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Research Article

Evaluation of the performance of moment resisting steel frames under near field and far field earthquakes based on energy conception

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ABSTRACT

Various researches show that other parameters are also involved in seismic response of structures and only the force-displacement issue in elastic or even bilinear elastic perfectly plastic states is not capable of justifying the entire seismic behaviors of structures. Therefore, researchers are seeking for propose a new method in the seismic design of structures. In this regards and during the last two decades, the subject of energy has been highly taken into consideration, because, they have found many of justifiable and applicable parameters and behaviors in seismic design of structures along with the achieved advances in this method. In the present paper, three structures with ordinary moment resisting frames and number of stories of 3, 6, and 12 have been subjected to equivalent static loading in SAP2000 (VER 16.0.0) software. Then, these structures have been nonlinearly analyzed in PERFORM-3D (VER 5.0) software under Loma Prieta, Landers, and Northridge earthquakes in far and near fields. The obtained results indicate that the input energy to structure is larger in the cases of near field (near fault) earthquakes.

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INTRODUCTION

One of the great challenges of human in the history of his habitation on Earth, has been dealing with natural hazards and protect his live and property, when facing these events. Iran is among the high seismicity countries of the world. In the recent years, averagely one earthquake with huge life and financial losses has occurred in a part of the country in each 5 years and unfortunately, Iran is among the countries that earthquake is always accompanied by the possibility of high life losses.

Today, it is well known that the structures designed based on existing standards will suffer heavy losses in strong earthquakes. However, some seismic design regulations

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(especially in the primary design of structures) are still built on the basis of elastic analysis and using from a static load equivalent with earthquake [1, 2].

Various researches show that the destructive effect of the earthquake is highly influenced by the seismic input energy to structures during earthquake that its prediction is not completely possible by nonlinear response spectra or displacement.

For the first time, Housner (1956) proposed an analysis of limit design based on energy, in which the adequate energy absorption capacity of structure against strong earthquakes was being proposed as a factor of safety and health of the structure. He had expressed that during earthquake, a part of the earthquake energy is dissipated and the other part remains as kinetic and strain energy [3]. Zahrah and Hall (1984) studied the influencing parameters on seismic energy absorption in single degree of freedom systems and concluded that ductility does not consider parameters of the duration of string ground motion, frequency content, and cumulative plastic deformation, singly [4]. Akiyama (1985) published a book in the field of limit state design of structures, in which the fundamental principles of energy method were descripted using the method proposed by Housner and on this basis; he presented a method for the design of steel structures [5]. Uang and Bertero (1988) are among pioneer researchers in the field of energy method that have caused to the development of researchers in this field [6, 7]. They evaluated the use of input energy method to be useful for selecting design earthquakes and introduced input energy as a reliable parameter for defining damage potential of structures. Moreover, their studies specified some ambiguities existing in the previous researches related to input energy and the calculation of remained energy dissipation capacity. Friswell and Cao (2008) studied the influence of earthquake induced energy concentration on the nonlinear response of RC buildings and observed that most of energy concentration is seen in the vicinity of the main period of structure [8]. It was determined by the performed studies that approximately the entire influencing parameter on the seismic behavior of structures find justifiability in the form of energy conception. Structures are entered inelastic region under the effects of sever earthquakes, hence, the study of inelastic behavior of structures subjected to these earthquakes seems to be necessary.

The present research aims to investigate how the relative displacement and hysteresis energy are distributed among stories of moment resisting steel buildings designed in accordance with building design regulations against earthquake (2800 Iranian earthquake standard, 4th edition [9]). Recently Rong and Li [10] undertook a probabilistic assessment of the effect of potential blast loadings and their resultant damage scale on building structures. Using Monte-Carlo simulation and single-degree-of-freedom (SDOF) system, they examined the maximum displacement and displacement ductility factor of a reinforced concrete structure with flexural frames under blast loadings.

Stewart and Netherton [11] investigated the effect of window glazing damage subjected to explosive blast loading. They used structural reliability techniques to derive explosive fragility curves. In this research, the structure was subjected to explosive loading for a variety of scenarios. They obtained a risk-based measure for calculating the probable damage of a structure subjected to explosive loading. Parisi and Augenti [12] performed a research on the ability and robustness of a RC building, which was designed, based on seismic design codes and subjected to explosive loads. In their research, they generated scenarios based on the location and the amount of explosives. A Pushdown analysis was performed to evaluate the robustness of the building against explosive load. Cizelij et al. [13], proposed an analysis method for a structure subjected to blast load. Their proposed method predicted failure and non-linear responses. The obtained results were comparable to dynamic simulations.

