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RELATIONSHIP BETWEEN LOCAL AND GLOBAL DUCTILITY DEMAND IN STEEL MOMENT RESISTING FRAMES

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SUMMARY

This paper includes the seismic behavior and inelastic response of steel moment resisting frames in order to study ductility demand on the basis of the Iranian code of practice for seismic resistant design of buildings (Standard 2800). The inelastic behavior of the two-dimensional frames under three records of Tabas, Naghan and El Centro, has been studied. A typical 3-bay frame with different stories (3, 6, 9, 12, 15) has been adopted. Ductility demand for each story of the steel frames was determined and the critical values are obtained. The effect of the parameters such as period time of vibration and P-Δ effect on local and global structural ductility demand has been studied. A primary relationship has been proposed between local and global ductility demands in different levels of ductility. With the help of this relationship, one can determine the critical local ductility demand of structures with respect to number of stories in any desired level of global ductility.

Keywords: ductility demand – steel moment resisting frame – earthquake forces

INTRODUCTION

In severe and most of moderate earthquakes, the structures pass the elastic limit and reach the inelastic state. The ductility under such earthquakes becomes very important. Designing structures on the basis of their elastic behavior towards intense earthquakes doesn't seem to be economical. The philosophy of designing earthquake resistant structures is based on the absorption of energy in inelastic deformation state during severe earthquakes. However, the complication and time consuming of nonlinear analysis limits this type of analysis to research activities rather than in practice.

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The method, which is applicable in all building codes of seismic design, incorporates the behavior factor (R). Behavior factor is a factor which includes the inelastic behavior of the structure and is the indication of the hidden resistance of the structure in a specific inelastic level by use of which structure is designed for much lower loading than the forces produced in a severe earthquake. Moreover, the inelastic deformation capacity of structures is defined by a factor called ductility factor, which is the ultimate deformation to yield deformation. In fact this factor indicates the rate of delay caused by the structure between the yield and damage state. Thus, the structure behavior factor depends directly on its ductility factor.

Using the analysis of two an 8 and 20-story frames under Mexico and El Centro records, Lee (1997) concluded that the ductility demand of system-level of multi-story steel structures is approximately between one third and half of the maximum rotational ductility demand of the element. His conclusions also indicated that the maximum rotational ductility demand of an element is considerably greater in weak column-strong beam than that of in strong column-weak beam. The system ductility demand for the two different frames is more or less the same [2].

Mahmoodi (2000) studied behavior of concrete moment resisting frames with different stories using inelastic analysis with nonlinear static method and also considered global and local (members) ductility capacity of the frames. They used displacement ductility and rotational ductility to determine global and local ductility, respectively, and proposed a formula for them in two states so that they could reach global ductility capacity of the structure once based on ductility capacity of beams and once based on ductility capacity of columns [1].

Story ductility for assessing the seismic damage may be used. The ductility used in code regulations mostly refers to system or global ductility. Thus, the comparison of these two kinds of ductility seems to be necessary for the evaluation of structural ductility demand to achieve the best design. In this research, the ductility demand, necessary for making the seismic design (demand/capacity), is evaluated. Although the capacity here is not aimed at, the capacity ductility is considered as an initial parameter of the design. For this reason a method that can acceptably reflect the relationship between story (local) and system (global) ductility demand in multi degree of freedom systems is to be considered. For the reason of variety and plurality of parameters involved in the ductility, there is no mathematical relationship between local and global ductility of structure that is one of the most complicated scientific subjects in inelastic analysis. In this paper, the effects of the number of stories and bays, period of structure, type of record, strain hardening and P-Δ effect are studied. An attempt is made to achieve a logical relationship between the story ductility in terms of number of stories and the different levels of global ductility of the structure by eliminating some of the low-effective parameters.

Steel moment resisting frames of 3-bay with different number of stories (3, 6, 9, 12, 15) are taken for the study. In all the frames, the stories are 3 meters high, 4 meters wide and bays length is 5 meters. The local soil chosen is type II (medium soil), importance factor is 1 and the building function is assumed as residential. The design acceleration is 0.35g. The dead load is taken, as 600 kg/m^2 and live load are 200 for stories and 150 kg/m^2 for the roof. Iran’s 2800 code and the AISC regulation are used for design.

ANALYSIS

The inelastic analysis of the structures under static and dynamic loading is performed by the nonlinear analysis software “DRAIN-2DX [3]”. Time history analysis is used to determine the maximum displacement response, and the Push-Over analysis to obtain yield displacement of the stories and the structure as a whole.

