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Study on the Seismic Response Parameters of Steel Medium-Height Buildings with Framed-Tube Skeleton under Near-Fault Records

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ABSTRACT: In this research, the performance abilities of tube type lateral load resistant framed systems are studied in order to assess the dynamic response properties of mid-rise steel structures under effects of far and near-field ground motions. For this purpose, three 10 story structural models with separated framed tube based skeletons were selected and designed. The structural models have been designed according to the Iranian seismic code 2800 (4th edition). The main criterion which was considered to select powerful ground motions for performing nonlinear time history analyses is the existence of energized coherent velocity pulses as well as high amplitude acceleration spikes in the time history of each earthquake record. Assessment of the analytical results should emphasize the importance of both lateral displacement and drift parameters which must be taken into account during the structural design phase. Furthermore, it was concluded that the maximum drift demand is more than 0.035 and the upper level of rotation of rigid connecting zones was obtained more than 5 percentages of a radian. As a general note, it was concluded that the seismic response parameters of mid-rise steel framed tube structures are intensively influenced by those strong earthquake records which contain powerful forward directivity effects and are able to emerge long period pulses in their time histories.

1 INTRUDUCTION

A study on the major characteristics of ground motions which are called earthquakes, has a long history. Damages caused by an earthquake depend on a variety of factors, such as the frequency content, duration, maximum amplitude of powerful earth movements and also dynamic qualities of the structure. The general way to categorize earthquake records is based on the distance from the fault rupture surface, which include two groups of near-field and far-field records. Observations and assessments of structural damages during huge earthquakes such as Northridge 1994, Kobe Japan 1995, Chi-Chi Taiwan 1999 and Bam Iran 2003 indicate the overly destructive influences of strong and powerful near-fault records.

Therefore, one of the most common issues in engineering seismology is the assessment of the physical characteristics of strong ground motions in near-fault zones and their effects on the performance of specific structures especially medium to high-rise buildings.

Generally, the desirable seismic performance of a building occurs when the characteristics of its dynamic behavior reveal themselves as consistent and uniform in regards to the structural skeleton. This essential concept is very important, especially for assessing drift parameter changes. It needs to be acknowledged that the observation of damages to buildings located near to the active faults, reveals the important fact that most of structural damages occur in specific heights and levels (Khaloo et al 2015, Naeim 2001, Gupta et al 2013, Chen 2003, Akkar et al 2004, Shahrouzi et al 2015). Moreover, it has to be considered that lowering the risk of an earthquake is impossible and the basic logical solution is lowering the vulnerability of the building. So it is possible to compile a vast and general database by studying the behavior of the structures under powerful earthquake records, in order to reach a better understanding of the nature of registered near-fault records and their influences on the structure's behavior.

It is worth mentioning that one of the most important topics in engineering seismology and design is assessing the physical characteristics of recorded ground motions registered at the sites near to active faults and their influences on the performance of specific buildings, especially medium to tall ones. In addition, it is important to perform more researches in order to achieve better understanding about the strong pulse-type and wave-like ground motions. The pulse period parameter plays an important role in generating and developing inelastic transformations under influencing of the aforementioned type of ground motions. The proximity of the distinct pulse period in the time history of near-field records to the natural period of structure can cause remarkable intensification in seismic response parameters of the building (Akkar et al 2005, García 2012, Kalkan et al 2006, Elnashai et al 2012, Mavroedis 2002, Sofi et al 2015).

One efficient structural skeleton which is used in construction of medium to tall buildings, is called rigid tube or framed tube system. This structural skeleton is applied as a lateral resistant system in many steel and concrete buildings. It has four façade rigid frames which are located around the structure plan and create a quasi-flexural tube-type skeleton, called framed-tube. This system's behavioral nature is in a way more complicated than the performance of a pure solid tube-type framework. The existence of casements between columns and girders reduces the total rigidity of this structural system and directly influences its efficiency. Moreover, the aspect ratio of casements is affected by girder section height and the column element width (Smith 1991, Al-Kodmany 2012, Moon 2007, Gunel et al. 2007, Taranath 2005).

Paying careful attention to subjects and concepts of the engineering design of framed-tube structures and also a thorough understanding of the dynamic behavior of their major components, which consist of deep girders and large-section columns, would help optimize the seismic behavior of these structures. Based on this fact, it is necessary to be extra careful in structure plan geometry, span dimension and also configuration of rigid frames in the internal and lateral plans of framed-tube. The system provides flexibility in architectural plan-forms by contemplating distinct mix of cells to various height of building. In case the structures are taller, the efficacy of framed tube skeleton may decrease constantly and the structural demand such as the lateral drift should be controlled and improved (Shin et al. 2010, Gunel et al. 2007, Loulelis 2012).

If by changing inner rigid frame arrangement in the plan of framed tube systems as well as the position of transfer floor in the height of building, it becomes possible to optimize the seismic behavior of these structures and reduce the occurrence of shear lag effects. Hence, there is the opportunity of decreasing the consumption of side materials by maintaining desirable qualities of the seismic design. Additionally, the subject of building resistance against the wind and earthquake loads have been the crucial point in the designation associated with new structural systems.

It should be noted that, planning and completing the two studied models which include the bundled tube and castled tube systems, beside the basic framed tube structure, are based on this fact. Three companion framed tube based resistant structural systems are considered in this study. Furthermore, the existence of combined rigid frames in the internal arrangement of the framed tube structure plan, can lead to remarkable reduction of inconsistent axial stress in lateral columns and a remarkable decrease in shear lag effects (Choi et al. 2015, Azhdarifar et al. 2015, Elawady et al. 2014, Movahed et al. 2014, Movahed et al. 2012, Afsary et al. 2014, Azad et al. 2014).

The studied seismic and engineering design topics discussed in this research are as follows:

- Study on the analytical characteristics of near-field earthquake records which have directivity effects
- Nonlinear seismic assessment and analysis of three studied structures with different rigid frames configuration based on the tube-type resistant skeletons

1.1 *Research Process*

Based on the Figure (1) the structural systems studied in this research, include single framed tube, bundled tube and castle tube having a symmetric geometrical plan. All models are designed based on the concept of medium ductility level according to codified provisions of the Iranian seismic code 2800 (fourth edition) and Iranian National Building Code (Steel Structures -

Division 10). It is worthy of mention that the study of changes in inner rigid frame installations in combined framed tube structures, in order to reach a desirable positioning of resistant systems and reducing structural demands such as drift, base shear, axial stress and shear lag problem, has been considered during the design process. Therefore, a comprehensive study of the mentioned issues is performed in this research. The seismic performance level of all structural parts of the three models are assessed and the maximum amounts of base shear, acceleration, velocity, displacement and drift are numerically determined.

The chosen records include a number of near-field ground motions records having forward directivity effects as well as an almost strong far-field record which named El Centro 1940. The main criterion in choosing powerful ground motions to perform time history analyses, has been the presence of long and high-amplitude velocity pulses along with strong acceleration spikes in the time history of the record.

Structural application of bundled tube systems in medium to tall buildings can reduce seismic demands remarkably. The studies conducted in this research follow the same analytical path and three companion structural models with different arrangement of tube frames are chosen for a prototype 10-story steel building. The details of the plan, general view and structure sections are shown in Figure (1). The structural analysis process was first performed by both modal and linear static analyses. Then required nonlinear time history analyses were conducted under three-component strong records. The selected records contain wave-like features in the corresponding time history. It is notified that all the aforementioned records were taken from the strong motion database of the Pacific Earthquake Engineering Research Center.

