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Research Article

STUDY OF EFFECT OF COLUMNS STIFFNESS ON SEISMIC BEHAVIOR OF CONVERGENT BRECED FRAME

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ABSTRACT
By the convergent braced frames, some factors such as the possibility of buckling of braces and low columns stiffness have led to have a Strength Reduction Factor in Seismic Regulations for the structural system; and compared with other structural systems it couldn't be proposed as an efficient seismic resistant system. In this study, computerized modeling of the convergent braced frames, nonlinear static analysis (Pushover) and dynamic time history analysis have been developed and with the aim of improving the seismic behavior, the effects of axial and bending stiffness of the columns in lateral resistant system have been discussed. According to the results, increase the axial stiffness of the columns will lead to improve the seismic behavior and increase the ductility of these frames, but bending stiffness of the columns have insignificant impact on improving the behavior of these frames and also causes to reduce the ductility of the frames.

Keywords: *Seismic Behavior*

INTRODUCTION
Convergent braced frames are a type of system resistant to earthquake; so it could be useful in normal steel structures particularly in building constructions because of easily designing and implementation. These frames amortize the load arising from earthquake through a truss behavior and axial forces in the braces and columns. Some factors such as buckling of braces and creating a soft-story mechanism due to low stiffness of the columns have led to consider Strength Reduction Factor for these frames in Seismic Regulations; it couldn't be considered as an efficient seismic system in comparison with the other structural systems.
For this reason, during recent years, various researches and studies on seismic behavior of convergent frames and increase of the efficiency of these frames have been done; and now we can mention to some of them: the idea of using non-buckling braces (Arias, 1970), optimum seismic designing by the use of Deformation Uniform Distribution Theory (Building and Housing Research Center, 2005) and the use of tressed columns (Clark *et al.,* 1999).
Some studies (ETABS, Extended 3D Analysis of Building Systems, 2011) show the effect of stiffness of the columns in order to increase the seismic effectiveness of the convergent frames. In this study, modeling of the convergent braced frames, nonlinear static analysis (Pushover) and dynamic time history analysis have been developed and the effects of stiffness of the columns on seismic behavior of convergent frames have been discussed in order to improve the seismic behavior of frames.
Nonlinear Static Analysis (Pushover)
In this study, through a computerized modeling of the convergent braced frames in two-dimensional mode and a nonlinear static analysis (Pushover), the seismic behavior of these frames have been investigated and discussed. Nonlinear Static Analysis helps to study the behavior of frame in a non-linear area until fracture moment.
Thus the criteria provided in Seismic Improvement Instructions (Gregory *et al.,* 2006) have been used in the field of nonlinear static analysis. ETABS Software (Moghaddam *et al.,* 2005) has been used for modeling and analysis of frames. The first step to use a nonlinear static analysis is to introduce a definition of plastic joints in order to incorporate the nonlinear behavior for the frame members. Plastic joints should be defined according to Load-Deformation Curve of steel members provided by Seismic Improvement Instructions as shown in Figure 1.

