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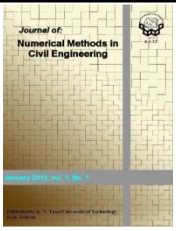

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Evaluation of Damage Index of Eccentrically-Braced Frames according to Link Beam's Length with Soil-Structure Interaction Effects

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Abstract:

Due to features such as ductility and stiffness, the eccentrically-braced frames(EBF) have a good performance against seismic loads and have been considered by designers. Previous studies indicate that the soil underlying the structures affects their seismic behavior. In the case of EBFs, the link beam plays an imporatnt role in the seismic behavior of the system and thus, investigation into the effect of the geometric characteristics of the link on general behavior of the system, would be of utmost significance. In this respect, length of the link beam has been considered as the main variable in this study, taking the effects of soil-structure interaction (SSI) into account.Dynamic time-history analyses considering different lengths for the link beam with and without inclusion of the SSI, have been conducted, aiming to obtain damage indices. The results indicate that as the length decreases, in retrun, damage index (DI)increases and vice versa. Additionally, it was found that when the ratio of length of the link to that of the bay is approximately equal to 0.5, the DI values drop significantly. Also, results showed that considering the effect of SSI, applied general changes on the value of D, and showed different effects at various lengths of the link beams.

1. Introduction

Earthquakes are natural disasters that take the lives of thousands of people every year and cause considerable financial loss. As a result, designing safe, reasonably priced buildings is a major priority. In this context, among the existing structural systems, eccentrically braced steel frames (EBFs) could play an important role. These frames have been effective owing to their proper flexibility and stiffness leading to their broad acceptability for engineering practices. An EBF consists of beams, columns, braces and links. Inelastic actions are restricted to the links while the other components are necessarily meant to remain elastic under seismic excitations.

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In EBFs, application of short links is more preferable, owing to their greater stiffness and ductility. Short links yield in shear and mitigate the earthquake input energy via cyclic plastic deformation, while developing some hardening [1]. Previous studies [2-11] have managed to develop design provisions [12-16] for the EBFs. In such structures, length of the link beam is a key parameter given that the seismically-induced loads to the structure are dissipated via shear-flexural behaviour of the links. In 2014, Kuşyılmaz and Topkaya proposed a formulation to compute the fundamental period of the EBFs. The model adopts the rigid plastic deformation mechanism of the EBFs as a basis and demands knowledge of the normalized link length averaged over all stories. They found that the normalized link lengths depend on the seismic hazard, braced bay width and height of the building. They concluded that their proposed approach enhances the estimates in contrast to those provided by the relations given in ASCE7-10 [17]. Ezoddin et al. investigated the effect of different link beam lengths in the reinforced concrete frame retrofitted with the linked column frame system. They found that the model with the ratio of e/L =0.45 has a better performance than other different lengths of the link beam. In this model, the stiffness of the LC frame has increased about 78% in comparison with the model with the ratio of e/L that is more than 0.6[18].

