Seismic Performance and Retrofitting of Steel Building

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Abstract: Some special Engineering firms are taken for rehabilitation by Performance based seismic design (PBSD). The existing building that has high value of facilities is important to make functional after immediate post-earthquake. Current codes and provisions cannot cover all structures located in active seismic zone and these structures are not capable of withstanding seismic action. Furthermore, heavy active earthquakes in urban areas have obviously established an urgency to measure performance of the existing building, upgrade and strengthen these seismic undersupplied structures. Many researchers worked in recent years to measure the performance of the building structures and develop various strengthening and rehabilitation techniques to improve the seismic performance of structures. The main objectives of this research are to evaluate the seismic performance of the steel frame building is designed as a multi-storey office building under seismic action located in Timisoara, Romania and using pushover analysis for the Life Safety performance level under an earthquake hazard level with 10% probability of exceedance in 30, 50, 100, 225, 475 and 975 years. The seismic performance of the building is measured by the push-over analysis by FEM software SAP2000. For this push over analysis, the target displacement of the top of the building is measured for life safety performance. The demand curve for the life safety, emergency occupancy, Local damaged, structural damaged, collapse of the building is conducted for different seismic actions. Capacity curve of the building is compared to the demand curve for checking the performance mentioned above. The capacity curve is less than the demand curve for all seismic actions. The building must be retrofitted for increasing the performance during seismic actions. The steel building is retrofitted by providing the steel bracing. The bracing size used is TUB-168.3x4 mm in the direction of tension and the performance of the building is tested by using pushover analysis for the same conditions that are done for unbraced structure. The performance of the building again determined for the same seismic actions. The lateral displacement of the building has significantly improved. The capacity curve coincides the first four accelerations for unbraced structure. The capacity curve is more than the demand curve and coincide all demand curves for all return periods and all accelerations for braced frame. The size of concentric tension brace is bigger; that is why no plastic hinges formed for all peak ground accelerations.

Keywords: Seismic Action, Return Period, Seismic Performance, Capacity-Demand Curve, Retro-Fitting

1. Introduction

Civil engineering structures like Building structures are usually mostly vulnerable to seismic action [1]. Casualties and the structural losses due to structural vibration response is being protected by measuring the seismic performance of the building. Proper seismic resistant design along with its application in construction practice and monitoring through the service life of structure are the basic requirement for ensuring tolerable safety against seismic and other disaster [2]. The seismic performance of the existing building structures is unsatisfactory for upcoming hazard if the structures are not designed properly and seismic provisions are not followed properly during construction [3]. The structure has already experienced seismic hazard in its life time then the seismic performance of this structure is too low. Moreover, structural damage and unexpected collapse can occur due

to the presence of deficient capacity for resisting seismic load in existing structural condition [4]. For these instances effective seismic evaluation is required for enhancing the seismic performance of this type of structures. Seismic assessment report will say the present condition of the structure and the decision will be made for the further improvement if the structure will fail during earthquake or will not remain functional. The decision, whether the structure is required to be repaired, retrofitted or demolished greatly depends on the extent of deficiency of structure, economic feasibility, desirable service life of the upgraded structure, availability of materials and technology present [5]. In case of structural retrofit, the retrofitted structural response depends on other influencing factors. An optimum strategy should select so that maximum desirable response can be achieved for satisfaction of other influencing factors [6]. Energy absorption can be the effective technique to avoid building response far exceed its elastic strength capacity. Dynamic characteristic of the building could be the desirable methods to mitigate undesirable behavior of the structure during seismic action [7, 8]. Many existing structures not designed to withstand seismic forces have now become outdated due to development of more stringent design codes and specifications. Furthermore, recent earthquakes have prompted an urgency to repair and retrofit these seismic deficient structures to reduce the damage and casualties. Practically no earthquake resistance structure exist, proper retrofitting and rehabilitation method can particularly improve the seismic performance of a structure. During past heavy seismic mostly column failures occurred for the building structures, which also include shear failure and shear cracking, have been detected in a RC structure [9].

