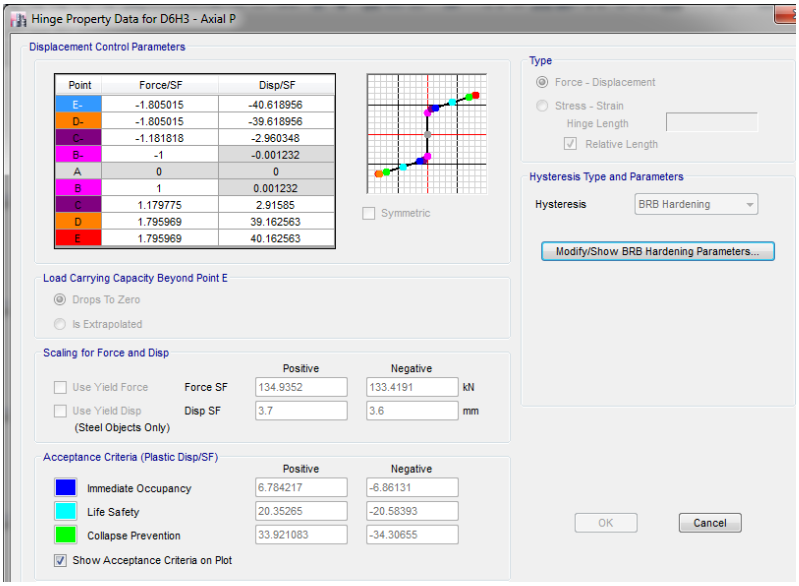

Figure 9-19: Plastic hinge property data of the BRB member StarBRB_1.0

Also, StarBRB_2.0, StarBRB_3.0 and StarBRB_4.0 have modeled at the same way

- **The configuration1 of BRBs**

Building has been braced by BRBs according to the configuration1 in the figure9-12

The sections of BRBs used are listed in the table9-4 according to the story number.

The story	Section of the brace
Story 1	**StarBRB_2.0**
Story 2	**StarBRB_3.0**
Story 3	**StarBRB_2.0**
Story 4	**StarBRB_1.0**

Table 9-4: BRB members used according to story number

- **The results configuration1 of BRBs**

The obtained PushOver curve (capacity curve) is illustrated in the figure9-20, where the building collapse at max base shear 2889.04KN with 245.94mm corresponding roof displacement.

Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure9-21, the building have performance point detailed in the table9-5, but unfavorable plastic hinges formed in columns at many different stories, thus unfavorable deformation mechanism of the building at the performance point, based on this location of the performance point on the capacity curve and according to performance requirements in Eurocode, the structure can be labeled in Limit State of Near Collapse(NC), consequently sufficient for level C.

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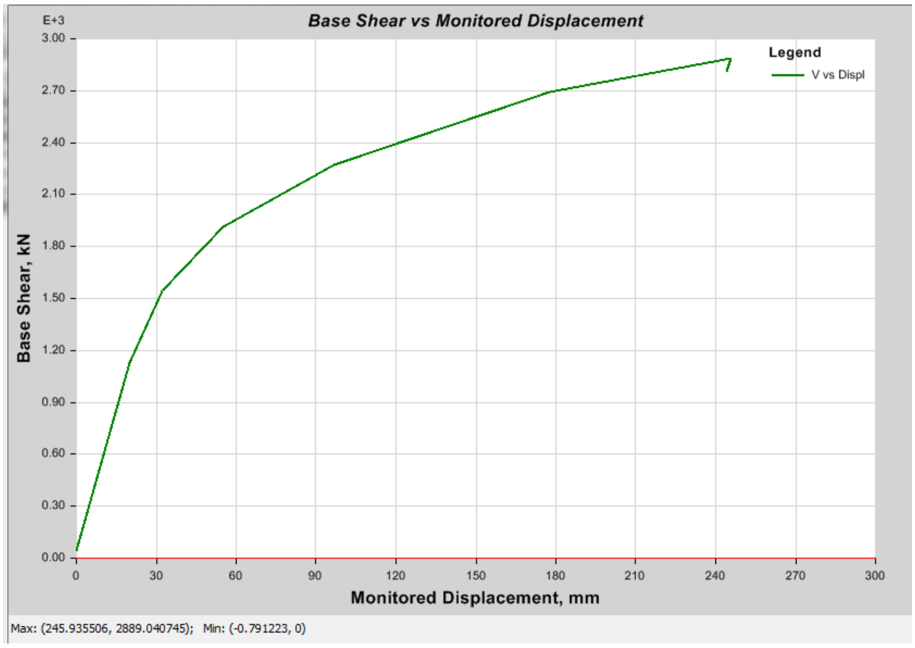