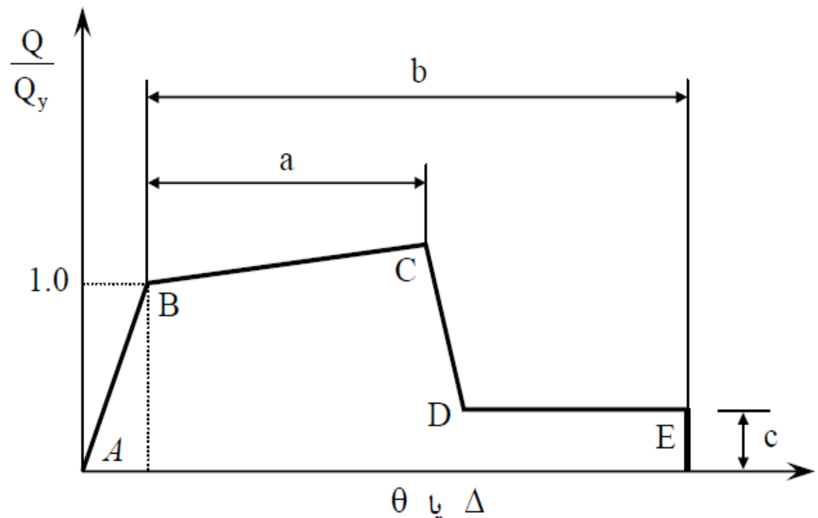

Figure 1: The Load-Deformation Curve of Steel Members

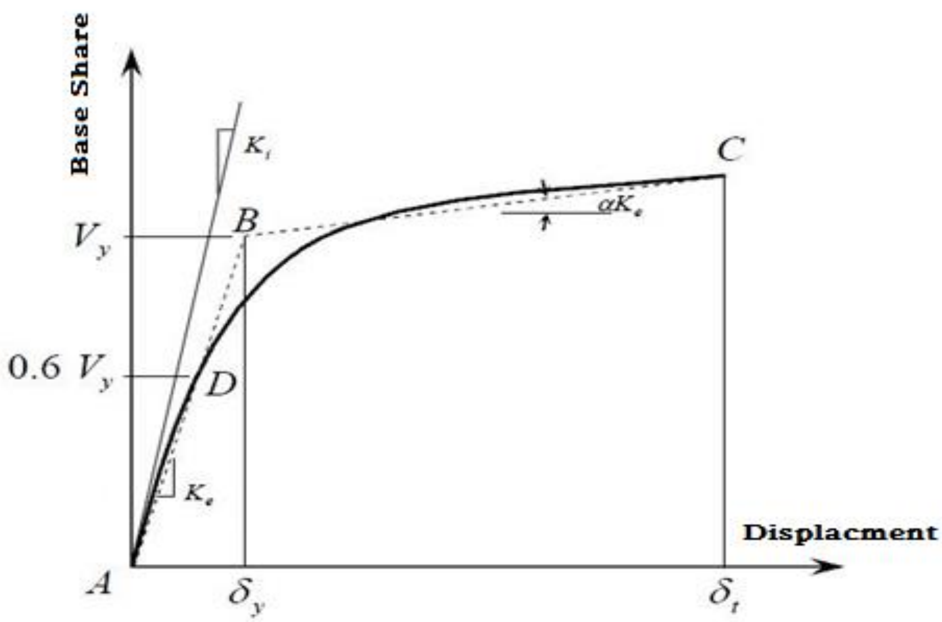

Figure 2: The capacity curve and two-line ideal curve

Points A, B, C, D, E in Figure 1 are considered to determine deformation of plastic joints and the values of rotation (θ) or displacement (Δ) are different according to the type of member; has been mentioned by Seismic Improvement Instructions; and it is the criteria for nonlinear behavior of steel members. In Figure 1, Q is maximum load of the steel member and Q_y is the member's yielding.

By the second step it is necessary to define loading of nonlinear static analysis defined. The loading modes include gravity loading and lateral loading. At first the gravity-load will be applied to the frame based on Equation 1.

$$COM = 1.1(D + L) \tag{1}$$

In which "D" is Dead load and "L" is live load on the frame. By applying the gravity-load, the lateral load will be applied to the frame. According to terms of Seismic Improvement Instructions; the lateral load has

been considered in accordance with the pattern of loading of the first vibration mode; and center of mass at the last storey was determined as control point, then it was pushed over to the desired displacement. The desired displacement equals to 3% of height of the frame in accordance with the level of safety at convergent braced frames is considered. In the third step, by the use of results of nonlinear static analysis, Capacity curve was extracted and become changed into two-line ideal curve. The two-line ideal curve should be used to determine the seismic parameters such as ductility of frame. Figure 2 shows Capacity curve and two-line ideal curve.
According to Figure 2, to obtain a two-line curve, point B must be set in such a way that the capacity curve and two-line curve are equal. Also length of AD-line should be considered about 0.6 of AB-line.
By the use of two-line ideal curve, ductility of frame can be obtained from Equation 2. Ductility is an important parameter for seismic behavior and if it is improved, the seismic behavior and behavior factor of the system will be improved.

$$\mu = \frac{\delta_t}{\delta_y} \tag{2}$$

In which, δ_t is the maximum load-displacement and δ_y is displacement of yielding in the frame. According to above discussion, the nonlinear static analysis of convergent braced frames has been done and the effect of increase the axial and bending stiffness of the columns in seismic behavior has been studied.

Time History Dynamic Analysis

In this paper, by the use of time history dynamic analysis, the dynamic effects of seismic behavior of convergent braced frames has been studied and the results of nonlinear static analysis have been discussed. Time history dynamic analysis simulates occurrence of the earthquake really through impression of acceleration of ground on frame levels. It was known as the most accurate method for applying the earthquake force. This method requires the selection and scaling of accelerographs recorded in previous earthquakes that are used as input analysis. In this paper, Iran's Seismic Regulations (Office of Technical Affairs, Develop Criteria and Risk Reduction, 2006) is used for selecting and scaling. Representing a definition for design earthquake is the first step to do time history dynamic analysis because it shows the maximum earthquake's effects on a region; thus selection and scaling of accelerographs should be done according to the results. The design earthquake is defined by Equation 3.

$$Sa = \frac{ABI}{R} \tag{3}$$

In which, Sa is spectral acceleration, A is base acceleration, B is reflection coefficient, I is significance coefficient and R is the behavior coefficient. Ration of base acceleration indicates the risk of seismicity in a region. Reflection coefficient represents the response of the structure to the ground motion and is determined by the type of soil in different periods. Significance coefficient with regard to classification of the structures could be determined in terms of importance of usage; behavior coefficient should be determined according to the type of lateral loading system which comprises of ductility, excess resistance and uncertainty value.

Table 1: Selected accelerographs for time history dynamic analysis

PGA (cm/s^2)	Significant Duration (sec)	Closet Distance(km)	Magnitude	Earthquake
238	23	8	6.2	**BONIABAD**
635	30	41	7.5	**AB-BAR**
124	26	45	6.9	**MOHAMAD-ABAD**