ENERGY-BASED DESIGN PHILOSOPHY

Resisting design of structures against earthquake with energy conception or limit design are based on the assumption that it is possible to predict energy demand during an earthquake or a set of earthquakes or the expression of energy capacity of a structural member or system.

Energy equations are written as follows [14-16]:

$$E_I = (E_K + E_S) + (E_D + E_H) \tag{1}$$

where, E_I is input energy, E_A stored elastic energy, E_K kinetic energy, E_D dissipated energy caused by equivalent hysteretic linear viscous damping, E_H dissipated energy in residual plastic deformation, and E_S is the elastic strain energy. Generally, due to the close relation between input energy value (E_I) and area under the curve of squared gravity acceleration, the time history of input energy follows earthquake characteristics.

E_H is the energy dissipated in the elastic system behavior after yielding of members. Due to the direct relation of damages to the structure with hysteretic energy, this term of energy is the most important component of energy equation. The amount of energy exerted to structure and its absorption and dissipation can represent the overall performance of the structure against earthquake, however it does not present a model of how it behaves. In other words, the amount of hysteretic energy (E_H) in a structure is the index of damage level or its ductility, but it is not capable of representing damage distribution in various components of the structure or the mechanism of yielding or collapsing. Whereas, energy distribution in structure follows the structure model and its characteristics, largely. Damage distribution in a high-rise building is corresponding to its strength distribution in height. The presence of a weak story leads to damage concentration in that story and collapse of the structure, finally.

Viscous damping energy (E_D) is not of any influence in structural damage, but leads to reduce damage and is considered as the desirable component of the energy equation. Kinetic energy (E_K) has no effect on the structural damage but could be of interest as an index of non-structural damages. Elastic strain energy (E_S) has also no effect on the structural damages. This energy is stored as elastic work (product of multiplying force to displacement up to elastic limit) in members and reaches zero after the end of earthquake [17, 18].

MODELING

In order to study and investigate how the energy is distributed in the building with moment resisting frame system, a 3, 6, and 12-story structures respectively as short, medium, and high-rise structures have been selected with an identical story height of 3 m. Then, the structures were loaded in similar conditions and based on the standard of designing structures against earthquake (Iranian 2800 standard, 4th edition [9]) and sixth topic of national building regulations, by equivalent static procedure.

First, three structures have been subjected to equivalent static loading in SAP200 (VER 16.0.0) software, thereafter, these structures have been nonlinearly analyzed in PERFORM-3D (VER 5.0) software under Loma Prieta, Landers, and Northridge earthquakes in far and near fields. The story heights were considered constant and equal to 3 m and the span width have been adopted equal to 4 m in all structures. The stories' dead and live loads have been considered equal to 308 and 200 kg/m^2, respectively and for the roof; they were selected equal to 227 and 150 kg/m^2, respectively.

When designing the models, the beams in 3- and 6-story buildings' single IPE profiles were used, while in the 12-story buildings, the used profiles were single and double IPE, which were, in some cases, reinforced with a strap. As for the columns, in 3- and 6-story buildings, single and double IPE profiles were used, which were reinforced in some cases with a strap, while in 12-story buildings, BOX sections were employed.

In addition, external walls are of the type of ceramic wall with thickness of 25 cm and unit surface weight of 645 kg/m^2. The building application is residential with importance degree of medium (I=1) that is placed on type-II soil. The plan of the floors along with the number of columns are presented in Fig. 1 and the 2D model of the structure and the used sections are illustrated in Fig. 2. The soil–structure interaction was not taken into consideration too and the columns' bases were assumed to be inside the floor.

CHARACTERISTICS OF THE SELECTED ACCELERATION RECORDS

For conducting time history nonlinear dynamic analysis, it is required to select earthquake records. The amount of input energy to structure is much influenced by earthquake record rather than structure properties.

For this purpose, 3 ground motion records were selected. 9 records were considered for near fault and 9 records for far fault cases. It is noteworthy that for being consistent with site conditions, all of these records are selected in same type soils (type-II soil). Relatively complete characteristics of these records are presented in table 1.

