Assessing Seismic Behavior of Eccentrically Braced Frames (EBFs) Due to Near-Field Ground Motions.

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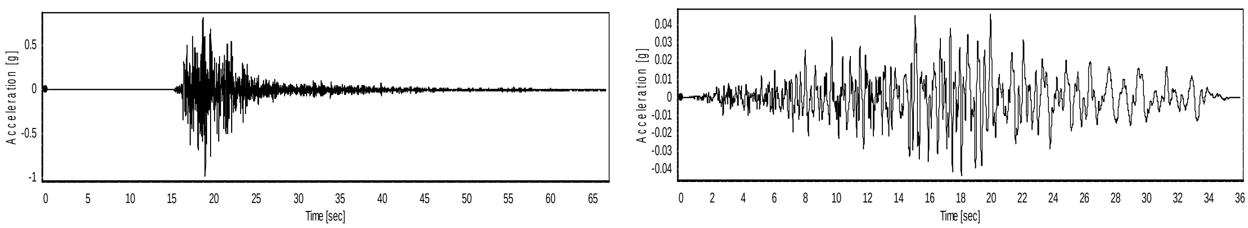
ABSTRACT:
Near-field ground motions have caused much damage in vicinity of seismic sources during recent earthquakes. Eccentrically braced frames have convinced ductility and enough stiffness. This research aims to: investigate the nonlinear dynamic and nonlinear static response of buildings with EBFs due to near-field and far-field ground motions and compare the results for EBFs with short and EBFs with long link beams. To obtain this objective, 3-D steel buildings in 3, 5, 8 and 15 stories by short and long link beams were modeled. 9 near-fields with 3 far-field ground motions were utilized as input ground motions. It is found that in near-field regions, the demands of structures have larger values as compared with far-field regions. Based on nonlinear analysis, the values of story displacement, inter-story drift, story acceleration and velocity, base shear, for shear link-beams systems and moment link-beams systems under both near and far-field earthquakes were investigated and the results have been discussed.

KEYWORDS:
Near-field, Eccentrically braced frames (EBF), Nonlinear behavior, 3-D steel building, Far-field, Link-beam.

1. INTRODUCTION TO NEAR- FIELD EARTHQUAKES

After Loma Prieta 1989 earthquake, Mohraz has divided earthquakes in 3 groups:
Near-field earthquakes: the distance between site and fault is less than 20 km
Mid-field earthquakes: the distance between site and fault is between 20 km to 50 km.
Far-field earthquakes: the distance between site and fault is larger than 50 km. [1].
This classification according to distance is not so exact, in some researches the distance of near-field is consider 10 to 15 km. [1996 SEAOC Blue Book].
Near-field earthquakes have some characteristics that differs them from far-field ones. These earthquakes have higher accelerations and restricted frequency content in higher frequencies than far-field ones. Also their records have pulses in beginning of record with high period and high domain. These pulses are much considerable when the Forward directivity takes place, therefore the records change from Board-Band condition to Pulse-Like ones. These pluses result in occurrence of amount of maximum of Fourier spectrum in limited periods unlike the amount of maximum of Fourier spectrum in far-field earthquakes that occur in wide-ranging of periods. In Fig 1 we can see the differences between bam (near-field) and Morgan (far-field) records. [2]&[3].



a: Bam earthquake's record b: Morgan earthquake's record
Fig1. Comparing the differences between bam (near-field) and Morgan (far-field) earthquakes

These pulses also cause that the responses of structures exposed to them is more affected by Wave-Like terms than Mode-Like terms. [3]. In this situation the response of structure get from accumulation of waves move in structure. Other effects of pulses is send out the maximum of domain to the smaller periods that causes to increase in virtual stiffness, base shear, ductility demand and decrease in damping of structures. [4]. The ratio of vertical to horizontal spectrum in near-field earthquakes is much more than far-filed ones. In codes this ratio often consider as 2/3. But in near-field earthquakes this ratio in short periods can reach to number 2. [4].

The above discussions show that there is lot of differences between near-field and other earthquakes that cause to different responses of structures under these earthquakes.