The earthquake records considered in this research are Tabas, Naghan, and El Centro whose peak ground accelerations are 0.93g, 0.72g and 0.35g respectively. These records were normalized to 0.5g and 1g.

Determination of local and global ductility

Local and global ductility should be determined in order to study the ductility demand relationship. The local and global ductility is defined as following:

$$\mu_L = \frac{d_{\max}}{dy} \tag{1}$$

In which μ_L is the local ductility, d_{max} is the maximum displacement of the story which has been obtained under different records, and d_y is the corresponding yield displacement of the story that can be obtained with several methods.

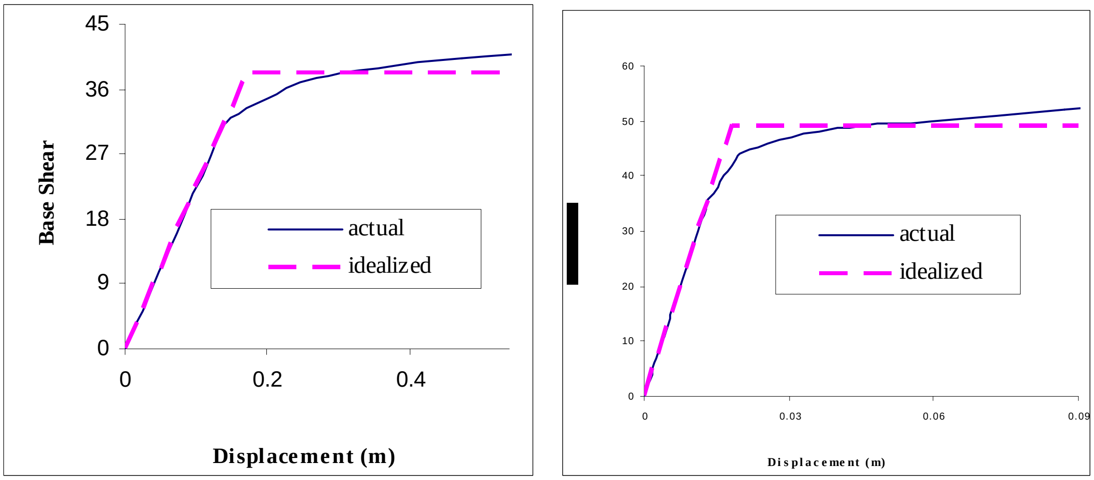
To determine the global ductility a formula similar to equation (1) has been used.

$$\mu_g = \frac{D_{\max}}{D_y} \tag{2}$$

In which μ_g is the global ductility, D_{max} is the maximum displacement of the structure (roof), and D_y is the yield displacement of the whole structure.

Story and global yield displacement of structure

After designing the frames, the static analysis (Push-over) was used to obtain the story and global yield displacement of the structure. For instance to determine the yield displacement of the first story a concentrated force is exerted on the story level and, then by increasing this force up to which the relative displacement reaches 0.03 times story height, one can obtain curves of relative displacement verses story base shear. An elasto-plastic model for the above curves can be considered, so that the effect of this model would be equal to the effect of the real curve [5]. In this method, drawing the complete elasto-plastic curve is based on the equaling of the structure energy absorption. It means that the area under the curve that indicates the amount of energy exerted to the structure should be equal in the elasto-plastic and the actual case. The yield point of the story can be obtained from these curves (fig.1).



a- Whole structure **b- First story**

Fig.1 Elasto-Plastic curve of the 6-story building

The global yield point can be obtained in the same manner as that of the story yields point, except that the loading pattern is inverted triangular. The ultimate limit for the above curves is 0.03 times the building height.