2. Description of the Building

The building is considered for this research is three storey office building. The location of the building is in Timisoara, Romania. First span of the building is 6.5m and second span is 3.0m. Bay distance is 5m and the storey height from the bottom is 3.5m, 3.0m and 3.0m respectively. The soil type of that area is B and the peak ground acceleration (PGA) is 0.16g. European steel cross section HEB 180 and IPE 330 was used for the columns and primary beams respectively. Gravity load acting on the structure consists of permanent load 4.88 kN/m^2 for roof slab and 3.70 kN/m^2 for floor. Live load 3.0 kN/m^2 acting on the floors and no live load acted on the top floor. Live load for external and internal wall 1.0kN/m^2 and this live load also acts on the floor only. Snow load for the roof slab is 2.5 kN/m^2 but its not acted on the other floor. Structural model of the building is shown in Figure 1.
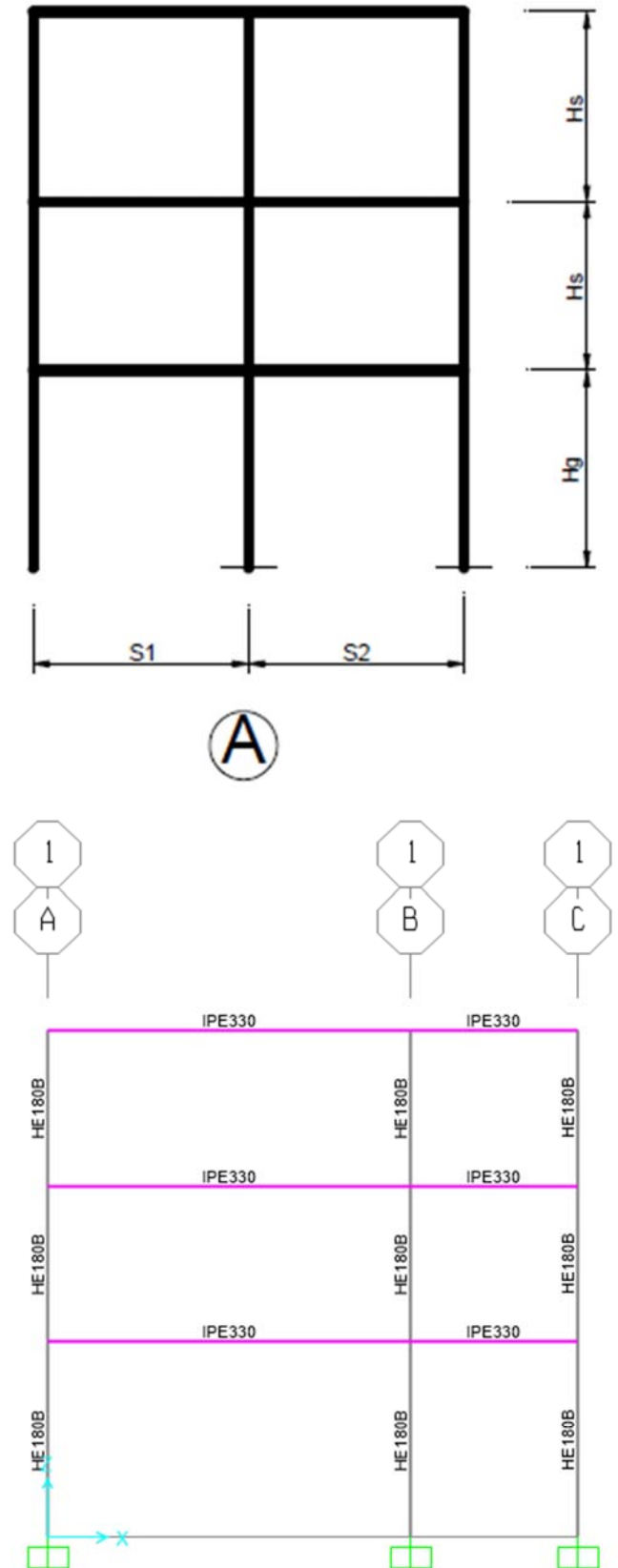

Figure 1. Structural model of the steel building.

The standards and codes applied to measure seismic performance of this structural project are the following:
i.   EN 1990 Eurocode 0: Basis of Structural Design [12]

ii.   EN 1991-1-3: Snow loads [13]
iii. EN 1991-1-4: Wind actions [14]
iv.   EN 1991 Eurocode 1: Actions on Structures [15]
v.   EN 1991-1-1: Densities, self-weight and imposed loads [16]
vi.   FEM Software: SAP 2000; Autodesk Robot Structural Analysis Professional 2017 [17].
vii. EN 1993 Eurocode 3: Design of Steel Structures [18-19]
viii. EN 1998-1: Design of Structures for Earthquake Resistance [18-19];
ix.   Part 1: General rules, seismic actions and rules for buildings [19].
x.   National Annexes: Romania.
xi.   FEMA 356 Guideline.

3. Research Methodology

The research work has done by three steps. First step is to consider all loads coming to the building including seismic according to peak ground acceleration. To identify the plastic hinges to the members done by the push over analysis in the second step. Finally, the seismic performance is evaluated and decided retrofit the existing building and how much improved after retrofitting. The steel section used in the building has selected some important mechanical properties. The coefficient based on the statistic characterization of steel products γ_{ov} is taken as 1.10, as recommended by EN 1998-1 6.2.3 (a) [12]. Steel grade S355 was used in the beams; columns and bracings. The density of steel taken in the design is 78.50 kN/m^3.