2. ECCENTRICALLY BRASED FRAMES

In eccentrically braced frames, braces in each span are located with distance in longitudinal axis of beam or with distance by beam to column connections. In these systems lateral behavior of structure is the combination of axial forces, shears and moments of beams and columns in braced spans and the compressions and tensions of braces.

These systems are expected to withstand significant inelastic deformations in the links whereas other segments of system (out of link beam segments) shall be designed to remain essentially elastic. Therefore, although it has convinced ductility, it has enough stiffness too. The EBF's ductility and stiffness change by its length of link beam and therefore can be set by the designer to get proper condition. The object of designer is not to prevent of producing of hinges, but also the object is to controlling the place of hinges Productions, and checking the capacity of rotation of link beams. [5].

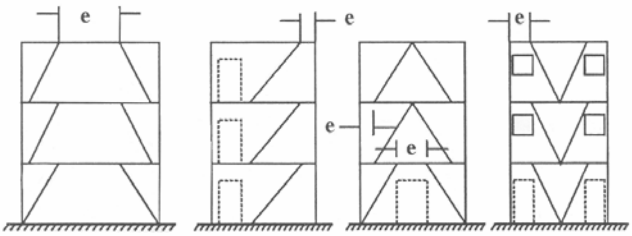


Fig 2. Samples of eccentrically braced frames

1.1. Mechanism of Link-Beams

The length of link beams affect the behavior of EBF's in linear and non-linear regions. In high latral forces the plastic hinges were created in link beams that the kind of these hinges indicates the mechanism of link-beams. by writhing the stability equation we have these two boundaries. In these equations e is the length of link-beam.

$$e \leq \frac{1.6M_p}{V_p} \quad \text{Shear Link-beams} \tag{2.1}$$

$$e \succ \frac{2.6M_p}{V_p} \quad \text{Moment Link-beams} \tag{2.2}$$

When the length of link beam is between these limitations both shear and moment mechanisms occur. UBC code limits the ultimate rotation of link beams, γ_u =0.09 for shear ones and γ_u =0.03 for moment ones. AISC limitations are γ_u =0.08 for shear link and γ_u =0.03 for moment links. These limitations in Iran's code are γ_u =0.08 for shear link and γ_u =0.02 for moment links. [5].

3. RECORDS

All near-field records except Bam and Chichi records are chosen from collection of 22 records that gathering by Somerville et al in 1997. All the records were registered in soil D according to NEHRP, Zone 4 according to UBC97 and type II according to Iran's code (2800) or recover for this type of soil. All of them have distance less than 10 km and for all of them $6.2 \le M_w \le 7.4$. [6], [7], [8], [9].

Table 3.1 Specifications of near-field ground motions

Earthquake	Year	Station	Distance(km)	M_w	Duration (sec)
Tabas	1978	Tabas	1.2	7.4	32.840
Bam	2003	Bam	1	6.8	66.555
Loma prieta	1989	Los Gatos	3.5	7	24.96
Mendocino	1992	Petrolia	8.5	7.1	35.98
Erzincan	1992	Erzincan	2	6.7	20.775
Landerz	1992	Lucerne	1.1	7.3	48.12
Northridge	1994	Olive View	6.4	6.7	39.98
Kobe	1995	JMA	0.6	6.9	47.98
ChiChi	1999	TCU068	1.09	7.6	90.00

We use 3 far-field records to complete the comparison. All far-field records have distance above 50 km and in their records there are not any pulses. [7],[8],[9],[10].

Table 3.2 Specifications of far-field ground motions

Earthquake	Year	Station	Distance(km)	M_w	Duration (sec)
Tabas	1978	Ferdoos	94.4	7.4	40.00
Morgan		Morgan	76.25	6.8	35.995
Landerz	1992	12026 Indio	55.7	7.3	60.00

4. MODELING AND DESIGN

In this research the EBF systems with short link-beams and long link-beams have modeled. Short link-beams considered equal to 0.5 m and long link-beams considered equal to 3.0 m, in 3, 5, 8 and 15 numbers of stories. The height of each story is 3 m. for each model loading and complete design is separately done according to Iran's Earthquake code (2800) (much similar to UBC97) and Steel Design Code (much similar to AISC89). For doing all steps of analysis and design we use program Sap2000 V8.3.1.