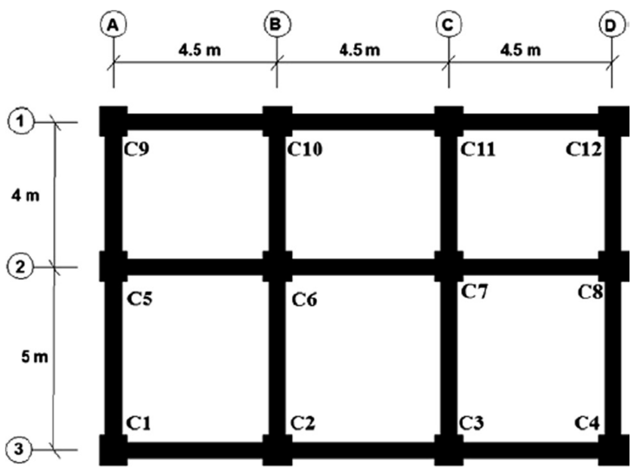

Figure 1. Plan of stories of the structure.

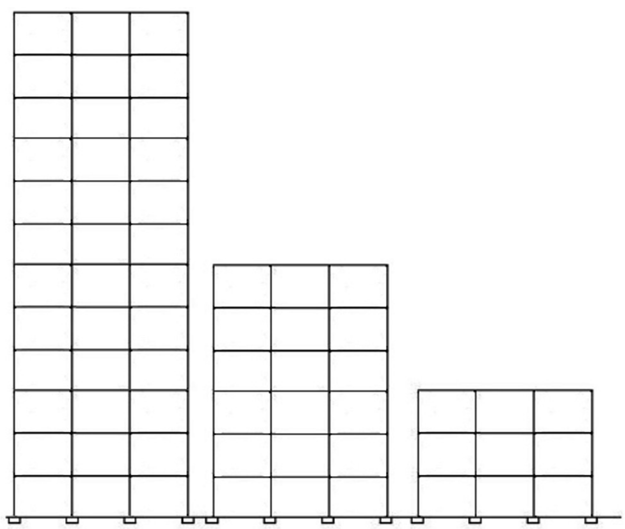

Figure 2. 2D model of the structure.

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Table 1. Characteristics of studied earthquake records.

	Earthquake record	Site Properties	Distance (km)	PGA(g)	PGV(Cm/S)	PGD(Cm)	Duration (s)
FAR FAULT	LANDERS-FAR-X	Soil	69.21	0.114	55.891	32.274	49.98
	LANDERS-FAR-Y	Soil	69.21	0.146	47.526	17.469	49.98
	LANDERS-FAR-Z	Soil	69.21	0.06	43.225	12.828	49.98
	LOMA PRIETA-FAR-X	Soil	71.23	0.098	35.903	9.159	39.99
	LOMA PRIETA-FAR-Y	Soil	71.23	0.113	40.596	16.161	39.99
	LOMA PRIETA-FAR-Z	Soil	71.23	0.043	54.81	12.556	39.99
	NORTHRIDGE-FAR-X	Soil	53.24	0.1	19.340	1.940	31.98
	NORTHRIDGE-FAR-Y	Soil	53.24	0.094	24.458	3.859	31.98
	NORTHRIDGE-FAR-Z	Soil	53.24	0.07	14.70	1.153	31.98
NEAR FAULT	LANDERS-NEAR-X	Soil	11.03	0.273	52.169	17.378	43.98
	LANDERS-NEAR-Y	Soil	11.03	0.283	78.999	28.832	43.98
	LANDERS-NEAR-Z	Soil	11.03	0.18	43.232	17.654	43.98
	LOMA PRIETA-NEAR-X	Soil	0.16	0.644	45.614	7.696	39.985
	LOMA PRIETA-NEAR-Y	Soil	0.16	0.482	51.81	13.912	39.985
	LOMA PRIETA-NEAR-Z	Soil	0.16	0.457	22.399	14.911	39.985
	NORTHRIDGE-NEAR-X	Soil	9.87	0.262	51.786	12.065	60.01
	NORTHRIDGE-NEAR-Y	Soil	9.87	0.381	52.249	4.903	60.01
	NORTHRIDGE-NEAR-Z	Soil	9.87	0.181	17.557	4.375	60.01