Della Corte et al. numerically studied response of the EBFs. They managed to develop an analytical model to estimate over strength of the links. They also found that in common cases, an over strength equal to 1.5 is approved by the theoretical efforts for a link plastic rotation of about 0.08 rad. However, in the case of very short links with compact cross sections and perfect axial restraints, greater over strength values of up to 2 could be derived [1]. In 2011, Gulec et al. reviewed and statistically evaluated the test data on 82 links and finally developed fragility functions for the shear and flexure-critical links. Interestingly, they attributed the damage states to repair levels including cosmetic, concrete slab replacement, heat straightening and link replacement [19]. Common dynamic analysis methods usually ignore the stiffness of soil underlying the buildings and assume a rigid base for them, leading the structural responses to be merely influenced by dynamic characteristics of the structure. Notably, this state occurs only if the building rests on rock stratum. Actually, significant flexibility of the soil beneath the foundations is considered as the origin of errors in analysis and design, undermining the seismic reliability of structures. A quick review on the literature reveals that in seismic events, stratum's flexibility and its interaction with structure can intensify the displacements and internal forces developed in the structural responses. Jonathan et al. presented a numerical study of damage index of a 2d steel building with eccentrically braced frame using OpenSees. In this study the behavior of EBF building is identified by observing the monotonic and semi-cyclic pushover analysis. Natural frequency that also measures degree of damage is identified using SAP2000. By determining damage index and natural frequency, the correlation between the two can be observed [20]. According to studies conducted by Gatmiri and Tajaldini [21], nonlinear behavior of soil underlying the structures can significantly increase their dynamic response. The soil–structure system is certainly more flexible than the commonly assumed fixed-base model. As a result, the soil–structure system has a longer natural period compared to the fixed-base structure. Moreover, it usually has a higher damping ratio, due to the radiation damping in the soil, which can drastically influence the response of the structure [22]. According to studies by Yin et al on the replaceable links in eccentrically braced frame subject to cyclic loading, it was observed that the links in this shear device had inelastic deformation concentrated in the link showing extremely stable hysteresis behavior, and damaged links were replaced easily as end-plate connections were adopted. This paper proposes a piezoceramic patch transducer-based active sensing approach to monitor the crack onset and development of the EBF when subjected to dynamic loadings [23].

Numerous studies have been carried out regarding the effects of SSI on different structures and calculating their damage index. Some of this research has been accomplished on reinforced concrete (RC) structures [24-28] and some on the steel structures [29-32]. Only few studies have been dedicated to the investigation of the effects of the length of the link beam on the damage index in eccentrically braced steel frame systems. Bitarafan and Vahdani investigated the effect of soil- structure interaction on damage indices of reinforced concrete frames. The result of their study shows that the overall effect of soil-structure interaction was represented using the sum of absolute DI changes parameter. The value of this parameter computed at storey level was shown to decrease by increase in the ductility demand level particularly for structures positioned on loose soils[33]. Assessing the effect of SSI on damage index of RC frames was studied by Bitarafan and Vahdani .The result of this study shows that the value of DI parameter computed at storey level was shown to decrease by increase in the ductility demand level particularly for structures positioned on loose soils[42].

Based on a research by Najafi and Tehranizadeh [34], the lateral displacements of up to five story buildings with a short link beam are less than those of the buildings with the long link beam. However, these results are converse in structures with more than five stories. Moment frames have a higher ductility than braced frames and the ductility of eccentric frames with long link beams increases with the number of stories, while it stays the same or decreases in the other systems. In addition, the base shear of eccentrically braced frame with a short link beam is higher than that of the same frame with a long link beam which is due to the greater ductility and nonlinear behavior of the latter. The ratio of the base shear to the weight of the building in the eccentrically braced frames is higher than that of the moment frames. Mohebi and Chegini presented a new damage index for steel MRFs based on incremental dynamic analysis. Result shows that increasing the period as well the number of floors along with the presence of some levels of inconsistency in structures caused a decline in the correlation between the proposed damage index and the comparative indices [43].

Review of the literature indicates that in spite of the fact that extensive researches have been conducted on the EBFs covering various aspects of this system, no studies have been conducted to account for the SSI effect in determination of the damage indices of this lateral load-resisting system. Thus, this study aims to develop a series of damage indices by taking into account the SSI, as well as different link lengths.

2. Modeling of Structures

To evaluate the effect of link length on the EBFs' damage index (DI), a six story building of 3.2 m height with three bays has been studied once by considering the soil-structure interaction and once without it. For each state, the lengths of the bays are equal to 5 and 6m, respectively. The structural members are designed once with the link lengths of 60 and 240cm. The characteristics of beams, columns and braces have been obtained using ETABS software based on seismic criteria in the American Institute of Steel Construction code, AISC 360-2010. For the structure designed with 5m bays, the length considered for the link beam starts at 60 cm and then, incrementally, 10cm is added to it for each model until the total length reaches 300cm.Then, effect of the primary length of the link beam on DI of the EBFs with different link lengths is specified. It is to be noted that in this study, the supports and the joints of the columns and beams are fixed. For the structure designed with the 6m bays, the primary length of the link beam is 240 cm. The characteristics of the designed elements for each state are given in Tables 1 to 3.