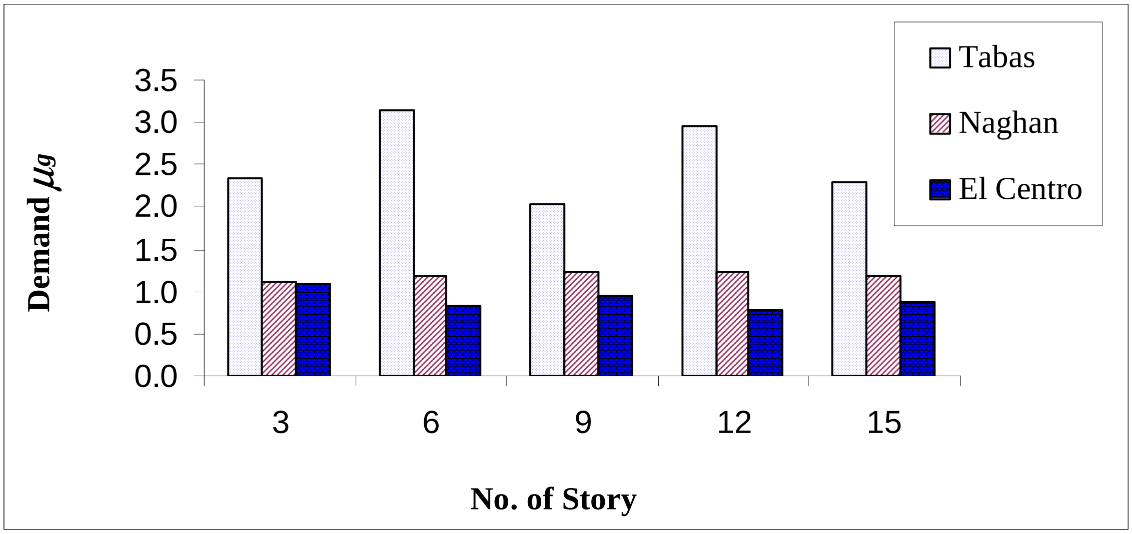


Fig.2 Comparison of global ductility demand of the frames

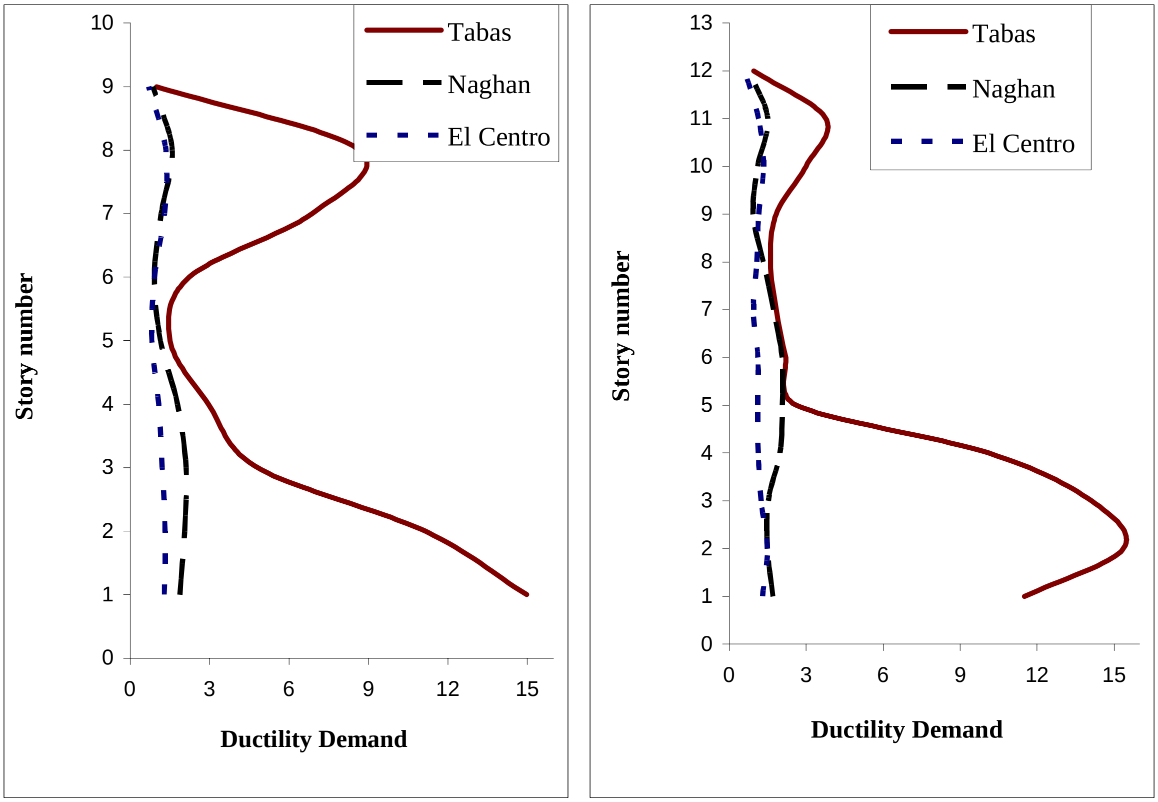


Fig.3 Comparison of story ductility demands of the 9&12-story frames

The ductility demand for different frames has been obtained under three mentioned actual and normalized records. The comparative curves of the global ductility demands of the 9 and 12-story frames are illustrated in figures 2 and 3 respectively. As it is shown, global ductility demands of the frames under Tabas record is greater than the two other records, because of its high peak ground acceleration (0.93g) and long duration. On the other hand, the ductility demand under Naghan and El Centro records which is near 1 indicates that the structure has just entered to nonlinear zone. Figure 3 shows that local ductility demand in the lower stories of mentioned frames under Tabas record is more than those under the other two records. The ductility demand in upper stories may be due to the effect of higher modes of vibration.

Effect of different parameters