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Variablesof each coefficient can be derived from Iran Seismic Regulations. By defining the design earthquake, at least three Accelerographs shall be selected. These accelerographs shall reflect the actual ground motion at the site, so the conditions of design earthquake shall be satisfied; and the magnitude of the earthquake, the fault distance and soil type shall be determined. Also at these accelerographs, time of intense motion must be at least 10 seconds or 3 times of the fundamental period of structure, whichever is greater. Time of intense motion in accelerographs should be determined by the use of accumulative energy distribution (UBC, 1997). Selected accelerographs are shown in Table 1.
The selected Accelerographs should be scaled or modified to become coordinated with the design earthquake. At the first step, all accelerographs should be scaled based on maximum value. It means that maximum acceleration of all is equal to acceleration due to gravity. At the second step, acceleration response spectrum should be calculated for each scaled accelerographs by applying a 5% damping. The acceleration response spectrum of each horizontal component in accelerographs should be combined together by the use of squares root and a single spectrum could be obtained for each earthquake. In the third step, the response spectrums were obtained and median response for 3 earthquakes was achieved and the median response spectrum in the periods of 0.2 T to 1.5 T has been compared with design earthquake spectrum. Thus the scale factor would be determined so that the median values recorded by accelerographs is not less than 1.4 times as much of similar value in standard design. Factor of 1.4 is multiplied by the standard design because of using the squares root. Finally maximum scale factor obtained in the periodic area should be scaled by accelerographs; and should be multiplied by the first step and also should be used in time history dynamic analysis. Fig. 3 shows the median spectrum of 3 earthquakes as compared with design earthquake spectrum.

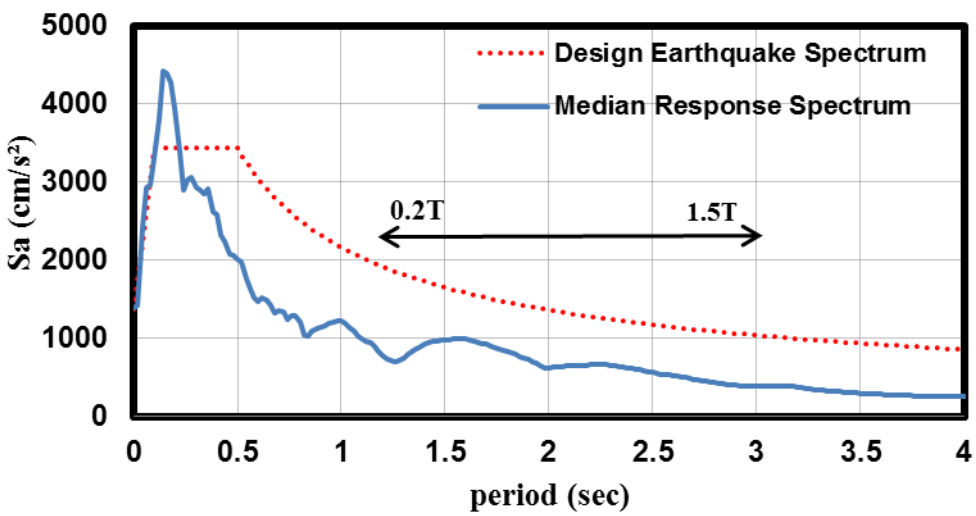

Figure 3: The median spectrum of three selected earthquakes and design earthquake spectrum

Structural Models
In order to study the effects of stiffness of the columns on the seismic behavior of convergent braced frames, the above said analytical methods has been used for two convergent braced frames converge with 5- and 12-storeys. Storey height was 3m and bay width was 4m. The fundamental period of frames was 0.38s and 0.73s, and the earthquake coefficients were 0.146 and 0.113 respectively. Regulations of UBC97 (Yoshihiro, 2005) and the allowable stress method have been used to design the frames. For each of the frames the nonlinear static analysis has been performed for 12 time as much and time history dynamic analysis has been performed for 12 times as much; so value of axial and bending stiffness of the columns was increased by 20% as compared with the original plan. Capacity curves obtained by nonlinear static analysis, ductility of two-line ideal curve, and relative displacement of storey's obtained by time

history dynamic analysis have been considered as criteria of assessment and comparison between different modes. Figure 4 shows the frames used in the static and dynamic analysis.