Table. 1: Member Sections (unit: mm) – 5 m bay- 0.6 m link beam

Section Properties	COLUMN	BEAM	BRACE
STORY 1	BOX200*10	PG-W300*12-F200*15	2UNP120
STORY 2	BOX200*10	PG-W300*12-F200*15	2UNP100
STORY 3	BOX180*10	PG-W300*8-F150*8	2UNP100
STORY 4	BOX150*10	PG-W300*8-F150*8	2UNP80
STORY 5	BOX150*10	PG-W250*10-F120*12	2UNP80
STORY 6	BOX150*10	PG-W250*10-F120*12	2UNP80

Table. 2: Member Sections (unit: mm) – 5 m bay- 2.4 m link beam

Section Properties	COLUMN	BEAM	BRACE
STORY 1	BOX200*10	PG-W270*12-F150*10	2UNP80
STORY 2	BOX200*10	PG-W270*12-F150*10	2UNP80
STORY 3	BOX180*10	PG-W270*12-F150*10	2UNP80
STORY 4	BOX150*10	PG-W240*10-F120*12	2UNP80
STORY 5	BOX150*10	PG-W240*10-F120*12	2UNP80
STORY 6	BOX150*10	PG-W180*8-F120*10	2UNP80

Table. 3: Member Sections (unit: mm) – 6 m bay- 2.4 m link beam

Section Properties	COLUMN	BEAM	BRACE
STORY 1	BOX200*15	PG-W300*12-F200*15 PG-W180*8-F120*10	2UNP80
STORY 2	BOX200*15	PG-W300*12-F200*15 PG-W180*8-F120*10	2UNP80
STORY 3	BOX180*10	PG-W270*10-F200*10 PG-W180*8-F120*10	2UNP80
STORY 4	BOX150*10	PG-W270*10-F200*10 PG-W180*8-F120*10	2UNP80
STORY 5	BOX150*10	PG-W270*10-F200*10 PG-W180*8-F120*10	2UNP80
STORY 6	BOX150*10	PG-W250*10-F150*10 PG-W180*8-F120*10	2UNP80

The gravity loads i.e., dead plus a fraction of live loads applied to the beams are 25 and 10 KN/m, respectively. According to the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard 2800), only 20% of the live load contributes to calculating the effective seismic mass. In this study, the total of the dead load and 20% of the live load is calclated in each level and applied to the joints. The elevated views of the modeled frame in SAP2000 and OpenSees have been shown in Figs. 1 and 2, respectively.

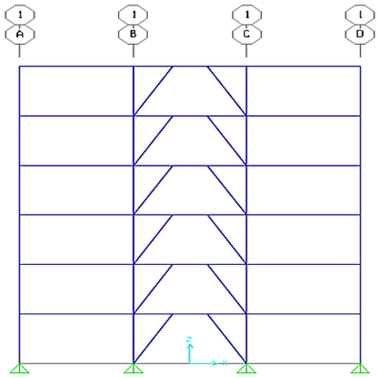


Fig. 1: elevated view of the frame in SAP2000

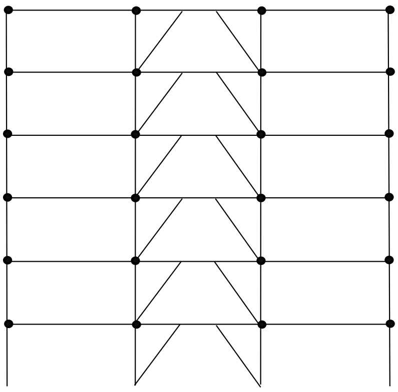


Fig. 2: elevated view of the frame in OpenSees

For nonlinear analyses, two-dimensional models were used to analyze the EBFs by the open-source finite element software, OpenSees. All columns, beams and braces were modeled using nonlinear beam-column elements with inelastic fiber sections as shown in Fig.3. Floor masses were lumped into the column nodes at each storey. Moreover, braces were assumed to have fully restrained end connections.