The Plan of structure in all stories is similar. This Plan has 5 longitudinal spans and 3 spans in other side. Each span has 4m length. The plan of models is regular, therefore, there are not any tensional effects unless accidental torsion, that considered equal to 5%. Consideration of soil is according to soil type II (Iran 2800 code) similar to zone 4 (UBC97). All models have residential use. The earthquake probabilistic hazard is considered very high. IPE and plate girders are used for beams, BOX sections are used for columns and UNP doubles are used for bracings. Plastic hinges definition, assignments and nonlinear static analysis are done according to FEMA273. $P-\Delta$ effects were considered in all analyses. All the sections were chosen by considering some conditions; the plastic hinges were produced only in link-beams, production of hinges has regular process, it means that before producing plastic hinges in all of stories, the structure don't go under instability and collapse mode .All the linear dynamic analyses are as modal transient time history modal analysis is done by Eigenvector Analysis. All the non-linear dynamic analyses are as Direct Integration transient time history. Direct Integration Analysis is done by (Hilber, Hughes, Taylor) method. [5], [10], [11], [12], [13].

5. EVALUATION OF RESULTS

5.1. Evaluation of Lateral Forces

For evaluation we use average of results for each system. As we can see in Fig.4 the EBF's with short link-beams can suffer more lateral forces than EBF's with Long link-beams in non-linear analysis, but in linear analysis the distributions and amounts of lateral forces in both system is near to each other. It shows that the non linear capacity of EBF's with Long link-beams is less than this system with short link-beams. In addition the modal participations are seen in all models and this participation has grown by increasing the number of stories.

The negative shears in high structures with Long link-beams have seen more than the other models. It is because of less base shear and more modal participations in this situation.

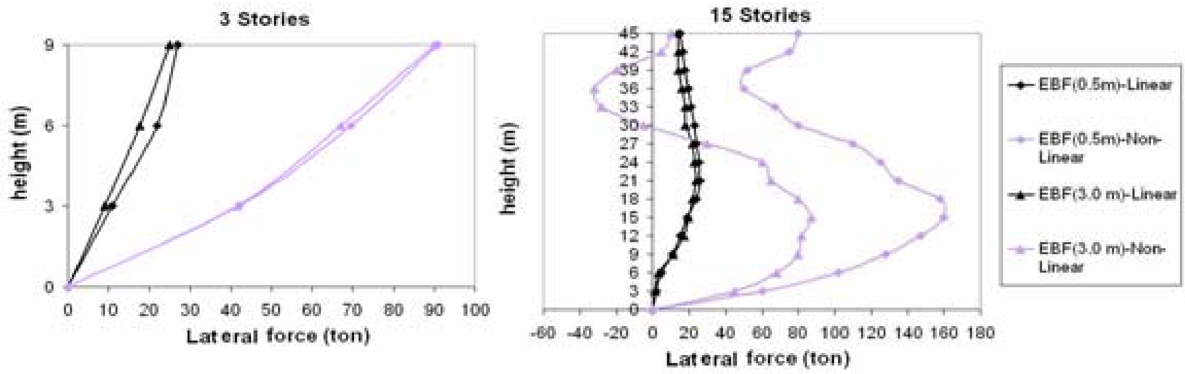
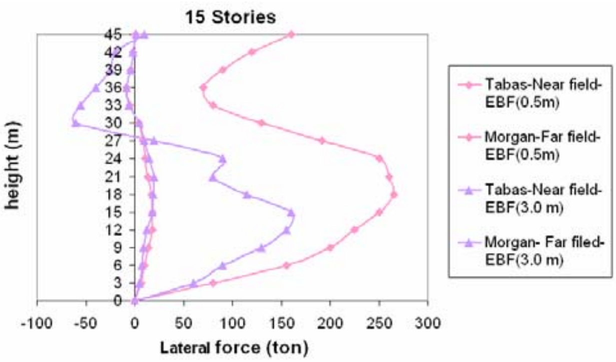


Fig.4. Lateral force distribution in different systems by different number of stories



-The lateral forces get from far-field earthquakes, is so less than lateral forces get from near-field earthquakes.