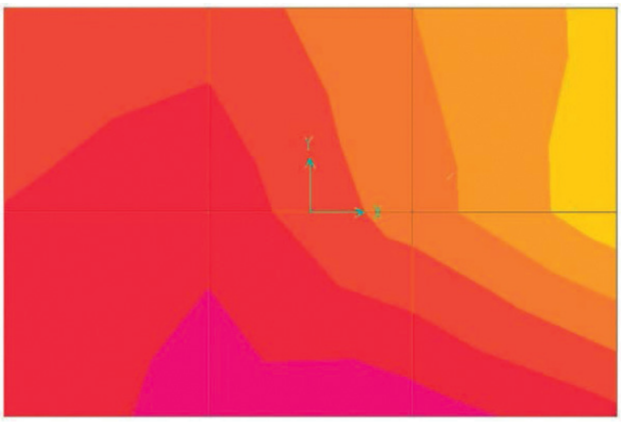

Figure 3. Maximum changes of surface stress of the first floor.

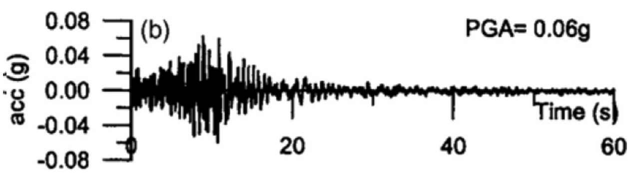

Figure 4. Earthquake acceleration records for LANDERS-FAR-Z.

According to the considered assumptions in the present study, the location of structures is of high seismicity and thus, the entire selected far fault acceleration records are scaled to 0.35 g with respect to standard 2800, 4th edition [9]. Moreover, in order to maintain the power of acceleration records and equalizing of relative risk, the entire near fault acceleration records are scaled to 1.5 times the standard spectra i.e., equal to 0.525 g. Maximum changes of surface stress of the first floor of the 3- story model has been shown in the Fig. 3. For Example, Earthquake acceleration records for LANDERS-FAR-Z been shown in the Fig. 4.

Figure 3. Maximum changes of surface stress of the first floor.

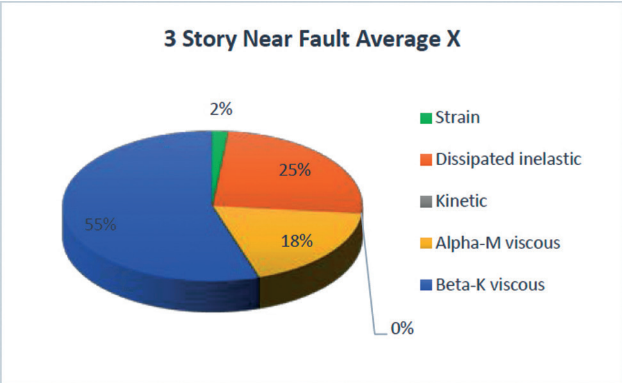

Figure 5. Three-story structure energy distribution under average near fault records of (X) component.

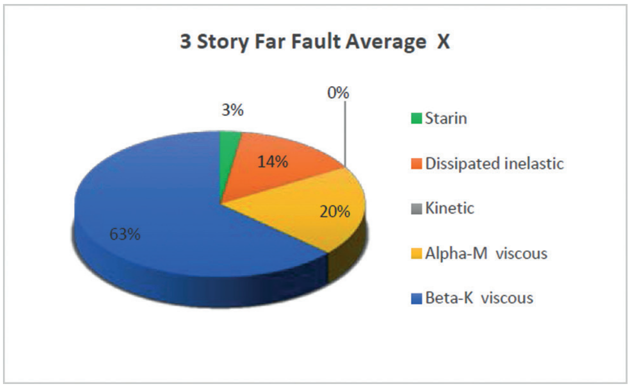

Figure 6. Three-story structure energy distribution under average far fault records of (X) component.

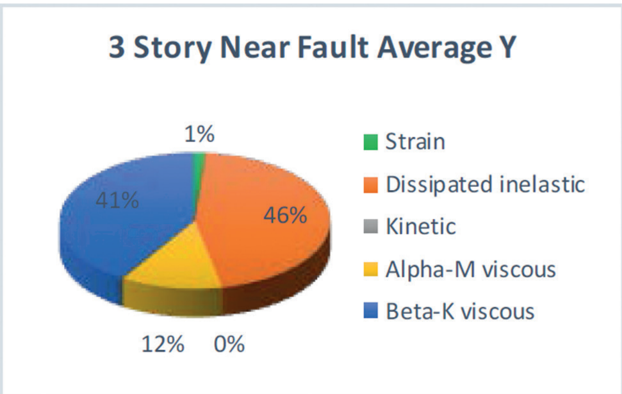

Figure 7. Three-story structure energy distribution under average near fault records of (Y) component.