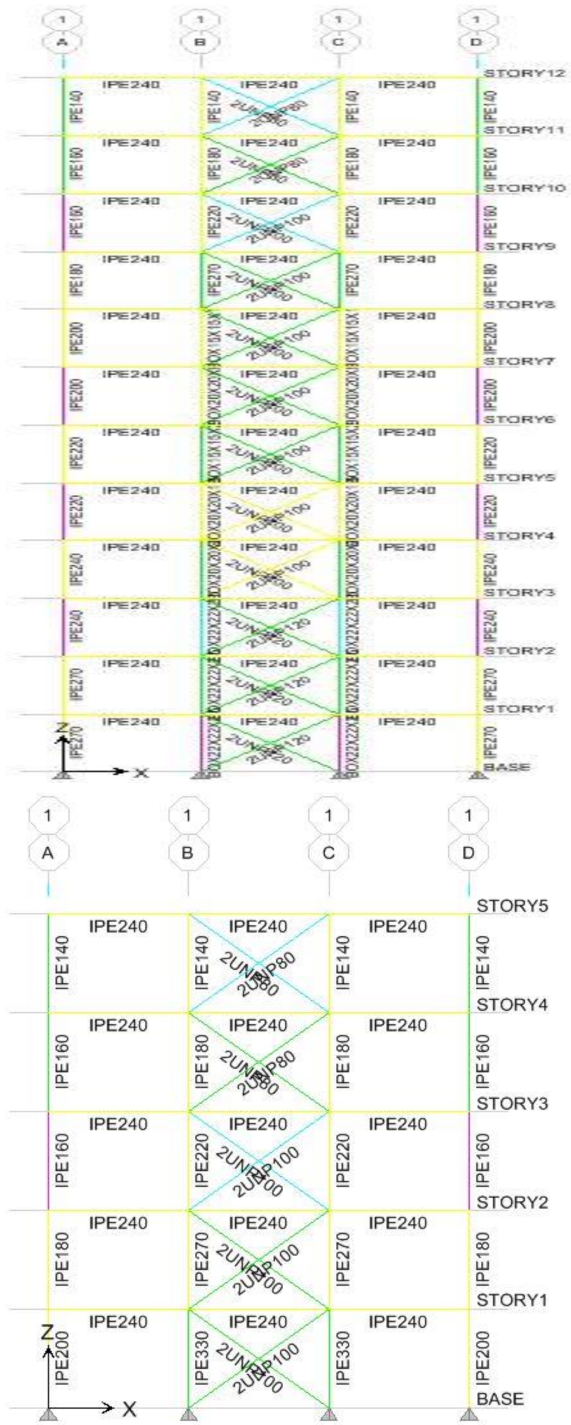

Figure 4: 5- and 12-storeys Frames used for static and dynamic analysis

The Results of Convergent Braced Frames Analysis

In this section, the results of the analysis of structural models are evaluated. Figure 5 and 6 show 5-storey frame capacity curve for axial and bending stiffness of the columns.