The period of vibration of the building frames is one of the effective parameters on ductility demand. In order to investigate this effect, five 6-story three bays frames having different period of vibrations are taken. The local and global ductility demand graph under Tabas earthquake is shown in figures 4 and 5.

As shown, the story ductility demand increases with the increase of the natural period of vibration up to 1.59 seconds (in this case) where soft story is formed. The same pattern is seen in ductility demand.

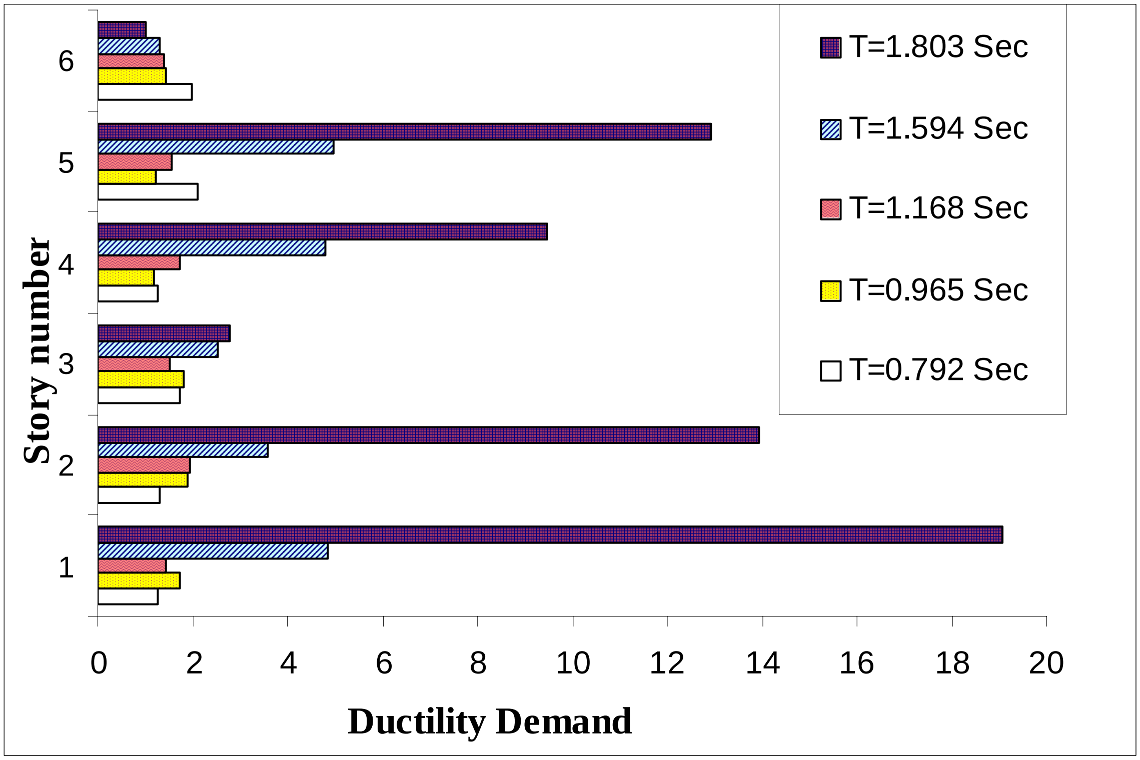


Fig.4 Variation of story ductility demand with period of vibration under Tabas earthquake

The effect of P-Δ on ductility demand was investigated. The results obtained show that the P-Δ effect on ductility of stories is insignificant in low-rise structures and is considerable in taller buildings only when the earthquake is severe. For example, the ductility demand of the critical story in the 12-story frame is equal to 4.51 while this value reaches 15.36 considering P-Δ effect, under Tabas earthquake. It is worth mentioning that the effect of this parameter on global ductility demand is less and is only considerable under Tabas earthquake.