Table 1. *Properties of materials used in the steel building.*

Grade	F_y (Mpa)	F_{ye} (Mpa)	γ_{M1}	γ_{M2}	γ_{ov}	E (Gpa)
S355	355	391	1.0	1.0	1.10	210

After several iterations, the following commercial sections are taken in the design, following the Eurocode standards.

3.1. Seismic Actions

The seismic action has been calculated as per the location provided in the assignment. Euro Code 8 has been chosen to figure out the seismic action. As per the code, the PGA for Timisoara is 0.16g. Similarly, the value of T_C has also been provided in the table 1 of this code which is 0.5s. From the table 2 of this code, the values of T_B and T_D are 0.15 and 2s respectively.

Table 2. *Values of the parameters describing the recommended type I elastic response spectra.*

Ground type	S (m)	T_B (s)	T_C (s)	T_D (s)
A	1.00	0.15	0.4	2.0
B	1.20	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.40	0.15	0.5	2.0

Elastic Response Spectra is calculated using EN 1998-1 (3.2.2.5 (4)). The value of "S" has been taken as 1.20 for soil type B. The model has been made for ductility class high.

3.2. Plastic Hinges Formation for Push over Analysis

The plastic hinges formation of the beams and columns are shown in the figure 2. For the beams plastic hinges type M and for the columns it is P-M. There are two methods for controlling the push over analysis. Force control that is done for the gravity load and lateral force is considered as displacement controlled. For both forces controlled and displacement controlled it is nonlinear static analysis. The lateral forces are calculated from the gravity load acting on the structures. For this frame calculated lateral forces are presented in the figure 4.
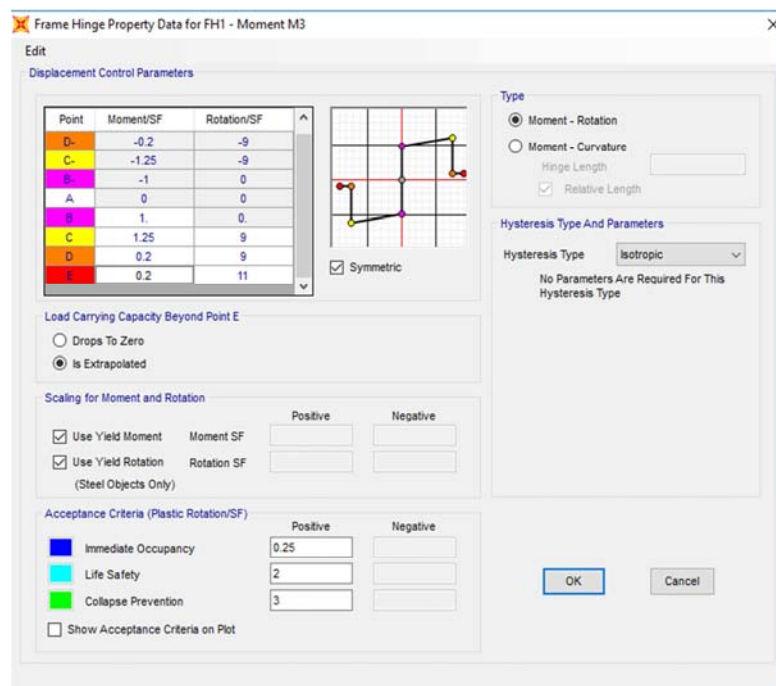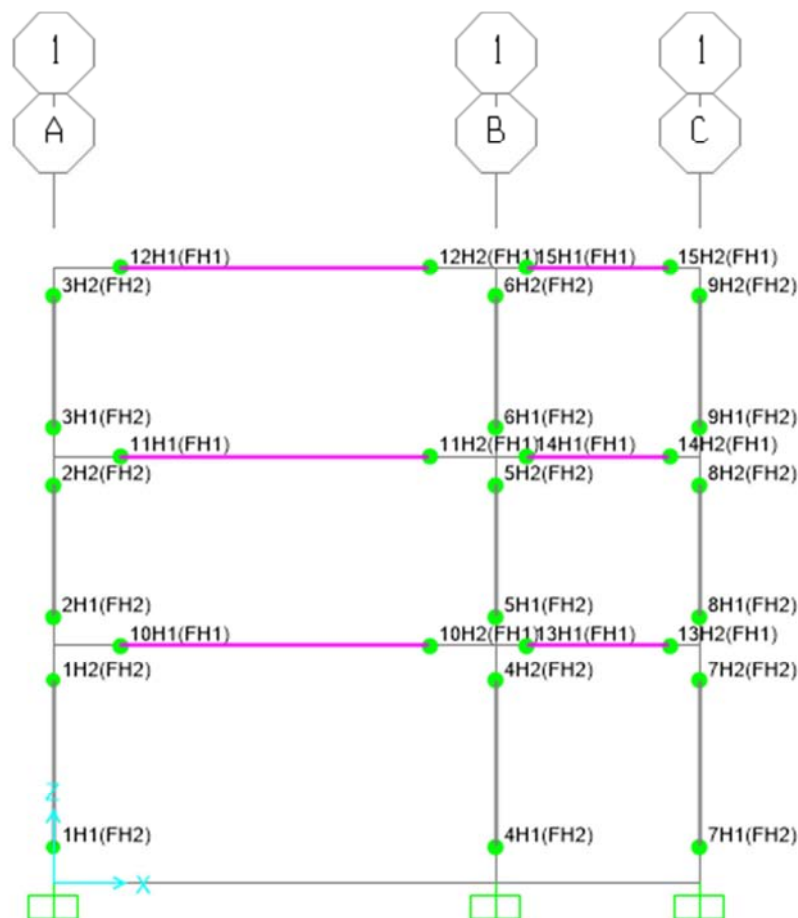
Figure 2. *Properties for push over analysis*

