International Journal of Trend in Scientific Research and Development (IJTSRD)
International Open Access Journal | www.ijtsrd.com
ISSN No: 2456 - 6470 | Volume - 3 | Issue – 1 | Nov – Dec 2018

Novel Approach on Performance-Based Aseismic Design Based on FEMA Requirements

Azer A. Kasimzade, Sertaç Tuhta, Gencay Atmaca, Ibrahim Alameri, Obaidullah Abrar
Ondokuz Mayis University, Faculty of Engineering, Department of Civil Engineering, Samsun, Turkey

ABSTRACT
Building codes related with performance-based aseismic design contain some performance goals and levels to increase the resistance of the structure to the earthquake effect. In the finite element nonlinear – pushover analysis plastic hinge formation is one of the essential data analyzed by researchers to distinguish the location of the building where larger potential damage may happen. If the number of plastic hinges in the structure is increased, the total capacity of the structure will increase proportionally. On this point of view reaching the maximum number of plastic hinges must be added as the new performance goal or level to the performance-based aseismic design codes, which will dial to the highest ultimate load of the structure. In this arrangement, a number of (n+1) plastic hinge can be formed to achieve the complete collapse of a known (n)th hyperstatic plane frame system. This paper presents an assessment of the aseismic performance of structure based on adding to the existing mentioned methods a new performance goal. On example of five-story plane frame system based on FEMA 440 methods, assessment results indicate that with decreasing the stiffness of the beams at the above stories the number of plastic hinges increased, and the total capacity of the frame was increased by 7.41, and 7.87%, respectively.

KEY WORDS: *Performance-Based Aseismic Design, Plastic hinges, Pushover Analysis, Plane Frame.*

1. INTRODUCTION

Generally, in displacement-based or force-based methods of seismic design codes, it is presumed that the structure enters the inelastic phase to dissipate the seismic energy to bear the lateral seismic loads or to attain the performance objectives. In this case, the residual deformations due to inelastic behavior, which are considered as ‘‘damages”, would depend on the number and layout of the seismic load resisting members and the magnitude of seismic load. These damages would remain in structure in the forms of story drifts or members’ deformations [1].

In the capacity design, it is aimed to allow damage to the buildings in severe earthquakes, to determine the distribution of this damage by the designer and to take measures. These precautions are provided by ductile power consumption before brittle power consumption in the load-bearing system and elements, determination of the places where damages will occur (such as joint and single load areas) and increasing the ductility in the designated places. Along with the ductile behavior, plastic deformation has been accepted in the design. The type and location of these damages are the most important elements of capacity design [2, 3].

Figure 1 clearly shows that the displacement between the stories is different. One of the most important points to be considered during the design is that the stiffness distributions of the beams are done correctly [2, 3].

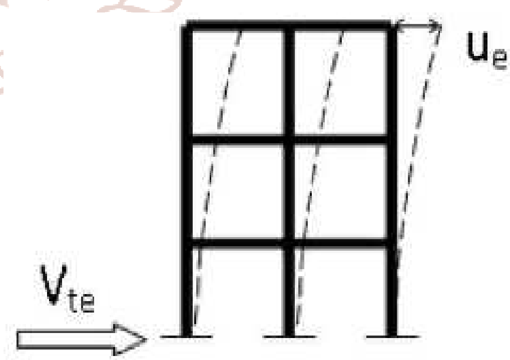


Figure 1 displacement of structure due to lateral loads

On the basis of the method of displacements of the finite element method, {F} is the known external node force, {U} is the node displacements of the system, and [K] is the structure stiffness matrix. Then,

$$[K]\{U\}=\{F\} \quad (1)$$

So,

$$[K]=\{F\}\{U\}^{-1} \quad (2)$$

As can be seen here, the stiffness is inversely proportional to displacement. In other words, the less the displacement, the greater the stiffness. Therefore, higher rigidity beams should be designed on the lower floors where there is little displacement. In this arrangement, the rigidity of the beams can be altered to the horizontal displacement of the building height length from the lower stories upwards, and a number of (n+1) plastic hinge can be formed to achieve the complete collapse of a known $(n)^{th}$ hyperstatic system. By reaching this situation, theoretically, the structure has the highest ultimate load. Otherwise, the structure collapses with fewer plastic hinges and less load. Certainly, other methods also may be developed for achievements new performance goal (reaching the maximum number of plastic hinges), which may be subject of research in the future.

