A PROPOSED LATERAL LOAD PATTERN USING SEISMIC ENERGY DISTRIBUTION ALONG THE HEIGHT OF BUILDINGS

M. Motamedi[1] and F. Nateghi-A.[2]

[1] *Assistant Professor, Dept. of Civil Engineering , Islamic Azad University, South Tehran Branch, Tehran, Iran and Postdoctoral Fellow, Dept. of Civil Engineering, The University of British Columbia, Vancouver, Canada*
[2] *Professor, International Institute of Earthquake Engineering & Seismology, Tehran, Iran*
Email: mmotamedi@civil.ubc.ca, nateghi@iiees.ac.ir

ABSTRACT :

In this paper, a new pattern for lateral load used in equivalent static method for seismic designing the structures, is proposed and effect of this pattern on distribution of earthquake energy absorption and damage along the height of the buildings is studied. Proposed pattern for lateral load is a triangular-rectangular pattern based on current triangular distribution in Iranian Seismic Code. A dual step absorbing energy system for steel frame connections is the other suggestion for improving the inelastic behavior of the steel frames against the severe earthquakes. The current triangular lateral load pattern in seismic codes provides the strength and stiffness more than seismic demand in upper stories and it affects the capacity-demand ratio variable along the height of buildings. Earthquake reports show that damage concentration usually happens in one or some of the lower stories of a building. Also inelastic dynamic analysis shows the plastic hinges occurring and their developing in lower stories, which causes the story mechanism and collapse of the structure. Permanent deformation of structural elements and soft story mechanism are one of the main reasons for buildings damage and their failure in major earthquakes. In order to investigate on effect of proposed lateral load pattern on energy absorption and damage distribution along the height of the buildings, two steel moment resisting frames, 4 and 9 story, with four analytical models by different lateral load pattern and connection behavior, were considered and subjected to a series of inelastic dynamic analysis due to the numerous records. The results of the inelastic time history analysis confirmed that using the triangular-rectangular lateral load pattern caused the better uniform earthquake energy distribution along the height of buildings and prevented damage localization in lower stories. The proposed lateral load pattern did not change the earthquake input energy in comparison to the current lateral load distribution and it was more effective for mid-height frame model.

KEYWORDS: Lateral load pattern, Seismic codes, Energy absorption, Inelastic dynamic analysis, hysteretic behavior.

1. INTRODUCTION

Multi-story buildings with various stiffness and strength over their height have experienced considerable damage in the past earthquakes. Damage due to a soft story is one of the most typical failure mechanism for mid-height buildings. Figure 1 shows this type of damage at the ground floor of a multi story hospital building during San Fernando earthquake in 1971. Several studies have shown that the ratio of stiffness and strength provided in the story elements has great influence on damage concentration in a story. By changing the design of structural elements, dynamic responses of the structure have been changed, as well as the distribution of structural damage along the height of the building has been changed. On the other words, difference in capacity-demand ratio in structural elements causes a variable (not uniform) distribution of hysteretic energy absorption along the height of a building and thus damage is localizing in a weak or soft story. In this situation the capacity of the other stories are not participating in lateral resisting. In the optimum structural design philosophy, most of the elements should yield in the same time during a severe earthquake. Current seismic codes use a triangular lateral load pattern for designing the structural lateral resistant elements, that seems concludes damage concentration. This paper, deals with a proposed lateral load pattern for achieving more uniformity in earthquake energy distribution and also for preventing damage concentration in one or some particular stories.