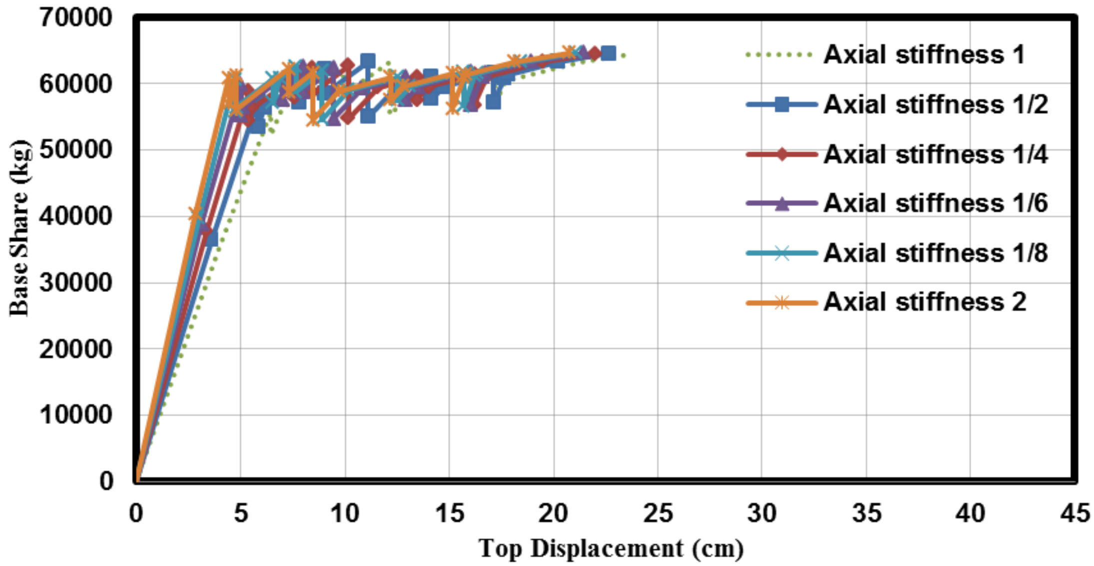

Figure 5: 5-storey frame capacity curves for different axial stiffness

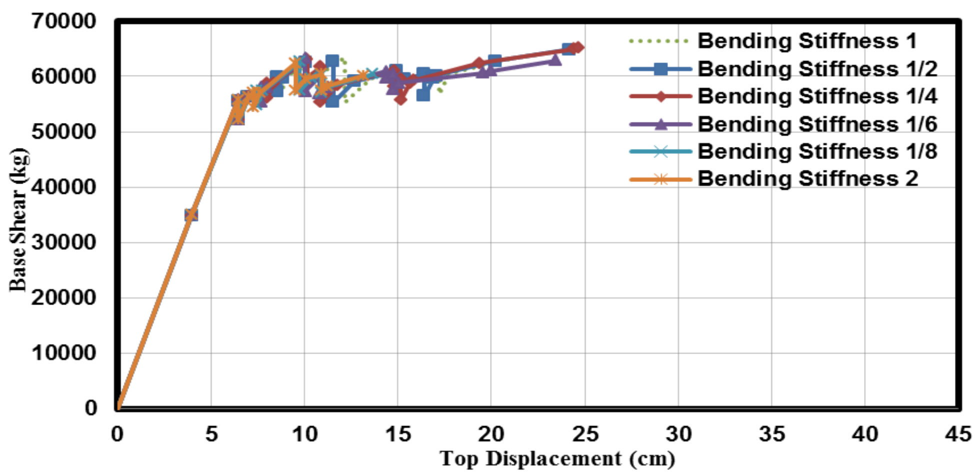

Figure 6: 5-storey frame capacity curves for different bending stiffness

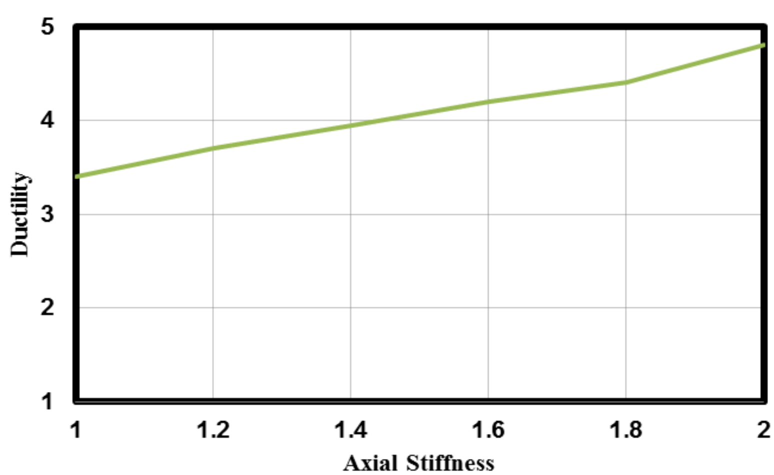

Figure 7: 5-storey frame ductility for different axial stiffness

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As seen in Figure 5, increase of the axial stiffness of the columns causes to increases the elastic stiffness of the frame; and also causes to reduce top displacement maximum to 13%. It also increases the axial stiffness, yielding shear frame from 3 to 10%. Figure 6 indicated that increase the bending stiffness of the columns had insignificant effect on capacity curve, because the columns are jointed to the convergent frame which revealed insignificant bending rigidity against the lateral loads. According to Figure 6, increase of bending stiffness more than 60% could be caused to sudden fracture of the frame. Figures 7 and 8 show ductility of 5-storey frame with axial and bending stiffness in the columns.

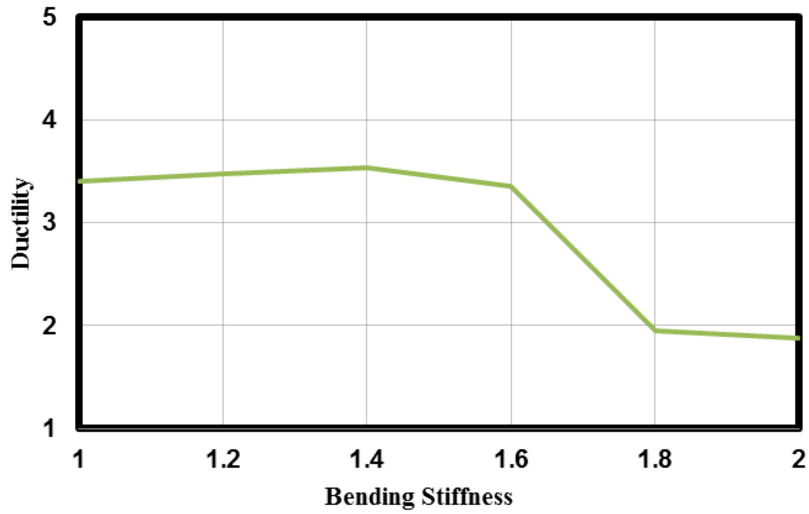

Figure 8: 5-storey frame ductility for different bending stiffness

Figure 7 shows that if axial stiffness of columns is increased, then ductility of frame will be increased, so that if the axial stiffness is increased double, ductility of frame will increase to 42% that is more effective to increase the behavior factor and improvement of the seismic behavior. But according to Figure 8, increase of bending stiffness while having an insignificant effect on increase of ductility in the lower stiffness, has influenced on ductility of the frame in the higher stiffness; then it caused to brittle fracture. To study the dynamic effects, time history dynamic analysis has been carried out. Figures 9 and 10 represent the relative displacement of a dynamic analysis for a 5-storey frame to show the axial and bending stiffness in the columns.