Zeris and Repapis [4] studied the seismic performance of existing RC buildings designed to different codes and concluded that buildings of the 90s, designed to modern codes exhibit an exceptionally good performance. Turker and Gungor [5] studied the Seismic performance of low and medium-rise RC buildings with wide-beam and ribbed-slab, The results indicated that the predicted seismic performances were achieved for the low-rise (4-story) building with the high ductility requirements and addition of sufficient amount of shear-walls to the system proved to be efficient way of providing the target performance of structure. Inel and Meral [6] evaluated seismic performance of existing low and mid-rise reinforced concrete buildings by comparing their displacement capacities and displacement demands under selected ground motions experienced in Turkey as well as demand spectrum provided in 2007 Turkish Earthquake. The results show that the significant number of pre-modern code 4- and 7-story buildings exceeds LS performance level while the modern code 4- and 7-story buildings have better performances. The findings obviously indicate the existence of destructive earthquakes especially for 4- and 7-story buildings. Significant improvements in the performance of the buildings per modern code are also obvious in the study. Almost one third of pre-modern code buildings is exceeding LS level during records in the past earthquakes. Shoeibi et al. [7] studied the performance for structures with structural fuse system Analyses results showed that in moderate earthquake hazard level, only fuse members yielded and other structural members remained elastic.

As seen in the above studies, the literature does not offer a study in performance of reinforced concrete structures by changing the stiffness of beams. So the aim of this study is to understand the effect of changing in beam stiffness in above stories to get the maximum bearing capacity of the frame.

2. Performance Based seismic design

2.1 The Performance-Based Design Process

Performance-based design starts with selecting design criteria articulated through one or more performance objectives. Each performance objective is a statement of the acceptable risk of incurring different levels of damage and the consequential losses that occur as a result of this damage. Losses can be associated with structural or nonstructural damage, and can be expressed in the form of casualties, direct economic costs, and loss of service costs. Figure 2 shows a flowchart which presents the key steps in the performance-based design process [5].

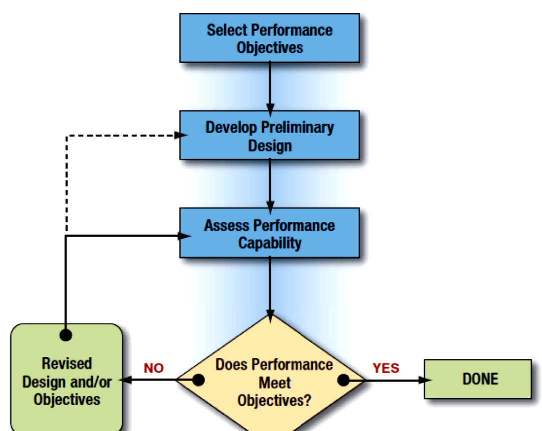


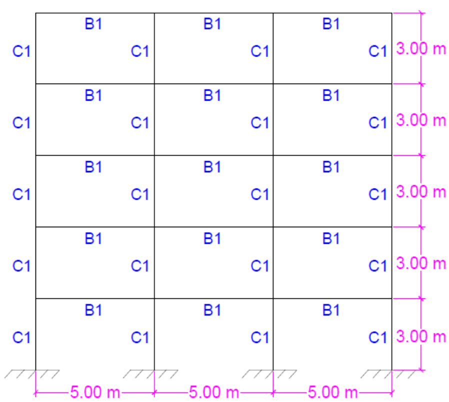
Figure 2 Performance-based design flow diagram [8].