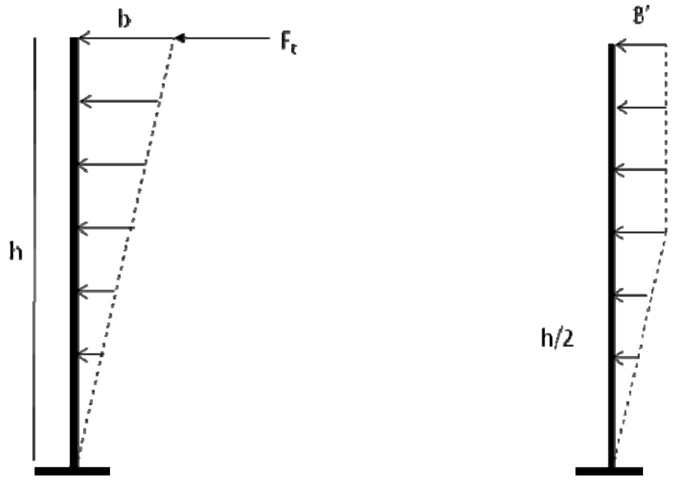
Figure 1 Damage due to a soft story at the ground floor in a multi story building during San Fernando earthquake in California, 1971

2. PROPOSED LATERAL LOAD PATTERN

In equivalent static method for seismic designing of buildings, base shear is distributed along the height of the building by assuming the linear dynamic behavior for the first mode of vibration of the structure. Most of the seismic codes present the triangular pattern for distribution of lateral load as it is shown in Figure 2(b). During severe earthquakes, nonlinear large deformations occur and the assumption of linear distribution of lateral loads is not valid. Figure 2 presents the proposed lateral load pattern which provides less design loads in upper stories and allows them to perform in plastic range. In this pattern B' is derived from the Eqn. 2.1.

$$B' = 2b/3 \tag{2.1}$$

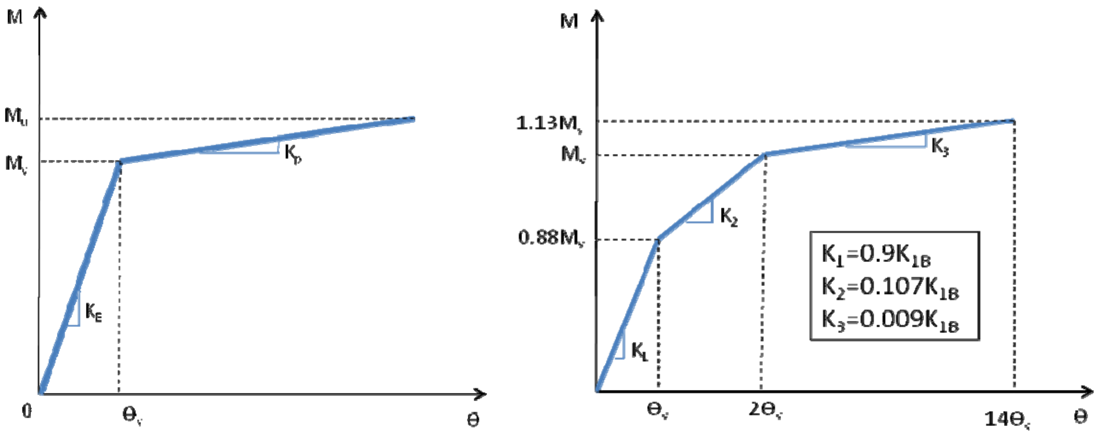
Where b and B' are defined in Figure 2. This equation is derived by equating the area of two different patterns; triangular pattern and proposed pattern. In this study, the effect of F_t, the higher modes effect parameter, is ignored.



(a) (b)

Figure 2 Lateral load distribution: a) Triangular common pattern used in the seismic codes; b) The proposed lateral load pattern

Providing a dual step absorbing energy system in steel frame connections is the other suggestion for improving the damage distribution along the height of the buildings. Basically, using this system delays on stiffness degradation after yielding point in the structural elements and allows the resisting elements in the other stories participate in lateral bearing system and absorb earthquake energy. Figure 3 illustrates the bilinear and proposed trilinear ideal model for elasto-plastic behavior of structural connections, respectively.