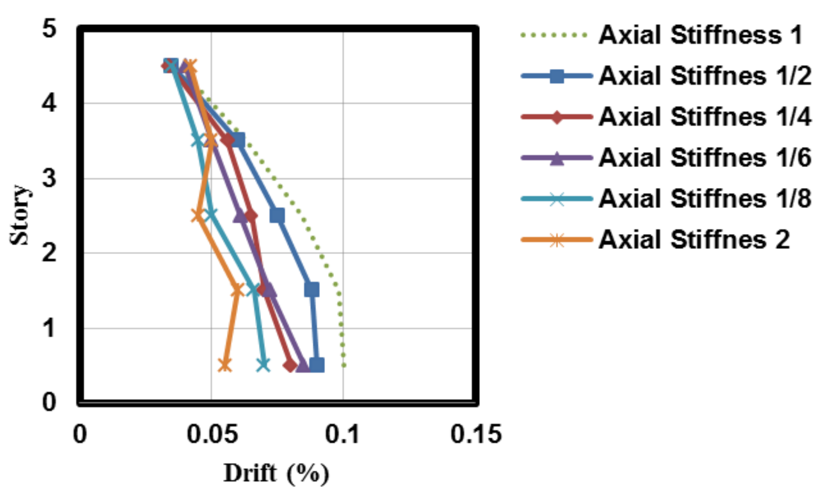

Figure 9: 5-story frame displacement for axial stiffness

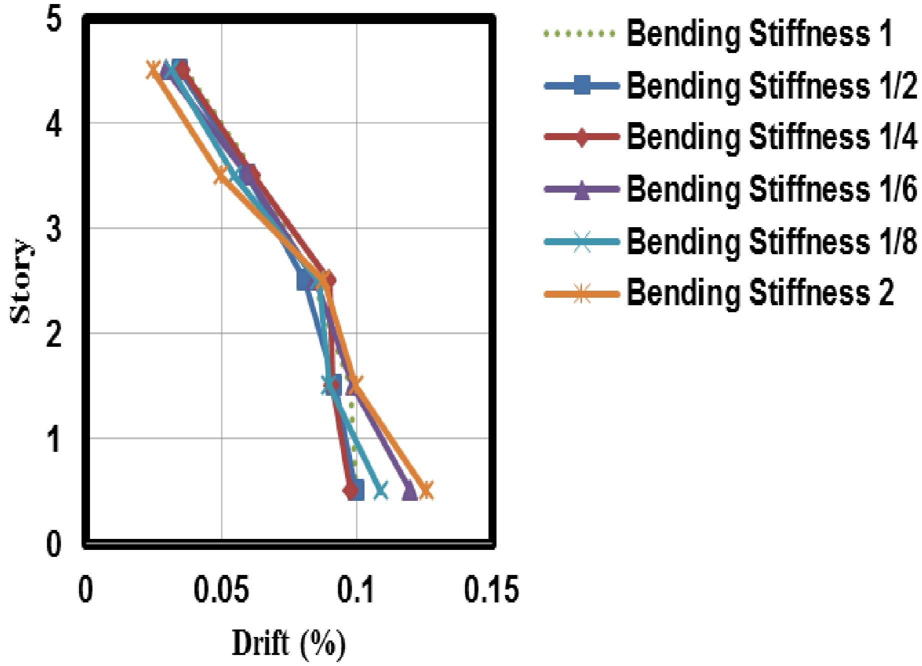

Figure 10: 5-story frame displacement for bending stiffness

According to Figure 9, increase of the axial stiffness of columns can reduce the lateral drift values, especially in the lower storeys. Figure 10 shows the insignificant effect of bending stiffness on reduction of lateral drift of storeys; and even increase the bending stiffness of the columns can increase the lateral drift of storeys. The results of dynamic analysis are similar to the results of static analysis, and prove that the axial stiffness of columns has positive effects on improvement of the seismic behavior of convergent braced frames. In order to evaluate the effects of columns stiffness on the seismic behavior of high frames, Static and Dynamic Analyses of a 12-story frame were carried out similar to a 5-storey frame; then the results have been evaluated. Figures 11 and 12 show 12-storey frame capacity curve for the various axial and bending stiffness.