-In EBF systems with short links by doing nonlinear analysis maximum of lateral forces is take place in upper stories in comparison with EBF systems with Long link-beams.

-The differences between amount of lateral forces in two systems when they go under near-field earthquakes is much more than when go under far-field ones.

Fig.5. Comparisons of lateral forces get from Tabas (near-field) and Morgan (far-field) earthquakes

5.2. Evaluation of Lateral Displacements

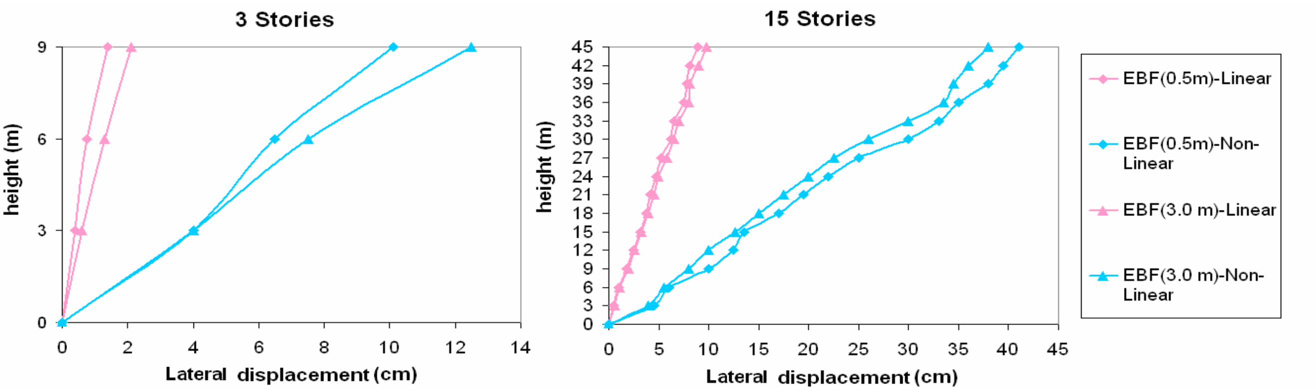
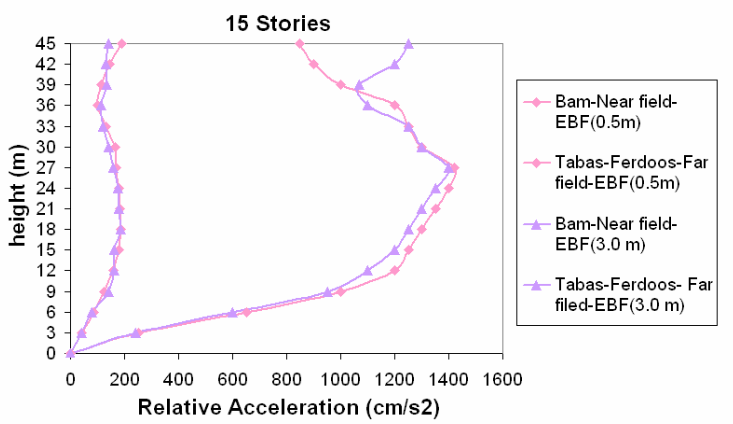


Fig.6. Displacements distribution in different systems by 3 and 15 stories

In 3 and 5 stories buildings the nonlinear dynamic in EBF's with Long link-beams is more than EBF's with short link-beams. But by rising the number of stories and extending the nonlinear behavior of structure as the EBF's with short link-beams have more ductility and can go in nonlinear part more than EBF's with Long link-beams, therefore the nonlinear displacements in EBF's with short link-beams become more than EBF's with Long link-beams. But the linear dynamic displacements in EBF's with Long link-beams is more than EBF's with short link-beams in all models, it is because less stiffness that theses systems have. In addition we could say that the displacements in EBF's with short link-beams have more partaking of nonlinear displacements than EBF's with Long link-beams. And as we could define ductility as nonlinear displacement where base shear is maximum divided by maximum elastic displacement, therefore it is obvious that the ductility of EBF's with short link-beams is much more than EBF's with Long link-beams.