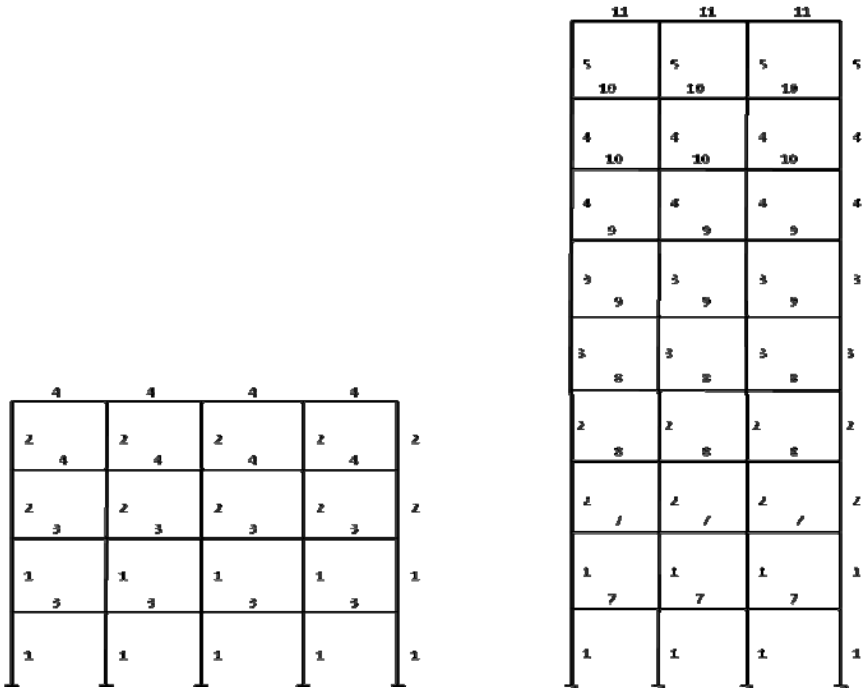


(a) (b)

Figure 3 Elasto-Plastic models for behavior of structural elements: a) bilinear ideal model; b) proposed trilinear ideal model

3. ANALYTICAL CASE STUDIES

A series of analytical studies were performed for investigating on effect of proposed lateral load pattern and materials model on distribution of energy absorption and story damage. Two residential steel buildings, 4 and 9 story, with moment resistant frame system in city of Tehran were considered. The plan and dimensions of buildings were similar to current construction style in Iran. 3 m for height of stories and 5 m for length of spans were selected. The type of steel materials conformed by ST 37 Iranian steel. The dead load and live load were 500 and 200 Kg/m^2, respectively for stories. 2800 Iranian Seismic Code and National Building Code of Iran, Chapter 10 were used for designing. Geometry of steel frames used for analytical studies are illustrated in Figure 4.



(a) (b)

Figure 4 Geometry of steel frames used for analytical studies: a) 4 story - 4 bay frame; b) 9 story - 3 bay steel

Each steel frame was designed in four models which are described in Table 1. Lateral load pattern and connection behavior are different in these four models.

Table 1 Definition of models used in analytical case studies

Model Title	Description of Model
Model # 1	Designed based on triangular load pattern and bilinear model for connections
Model # 2	Designed based on proposed load pattern and trilinear model for connections
Model # 3	Designed based on triangular load pattern and bilinear model for connections
Model # 4	Designed based on proposed load pattern and trilinear model for connections

4. NONLINEAR DYNAMIC ANALYSIS

The steel frames with a variety of four different models were studied by nonlinear dynamic analysis. Inelastic time history analyses were conducted using DRAIN-2DX software, a general purpose computer program for static and dynamic analysis of plane structures. The step-by-step integration scheme for dynamic analysis varies the time step during the analysis on the basis of input error tolerances. Energy balance computations are performed, identifying the static work, the energy absorbed by viscous damping, the kinetic energy, and the input energy. Simple inelastic beam column (Type04) and simple inelastic connection (Type05) which allows for translational as well as rotational force transfer were used for modeling the frames.

The values of moments and curvatures in Figure 3(b) were derived by try and error in several programs running to achieve the best behavior of the frame models. Basically, they should be measured by an experimental study of the connection specimen.

Four ground motion records were used for time history analysis. Scaling factors were selected for limiting the story drift in the same amount, between 0.013h – 0.018h, which is clarified by 2800 Iranian seismic code (about 4 to 5.5 cm). By using these selected scale factors, the maximum input earthquake energy for all the models were made equal. Characteristics of ground motion records used in nonlinear dynamic analyzing program, including duration, peak ground acceleration (PGA) and modified scaled PGA, are presented in Table 2.