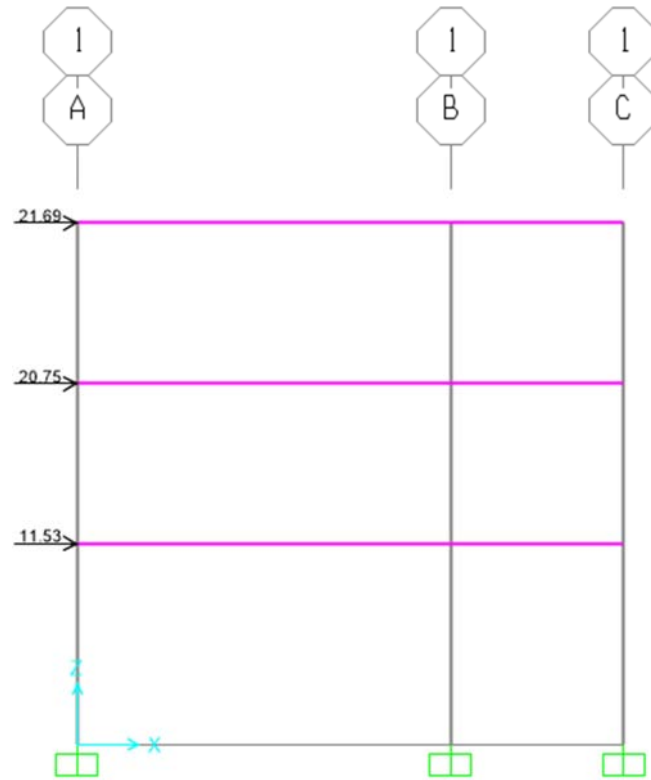*Figure 3.* *Hinge assignment to members.*

Figure 4. Lateral forces acting on each floor.

3.3. Target Displacement and Matrix Performance for Six Different PGA

The capacity demand curve found from the push over analysis for calculating the target displacement is shown in figure 5. The peak ground acceleration is calculated for six different return periods. Using the recurrence formula for

PGA is given in Romanian Code P100-3 even calibrated for Vrancea earthquake, a matrix may be built showing the performance objective possible to be achieved by a retrofitted building. The plastic hinges form for 0.27g and 0.34g PGA for emergency occupancy and local damaged of the structure is presented in table 3.
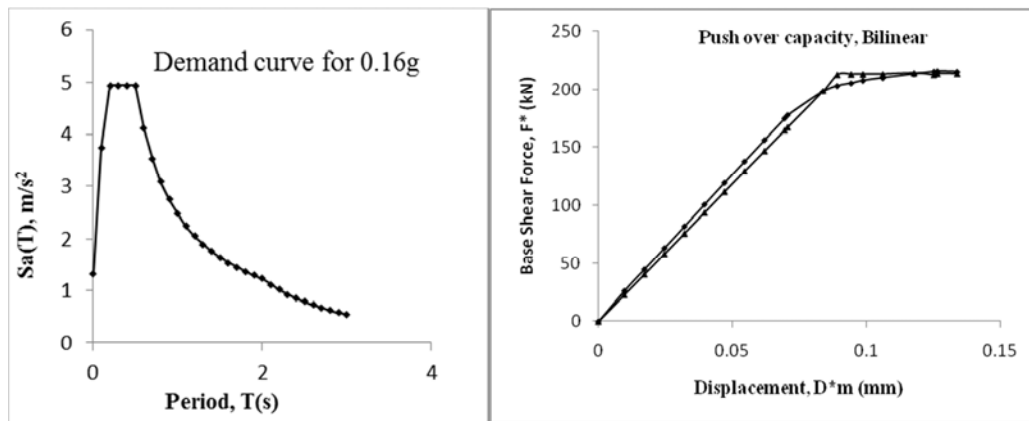

Figure 5. Push over capacity-demand curve for target displacement (PGA = 0.16g).