2. SCOPE OF THIS RESEARCH

2.1 *Describing of Studied Models*

As observed in Figure (1), the span lengths are fixed and equal 6 meters, the story height is 3.5 meters and the number of the spans in both X and Y are considered 6m. Classification of the site soil is of type II (Iranian seismic code). The earthquake probabilistic hazard is considered very high. All moment frames of the studied structural models are assumed based on a codified ductility factor. The whole earthquake resistant system of each studied structure is modelled as a three dimensional framework and the codified accidental eccentricity has been accounted in the design process. The structural behavior coefficient is equal to 5, i.e. R=5. The assumption of full rigid body motions is confirmed for the three studied models (Figure 1). The structure's loading is performed based on the Iranian National Building Code (Design Loads for Buildings - Division 6). The period of the first three modes of vibrations of the studied structures are shown in Table (1).

According to the information provided in this table, it is observed that due to the excess of the first lateral mode period compared to the first torsion period, the structure behavior is torsionally stiffness. It is in fact a desirable quality in structural design process and can be considered in positioning lateral modes in both X and Y directions (Figure 1). Moreover, design characteristics and concerns including allowed drift control, confirmation of the strong column/weak beam principle in all connections and approval of adequate resistance factor of panel zones, were also considered in the design process. The pinned beam members of the same floor level are grouped in the same section type. The column sections and girders change at every two floor levels. Section properties of all girders and columns in studied models of Figure (1) are represented in Table (2).

Table 1. Modal vibration periods of the structural models

Lateral Resistant Systems	T_1 (sec) The First Lateral Modes of X and Y Directions	T_2 (sec) The Basic Torsional Mode	T_3 (sec) The Second Lateral Modes of X and Y Directions
F.T.	2.20	1.33	0.83
B.T.	1.80	1.33	0.69
Ca.T.	1.80	1.19	0.68

Table 2. The structural members of the 10 story studied models (in millimeters)

Stories Groups	Interior Columns (Pinned Bents)	Interior and Exterior Columns (Rigid Bents)	Beams (Rigid Bents)

1-2	C400x25	C500x30x440x25	B500x15x250x25
3-4	C350x25	C450x30	B500x15x350x25
5-6	C300x20	C400x30	B450x15x350x25
7-8	C250x20	C350x30	B450x15x350x20
9-10	C200x15	C300x20	B400x10x250x20

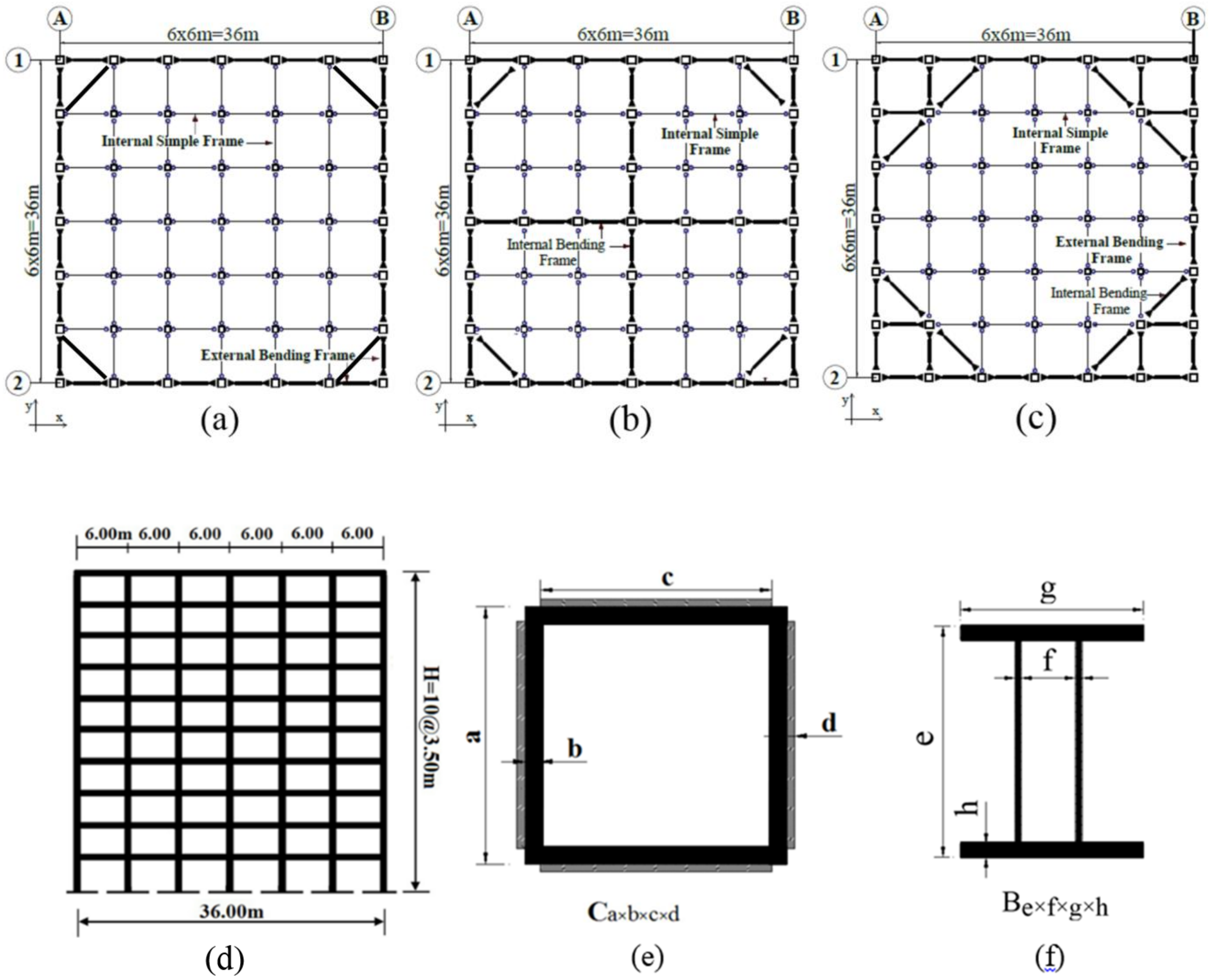


Figure 1. The studied structural models: (a) Plan of Framed tube (F.T.); (b) Plan of Bundled tube (B.T.); (c) Plan of Castled tube (Ca.T.); (d) The 10-story configuration (e) Columns section properties of 10-story models; (f) Beams section properties of 10-story model

2.2 *General Characteristics of Near-Field Earthquake Records*

It should be noted that one of the major characteristics of near-field records, especially when containing forward directivity effects, is having pulses with large period and amplitude which usually appear at the beginning of their time history. This is an important factor to differentiate between these types of records and those of far-field zones (Figures 2-a, b and 3-a, b). While the fault rupture propagation expands toward the site, the forward directivity effects will generally take place. Pulse-like near-fault ground motions which contain directivity effects are essentially a special class of ground motions. They have been particularly challenging to specify the codified seismic consistency assessments (Somerville et al. 1997, Gupta et al 2013, Somerville 2003, Stewart 2001, Baker 2008).

The presence of pulse-like features in the time history of near-field records causes the input kinetic energy of these movements to be many times larger than those in far-field records (Figures 2-c and 3-c). Therefore, it can impose the kinetic energy resulted from near-field ground motions to the building in a short time range. This process would usually cause a large and quick development in nonlinear seismic performance of rigid connections as well as main elements in lateral load resistant system of buildings.

Naturally, near-field earthquake records have relatively higher acceleration values and narrower frequency content with the larger amounts as compared to those of far-field records. Moreover, in the Fourier spectrum of these records, instead of the development of the maximum vertical axis components into a wide range of frequency domain (Figure 3-d), it is limited to a small range. Furthermore, sometimes even the distinct maximum vertical axis component would be revealed only at one particular frequency (Figure 2-d).

The presence of the structural two first lateral modes of vibrations up to the basic torsional mode which they all may take place on the energized band of the frequency content of the strong earthquake record, then it can cause the structure seismic response parameters to be considerably either strengthen or weaken with an unpredictable regime. Furthermore, the study on the process of comprising and development of plastic hinge mechanisms in medium rise to tall buildings structural skeleton during the intensive ground shakings, reveals the fact that the existence and continuity of coherent velocity pulses in the time history of the record has the main role.