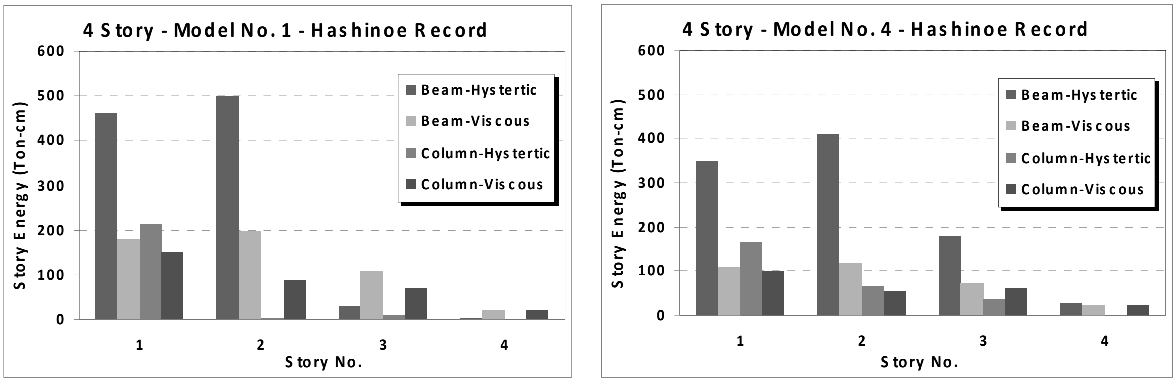
Table 2 Characteristics of ground motion records used in analyzing program

Ground Motion Records	Duration (Sec.)	PGA (g)	Modified Scaled PGA (g)
El-centro (1940)	53.74	0.348 g	0.52 g
Sanfernando (1971)	41.92	1.17 g	0.53 g
Taft (1952)	54.42	0.18 g	0.45 g
Hashinohe (1968)	36.04	0.2 g	0.2 g

5. RESULTS

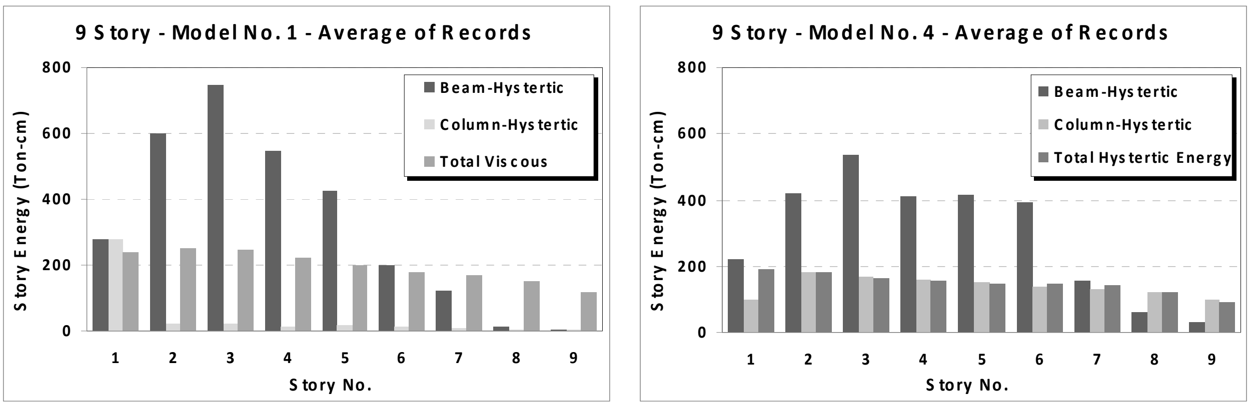
The results of analytical studies are presented. Figure 5 and 6 show the absorbed energy distributed along the height of the 4 and 9 story frame models, respectively. As it is shown in these figures, basically, the distribution of absorbed energy in columns was more uniform than the beams, especially in 9 story frame. So, the new proposed pattern was more sufficient to make uniformity of absorbed energy distribution in the beams. Also the effect of proposed lateral load pattern on making uniformity in taller frame model was greater than the shorter one.