Table 3. Seismic performance for different PGA and different conditions.

T_L	γ_I	a_g	$S_e (T^*)$ (m/s^2)	d^*_{et} (m)	d^*t (m)	$dt = \Gamma. d^*t$ (m)
30	0.67	1.05	1.67	0.038	0.038	0.050
50	0.79	1.25	1.98	0.045	0.045	0.060
100	1.00	1.57	2.50	0.056	0.056	0.075
225	1.31	2.06	3.27	0.074	0.074	0.098
475	1.68	2.64	4.20	0.095	0.092	0.123
975	2.14	3.35	5.33	0.120	0.105	0.141
PL/RP	30 yrs	50 yrs	100 yrs	225 yrs	475 yrs	975 yrs

T_L	γ_I	a_g	S_e (T*) (m/s^2)	d^*_{et} (m)	d^*t (m)	dt = Γ. d*t (m)
γ_I	0.67	0.79	1.00	1.31	1.68	2.14
PGA	0.11g	0.13g	0.16g	0.21g	0.27g	0.34g
a_g	1.05	1.25	1.57	2.06	2.64	3.35
PL/RP	30 yrs	50 yrs	100 yrs	225 yrs	475 yrs	975 yrs
PGA	0.11g	0.13g	0.16g	0.21g	0.27g	0.34g
IO/LD	x	x	x	x		
LS/SD	x	x	x	x	x	x
CP/NC	x	x	x	x	x	x

The seismic performance for different PGA is observed during the push over analysis. During seismic action emergency occupancy (IO) is possible and no local damaged (LD) occurred until 0.21g PGA. Life safety (LS), structural damage (SD), collapse prevention (CP) and near collapse (NC) of the structure are not hampered in all cases of peak ground acceleration.

4. Retrofitting of Steel Building

For improving the seismic performance and structural capacity the engineering method termed as retrofitting applied in changing the existing structures for structural behavior without impeding its basic intent of use [10]. It becomes necessary to improve the performance of structures including those facing loss of strength due to deterioration or which have crossed their predicted life span. The further deterioration of structural behaviour is prevented by retrofitting and it depends on the valid reasons and measures adopted. Development of structures are done by applying appropriate technique like repair, retrofit, renovation and reconstruction. The loads are calculated and analyzed the existing structures by a structural engineer and a decision has to be taken to add any additional member like steel bracing, shear walls, etc. Repairs and rehabilitation are smart/advanced technology for specialized field like skills and abilities. Construction engineering related to repairs and rehabilitation that ensure management, feasibility and economy of the construction. The existing buildings and during its service life are measured seismic resistance and technical interposition is done to avoid any accidental failure due to seismic hazard or other serious structural failure. The deterioration of the structures occurs due to various actions like Weathering action, Fire hazards, Natural disasters etc. Natural calamities including seismic, Flood, Tsunami, cyclones, Soil and structure interaction, defects in construction and poor materials used and poor workmanship are serious causes for deterioration of structural performance. Perform the technical evaluation of such structures, the decision to repair or replace a structure or its component has to be taken [10].
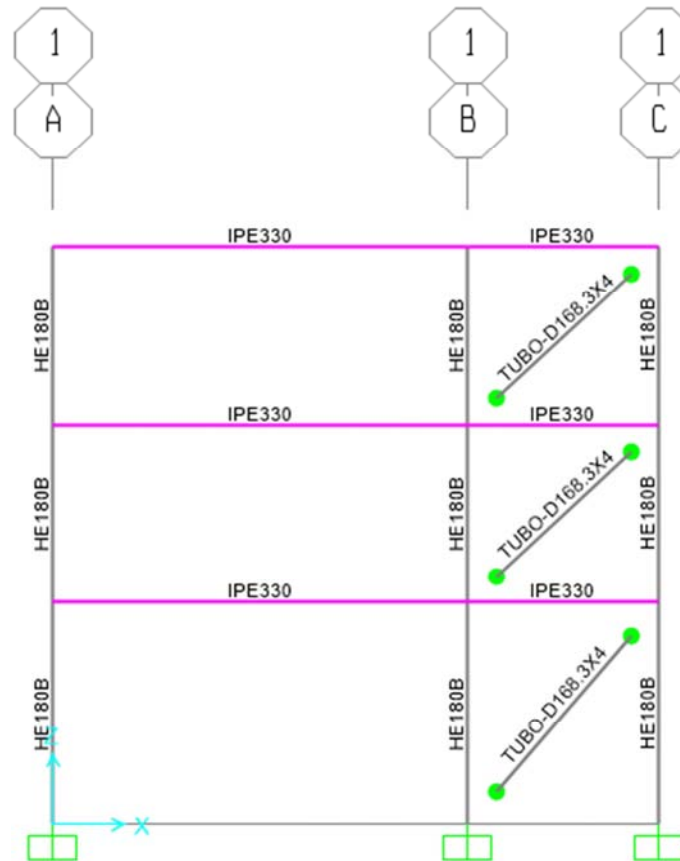

