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Evaluation of Behavior Factors Converged Crossover Braced Frames under Triangular Loading Pattern

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Abstract

The lateral load distribution pattern reflects the distribution of lateral inertial forces applied to the structure caused by the earthquake. Inertial forces caused by earthquakes with time changes and dynamic characteristics of the building are subject to change. But in the non-linear static analysis in order to avoid the complexity of this method, forces during analysis are considered constant. Hence analysis and design codes suggest different lateral load patterns to minimize the impact of this unrealistic simplicity. Pushover analysis is of non-linear static analysis methods that can be used to obtain structural capacity curve. Effective factors in determining the capacity curve of the structure is the lateral load distribution. This paper examines the triangular lateral load pattern in structures with convergent bracing previously placed under linear static analysis and a three-dimensional frame structure as an example was analyzed in the SAP2000 software. Therefore pushover analysis was performed on the several frames with convergent crossover braces (with 3,5,7,10,15 number of floors) and extra strength values, ductility and behavior factor is obtained and he results are compared with a nonlinear time history dynamic analysis. Also effect of the parameters affecting the rate of behavior such as, Iranian and American sections of beams and columns, double stud sections, will be examined for braces.

Key words: Force reduction factor, behavior coefficient, nonlinear static analysis, the triangular load patterns, convergent braces

1 Introduction

Behavior factor in the seismic design plays an important role and foundation and design philosophy is based on it, but is not sufficiently accurate and regulations are not sufficiently accurate in determining the values which in some cases can cause uncertainty in the seismic design. In other words, we cannot ensure that the use of this coefficient, it gives a favorable result. A proper plan, is a plan which structure can provide seismic requirements, such as good ductility and strength in severe earthquake and have minimum fatalities. One of the significant issues is dependence of responses to the strength and stiffness distribution of structure and dependence of this distribution on equivalent lateral load pattern. Since loading pattern can influence the arrangement of plastic hinges formed in the structure, therefore, the seismic response of structure, including the behavior coefficient will be affected. Earthquake loading due to the random nature and the other hand type (acceleration and displacement basis instead of force load) has a unique profile that analysis and design of structures has been faced with many difficulties and complexes. Because of the growing trend of regulations with the study of effects of earthquakes on buildings is started that their design have met gravity load. The current load pattern based on certain categories of possible plans have extracted for structures. Whereas achieving new models for better performance is still debated by researchers [1, 2].

2 Analysis Models

A range of convergent crossover braced frames with 2, 3 spans and (3, 5, 7, 10, 15) number of floors is investigated to cover a wide range of periods. In all examined frames with 5 meters length of span 3 meters height of floor is considered. Before performing the pushover analysis, first linear static analysis is done on above models and optimal sections are extracted and based on them pushover analysis is carried out. The roof system is unilateral so that the vertical load is applied on the frame. Thus the loading area of frame and the weight of the structure which are taken into account in seismic calculations have been calculated.

3 Selected Earthquakes Profiles

In order to consider the effects of ground motion on structural behavior, in the analysis of samples of three earthquakes accelerograms data with the different time duration and frequency content (CapeMendocino, Northridge, Sanfernando) is used.

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4 Analysis of Models and Results

Noting that the method of designing the structure significantly affects the behavior factor, in the frame design has been tried to analysis and design sections become identical with repeating the analysis several times and redesign. Also stress ratio (existing tension on allowable stress) in the final sections of design are primarily within 0.85 to 1. For nonlinear analysis of structure of nonlinear static analysis method, or the same increasing adaptive load method (pushover) was used under the triangular lateral load pattern to examine the structures designed based on this pattern and the nonlinear analysis under it, so the effect of this parameter on the effective coefficients related to it (ductility reduction coefficient and extra strength) will result in this study. During the increasing the load for the actual modeling of nonlinear behavior of structure, hardness of given up members have been involved in the next steps of increasing the load. Also initial analysis under a constant gravity load as full dead load plus 20% of live load is considered for each frame sample. The nonlinear analysis of frame is performed as in nonlinear analysis of structures. By allocating or anticipating plastic joints corresponding to those mentioned in tables of FEMA-356 and ATC 40 regulations, at appropriate locations of structural members or in other words the maximum stress points, nonlinear analysis is carried out. Anticipating joints according to the expected mechanical behavior of members in similar frames of figure 1 and 2 are dedicated to them [3, 4, 5].