Figure 9-20: Capacity curve of the BRBs-braced building according to configuration1

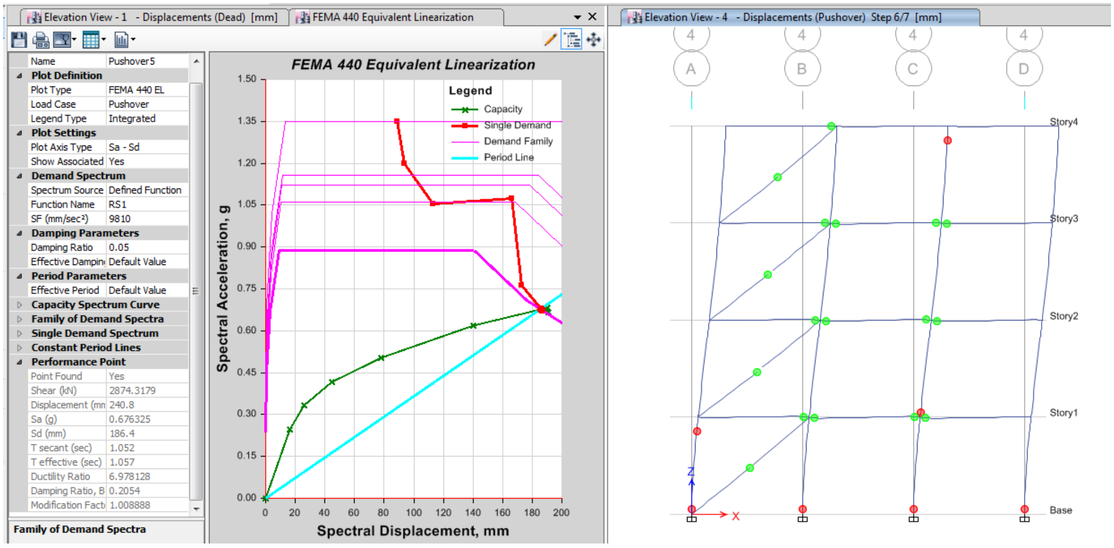

Figure 9-21: Evaluation the behavior of the BRBs-braced building under the demand of RS1

Performance Point Data			
Point Found	**Yes**	**T secant**	**1.052 sec**
Shear	**2874.3179 kN**	**T effective**	**1.057 sec**
Displacement	**240.8 mm**	**Ductility Ratio**	**6.978128**
Sa	**0.676325**	**Effective Damping**	**0.2054**
Sd	**186.4 mm**	**Modification Factor**	**1.008888**

Table 9-5: The structure response at the performance point under the demand of RS1

9-4. Retrofitting the building by Buckling Restrained Bracing with strengthening week columns

With the aim of get the favorable deformation mechanism of the building, under the demand of the response spectrum RS1, the week columns which have plastic hinges illustrated in figure9-21, have been strengthened,

- **The results**

Evaluation the seismic behavior results under the demand of response spectrum RS1 are shown in the figure9-22, the building have performance point detailed in the table9-6. Favorable plastic hinges formed in BRBs at all stories, plastic hinges formed in beams as well, and there is not any formed plastic hinges in columns, thus it is the favorite deformation mechanism of the building at the performance point, based on this location of the performance point on the capacity curve and according to performance requirements in Eurocode, the structure can be labeled in Limit State of Near Collapse(NC), consequently sufficient for level C.