2.2 Nonlinear Static Procedures

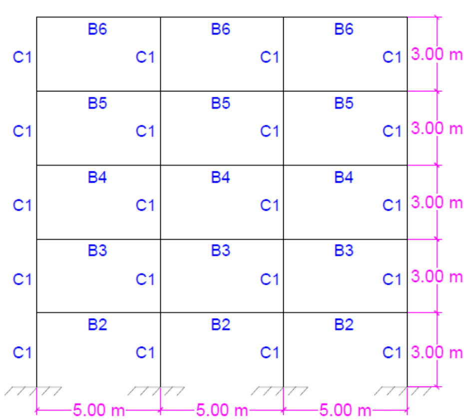
In Nonlinear Static Procedure, the basic demand and capacity parameter for the analysis is the lateral displacement of the building. The generation of a capacity curve (base shear vs roof displacement Figure 4) defines the capacity of the building uniquely for an assumed force distribution and displacement pattern. It is independent of any specific seismic shaking demand and replaces the base shear capacity of conventional design procedures. If the building displaces laterally, its response must lie on this capacity curve. A point on the curve defines a specific damage state for the structure, since the deformation for all components can be related to the global displacement of the structure. By correlating this capacity curve to the seismic demand generated by a specific earthquake or ground shaking intensity, a point can be found on the capacity curve that estimates the maximum displacement of the building the earthquake will cause. This defines the performance point or target displacement. The location of this performance point relative to the performance levels defined by the capacity curve indicates whether or not the performance objective is met. Thus, for the Nonlinear Static Procedure, a static pushover analysis is performed using a nonlinear analysis program for an increasing monotonic lateral load pattern [9,3]. An alternative is to perform a step by step analysis using a linear programming with composing FEM [3].

3. Example

A five-story concrete building has been designed and considered as the study building (figure 3a and 6b). The total height of the building is 15 m with a typical story height of 3 m.



a) Model 1



b) Model 2

Figure 3 mode 1 frame (a); model 2 frame (b)

C25 concrete and steel of yield stress = 4200 kg/cm^2 (grade 60) was used. The live load and finishing load used in this study are 2 KN/m^2 and 1.5 KN/m^2, respectively. According to the earthquake map of the Republic of Turkey, Zone 3 and ZC soil type had been selected.

Tables 1 show the details of the study frames considered in this study. In order to study the effect of beam stiffness configurations, the sections of columns kept the same in all frames. In model 1 the beam stiffness was kept constant at all stories but in model 2 the stiffness of the beams was reduced in the above stories.

Table 1 Cross sectional dimension and reinforcement

Element No.	B (cm)	H (cm)	Longitudinal reinforcement
C1	40	40	8ϕ16
B1	40	55	3 ϕ 14 top and bottom
B2	40	75	3 ϕ 14 top and bottom
B3	40	65	3 ϕ 14 top and bottom
B4	40	60	3 ϕ 14 top and bottom
B5	40	55	3 ϕ 14 top and bottom
B6	40	50	3 ϕ 14 top and bottom

3.1 Selecting performance level

Life safety performance level has been selected in this study and the maximum total drift for life safety performance level was observed as 2.0%.

3.2 Calculating Base Shear

The base shear force had been defined in Sap2000 by using UBC97 and the seismic zone 3 and type of soil ZC.

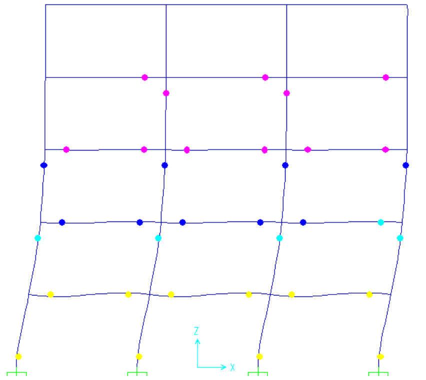
3.3 Model Acceptance Criteria

The nonlinear (M-θ) plastic hinge properties used in the studied frame members was selected according to FEMA 356 Table (6-7) for beams and Table (6-8) for columns.

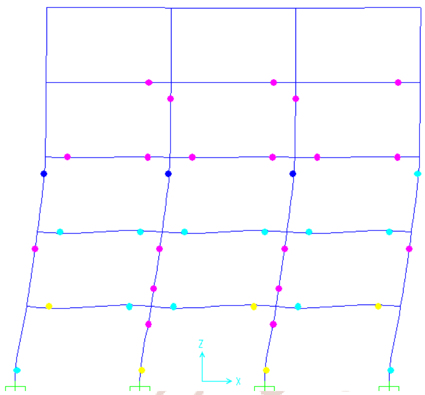
4. Results and Discussions

4.1 Plastic Hinge Formation

Figure 4 shows the hinge formation of the fixed beam stiffness (model 1) (a) and variable beam stiffness (model 2) (b). As expected, for the model 2 frame, the number of hinges occurred is more than that occurred in the model 1 frame. Table 2 summarized the plastic hinges formed in the beams and columns of model 1 and 2.