Maximum dynamic responses of both 4 and 9 story frame models including absorbed story energy, story drift and story shear due to average of records are illustrated in Figure 7. The proposed lateral load pattern and trilinear



(a) (b)

Figure 5 Absorbed story energy in 4 story frame model due to Hashinohe record : a) Model # 1; b) Model # 4



(a) (b)

Figure 6 Absorbed story energy in 9 story frame model due to average of records : a) Model # 1; b) Model # 4

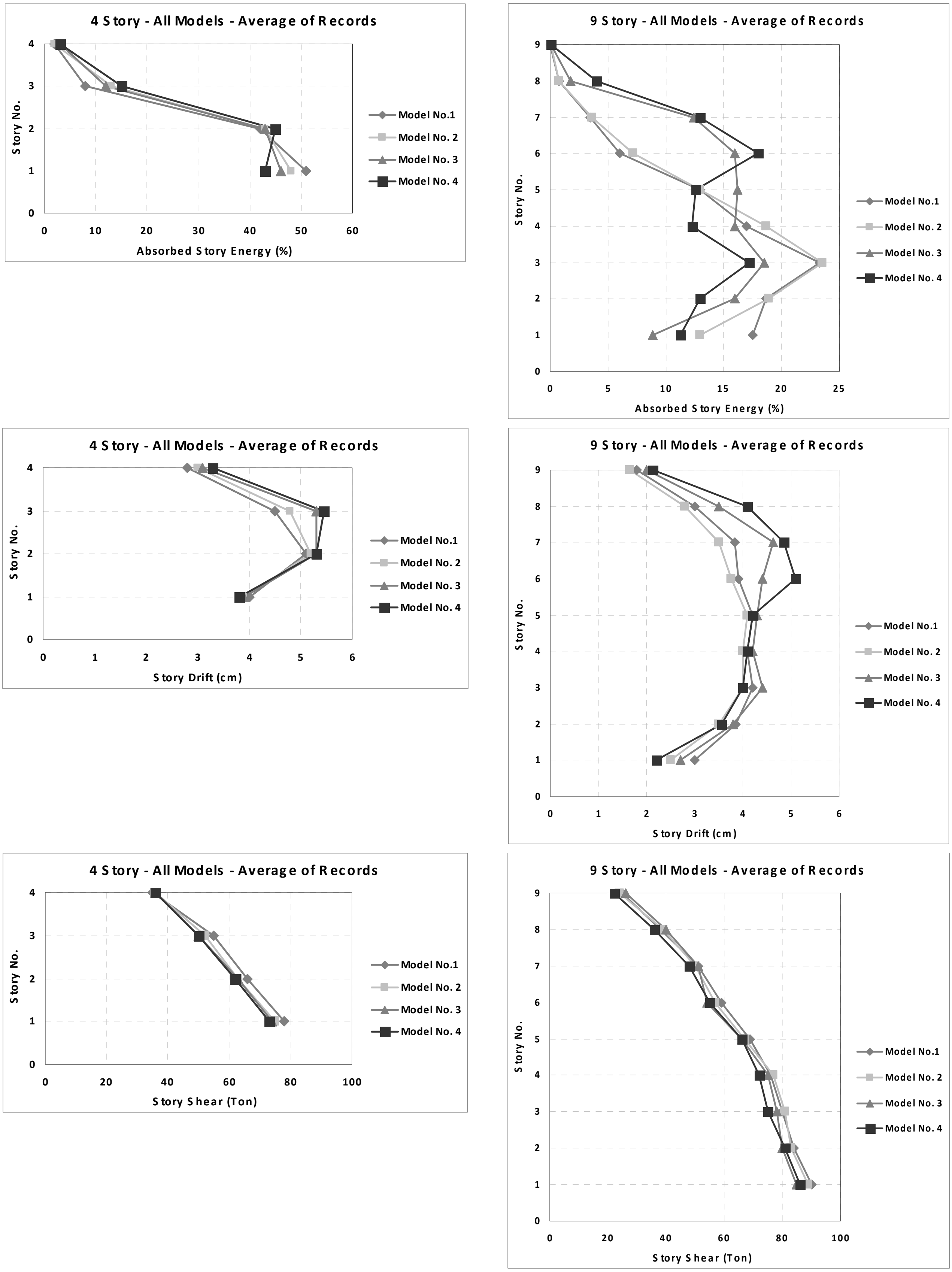
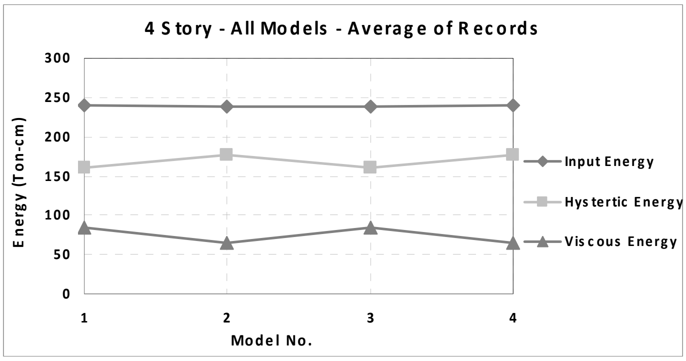
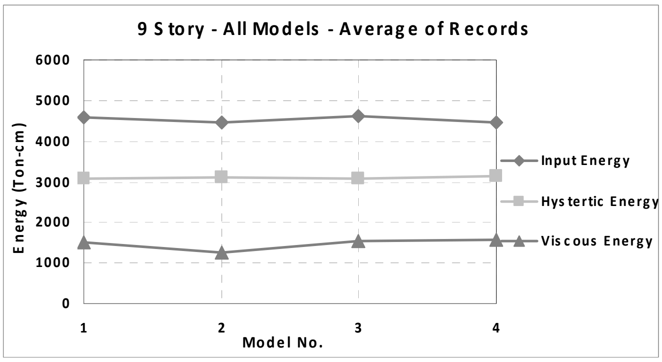