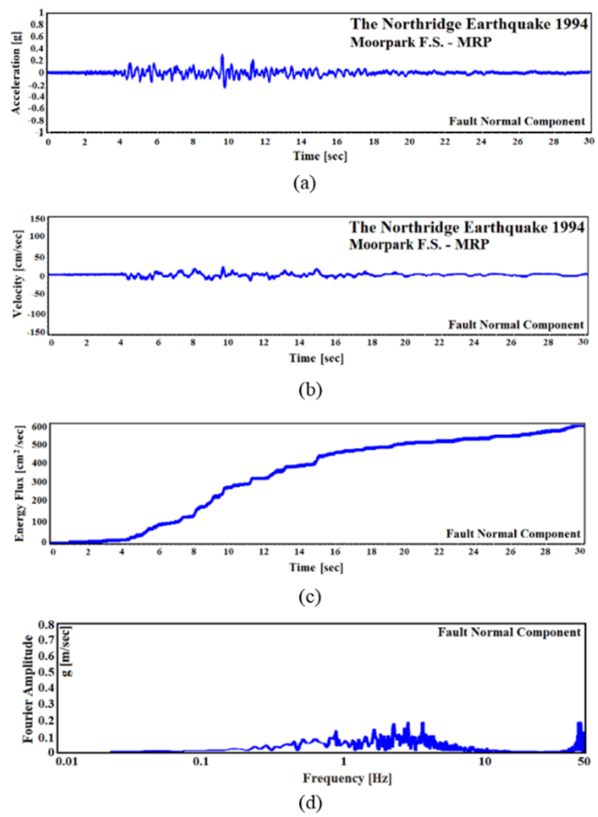


Figure 2. The fault normal component of the main near-field record due to the Bam 2003 earthquake which released in perpendicular direction respect to the fault rupture plate (TR component): (a) The recorded acceleration; (b) The ground velocity; (c) The related energy flux; (d) The corresponding Fourier amplitude spectra.

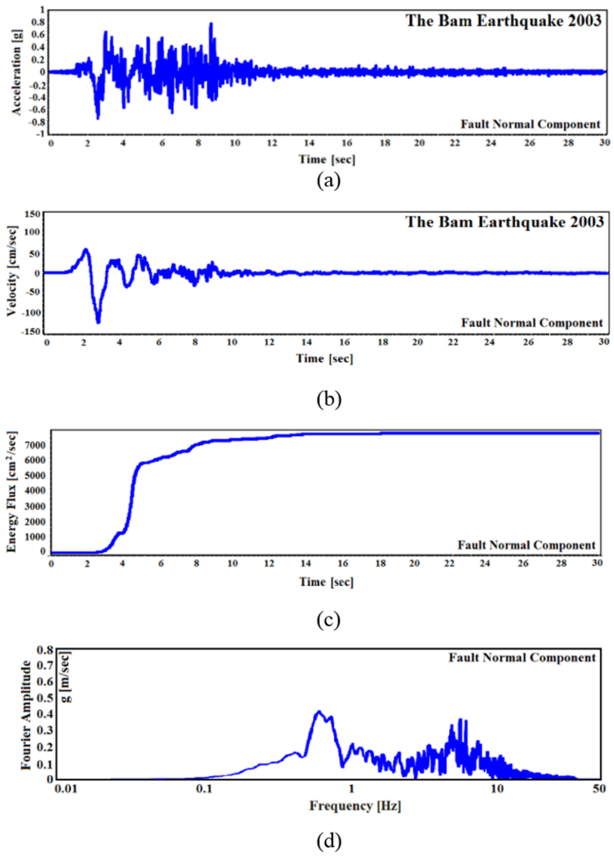


Figure 3. The fault normal component of the far-field record Moor park (MRP) due to the Northridge 1994 earthquake which released in perpendicular direction respect to the fault rupture plate (TR component): (a) The recorded acceleration; (b) The ground velocity; (c) The related energy flux; (d) The corresponding Fourier amplitude spectra

As indicated for many strong records, the velocity-type vertical axis components resulting from the Fourier spectrum would have large amounts even when correspond to higher modes of vibration of the structural system. Therefore, in the assessment of seismic behavior of medium-rise to tall buildings, it is important to pay attention accurately to the effects of the proximity of higher modes period especially for the basic torsional mode of vibration, to the corresponding vertical axis components obtained from the Fourier spectrum of a considered strong record. This process should be noted versus the periods equal to those resulted from the Eigen value analysis of the structure (Kalkan et al. 2007, Decanini et al. 2000, Kwok et al. 2011, Iwan 1995, Malhotra 1999, Trifunac et al. 2013, Zaghi et al. 2013).

Moreover, as shown in Figure 4 the powerful frequency band of the Fourier spectrum related to the fault normal component of Tabas and SCS records is almost located in the spectral domain corresponding with the lower modal frequencies resulted through eigen value analysis of the studied structures (Table 1). Obviously, as illustrated in Figure 4 the vertical axis components corresponding with the aforementioned domain of the Fourier spectrums are too high, especially for the first modal frequencies of the studied structures which may lead to more intense seismic responses.

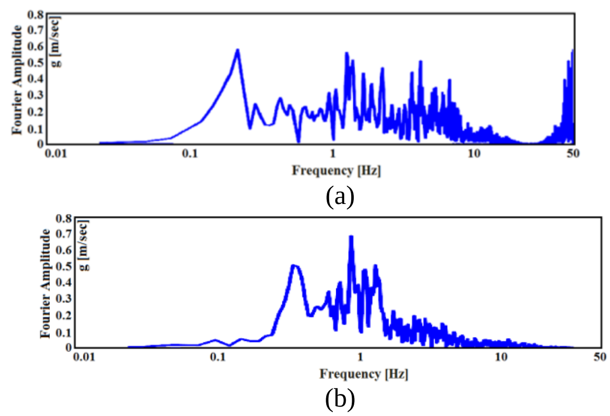


Figure 4. The corresponding Fourier amplitude spectra of the fault normal component (TR component): (a) the main near-field record due to the Tabas 1978 earthquake; (b) the Sylmar record (SCS) due to the Northridge 1994 earthquake

2.3 *The Applied Earthquake Records*

One of the most distinctive characteristics of near-field records is the capability of producing both of powerful short-term and long-term pulses in the velocity time history. It should be known that these velocity pulses appear differently, in which it depends on the remoteness or the proximity of the record station from the fault rupture plate and the epicenter area of the earthquake.

Nevertheless, the existence of powerful and long period pulses in the time history of each component of a strong near-field record can affect both, the seismic structural response parameters and the dynamic behavior characteristics of relatively long period buildings to a great extent. The significance of the above mentioned phenomenon increases by a raise in the durability of forceful ground vibrations cussed by a strong earthquake tremor.

The ensemble of selected earthquake records in this research, includes eight near-field ones which contain various tectonic directivity effects. The chosen records are introduced in Table (3). The physical characteristics of the chosen records cover a wide range of frequency content, strong ground motions duration and various high seismological amplitudes.

This ensemble includes seven powerful near-field ground motions having directivity effects which are the three-component records of Sylmar (SCS), Rinaldi (RRS), Jensen Filter (JFP) and Newhall W. Pico (WPI) from the Northridge earthquake 1994 in California and two other strong records of the Bam 2003 and Tabas 1978 great earthquakes in Iran. The last two ones are major recorded shocks of those mentioned Iranian earthquakes. Yet, the three-component far-field record of Moor-park (MRP) from the Northridge 1994 earthquake was also chosen as a relatively weak seismic tremor. The physical characteristics of ground motion recorded close to an earthquake source can be considerably different from those of far-field motion.