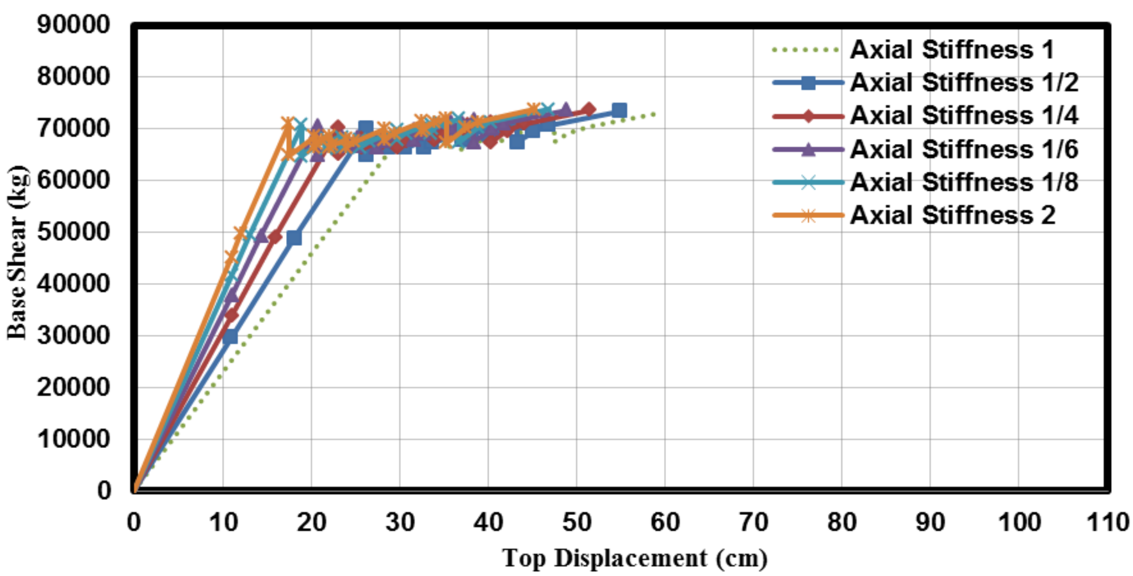

Figure 11: 12-story frame capacity curves for different axial stiffness

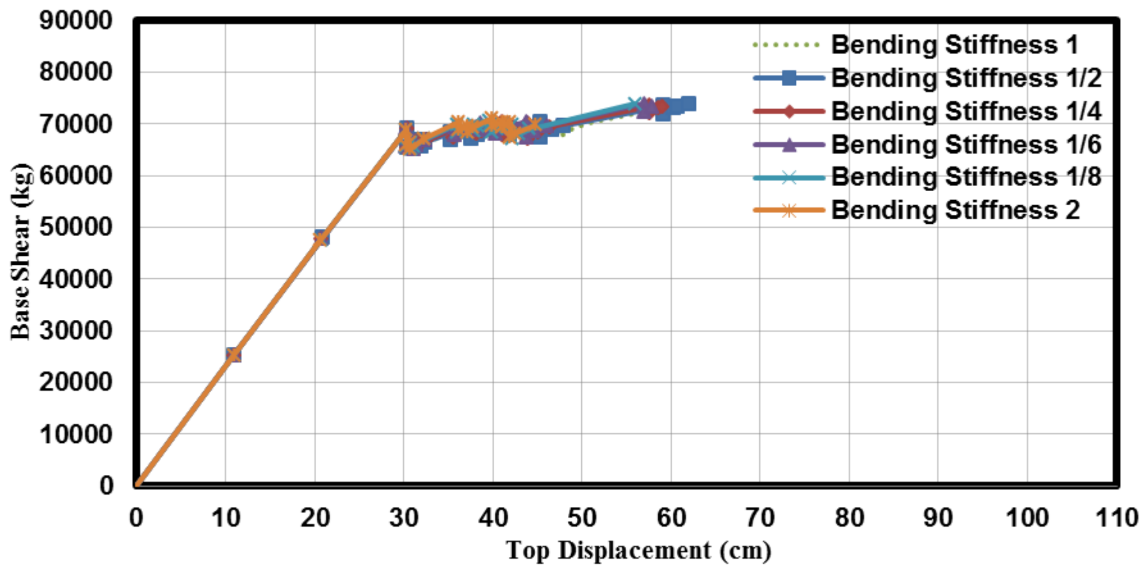

Figure 12: 12-story frame capacity curves for different bending stiffness

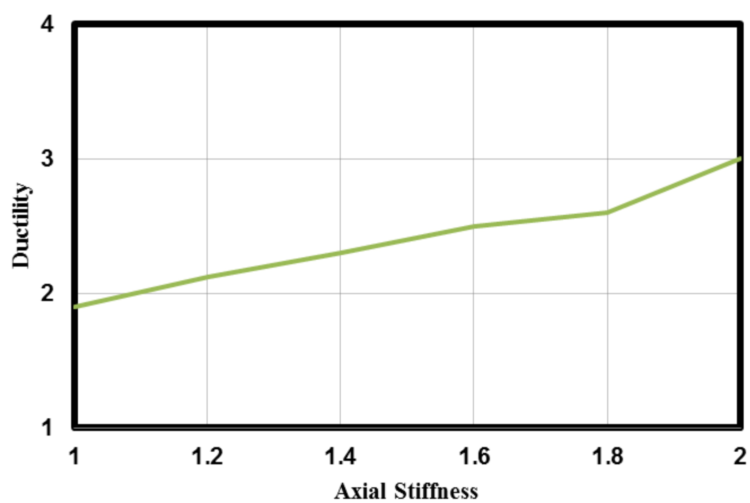

Figure 13: Ductility of 12-storey frames for different axial stiffness

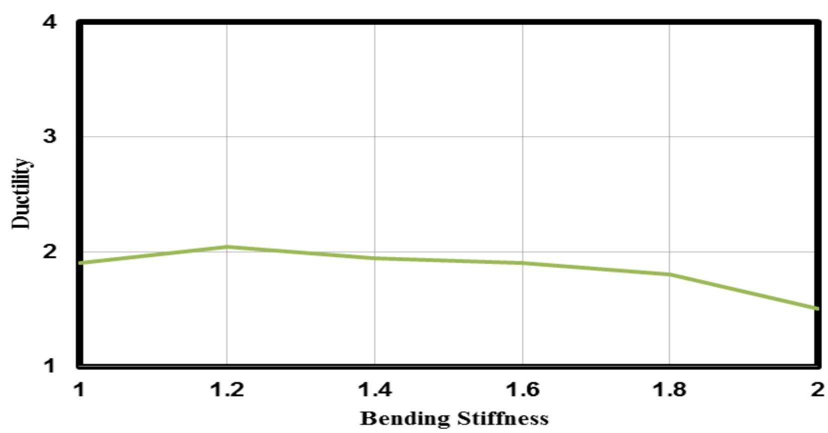

Figure 14: Ductility of 12-storey frames for different bending stiffness

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The results obtained for 12-storey frame are similar to 5-storey frame. Figure 11 shows that increase of the axial stiffness of the column causes to increase the elastic stiffness of the frame; and causes to reduce top displacement max. up to 30%. In Figure 12 it is clear that increase of the bending stiffness of the columns has no effect on the capacity curve and even increase of the bending stiffness of the columns more than 40 % caused to sudden fracture of frame. Figures 13 and 14 respectively have shown ductility of a 12-storey frame for the axial and bending stiffness of the columns.
Figures 13 and 14 also indicate that if the axial stiffness of columns is increased, the ductility of frame will be increased such that increase of the axial stiffness up double causes to increase the ductility of frame up 57%. But increase of the bending stiffness of the columns on high stiffness rate shall affect the ductility of frame and the frame which leads to brittle fracture. Figures 15 and 16, respectively show the relative displacement arising from dynamic analysis of a 12-storey frame for axial and bending stiffness of the columns.