5.4. Evaluation of Relative Accelerations



-Under near-field and far-field earthquakes and under both nonlinear and linear analysis the amounts of relative accelerations in EBF's with short link-beams are more than EBF's with Long link-beams.
- By increasing the height of systems more modal participation effects are seen.
- The amounts of relative accelerations gained form near-field earthquakes are much more these amounts get from far-field earthquakes.

Fig.8. Comparisons of rel- acceleration get from Tabas- Ferdoos st. (far-field) and Bam (near-field) earthquakes

5.5. Evaluation of Nonlinear Parameters

For each model, among nonlinear static analyses that have done we choose critical analysis that has less maximum nonlinear displacement for investigations. For investigation the behavior of structures we often use some parameters that are going in table 5.1.

Table 5.1. Nonlinear parameters

System-Number of St	Base-shear max Fmax (ton)	Base-shear yield Fy (ton)	Max-Dis Δ m (cm)	Yield-Dis Δy (cm)	μ	T (s)	R
EBF(e=0.5 m)-3	248.04	138.88	25.7	7.05	3.64	0.344	7.52
EBF(e=3 m)-3	259.661	192.27	31.37	10.6	2.96	0.749	7.17
EBF(e=0.5 m)-5	502.355	335.17	42.22	8.56	4.93	0.532	7.73
EBF(e=3 m)-5	365.655	308.04	42.72	13.78	3.1	0.86	8.76
EBF(e=0.5 m)-8	562.54	398.68	64.36	12.64	5.09	0.818	9.89
EBF(e=3 m)-8	472.01	368.58	58.08	17.035	3.41	1.18	8.67
EBF(e=0.5 m)-15	698.93	487.92	113.243	21.69	5.22	1.45	8.75
EBF(e=3 m)-15	469.021	402.49	98.721	23.45	4.21	2.02	8.34

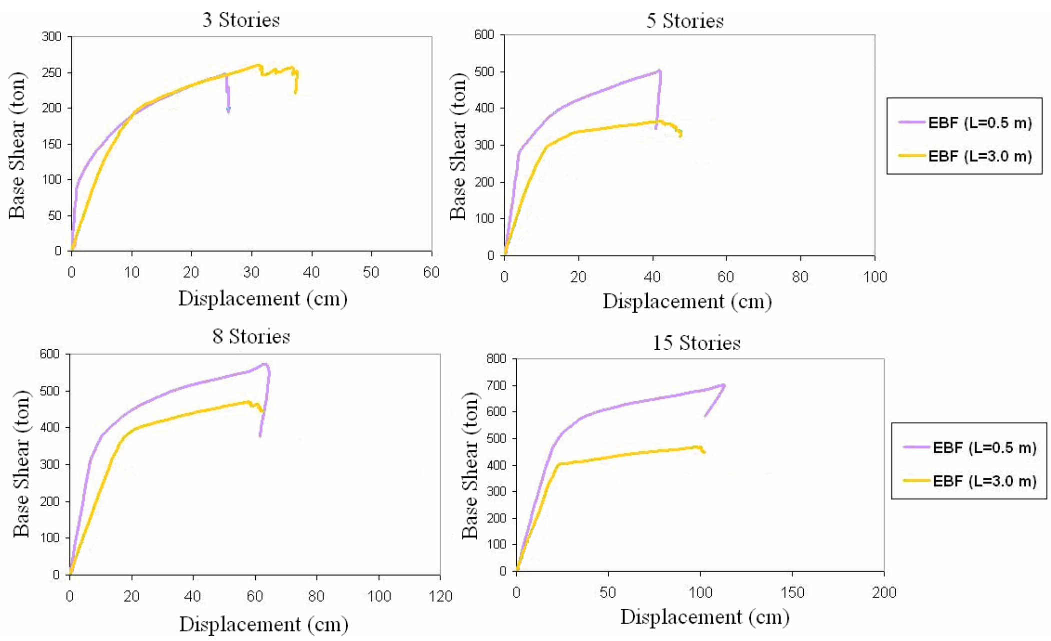


Fig.9. Base shear- displacements diagrams (Pushover Curves)