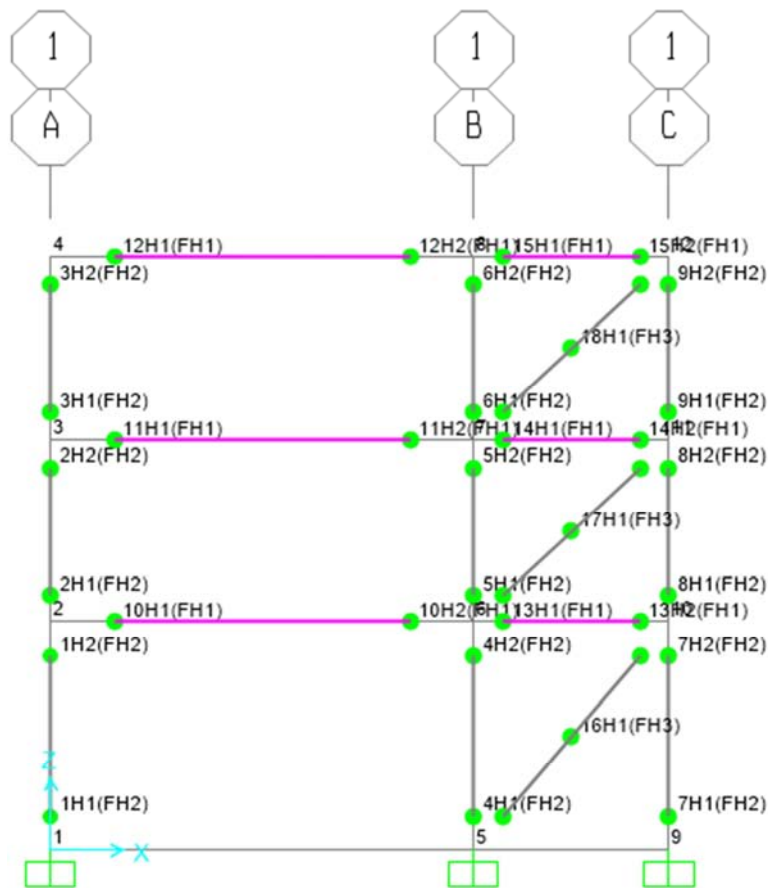**Figure 6.** *Structural model with diagonal bracing.*

Figure 7. Hinge assignment to members.

The possible improvement of seismic performance of existing steel building by the use of steel bracing. Three methods of seismic evaluation are employed for the purpose of the study i.e. Nonlinear Static Pushover Displacement Coefficient Method as described in FEMA 356, Improvement of Nonlinear Static Pushover Displacement Coefficient Method as described in FEMA 440 and dynamic time history analysis following the Indonesian Code of Seismic Resistance Building (SNI 03-1726-2002) criteria. The performance of this building could be categorized in between Life Safety (LS)-Collapse Prevention (CP) and plastic hinges

occur in columns [11]. The bracing size used is TUB-168.3x4 mm in the direction of tension and using pushover analysis for the Life Safety performance level under an earthquake hazard level with 10% probability of exceedance in 30, 50, 100, 225, 475 and 975 years. The analysis of the 3D frame structure is done using software SAP 2000. The structural model with diagonal bracing is shown in figure 6. Plastic hinges identified for retrofitted structure is shown in figure 7.

The capacity-demand curve after introducing the diagonal bracing increased from the push over analysis for calculating the target displacement is shown in figure 8.
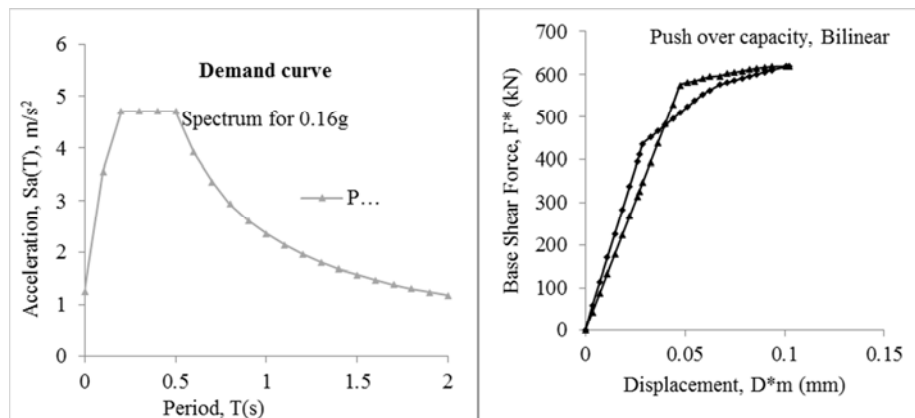

Figure 8. Push over capacity-demand curve for target displacement (PGA = 0.16g).