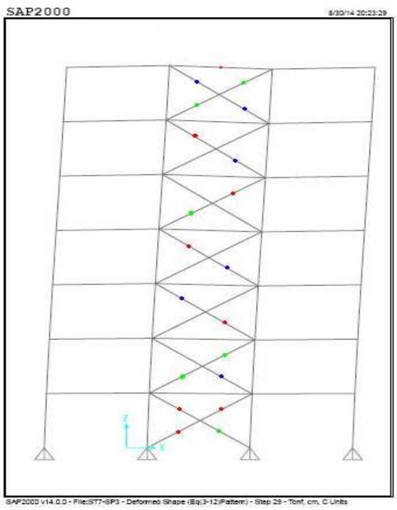

Figure 1: formation of plastic joint

To determine the structural behavior coefficient extra strength parameters R_s and force reduction coefficient due to ductility R_μ is needed.
Several methods for determining force reduction coefficient due to ductility considering ductility and period of a single degree of freedom structure is provided, here, Miranda method is used.

$$\Phi = 1 + \frac{1}{12\,T - \mu T} - \frac{2}{5T} e^{\left[2(\ln t - \frac{1}{5})^2\right]} \tag{1}$$

$$R_\mu = \frac{\mu - 1}{\Phi} + 1 \geq 1 \tag{2}$$

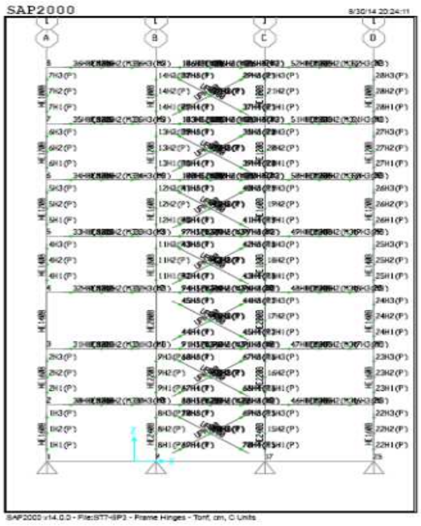

Figure 2: Assign of plastic joint

Based on the results of the analysis models, after the linear range, curve capacity of all models had an increasing rate due to strain hardening of materials and finally increasing the capacity of structure can be in this area. Summary of results are shown in tables one and two. Also, after the formation of plastic joints up to collapse area it has a downward rate and eventually strength of structure is gone and structure is destroyed. The results show that by increasing the number of floors from 3 to 7 the ductility of structure for triangular loading pattern lowers with a considerable slope and from 7-story to 15-story structures with a very small slope decreases so that it can be ignored. However, the ductility of structure generally decreases with increasing the height. This reduction is shown in Figure 3. Also results indicate that the ductility of structure for triangular lateral load pattern with increase in the number of spans is reduced with very small amount. Also with the increase in height of structure lateral capacity of structure is reduced. This is due to lateral forces dominating the forces of gravity with the increase in height of structure. As shown in Figure 4.[6]

Table 1. Summary of results for nonlinear static analysis of three-span structures designed with stud brace sections under triangular load pattern.

Story	μ	R_μ	R_s	R_W
3	8.44	4.64	1.807	8.384
5	8.3	5.40	1.131	6.108
7	6.75	5.34	0.958	5.114
10	6.36	5.74	0.845	4.216
15	6.18	5.62	0.848	3.112

Table 2. Summary of results for nonlinear static analysis of two-span structures designed with stud brace sections under triangular load pattern.

Story	μ	R_μ	R_s	R_W
3	9.21	5.976	1.815	10.847
5	9.06	5.993	1.214	7.276
7	7.22	5.573	1.065	5.936
10	6.36	5.738	0.973	5.583
15	6.49	5.826	0.929	5.413

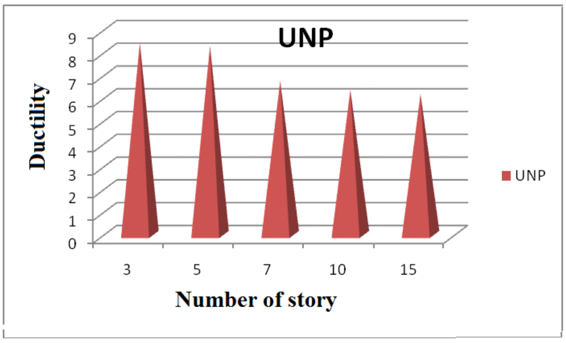

Figure 3: Ductility of three-span structures designed with stud brace sections under triangular loading pattern.

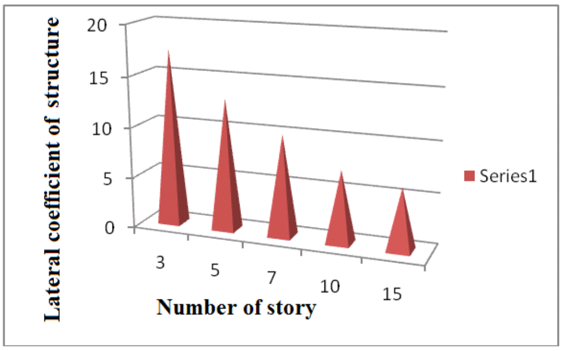

Figure 4: Lateral capacity diagram for three-span structures designed with stud brace sections under triangular loading pattern.