a) Model 1



b) Model 2

Figure 4 Hinge Severity Legend

Table2. Frames hinge count

Frame type	Performance Level				Total hinge count
	B-IO	IO-LS	LS-CP	C-D	
model 1	11	9	5	10	35
model 2	19	3	12	5	39

4.2 Performance Point Results

Performance point is assessed based on the FEMA 440 Displacement Modification, and FEMA 440 Equivalent Linearization methods, the results indicate that with decreasing the stiffness of the beams at the above stories the performance point base shear of the frame enhanced by 7.41, and 7.87%, respectively.

Table 3 Performance Point Results

Method	model 1 V (KN)	model 2 V (KN)	Difference in V (%)
FEMA 440 Equivalent Linearization	262.467	283.146	7.87
FEMA 440 Displacement odification	266.579	286.348	7.41

Conclusion

In the finite element nonlinear–pushover analysis plastic hinge formation is one of the essential data analyzed by researchers to distinguish the location of the building where larger potential damage may happen. If the number of plastic hinges in the structure is increased, the total capacity of the structure will increase proportionally. On this point of view reaching the maximum number of plastic hinges must be added as a new performance goal or level to the performance-based aseismic design codes, which will dial to the highest ultimate load of the structure. In this arrangement, a number of (n+1) plastic hinge can be formed to achieve the complete collapse of a known $(n)^{th}$ hyperstatic plane frame system. For achievements, new performance goal in presented research suggested by the reducing stiffness of the beams in the above stories based on inverse proportionality of the stiffness ($[K] = \{F\}\{U\}^{-1}$) to the displacement of the frame system.

On example of five-story moment resisting plane frame system the following conclusions can be drawn:

- From the nonlinear static pushover analysis it has found that most number of hinges occur for variable beam stiffness compare to fixed beam stiffness configurations. So in order to get more ductile frame it is recommender to reduce the stiffness of beams in upper stories.
- Based on FEMA 440 equivalent linearization, and FEMA 440 displacement modification methods, assessment results indicate that with decreasing the stiffness of the beams at the above stories the number of plastic hinges increased, and the total capacity of frame enhanced by 7.41, and 7.87%, respectively.

Certainly, other methods also may be developed for achievements new performance goal- reaching the maximum number of plastic hinges, which may be subject of research in the future.

References

1. S. Shoeibi, M. A. Kafi, M. Gholhaki, “New performance-based seismic design method for structures with structural fuse system” Engineering Structures 132, pp. 745–760, 2017

2. A. A. Kasimzade, E. Şafak, C. E. Ventura, F. Naeim, Y. Mukai, “Seismic Isolation, Sturcural Health Monitoring, Performance Based Seismic Design in Earthquake Engineering, recent

development" Springer, ISBN 978-3-319-93156-2, 2019.

3. A. A. Kasimzade, "Finite Element Method Foundation and Applications to Structural Analysis -Using MATLAB" Nobel Publisher, 2018.
4. Christos A. Zeris and Constantinos C. Repapis, "Comparison of the seismic performance of existing RC buildings designed to different codes" Earthquakes and Structures, Vol. 14, No. 6 505-523, 2018.
5. Kaan Turker and Ilhan Gungor, "Seismic performance of low and medium-rise RC buildings with wide-beam and ribbed-slab" Earthquakes and Structures, Vol. 15, No. 4 383-393, 2018.
6. Mehmet Inel and Emrah Meral, "Seismic performance of RC buildings subjected to past earthquakes in Turkey" Earthquakes and Structures, Vol. 11, No. 3 483-503, 2016.
7. Shahrokh Shoeibi, Mohammad Ali Kafi, Majid Gholhaki, "New performance-based seismic design method for structures with structural fuse system" Engineering Structures 132 745–760, 2017.
8. FEMA 543, "Risk management series design guiding for improving critical facility safety from flooding and high wind" Federal Emergency Management Agency, 2007
9. F. Naeim, H. Bhatia, R. M. Lobo, "Performance Based Seismic Engineering" The seismic design handbook, New York: Kluwer Academic Publishers, 2001, pp 757-792.