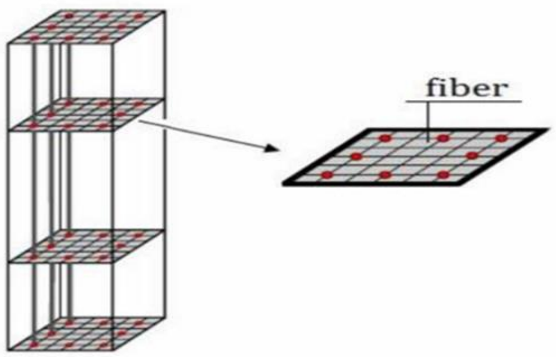


Fig. 3: Nonlinear Beam Column Element[35]

The Steel01 is the material used in the beams and columns' sections. The characteristics of hysteretic stress-strain relation for materials are shown in Fig. 4. The effective parameters of steel material include module of elasticity (E), the yield strength (Fy) and the strain-hardening ratio of the steel. The properties of the steel are given in Table 4.

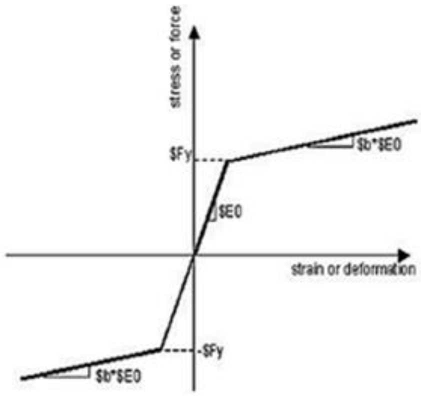


Fig. 4: hysteretic stress-strain relation for Steel01 [32]

Table. 4: Steel Material Properties

Materials	Characteristics	unit	Value
	Yield Strength (Fy)	MPa	400
Steel	Elastic Modulus (E)	MPa	210000
	Poisson's ratio (υ)	-	0.35

3. Effects of Soil-Structure Interaction (SSI)

The direct and substructure approaches are the most common techniques to include the SSI in seismic analysis of structures. Accordingly, the direct analysis evaluates the SSI by modelling a limited soil domain along with the foundation system, superstructure, transmitting boundaries along the perimeter of the soil domain, and interface elements between the foundation and soil. In this study, the direct approach is adopted for modelling SSI [36]. Moreover, modelling dynamic responses of the whole system is carried out in the open-source finite element software, OpenSees [35]. The finite element model of the system considered in this paper is shown in Fig. 5.

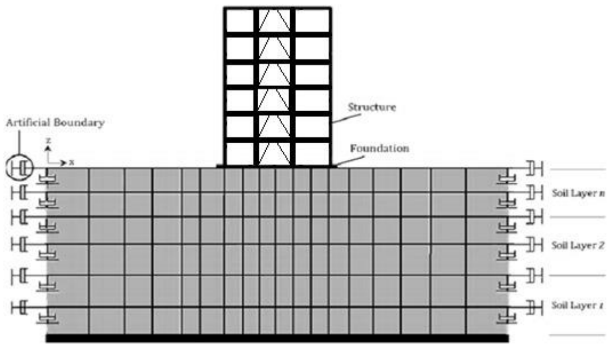


Fig. 5: Finite Element Model of the Structure

Based on previous studies, where distance between center of the structure to that of the soil model boundaries varies within 2 to 3 times of the foundation radius along vertical direction and also, 3 to 4 times of the radius in horizontal direction, impact of the reflexive waves would be insignificant [37]. Hence, herein, the total height and length of the soil domain are taken equal to 40m and 90m respectively, by employing the isoparametric four-node quadrilateral finite elements with two degrees of freedom per each node. Moreover, the modified pressure independent multi-yield-surface J2 plasticity model [38] was utilized as the soil constitutive model (Fig. 6).