The seismic performance for different PGA is observed   during the push over analysis. During seismic action

emergency occupancy is possible and no local damaged occurred for all PGA. Local safety of the occupants and structure is available after retrofitting. Structural damage has not occurred for any peak ground acceleration, collapse prevention is possible and near collapse of the structure are not hampered in all cases of peak ground acceleration shown in table 4.

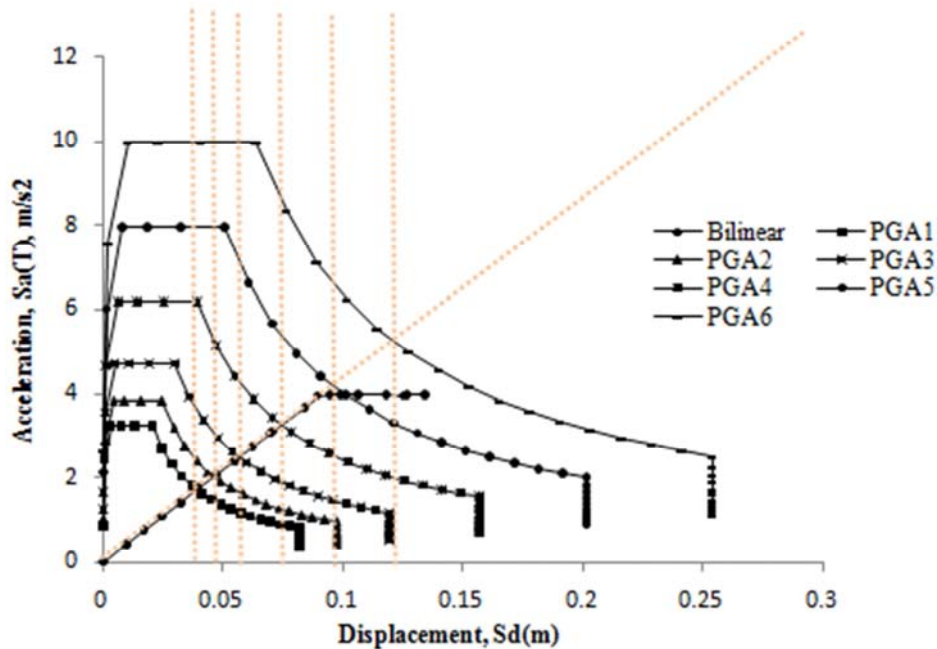*Table 4. Seismic performance for different PGA and different conditions after retrofitting.*

T_L	γ_I	a_g	S_e (T^*) (m/s^2)	d^*_{et} (m)	d^*t (m)	$dt = \Gamma.d^*t$ (m)
30	0.67	1.05	3.15	0.013	0.013	0.017
50	0.79	1.25	3.74	0.015	0.015	0.021
100	1.00	1.57	4.71	0.019	0.019	0.026
225	1.31	2.06	6.17	0.025	0.025	0.034
475	1.68	2.64	7.92	0.033	0.033	0.043
975	2.14	3.35	10.06	0.041	0.041	0.055
PL/RP	30 yrs	50 yrs	100 yrs	225 yrs	475 yrs	975 yrs
γ_I	0.67	0.79	1.00	1.31	1.68	2.14
PGA	0.11g	0.13g	0.16g	0.21g	0.27g	0.34g
a_g	1.05	1.25	1.57	2.06	2.64	3.35
PL/RP	30 yrs	50 yrs	100 yrs	225 yrs	475 yrs	975 yrs
PGA	0.11g	0.13g	0.16g	0.21g	0.27g	0.34g
IO/LD	x	x	x	x	x	x
LS/SD	x	x	x	x	x	x
CP/NC	x	x	x	x	x	x

5. Results and Discussions

The demand curve varies for the different peak ground acceleration and the highest demand for the seismic action of 0.34g. Capacity curve for the seismic performance is measured from the push over analysis by FEM software SAP2000. The bilinear capacity curve for the initial structure cut all demand curves. It indicates the demand curve is much more higher than the capacity curve. The initial structure is not strong enough to withstand seismic action. The comparison of capacity-demand curve is shown in figure 9. The maximum lateral displacement of the structure is 0.13m for 0.34g with respect to capacity curve.