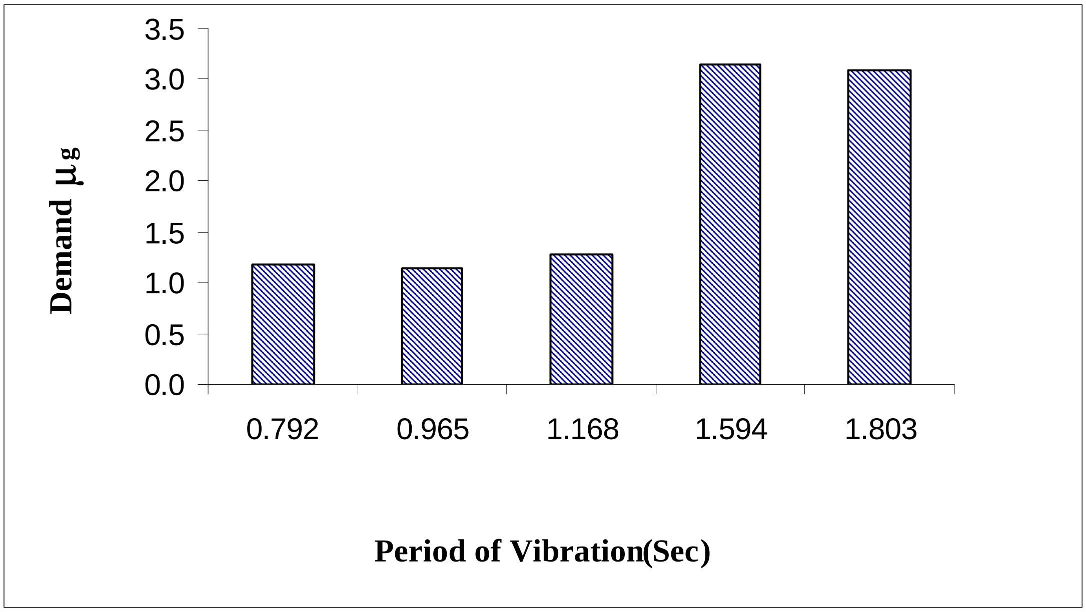


Fig.5 Variation of global ductility demand of the 6-story frame with period of vibration under Tabas earthquake

In table 1 and figure 6, the *P-Δ* effect on the local and global ductility demand of 9-story frame are shown.

Table 1- *P-Δ* effects on local ductility demand in the 9-story frame

Story No.	Story Ductility With p-delta			Story Ductility Without p-delta		
	Tabas	Naghan	Elcentro	Tabas	Naghan	Elcentro
1	14.97	1.98	1.29	5.03	1.92	1.06
2	11.15	2.06	1.32	4.10	2.05	1.11
3	4.82	2.12	1.22	3.50	1.95	0.99
4	2.96	1.80	1.08	3.01	1.69	0.98
5	1.52	1.15	0.82	1.66	1.09	0.83
6	2.23	0.92	0.92	2.00	0.91	0.89
7	6.87	1.18	1.33	3.75	1.13	1.21
8	8.65	1.59	1.44	4.57	1.55	1.36
9	1.00	0.87	0.71	1.00	0.90	0.70

Strain-hardening effect on displacement ductility response has also been studied. This effect on the global ductility demand of structure is very low especially under record with low peak ground acceleration like El Centro record, since the structures are less likely to reach to nonlinear zone. The decrease in ductility demand as the result of strain hardening is almost ignorable. In addition, the decrease in ductility demand in lower stories in consequences of the increase in strain hardening is more obvious.