Figure 7 Dynamic responses of analytical models including absorbed story energy, maximum story drift and maximum story shear due to average of records: a) 4 story frame; b) 9 story frame





(a) (b)

Figure 8 Difference in input energy, hysteretic energy and viscous energy in different models due to average of records: a) 4 story frame; b) 9 story frame

Elasto-plastic model changed the absorbed energy distribution to a uniform shape, especially for the 9 story model. The absorbed energy was increasing in the upper stories and decreasing in the lower stories up to 40%. The story drift in upper stories was increasing due to reducing of design loads. There was no changing in the story shear distribution for all the models. Figure 8 shows the input earthquake energy, hysteretic and viscous energy in all analytical models for the 4 and 9 story frames due to average of the records. As it shows, the amount of input energy was the same in all models. But, considering the proposed trilinear elasto-plastic model changed the amount of hysteretic and viscous energy in the different analytical models.

6. CONCLUSIONS

The purpose of this study was to evaluate the effect of proposed lateral load pattern on distribution of earthquake energy absorption along the height of the buildings and preventing of damage concentration. Important conclusions from this study, which were obtained by conducting several time history analyses with different models and due to the numerous records are:

1- The results of the inelastic dynamic analysis confirmed that using the triangular-rectangular lateral load pattern caused the better uniform earthquake energy absorption along the height of buildings and prevented damage localization in lower stories. The new lateral load pattern did not change the earthquake input energy in comparison to current lateral load distribution.

2- Using the dual step absorbing energy system in the structural connections had a considerable influence on increasing the total amount of hysteretic energy and also decreasing the viscous energy in the case study models.

3- Lateral load pattern had great effect on absorbed energy in the beams in comparison to the columns and using the proposed pattern for designing the case study models increased the uniformity of the absorbed energy in the beams.

4- Analytical studies showed that using the new lateral load pattern was more effective for mid-height buildings than the low-rise buildings as it was observed by the results of analyzing the 4 and 9 story case study models.

7. ACKNOWLEDGMENTS

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