It has to be mentioned that in this research, the target structural response parameters are obtained and analyzed in the X direction of the plan of the studied models (Figure 1). All the aforementioned records are applied to the studied models as natural tremors. This fact is especially important for the recorded ground acceleration in the near-fault areas. The mentioned events which are recorded near the fault slipping surface, represent the real behavior of the ground during the intensive rupturing.

2.4 *The Iranian Strong Earthquake Tremors*

Iran as one of the world’s most earthquake prone countries, has been exposed to many destructive earthquakes in the past long years. Historically, the three regions of Zagros, Alborz, and Khorasan in Iran are exposed to high seismicity. The movement of African plate toward the Asian plate, pushing the Arabian plateau and southwest of Asian, leads to the creation of faults and rupture on the earth crust in the most parts of Iran. According to the seismic macro zonation hazard map of Iran, most of the cities are located within the high to very high relative risk areas (Iranian seismic code, fourth edition). Among recent catastrophic disasters in Iran, the great 2003 Bam earthquake was the worst one. The Bam earthquake occurred in an area without any historically recorded major ground motion. On 26 December 2003, 5:26 GMT the Bam urban area was severely destroyed by a ground shaking tremor of Mw (moment magnitude) near to 6.6. The consequences of this moderate earthquake were tragic, almost all the city of Bam was devastated. It also caused considerable loss to man-made constructions, lifelines and infrastructures. The main source of this strong earthquake was under the city of Bam at a focal depth about 8 km. The preliminary observations and engineering assessments of damaged structures in the Bam city confirm the occurrence of seismological near field effects. As shown in Figure (5), the PGAs parameters corresponding to the strong ground shock recorded at the Bam governmental building station are about 0.65g, 0.81g and 1.01g respect to fault parallel, normal and vertical azimuthal axes. It should be noted that the vertical component is relatively strong as compared to the other simultaneous LN and TR ground recorded accelerations. The Fourier amplitude spectra due to three components of the acclerogram recorded at Bam station are shown in Figure (6). As illustrated in this figure, the peak values for the longitudinal component (LN component) can be denoted in the frequency domain of 0.6 Hz as well as the band of 4Hz to

6Hz too. The peak Fourier amplitudes for the transverse component (TR component) are also located between 4.5 to 5.8 Hz frequency axis, while this range changes to about 8.2 Hz for the vertical component (Figure 6).

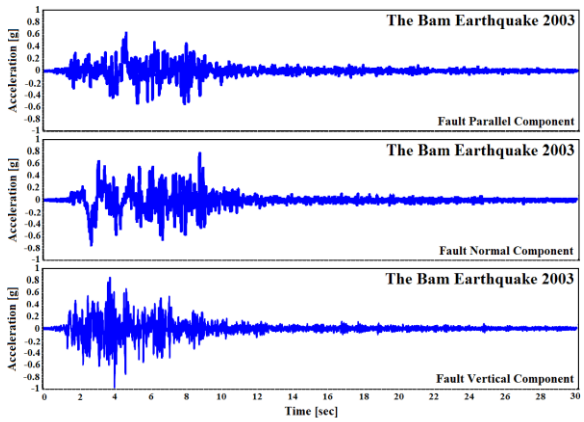


Figure 5. The corresponding fault-parallel, fault-normal and fault vertical components of the acceleration time histories recorded at BAM 2003 earthquake

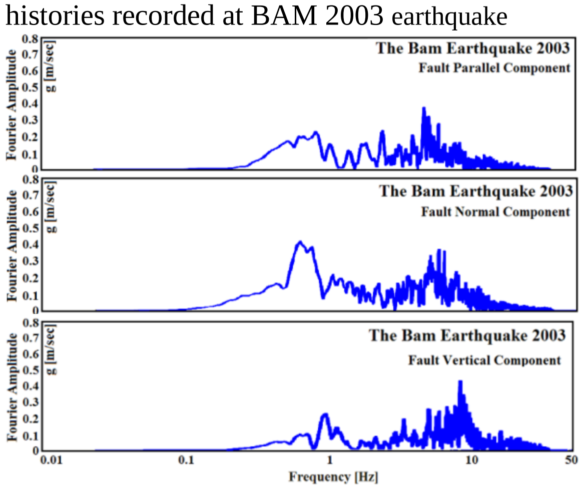


Figure 6. The corresponding Fourier amplitude spectra corresponding to the fault parallel, normal and vertical components of the main near-field record due to the BAM 2003 earthquake

Also, on 16 September 1978, a destructive earthquake with an estimated Ms 7.4 (surface magnitude) or M_b 6.5 (body magnitude) occurred in east-central Iran, devastating the city of Tabas with a more than 80 percent loss of its population, and severely damaging over 90 outlying villages to distances up to 80 km. This strong ground shock was associated with 75 to 85 km of discontinuous thrust faulting west and northwest of the epicenter (Berberian, 1979; Mohajer-Asbjai and Nowroozi, 1979). Berberian (1979) reported the local maximum vertical uplift and slip to be about 150 and 300 cm, respectively.

Seismological assessment results of the time history corresponding to the main ground shock recorded during the Tabas earthquake 1978, denote the existence of a number of strong pulse like features. Based on Figure (7), two distinct coherent pulses are illustrated corresponding to fault parallel and normal velocity time histories. These aforementioned pulses are almost in the time domain of 6s to 16.5s. Both of these high amplitude and long period pulses contain several spike type wavelets with a period of about 0.2 to 0.5s.

It is noticeable, the large velocity pulse due to the fault parallel component is considerably smaller than the one caused by the fault normal component. As reported in other researches, the more obvious characteristic of the TAB record is the capability of indicating companion energized velocity and displacement pulses. These pulse like features impose large amounts of kinetic energy on the resistant structural system of buildings. This process would lead to considerable structural damages in sites which are located in the vicinity of the active faults (Azhdarifar et al 2016).

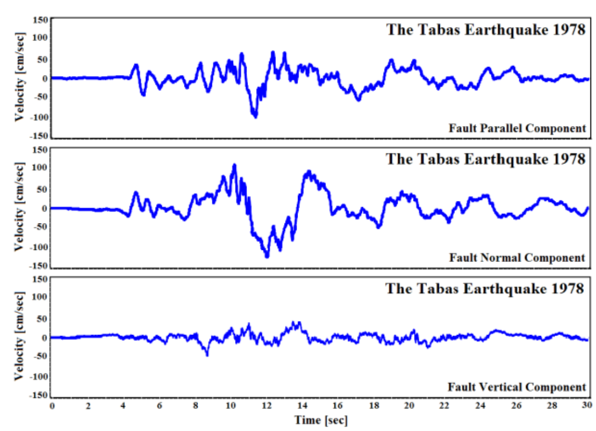


Figure 7. The fault parallel, normal and vertical time histories of the ground velocity corresponding to the acceleration recorded during the main shock of Tabas 1978 earthquake (TAB record).

2.5 *The Codified Hysteretic Loop*

Based on Fema 356 and Fema 440, in order to describe the nonlinear behavior of beams and columns in the modeling process of the studied structures, the nonlinear hinge M3 as well as the nonlinear hinge P-M2-M3 are applied for all beams and columns of the planar rigid frames respectively. The schematic nonlinear behavior of the noted hinges is illustrated in Figure (8) and Table (4). These default codified properties can be implemented numerically in well-known CSI computer softwares i.e. Sap2000 and Perform3D, which were used in this research.