Figure 9. Capacity-demand curve of initial structure.

The initial structure is retrofitted by providing the diagonal bracing in tension zone to increase the seismic performance. After providing the bracing the capacity curve of the retrofitted structure is higher than the demand curve for all kinds of peak ground acceleration. The comparison of capacity-demand curve is shown in figure 10. The lateral displacement in between 0.01 and 0.04m for the peak ground acceleration.
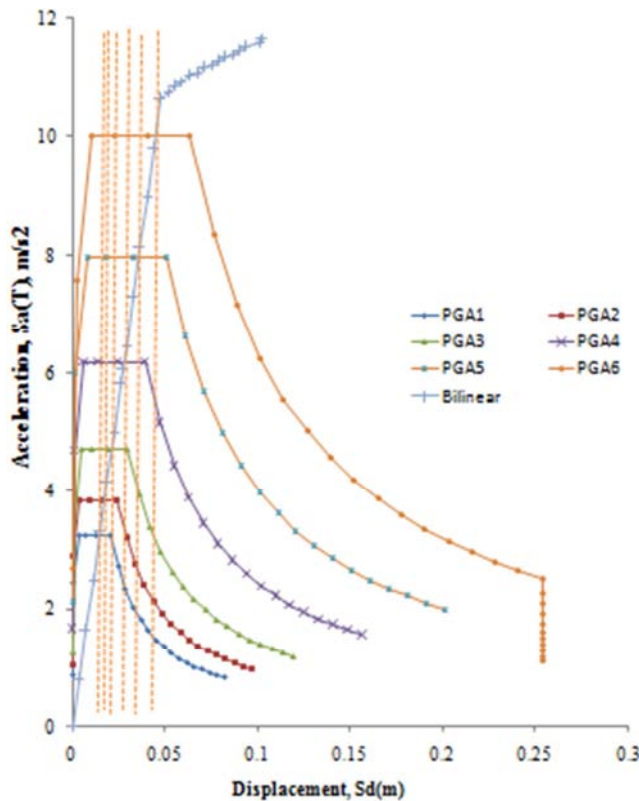
Figure 10. *Capacity-demand curve of retrofitted structure.*

The comparative study of the capacity curve for unbraced and braced frame is presented in figure 11. The curve of braced frame is much higher than that of unbraced frame. First plastic hinge mentioned in the figure has formed at 0.09m of lateral displacement for unbraced frame. The plastic hinge stated from 0.025m for the braced frame.
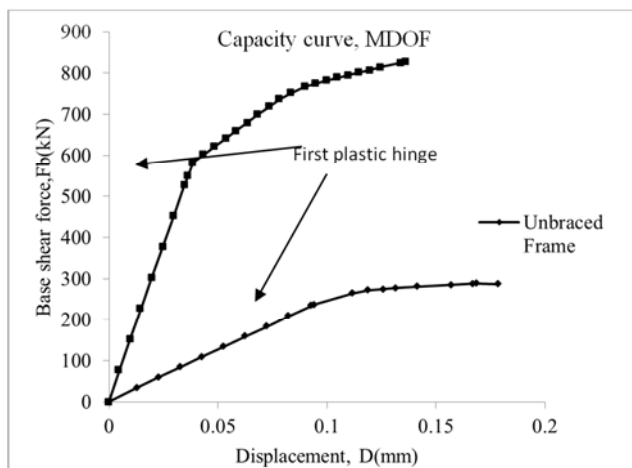

Figure 11. *Comparison of capacity curve of the initial and retrofitted structure.*

6. Conclusions

The seismic performance for unbraced frame and the seismic performance after retrofitting are evaluated by performing the push over analysis. The main conclusions for both cases are:

i. The unbraced structural system is safe for PGA1; PGA2; PGA3 and PGA4 and no plastic hinges formed.
ii. The performance matrix for PGA5; PGA6; the structure is safe for Life safety and Collapse performance but not safe for immediate occupancy.
iii. The seismic performance is measured by the capacity curve. The capacity curve shows higher value means the higher performance against seismic action. The performance matrix for PGA1; PGA2; PGA3; PGA4; PGA5; PGA6 in retrofitted structure (braced frame); is none i.e. the structure is safe there is no plastic hinges formed.
iv. The capacity curve coincides the first four accelerations for unbraced structure.
v. The capacity curve is more than the demand curve and coincide all demand curves for all return periods and all accelerations for braced frame.
vi. The size of concentric tension brace is bigger; that is why no plastic hinges formed for all acceleration. The section of bracing should be optimizing for different accelerations to minimize the cost of rehabilitation.

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