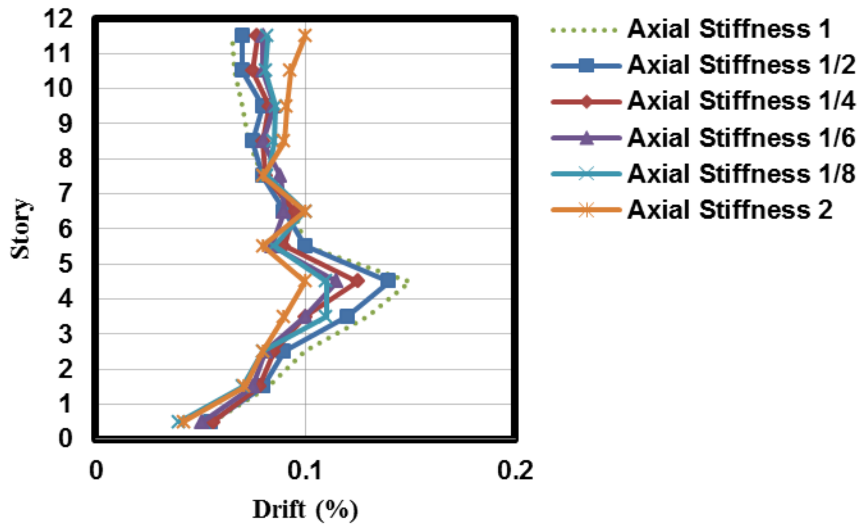

Figure 15: Relative displacement of 12-story frame for axial stiffness

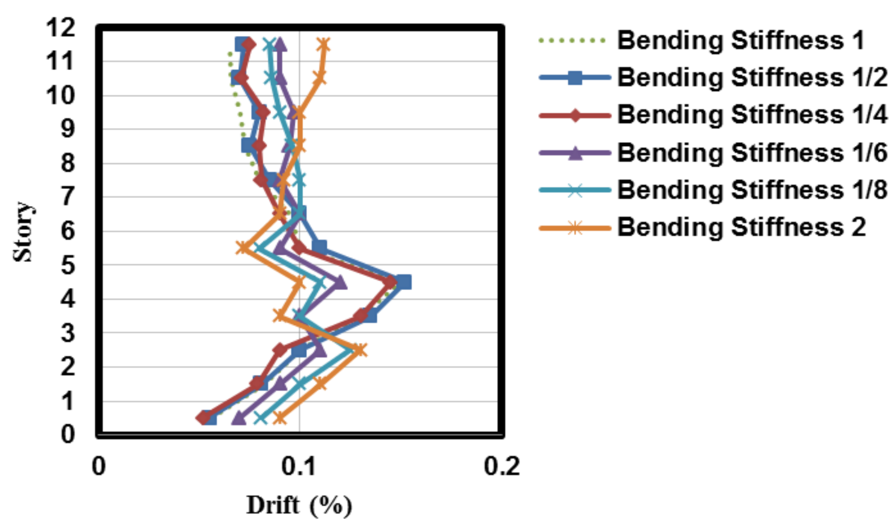

Figure 16: Relative displacement of 12-story frame for bending stiffness

As you can see, increase of axial stiffness of the columns reduces values of the lateral drift in the middle storeys, but the upper storeys have the contrary effect and increase the lateral drift. The results of dynamic

analysis are similar to the results of static analysis; and also indicate a positive effect of the axial stiffness on the middle storeys and somewhat one lower storeys. Also insignificant impact of the bending stiffness of columns on reduction of the lateral drift is observable; thus increase of the bending stiffness of columns can also increase the lateral drift at low and upper storeys.
Based on the results of nonlinear static analysis and time history dynamic analysis, for the short and long convergent braced frames, increase of the axial stiffness of the columns has a positive effect on improvement of the seismic behavior and also ductility. While increase of the bending stiffness of the columns has contrary results and can reduce the seismic performance.

RESULTS AND DISCUSSION

Here in this paper, the effect of the stiffness of columns in seismic behavior of the convergent braced frames was studied. The main purpose of this paper is to provide a mechanism to increase the seismic efficiency of convergent braced frames.
By the use of the nonlinear static analysis and evaluation of the capacity curve of these frames to fracture boundaries, effects of the axial stiffness and bending stiffness of columns has been evaluated; thus through the dynamic analysis the dynamic effects and results of static analysis were studied and evaluated. In general, the following results can be taken from this study:
1) The results gained by the short and long frames indicate the positive effect of increase of axial stiffness of columns and increase of ductility as well as improvement of the seismic behavior of frames, so that by increase of double axial stiffness, ductility can be increased up to 40-60%.
2) In the short and long frames, increase of the bending stiffness of columns has shown an insignificant impact on increase of seismic efficiency; even it can lead to reduce ductility and brittle fracture of the frames.
3) Through increase of the height of the frame and participation of the vibrational modes, the effect of axial and bending stiffness of the columns on the upper storeys will be reduced and can even increase the relative displacement of the storeys. So, in long frames, increase of axial stiffness of the columns could be suggested only in the middle and lower storey.
4) According to the results, it is recommended that into the convergent frames there are used some sections which have significant axial stiffness as compared with the bending stiffness. For this reason, the structure shall have high cross-sections with low depth.
5) Increase of ductility due to increase of axial stiffness of columns will lead to increase of behavior coefficient of the frame, so Seismic Regulations could be included some standards to supply the least axial stiffness rate in the columns, in order to allocate more behavior coefficient to the convergent braced frames.

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