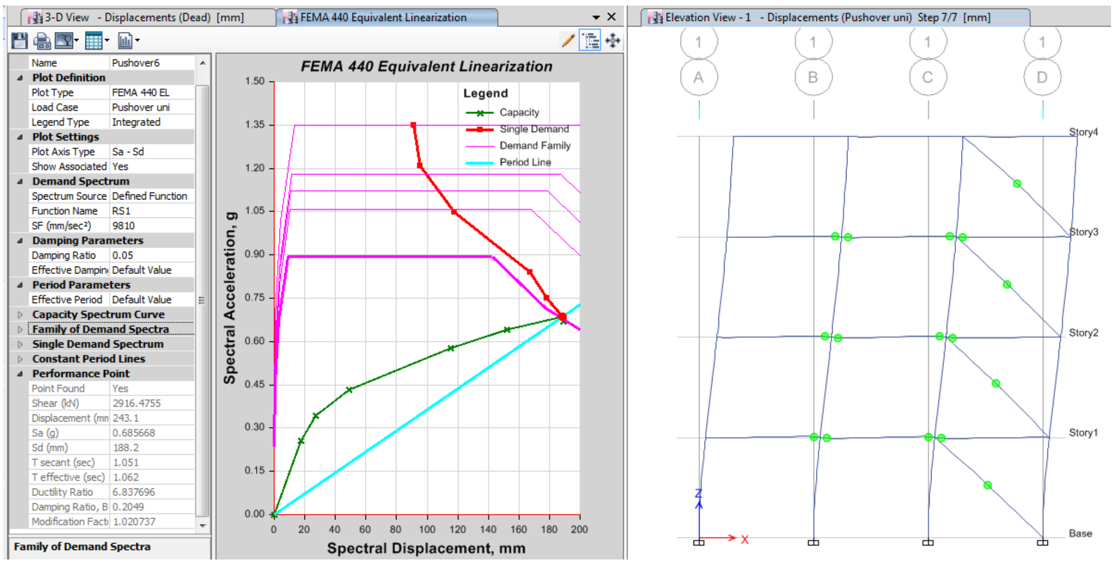

Figure 9-22: Evaluation the behavior of the BRBs-braced building with strengthened columns under the demand of RS1

Performance Point Data			
Point Found	**Yes**	**T secant**	**1.051 sec**
Shear	**2916.4755 kN**	**T effective**	**1.062 sec**
Displacement	**243.1 mm**	**Ductility Ratio**	**6.837696**
Sa	**0.685668**	**Effective Damping**	**0.2049**
Sd	**188.2 mm**	**Modification Factor**	**1.020737**

Table 9-6: The structure response at the performance point under the demand of RS1

10. Conclusion

Retrofitting the building by columns R.C-jacketing1, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, to 2410.13KN with 246.36mm corresponding roof displacement, which means 28 percent, but the capacity spectrum does not intersect the demand spectrum, thus the building still does not have performance point, and still insufficient.

Retrofitting the building by columns R.C-jacketing2, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, to 2871.09KN with 245.23mm corresponding roof displacement, which means 53 percent, but the capacity spectrum does not intersect the demand spectrum, thus the building still does not have performance point, and still insufficient.

Retrofitting the building by mass reduction, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, to 2196.24KN with 196.17mm corresponding roof displacement, which means 17 percent, but the capacity spectrum does not intersect the demand spectrum, thus the building still does not have performance point, and still insufficient.

Retrofitting the building by mass reduction and jacketing columns, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, to 3634.522KN with 177.20mm corresponding roof displacement, which means 93 percent, the building has performance point and acceptable deformation mechanism of the building, according to Eurocode, the structure in Limit State of Near Collapse (NC), consequently sufficient for level C.