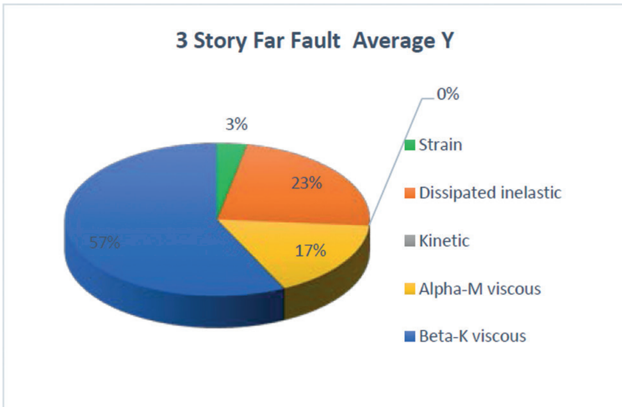

Figure 8. Three-story structure energy distribution under average far fault records of (Y) component.

RESULTS AND DISSUASION

The considered models in the research have been first analyzed by linear static analysis using SAP200 software and after obtaining stress ratios of structure elements where had been in the range of 0.9 to 1, they were evaluated by PERFORM-3D software under far and near fault earthquake records in the range of nonlinear behavior.

In this project, acceleration records of three earthquakes are selected and in order to study the actual influence of these earthquakes on the structure, it is used from all three components of accelerations records i.e., tow horizontal and one vertical components. Therefore, the structure is first subjected to each horizontal components (X) and (Y), separately, then it is subjected to both horizontal axes (XY), simultaneously, and finally it is subjected to the

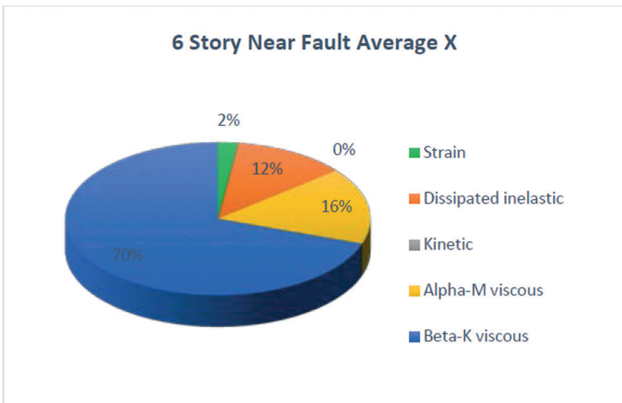

Figure 9. Six-story structure energy distribution under average near fault records of (X) component.

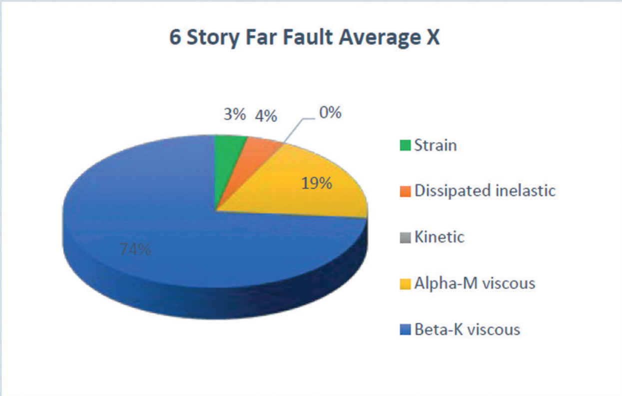

Figure 10. Six-story structure energy distribution under average far fault records of (X) component.

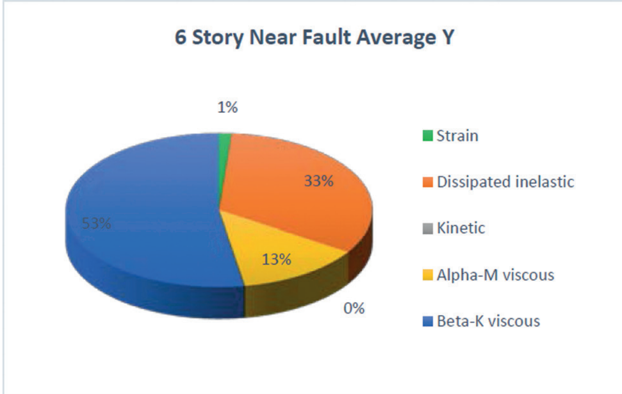

Figure 11. Six-story structure energy distribution under average near fault records of (Y) component.