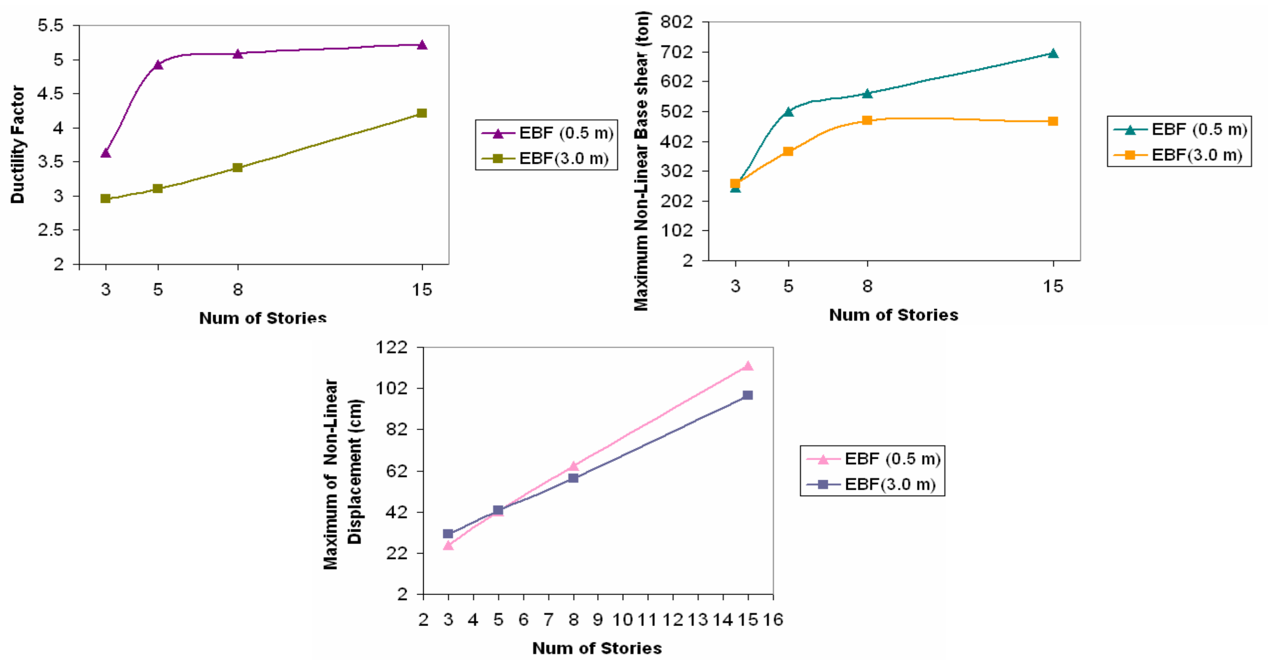


Fig.10. Nonlinear parameters according to number of stories

The shape of diagram of ductility factor against num of stories for short link-beams systems differs by the EBF systems with long link-beams. EBF's with short link-beams have more ductility and also more maximum base shear that make better nonlinear function and more energy dissipating. For these systems by increasing the number of stories the rate of increase in ductility decrease or ductility be constant, but in long link-beams systems, the rate of increase in ductility continue in high level structures as in low ones. The maximum displacement in low level structures by long link-beams is more than short-link ones. But by increasing the number of stories and expanding the nonlinear domain the building can go more in nonlinear area and so the displacement for EBF systems with short link-beams that have better nonlinear ductility, become more than EBF systems with long link-beams.

5.6. Comparison of Ductility Factors Get by Nonlinear Dynamic and Nonlinear Static Analysis

After doing nonlinear time history analysis, we get average of lateral forces for near and far field earthquakes. By using these average lateral forces we can get the ductility demands under earthquakes. That will be shown in Fig 11.