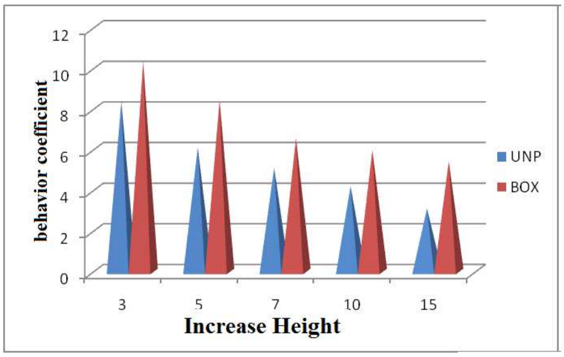

Figure 5: Comparison of behavior coefficient of three-span structures designed with stud brace sections and can brace sections under triangular loading pattern.

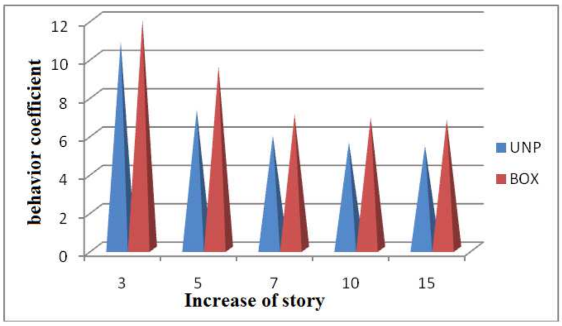

Figure 6: Comparison of behavior coefficient of two-span structures designed with stud brace sections and can brace sections under triangular loading pattern.

By comparing the results of the nonlinear static analysis and nonlinear dynamic analysis of samples we observed that differences in results are neglectable. As shown in Figure 1,2,3.

Table 3. Summary results of nonlinear dynamic analysis of structures with stud braces sections under seismic records (CapeMendocino, Northridge, Sanfernando) related to two-span two story structure.

R_w	R_s	R_μ	V_s (ton)	V_e (ton)	V_y (ton)	S.F (g)	REC
7.276	2.31	3.15	17.01	148	46.98	0.64	Cape
8.143	2.21	3.76	17.01	165.2	43.95	0.88	Sanfernando
7.861	2.41	3.26	17.01	149.21	45.87	0.50	Northridge
7.276	2.31	3.15	17.01	148	46.98	0.64	Cape

5 Conclusions

In this paper convergent crossover braced frames for can and stud brace sections, have been designed under the triangular lateral load patterns and nonlinear static analysis. According to the results of ductility, extra strength behavior coefficient of each frame is determined by the triangular lateral load pattern.

1- By comparing this type of braces with divergent brace type we observed that the ductility and behavior factor values for all samples is less than divergent braces.

2- Structure during strong earthquakes will not have linear behavior and linear response will not represent a real structure in the earthquake. Thus, the lateral load pattern in regulations is basically lacks a rational basis.

3- By careful analysis, we can guess optimized strength distribution pattern for different frames and reduce structural damage in the earthquake.

4- Generally with regardless of some results we can say that obtained of the average behavior coefficient values under a triangular lateral load pattern ($R_w = 6$) is less than the recommended amount in the 2800 code.

6- It can be well seen that the ductility values of designed structures with brace studs is more than can sections. So with an overview of the designed system with stud brace section is more shapeable than the designed system with can brace section.

7- Generally the obtained ductility and behavior coefficient for all designed systems decreases with increasing the height of structure. This is a mismatch with the constant showing in regulations.

8- The ductility of systems with 3 and 5 floors designed with can brace sections, under triangular load pattern is about (57-60%) and systems with 7 to 15 floors is about (90-95%) of systems designed with stud bracing sections.

9- The behavior coefficient of systems with 3 and 5 floors designed with stud brace sections, under triangular load pattern is about (50-70%) and systems with 7 to 15 floors is about (90-98%) of systems designed with can bracing sections.

10- Nonlinear dynamic analysis obtained results of the samples shows the accuracy of the results obtained from the nonlinear static analysis of the samples that with a reasonable accuracy, expresses behavior and failure mechanisms and distribution of ductility in frames.

11- Generally considering a regulation lateral load pattern in designing different structural systems and applying a coefficient as behavior coefficient for each type of structural systems regardless of the amount of its extra strength and ductility, it cannot be a guarantee of its stability under earthquake. Generally, seismic behavior of structures is related to many factors. The most appropriate design method is considering characteristics of each structure and apply it to the design method.

Furthermore, the results show American sections (w) gives us better behavior coefficient than Iranian sections (IPE, IPE), it can clearly be seen that the main cause of the difference is the component of behavior coefficient ductility. So with an overview, we can understand that systems designed with American sections are more shapeable than systems designed with Iranian sections.

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