Table 3. The selected earthquake records

Ground Motion	Component	Duration (sec)	PGA (g)	PGV (cm/s)	PGD (cm)	Magnitude M_W	PGV/PGA (sec)	PGD/PGV (sec)
Tabas 1978 Tabas City - 3.0km	LN	30.00	0.836	97.7	39.9	7.4	0.12	0.40
	TR		0.851	121.3	94.5		0.14	0.78
	UP		0.688	45.5	17.0		0.06	0.37
Bam 2003 Bam City - 1.0km	LN	30.00	0.635	59.6	20.7	6.6	0.09	0.34
	TR		0.793	123.7	37.4		0.16	0.30
	UP		0.999	37.66	10.11		0.03	0.26
Northridge 1994 Sylmar (SCS) - 6.40km	LN	30.00	0.897	102.23	45.28	6.7	0.11	0.44
	TR		0.612	117.47	54.16		0.19	0.46
	UP		0.586	34.59	25.63		0.06	0.74
Northridge 1994 Newhall (WPI) - 7.10km	LN	30.00	0.325	67.4	16.1	6.7	0.21	0.23
	TR		0.455	92.8	56.6		0.20	0.61
	UP		0.290	37.2	13.3		0.13	0.35
Northridge 1994 Jensen Filter Plant (JFP) - 6.10km	LN	30.00	0.593	99.10	23.96	6.7	0.16	0.24
	TR		0.424	105.95	50.69		0.25	0.47
	UP		0.399	33.91	8.89		0.08	0.26
Northridge 1994 Rinaldi (RRS) - 7.10km	LN	30.00	0.472	72.72	19.82	6.7	0.15	0.27
	TR		0.838	166.87	29.79		0.19	0.17
	UP		0.852	51.01	11.71		0.06	0.22
Northridge 1994 Tarzana (TAR) - 7.10km	LN	30.00	0.99	76.77	29.21	6.4	0.07	0.38
	TR		1.77	109.67	36.56		0.06	0.33
	UP		1.04	73.69	20.52		0.07	0.27
El Centro 1940 (ELC) – 8.30km	LN	30.00	0.215	30.2	23.91	7.0	0.14	0.79
	TR		0.313	29.8	13.32		0.10	0.45
	UP		0.205	10.7	9.16		0.05	0.85

Fault Parallel Component: LN, Fault Normal Component: TR, Fault Vertical Component: UP

Table 4. The defined seismic performance levels based on Fema 356

Acceptance criteria	Plastic rotation angle
IO- Immediate Occupancy	$1\theta_y$
LS- Life Safety	$9\theta_y$
CP- Collapse Prevention	$11\theta_y$

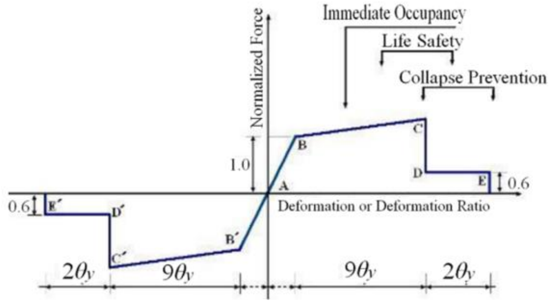


Figure 8. The Fema 356 model of nonlinear behavior of beam-column element

3. ASSESSMENT OF THE RESULTS

A number of nonlinear dynamic time history analyses have been conducted for all studied structural models (Figure 1) subjected to the selected earthquake records as noted in Table (3). The mentioned analyses have been accomplished by the use of the Newmark-beta integration method through the average acceleration criteria as well as the numerical parameters of γ=0.50 and β=0.25 (Chang 2003, Miranda et al 1989, Chang 2009). The illustrated analytical results include the graphs, related to envelop maximum amounts of obtained structural responses parameters. The noted seismic structural response indicators, sequentially include the relative base shear as proportion of the calculated seismic base shear, absolute acceleration, relative velocity and the maximum dynamic displacement of all floor levels as well as the seismic drift demand of each level.

In graphs related to the absolute acceleration, relative velocity, maximum displacement and drift of floor levels, the perpendicular axis shows the story number. Moreover, the horizontal axis sequentially belongs to the envelop maximum of the aforementioned response parameters. The acceleration response spectrum corresponding LN component to each of the chosen records is displayed in Figure (9), in which the first lateral mode period of the studied models F.T., B.T. and Ca.T. are specified too, based on Table (1).

Having notes to Figure (9) indicate that the spectral areas of higher accelerations are relatively located at lower periods less than 1sec. Meanwhile, the location of the first mode period of the structures B.T. and Ca.T. are in the spectral area of higher acceleration as compared to the one related to the studied model F.T. Hence, the obtained base shear amount of the models B.T. and Ca.T. would be larger than the one due to the structure F.T. The analytical ratios of the calculated base shear versus total seismic mass of structure as well as the codified static base shear due to the studied models are presented in Figure 10. It is evident that the dynamic base shear values of the studied models which are affected by powerful near-field records are distinctly greater than those ones subjected to the far-field ground motions.

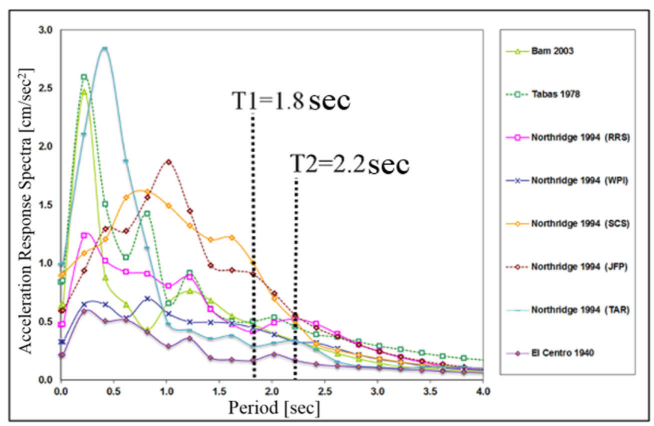


Figure 9. The acceleration response spectra of the chosen earthquake records as well as the specification of the axis of first lateral vibration modes corresponding to the studied models as indicated in Table 1.

The envelop curves of maximum absolute acceleration and relative velocity of floor levels of three different studied framed tube arrangements are presented in Figures (11) and (12). The illustrated curves in these figures denote that the near field earthquake records which display coherent directivity pulses in their time history, are strongly able to impose intensive higher amplitude vibrations on the structural resistant systems. The obvious results of this process are the distribution of acceleration and velocity demands to floor levels at distinctly higher amounts, as compared to the ones resulted from far-field records.

Furthermore, one of the important and measurable response parameters to assess the structures seismic performance is maximum relative displacement, i.e. drift of floor levels. This important factor has a specific permitted limit as recommended in the seismic codes. The envelop curves of maximum displacement and drift demands, obtained from the performed nonlinear time history analyses under the records of Table (3) are shown in Figures (13) and (14). Analytical results prepared through applied near fault records which contain pulse features, show a remarkable increase in the calculated amounts of displacement and drift demands of the studied models.

Yet, the amounts of drift demand are compared with the permitted value which denoted in the Iranian seismic code 2800 (fourth edition) and is 0.02. It is observed that for all 10-story studied structures, the far-field recorded ground motion ELC creates an almost consistent low-amplitude drift demand at the structure height domain. Maximum drift demand in Ca.T. and B.T. are generated by the JFP record which creates a relative displacement of 3.5% in the 7th floor of these models and the maximum drift in F.T. created by the RRS record is about 3%. It is observed that the maximum demand is relatively focused at the higher levels of the studied models.