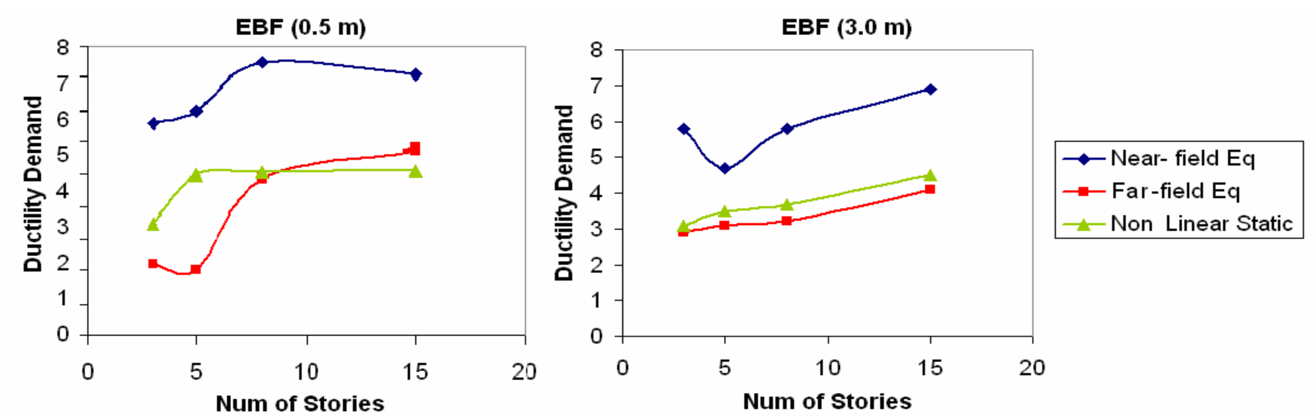


Fig.11. ductility demands under near-field, far-field earthquakes and nonlinear Static analysis

For both EBF's with short and long link-beams, the ductility demands in near-field earthquakes are much bigger than the ductility get by static nonlinear analysis. However the ductility demands in far-field earthquakes are less than the ductility's get by static nonlinear analysis except for 15 stories by short link-beams EBF. The amount of ductility bigger than static nonlinear ductility means that before the structure can get to ultimate nonlinear operation, the building goes to collapse. The shape of diagrams for EBF (LB=3.0 m) and EBF (LB=0.5m) and also for near and far-field earthquakes are different, consequently for getting the ductility demands in near-field earthquakes we can not use a modification factor to the ductility demands in far-field earthquakes and we must do analysis for near-field earthquakes independently.