Retrofitting the building by conventional steel braces according to the configuration1, and assuming that bracing members work both on compression and tension, produce unfavorable dominator mode for deformation shape of the building, which is the torsional mode, because of the difference in compression and tension resistance of the steel bracing members,

Retrofitting the building by conventional steel braces according to the configuration2, and assuming that bracing members work both on compression and tension, produce "saw-tooth" effect on the capacity curve, due to the buckling of compressed braces.

Retrofitting the building by conventional steel braces according to the configuration2, and assuming that bracing members work only on tension, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, to 3600.14KN with 235.15mm corresponding roof displacement, which means 92 percent, the building has performance point but unfavorable deformation mechanism at the performance point was produced, and according to Eurocode the structure is in Limit State of Significant Damage(SD), consequently sufficient for level B

Retrofitting the building by BRBs according to the configuration2, raises the capacity curve from 1879.59KN max base shear for the existing building with 245.68mm corresponding roof displacement, 2889.04KN with 245.94mm corresponding roof displacement, which means 54 percent, the building has performance point but unfavorable deformation mechanism at the performance point was produced, and according to Eurocode the structure is in Limit State of Near Damage(SD), consequently sufficient for level C

Retrofitting the building by Buckling Restrained Bracing with strengthening week columns, gave the favorite deformation mechanism of the building at the performance point.

The figure9-23 depicts comparison between the capacity curves of the existing building and all the retrofitted buildings.

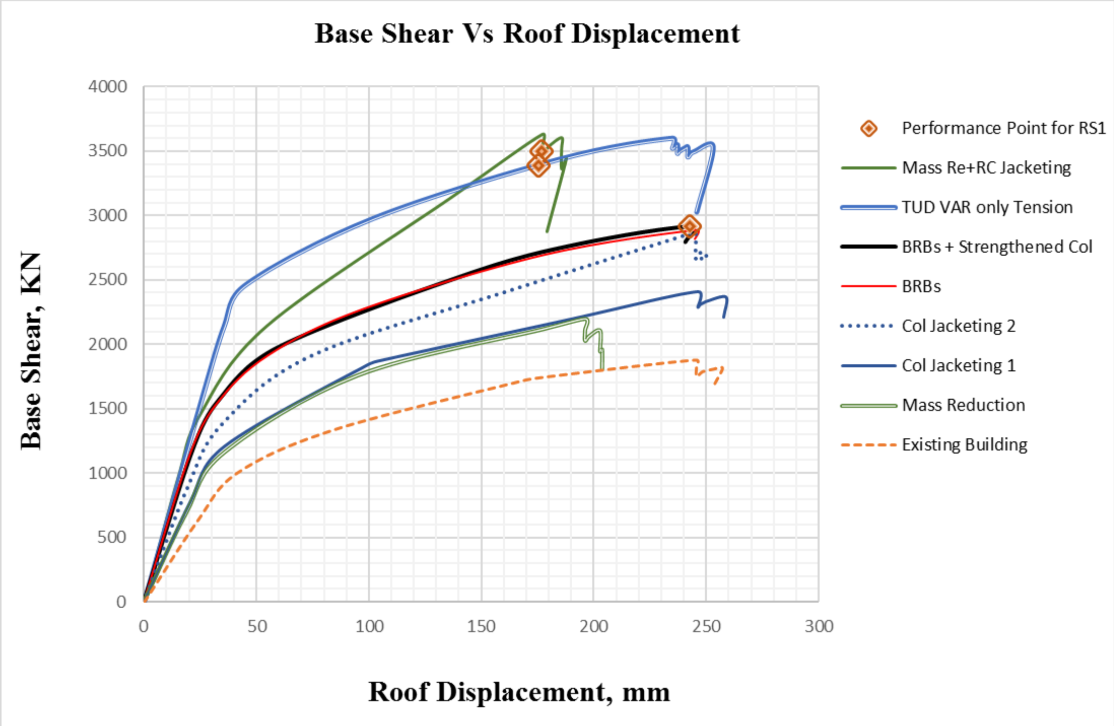

Figure 9-23: Final comparison

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