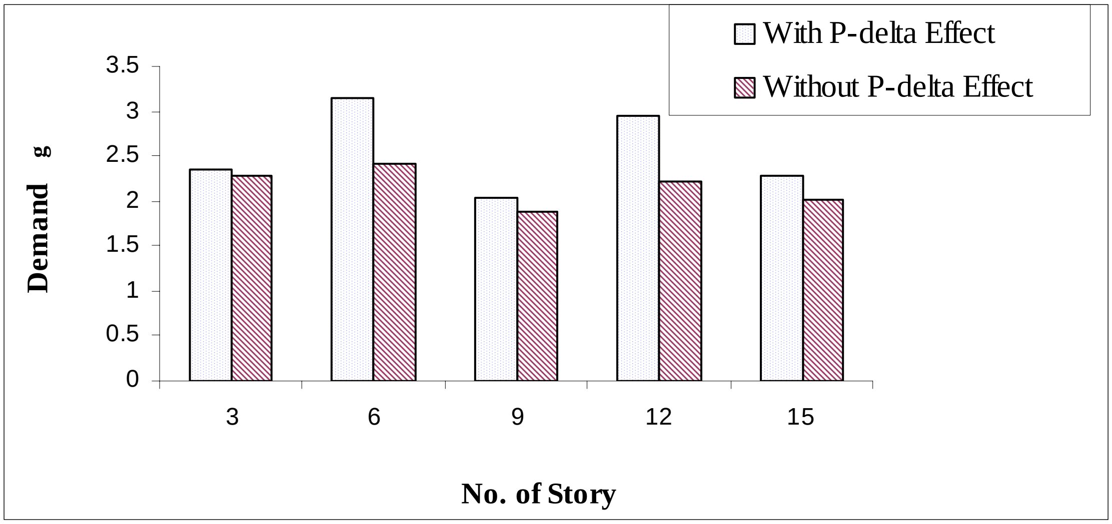


Fig.6 ***P-Δ*** **effect on global ductility demand of the frames under Tabas earthquake**

Table 2- Strain hardening effect on local ductility demand in the 6-story frame under Tabas earthquake

Story No.	**Story Ductility With Strain Hardening Variations**				
	0.02	**0.60**	**0.10**	**0.15**	**0.20**
1	**4.84**	**4.25**	**3.82**	**3.36**	**3.04**
2	**3.52**	**2.94**	**2.81**	**2.69**	**2.54**
3	**1.29**	**1.74**	**1.66**	**1.71**	**1.72**
4	**0.44**	**0.91**	**1.51**	**1.67**	**2.07**
5	**4.78**	**2.95**	**2.08**	**1.88**	**1.63**
6	**0.60**	**0.66**	**0.63**	**0.63**	**0.64**

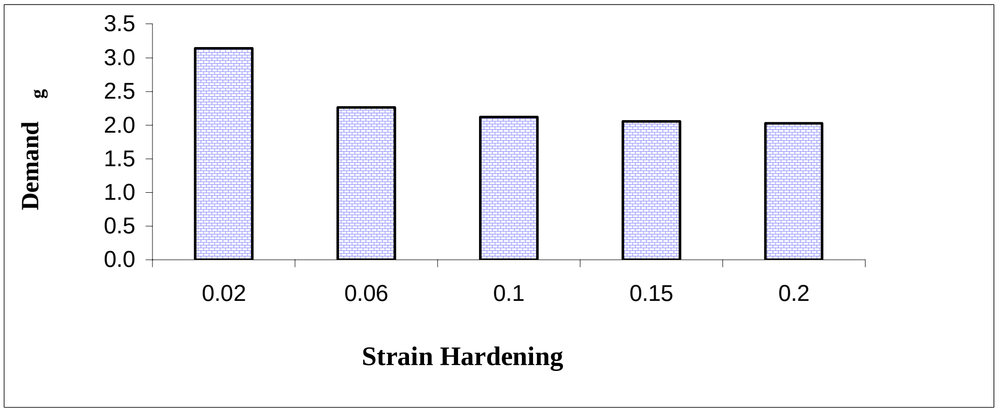


Fig.7 Strain hardening effect on global ductility demand in the 6-story frame under Tabas earthquake

The effect of the number of bays on local and global ductility demand has been studied. The results indicate that, the local and global ductility demand of structures with different numbers of bays don't change significantly. This conclusion is observed in all the three records.

Relationship between local and global ductility demand

Since each structure has different local ductility demands with respect to number of stories, finding a relationship between these demands in all the stories is not possible. Thus, critical ductility demand may be used. Critical story in a structure is defined as the story that has more ductility demand than other stories. The structure collapse or come to its ultimate limit when one story or more stories reaches the critical state. Using critical story, seem to be logical. Here, for instance, the comparative curves of global and critical story ductility demands of the structures under Tabas and El Centro records are shown in figure 8.