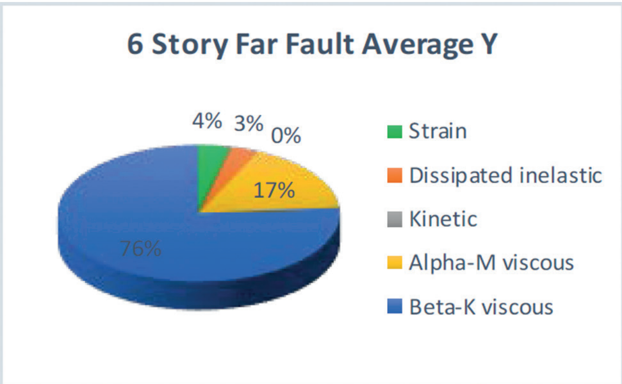

Figure 12. Six-story structure energy distribution under average far fault records of (Y) component.

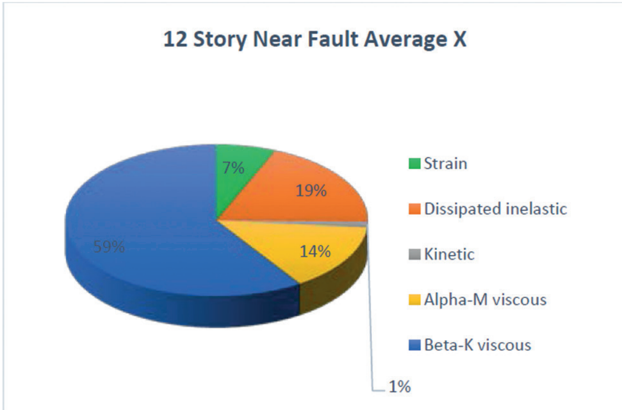

Figure 13. Twelve-story structure energy distribution under average near fault records of (X) component.

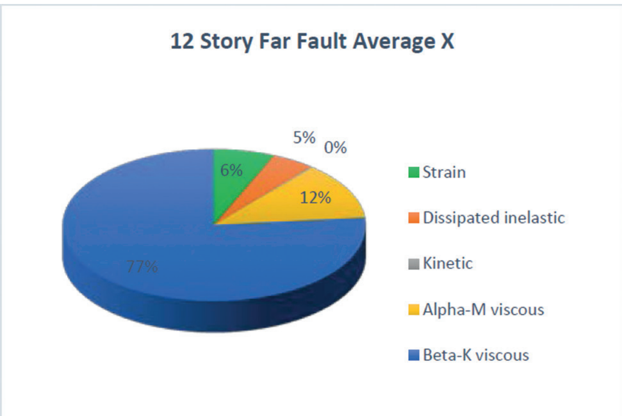

Figure 14. Twelve-story structure energy distribution under average far fault records of (X) component.

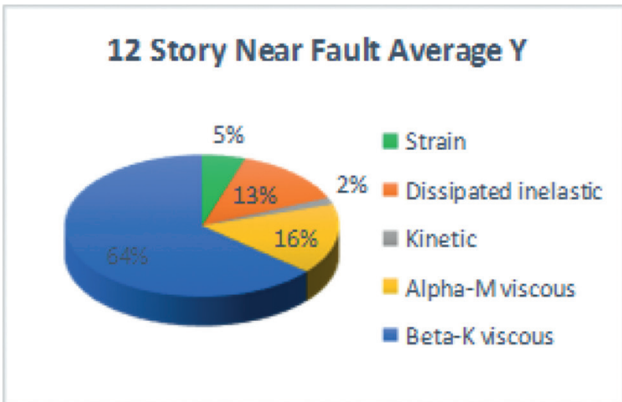

Figure 15. Twelve-story structure energy distribution under average near fault records of (Y) component.