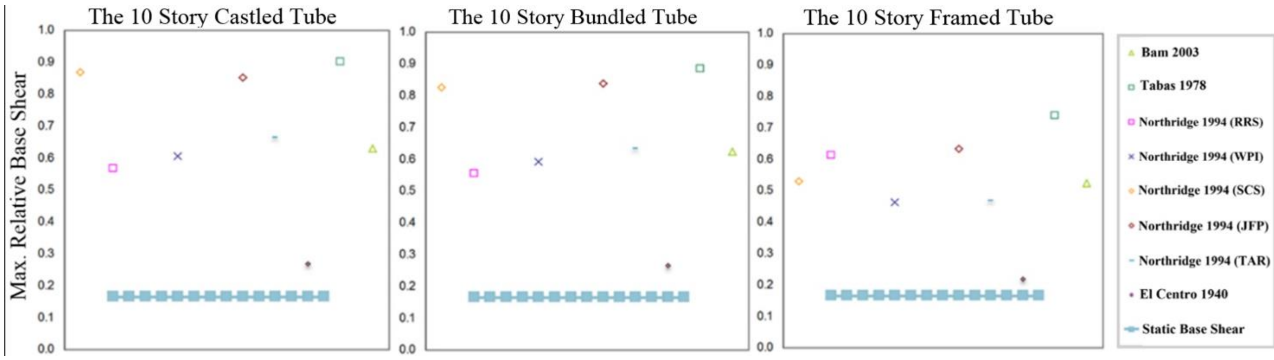
In order to have more accurate study on the analytical results, the velocity response spectra of all earthquake records are drawn for the LN component and the period of the first three modes of the studied structures are shown separately as dashed lines on the velocity response spectrum in Figures (15) and (16). These figures illustrate the spectral location of first and second vibration modes of the structures Ca.T. and B.T. are in the section with almost greater vertical amounts. This feature is more evident for the velocity response spectra of Tabas, SCS and JFP records.

It is witnessed that the more contribution of a few number of lower frequency modes of vibration, have distinct predominant effects on total seismic response of the studied structures. Furthermore, the distinct result caused by this phenomenon would also be a wide distribution of plastic hinges along with great amounts of drift parameter on the whole body of resistant structural skeleton. The maximum drift demands are mainly focused in lower and mid-levels of Ca.T. and B.T., while in F.T. these demands reach their maximum amount in mid and higher levels.

As follows, by drawing the models façade in the X direction of the plan and displaying the formation of the plastic mechanism on it subjected to the JFP and Tabas records, the detailed visualization of different dissipation processes of earthquake kinetic energy can be observed which influenced by the first large period modes of vibrations (Figures 17 and 18). In all three models under the near-fault records, there are various formation mechanisms of plastic hinges in several performance levels. These plastic hinges occur in many parts of the studied structures, while no plastic hinges formed in any of the three studied models under influence of the far-field record ELC 1940.

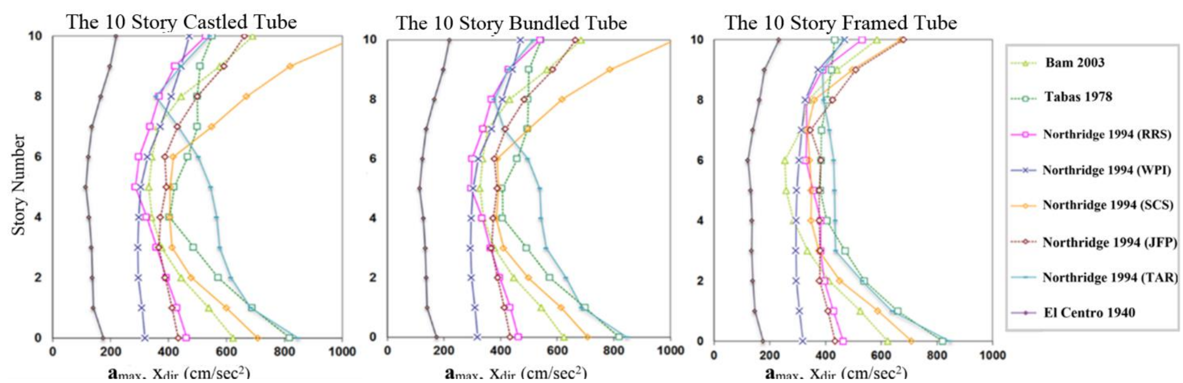
In addition, based on having comparisons among the illustrated graphs of the seismic response parameters in Figures (10) to (14), it is observed that the models B.T. and Ca.T. represent a lot of behavioral similarities. Furthermore, the generated plastic hinge mechanism in the Ca.T. model reveals a few more consistent form than the one of the B.T. structure, as shown in Figures (17) and (18). A precise review of Figures (19) to (21) denote that both of the Ca.T. and B.T. models can generally display higher structural efficiency as well as relatively better internal stress resultant distributions than the F.T. structure. Meanwhile these bents contain a few more rigid frames and panelized bents than the F.T. structure.

The distinct outcome though this research is a relatively reduction of shear lag effects in columns by using the Ca.T. arrangement in internal panelized frames of the total structural skeleton. It is apparent that the Ca.T. model shows a 40% and 25% reduction in the concentration of axial force resultants in its peripheral columns compared to those of F.T. and B.T. models.



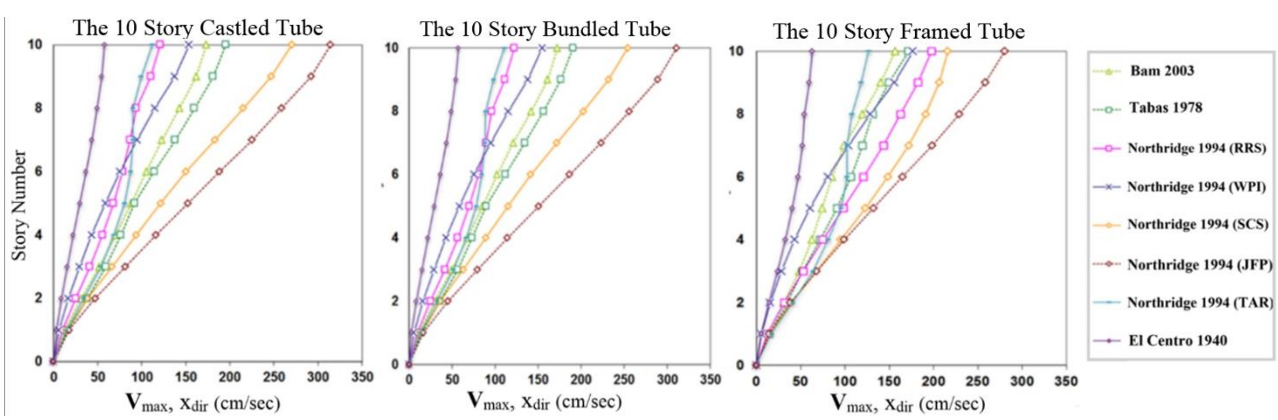
(a) (b) (c)

Figure 10. The maximum relative seismic base shear of, (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



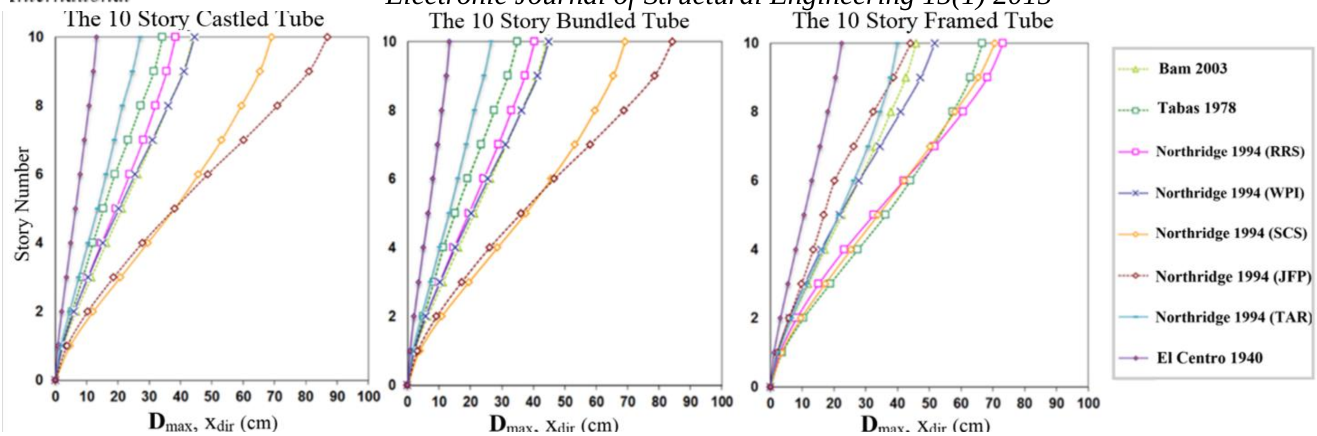
(a) (b) (c)