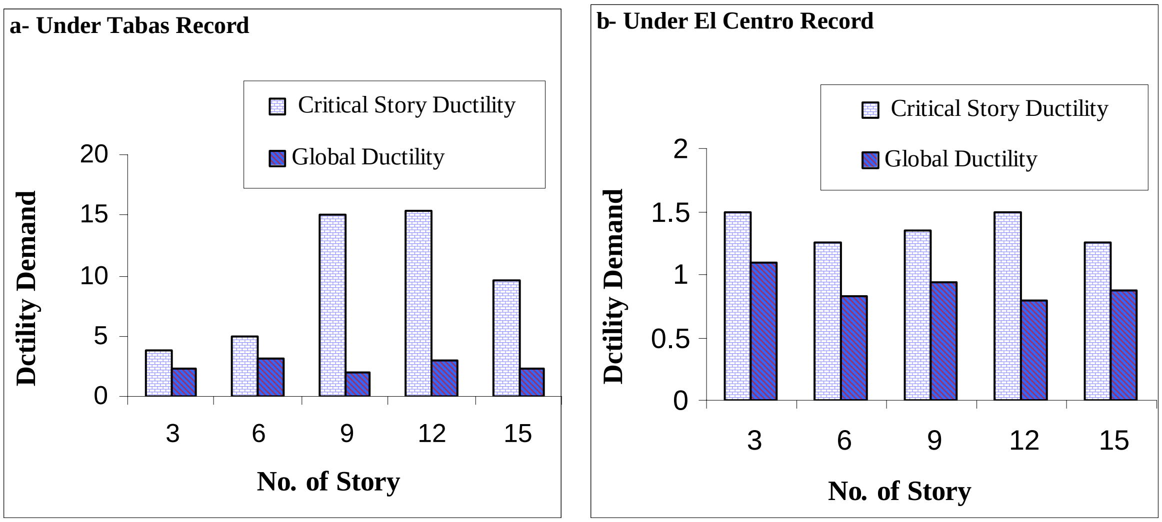
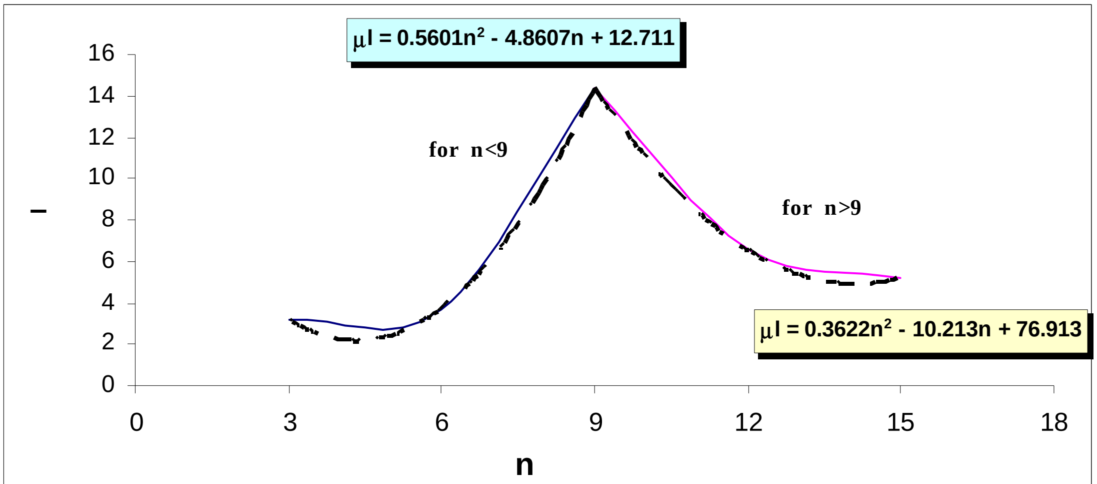