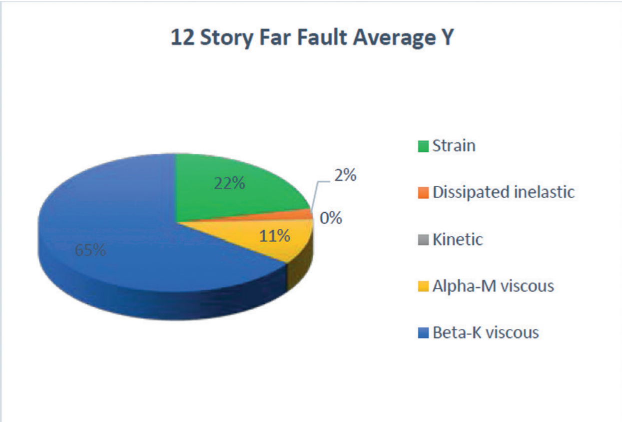

Figure 16. Twelve-story structure energy distribution under average far fault records of (Y) component.

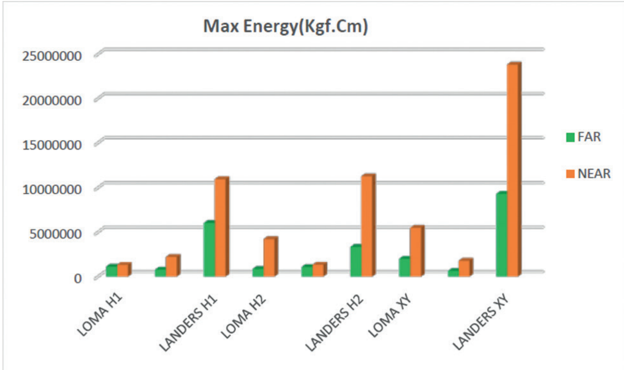

Figure 17. Input energy to three-story structure for far and near field records.

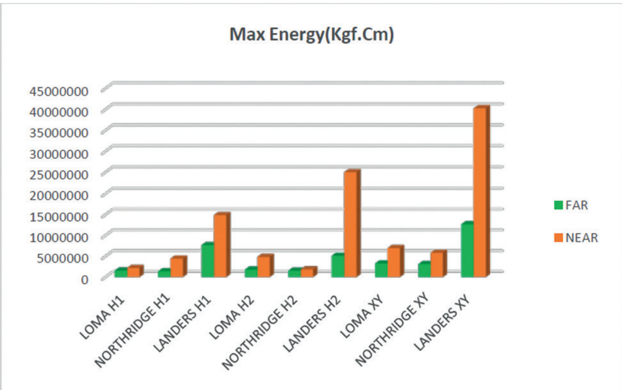

Figure 18. Input energy to six-story structure for far and near field records.

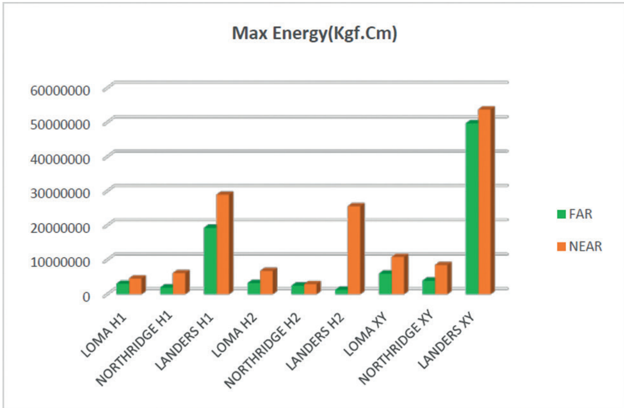

Figure 19. Input energy to twelve-story structure for far and near field records.

combined effect of the two horizontal and one vertical components (XYZ). Due to not use from cantilever and long span beams and the lack of concentrated (point) load on the beams, the vertical axis has not had a significant influence on the results and the structure has had identical results under two-component and three-component records, thus, the results of three-component records are not presented, separately.

INPUT ENERGY TO STRUCTURE DISTRIBUTION WITH SEPARATION OF THE CONSTITUENT TERMS

The amount of contribution of each energy terms from the total input energy to 3, 6, and 12 story structures is equal to average of records in the mode of single horizontal component (X), single vertical axis (Y), and in two states of far and near fault records, are illustrated in figure 5- figure 16.

The diagrams indicate that in all three structures (3, 6, and 12-story structures), the inelastic dissipated energy involves a high contribution of the total input energy to structure, which is much higher in the near fault records as compared to far fault records. The occurrence of relative damage to the structure will be more in the near fault records. Therefore, structures subjected to far fault earthquakes show more appropriate behavior.