5.7. Distribution of Ductility Demands in Height of Structures

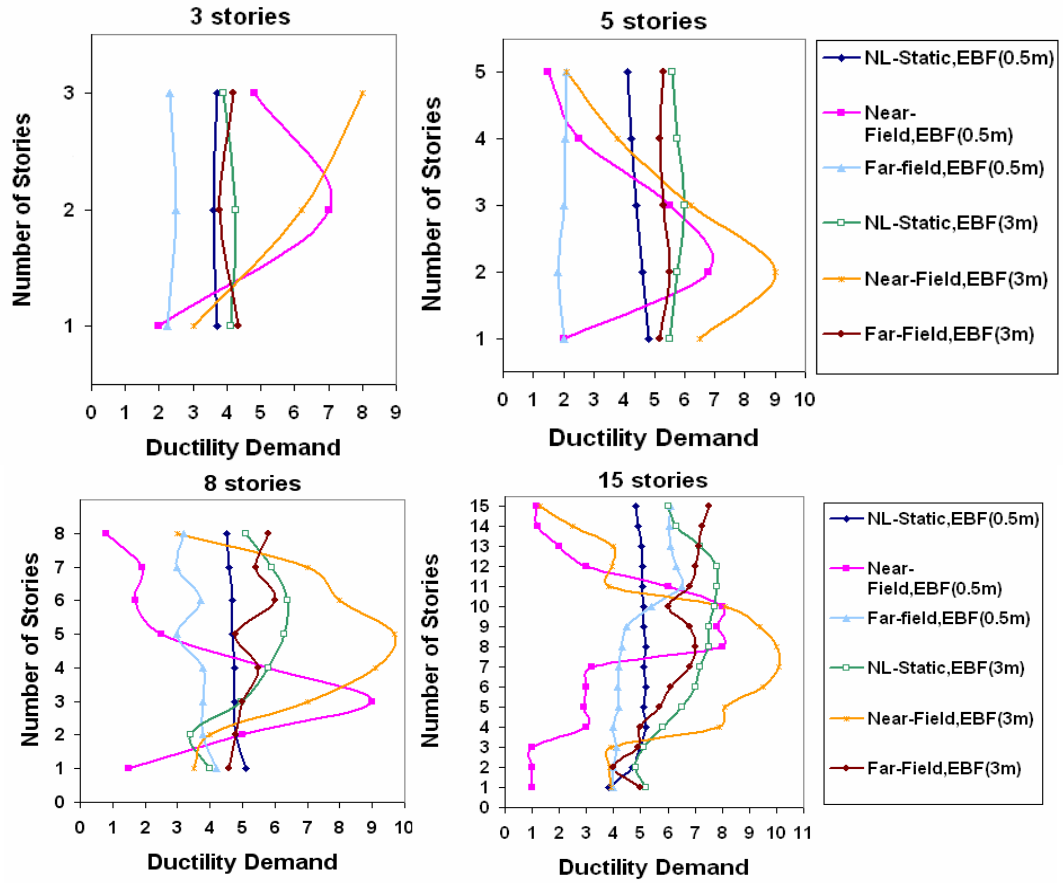


Fig.12. Distribution of ductility demands in height of structures

By increasing the height of structure and increasing the period of building the maximum ductility demand occurs in higher stories. Distributions of waves in height of structures and participation of higher modes cause to changes in distribution of ductility in height. These changes have been seen in higher building and under near-field earthquakes more. By increasing the height of structure and increasing the period of building the story that the maximum ductility demand occurred, goes higher and the distribution of ductility under near-field earthquakes are much different by the distribution of ductility under static nonlinear, so this matter cause a big amount of ductility demands in structures, specially in middle and upper stories. Similarities between distribution of ductility under far-field earthquakes and distribution of ductility under static nonlinear are much more than Similarities of distributions of ductility under near-field earthquakes. So in near-field regions it looks necessary that linear and nonlinear static analyses are not sufficient and the nonlinear dynamic analysis must be used to get precise responses.

6. RESULTS

-By increasing the height of systems more modal participation effects are seen. These effects are seen in EBF's with Long link-beams more than EBF's with short link-beams.

- The nonlinear displacements in EBF's with short link-beams become more than EBF's with Long link-beams.

But the linear dynamic displacements in EBF's with Long link-beams is more than EBF's with short link-beams in all models

-The differences between amount of lateral forces in two systems when they go under near-field earthquakes is much more than when go under far-field ones.

-In EBF systems with short links by doing nonlinear analysis maximum of lateral forces is take place in upper stories in comparison with EBF systems with Long link-beams.

-The negative shears in high structures with Long link-beams have seen more than the other models. It is because of less base shear and more modal participations in this situation.

-the EBF's with short link-beams can suffer more lateral forces than EBF's with Long link-beams in non-linear analysis, but in linear analysis the distributions and amounts of lateral forces in both system is near to each other.

- Under near-field and far-field earthquakes and under both nonlinear and linear analysis the amounts of relative accelerations in EBF's with short link-beams are more than EBF's with Long link-beams.

-EBF's with short link-beams have more ductility and also more maximum base shear that make better nonlinear function and more energy dissipating. For these systems by increasing the number of stories the rate of increase in ductility, decrease or become constant, but in long link-beams systems, the rate of increase in ductility continue in high level structures as in low ones.

-By increasing the height of structure, the maximum ductility demand occurred in higher stories, and the distribution of ductility under near-field earthquakes are much different by the static nonlinear ductility's, so this matter cause a big amount of ductility demands in structures, specially in middle and upper stories.

- Similarities between distribution of ductility under far-field earthquakes and distribution of ductility under static nonlinear are much more than Similarities of distributions of ductility under near-field earthquakes. So in near-field regions it looks necessary that linear and nonlinear static analyses are not sufficient and the nonlinear dynamic analysis must be used to get precise responses.

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