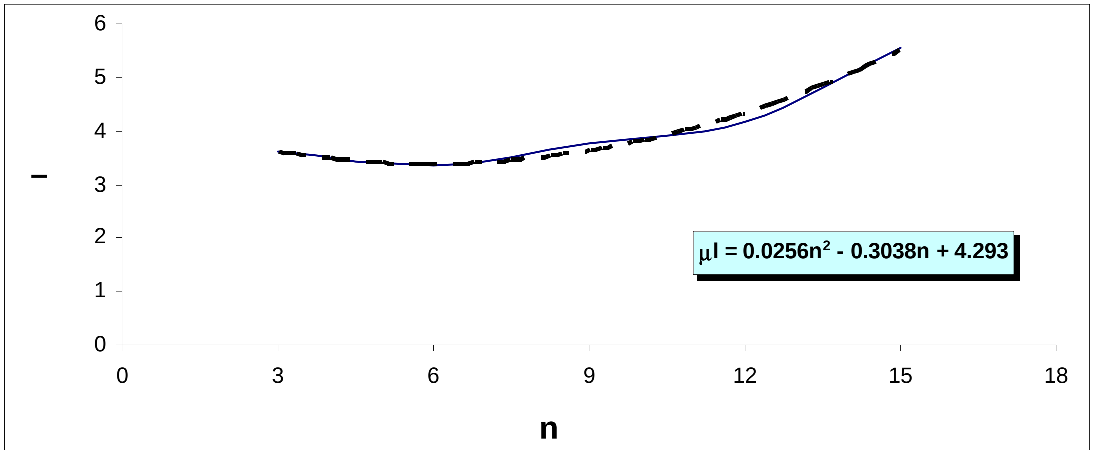
Fig.8 Comparison of local and global ductility demand of the multi-story frames

Different levels of global ductility demand of the structures have been considered and their corresponding critical story ductility demands were obtained by changing the peak ground acceleration of the three records. Due to the variety of ductility demands under different records, an attempt is made to classify and generalize ductility demand to find the logical relationship. The ductility levels have been considered in three global ductility demand limit; 1, 2 and 3. It is worth mentioning that some of the structures is collapsed in the higher levels of 4, 5.

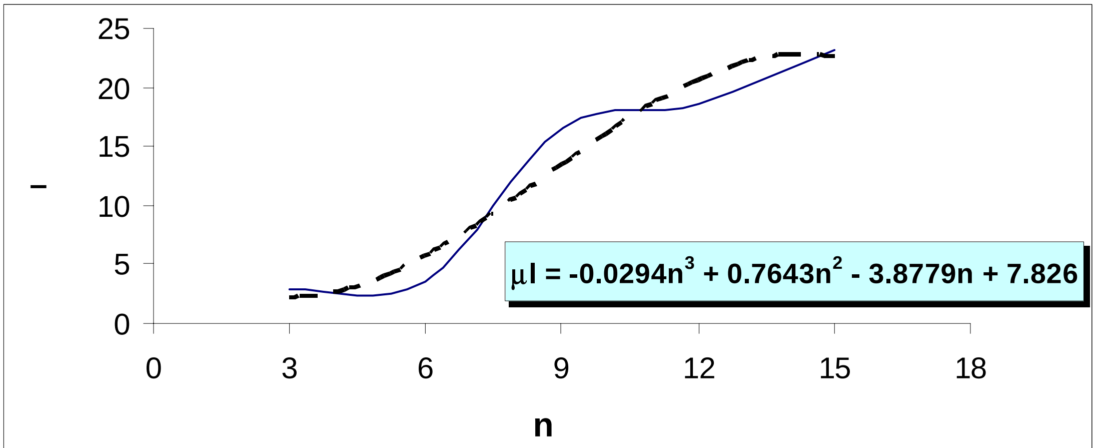
Curves are drawn for the critical story ductility demand verses number of stories in the levels of global ductility demands. A relationship between critical story ductility demand and number of stories in different levels of global ductility demand is proposed by fitting 2nd and 3rd degree order curves. These relationships have been obtained under Tabas, Naghan, and El Centro earthquake.
In figure 9, three examples of such relationship are shown for ductility demand of two.



a- Tabas Record



b- Naghan Record



c- El Centro Record

Fig.9 Regression curves of critical story ductility demand verses number of story in global ductility level of 2

CONCLUSION

The following conclusions are drawn from the studies carried out in this paper:

1. The ductility demand of the critical story in most cases occurs in the lower stories (first or second) of the structure and the amount is significantly high in tall structures especially under severe earthquakes.
2. The critical local ductility demands of the structures under Naghan and El Centro earthquakes are 1.30 to 1.89 times the global ductility demand. This proportion changes to 1.59 to 7.34 under Tabas earthquake.
3. The local and global ductility demands increase when the fundamental period of the structure increases specially in the lower stories.
4. The results indicate that the ductility demand of the lower stories under variation of peak acceleration and type of record do not significantly vary.

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