TOTAL INPUT ENERGY TO STRUCTURE

The amount of total input energy to 3, 6, and 12-story structures are illustrated (figure 17 – figure 19) for all records in the modes of single horizontal component (X), single horizontal component (Y), the combined two horizontal components (XY), and in two states of far and near fault records.

The obtained results represent that the input energy to structure for near fault earthquake records is greater than far fault records. Moreover, it is observed that with increase in the building height, the input energy to structure is increased.

CONCLUSIONS

In the present research, three steel buildings of 3, 6, and 12 stories with ordinary moment resisting frames have been subjected to far and near fault earthquakes and the following results are obtained from nonlinear dynamic analysis of them.

- It was concluded form investigating input energy to buildings that the inelastic dissipated energy involves a high contribution of the total input energy to structure.
- According to the results of performed analyses, it was determined that the inelastic dissipated energy has a much higher contribution in near fault records in comparison with far fault earthquake records and the occurrence of relative damage to the structure will be more in the near fault records.
- It was observed that the input energy to structure is increased with increase in the building height.
- The obtained results indicate that input energy to structure for near fault earthquake records is greater than far fault records.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Hart GG. Earthquake forces for the lateral force code. Struct Damage Tall Build 2000;9:49–64.
[2] Copra AK, Cruz EF. Evaluation of building code formulas for earthquake forces. J Struct Eng ASCE. 1986;115:1881–1899. [CrossRef]
[3] Housner GW. Limit Design of Structures to Resist Earthquake. Proc First World Conference on Earthquake Engineering, Berkeley California, 1956:5–13 [CrossRef]
[4] Zahrah TF, Hall WJ. Earthquake Energy Absorption in SDOF Structures. J Struct Eng ASCE 1984;110:1757–1772. [CrossRef]
[5] Akiyama H. Earthquake resistent limit-state design for buildings. University of Tokyo, 1985.
[6] UBC/EERC-88/13. Ground Motion on seismic Design of Building Structures. Earthquake Engineering Research Center, University of California, Berkeley, 2013
[7] Uang CM, Bertero VV. Implication of recorded earthquake ground motion on seismic design of building structures. earthquake engineering research center, University of California, Berkeley, 1988.
[8] Cao H, Friswell MI. The effect of energy concentration of earthquake ground motions on the nonlinear response of RC structures. Soil Dyn Earthq Eng 2009;29:292–299. [CrossRef]
[9] Standard 2800. Regulations of designing buildings against earthquakes. 4th ed. Housing Research Center, Iran, 2017.
[10] Rong HC, Li B. Probabilistic response evaluation for RC flexural members subjected to blast loadings. J Struct Saf 2007;29:146–163. [CrossRef]
[11] Stewart MG, Netherton MD. Security risks and probabilistic risk assessment of glazing subject to explosive blast loading. J Reliab Eng Syst Saf 2008;93:627–638. [CrossRef]
[12] Parisi F, Augenti N. Influence of seismic design criteria on blast resistance of RC framed buildings: A case study. J Eng Struct 2012;44:78–93. [CrossRef]
[13] Cizelj L, Leskovar M, Čepin M, Mavko B. A method for rapid vulnerability assessment of structures loaded by outside blasts. J Nucl Eng Design 2009;239:1641–1646. [CrossRef]
[14] Faghihmaleki H, Najafi EK, Aini A H. Seismic rehabilitation effect in a steel moment frame subjected to tow critical loads. Int J Struct Integr 2017;8:25–34. [CrossRef]
[15] Abdollahzadeh GR, Faghihmaleki H. Proposal of a probabilistic assessment of structural collapse concomitantly subject to earthquake and gas explosion. Front Struct Civil Eng 2018;12:425–437. [CrossRef]
[16] Abdollahzadeh GR, Faghihmaleki H. Probabilistic two-hazard risk assessment of near-fault and far-fault earthquakes in a structure subjected to earthquake-induced gas explosion. J Build Eng 2017;13:294–304. [CrossRef]
[17] Turhan C, Kazanasmaz T, Akkurt GG. Performance indices of soft computing models to predict the heat load of buildings in terms of architectural indicators. Sigma J Eng Nat Sci 2017;3:1358–1374. [CrossRef]
[18] Khalifa AH. Effect of roof pond on the energy and exergy performance of a single space building. Sigma J Eng Nat Sci 2017;3:1275–1293. [CrossRef]