Figure 11. The envelop of stories maximum acceleration of, (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



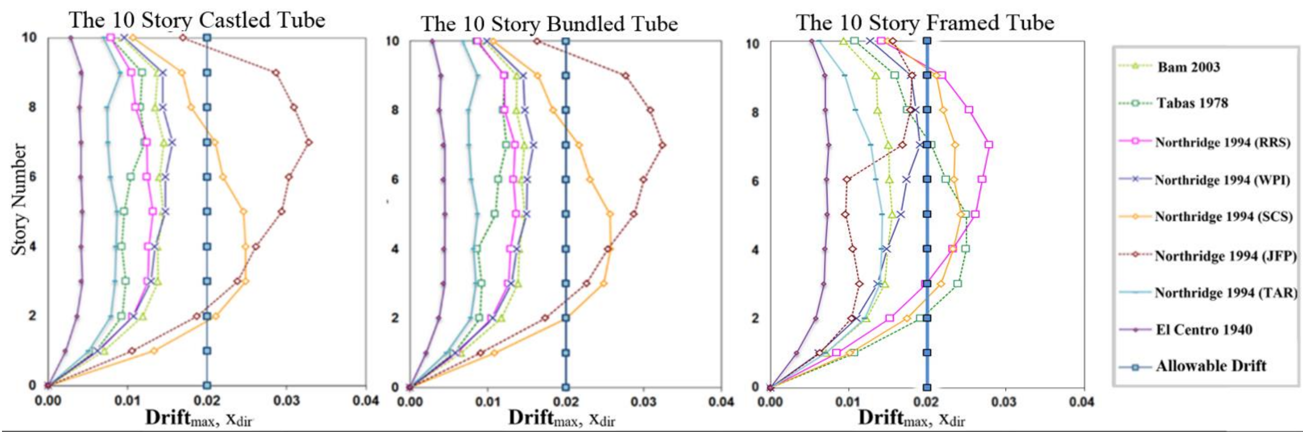
(a) (b) (c)

Figure 12. The envelop of stories maximum velocity of, (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



(a) (b) (c)

Figure 13. The envelop of stories maximum displacement of, (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



(a) (b) (c)

Figure 14. The envelop of stories maximum drift of, (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;

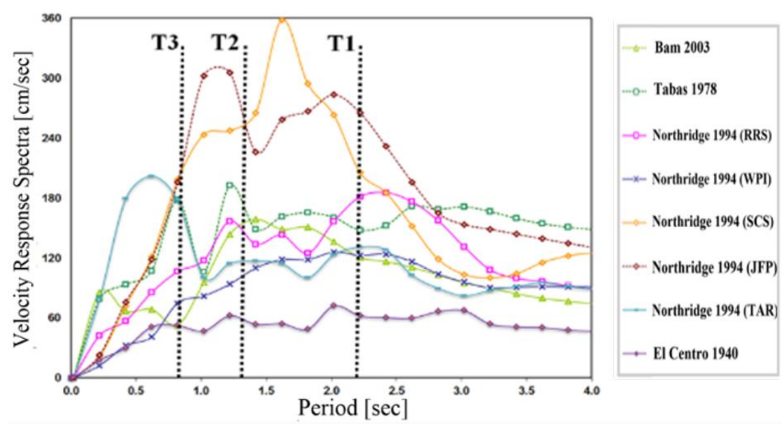


Figure 15. The velocity response spectra corresponding to the LN component of the selected records and illustration of period axis of the first three vibration modes related to the B.T. and Ca.T. studied models in Table (1).

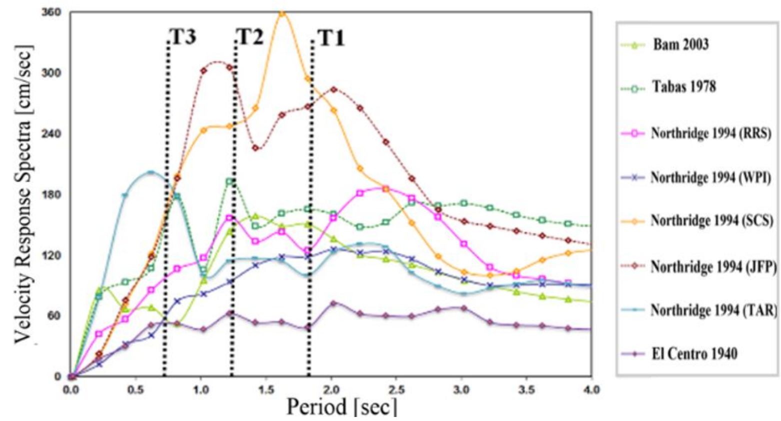


Figure 16. The velocity response spectra corresponding to the LN component of the selected records and illustration of period axis of the first three vibration modes related to the F.T. studied model in Table (1).

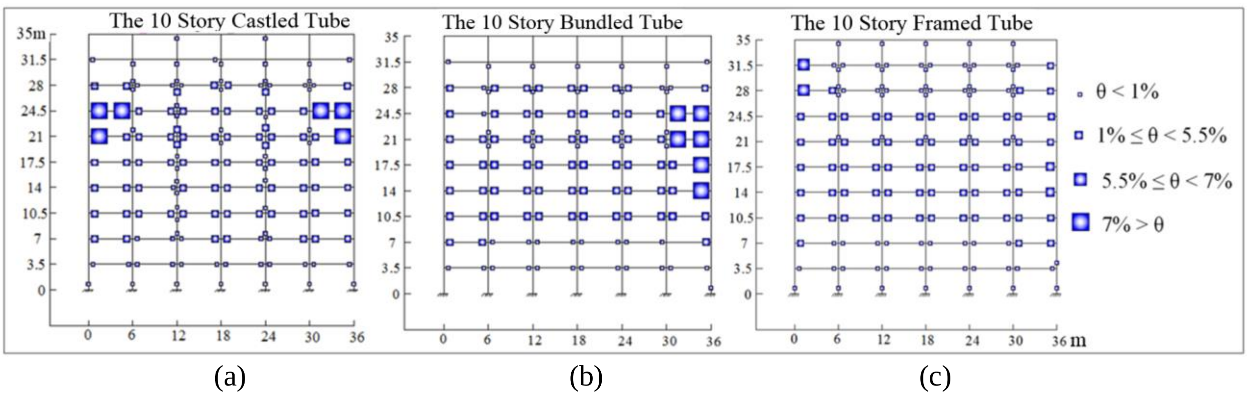


Figure 17. The maximum rotation of girders and columns under the JFP record in X direction of plan (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;

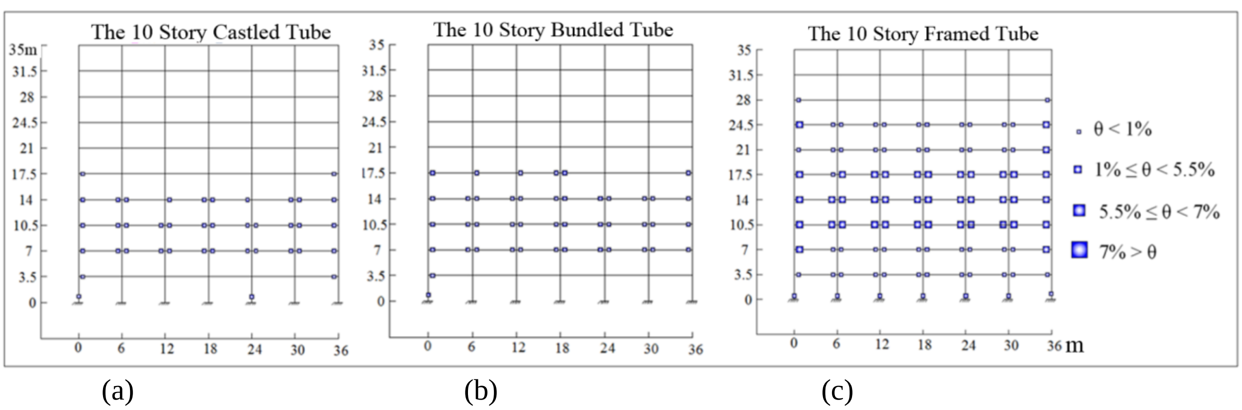
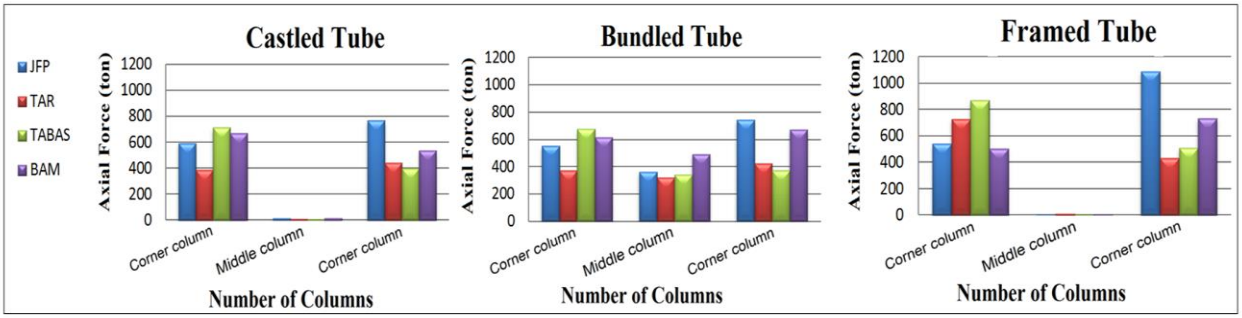
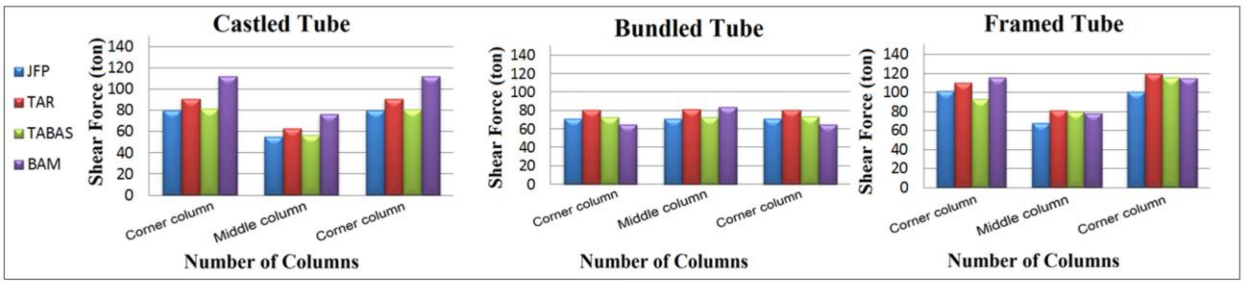


Figure 18. The maximum rotation of girders and columns under the Tabas record in X direction of plan: (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



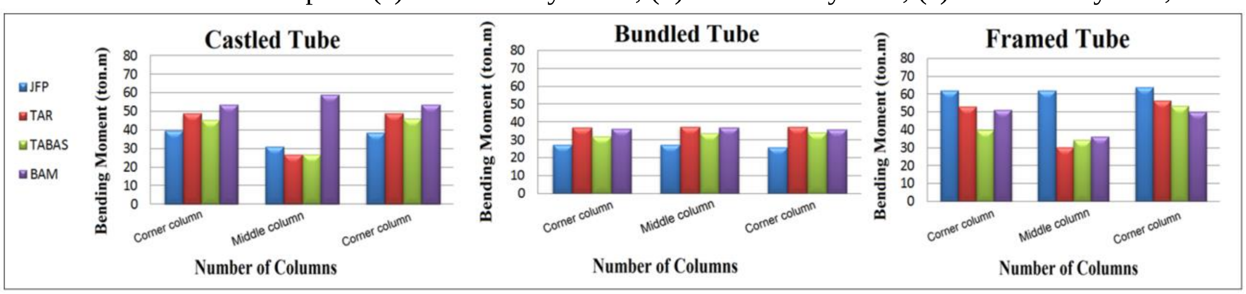
(a) (b) (c)

Figure 19. The distribution of maximum axial force in corner and middle perimeter columns located in X direction of plan: (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



(a) (b) (c)

Figure 20. The distribution of maximum shear force in corner and middle perimeter columns located in X direction of plan: (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;



(a) (b) (c)

Figure 21. The distribution of maximum bending moment in corner and middle perimeter columns located in X direction of plan: (a) The 10-story Ca.T.; (b) The 10-story B.T.; (c) The 10-story F.T.;

4. CONCLUSION

The main goal of this research is to perform the more complete studies on important characteristics of near-fault earthquake records and their effects on the seismic performance of framed tube-type structural systems with various skeletal arrangements. In this article, the seismic performance of three 10-story steel studied models with different framed tube-type bents are assessed under strong near-field records which have velocity pulses. The analyses results of this research indicate that the presence of long period coherent velocity pulses in the time history of strong ground motion causes intense inelastic demands in medium-rise framed tube skeletons which may lead to lack of the codified seismic performance limits.

Furthermore, it is denoted that emerging of surpassing directivity effects in near-field records cause the overall plastic hinges mechanism which generated in the resistant structure of the building, has larger numerical parameters in the domain of nonlinear dynamic behavior.

Three mid-rise rigid frame tube-type resistant skeletons were considered in this study. These companion rigid tube-type skeletons named framed, bundled and castled tube structural systems respectively which are different in plan arrangement. It is noticeable that having a decent distribution of inner rigid bents configuration in framed tube-type structures, can lead to a more desirable distribution of axial and shear force resultants as well as maximum bending moments, especially in the perimeter columns of plan. Moreover, this structural phenomenon can reduce the shear lag effects almost up to 40% and 25% respectively in seismic performance of both systems of castled and bundled tubes. This is more evident as compared to the corresponding results of flexural framed tubes. The distinct outcome though this research is a relatively reduction of shear lag effects in columns by using the Ca.T. arrangement in internal panelized frames of total structural skeleton.

The formation and development process of nonlinear hinges mechanisms during intensive ground shakings caused by strong earthquakes, clearly portrays the conceptual relationship between the drift demand and the ductility parameter. Assessing the formation process of overall plastic mechanisms in all three studied medium-rise structural models indicates that most of the generated inelastic hinges are created in almost middle height levels of the resistant skeleton.

Nevertheless, the results of this study show that large velocity pulses displayed in the time history of energized records due to the Northridge earthquake 1994 can impose severe inelastic demands in the seismic response parameters of mid-rise steel structures. Furthermore, the general drift demand is more than 0.03 and the maximum values of absolute acceleration and relative velocity of stories are greater than 1g and 300 cm/sec in the X direction of plan of the studied models, respectively. As compared to the ones resulting from far-field records, those are less than 0.2g and 50 cm/sec, respectively.

The illustrated outputs of the analyzed models indicate that the existence of high-amplitude coherent velocity pulses as well as powerful acceleration spikes in time history of damaging near-field records causes a series of intensive severe inelastic seismic demands. This process may lead to the maximum drift demand to be more than 0.035 and the upper limit of rotation of rigid connecting zones are obtained more than 5 percentages of a radian. Near field ground motions containing forward directivity effects impose higher dynamic base shear resultants in the studied models than broad-band far-field ground shaking. Furthermore, sever displacement demand would obtain more than 80cm.

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