In Table 5, the soil properties considered for the sake of numerical modeling are given. Furthermore, the vertical and horizontal Lysmer-Kuhlemeyer [39] dashpots as shown in Fig. 5, are applied in the free-field boundary of the soil so that radiation damping could be modeled and reflection of the outward propagating waves back into the model, could be prevented.

Table. 5: Soil Properties

Density (γ)	kPa	14
Shear Modulus (G)	kPa	61740
Cohesion (C)	kPa	40
Friction Angle (φ)	Deg	5
Shear Wave Velocity (v)	m/s	210
Poisson's Ratio (υ)	-	0.4

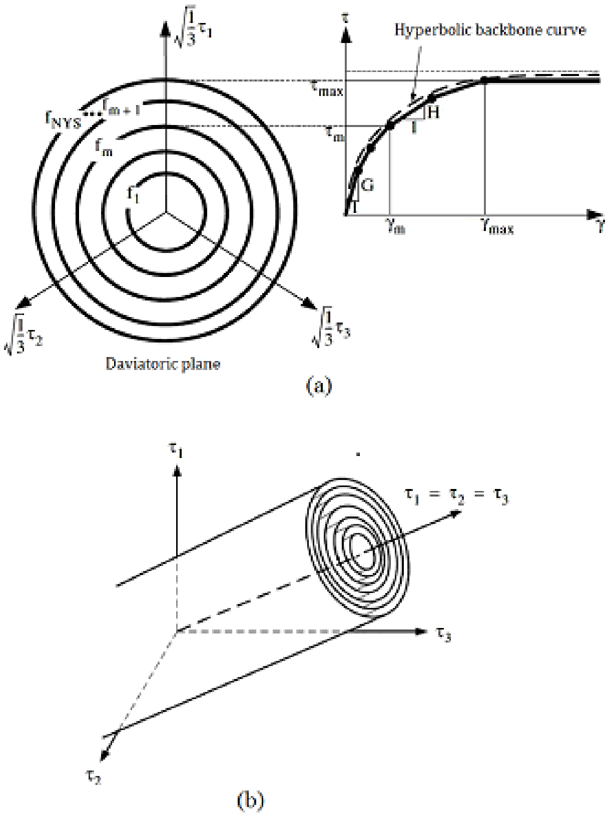


Fig. 6: Yield surfaces of multi-yield-surface J2 plasticity model; (a): Octahedral shear stress-strain (b) Von-Mises multi-yield surfaces [38]

4. Damage Index

In order to design or assess the structures, particularly in compliance with performance-based design approaches, irrespective of the size or complexity, their performance has to be evaluated. Accordingly, measures capable of quantifying the performance levels are sough-after. In this respect, the most efficient method might be to experimentally assess the structures, which is a time-taking and costly process [40]. To tackle such challenges, damage indices have been developed to assist the practitioners so that the structural damages can be measured. In this respect, a number of researchers have conducted studies and managed to develop indices amongst which, the damage index proposed by Park and Ang (1985) is the earliest and most popular index [41].This Damage Index (DI) formulation has received wide attention due to the general applicability and the clear definition it provides for different damage states [33].This damage index varies between zero i.e. intact and one i.e. collapse. This index is defined for a structural member as follows:

$$D = \frac{\delta_m}{\delta_u} + \frac{\beta}{f_y \delta_u} \int dE_h \qquad (1)$$

Or

$$D = \frac{\delta_m}{\delta_u} + \beta \int \left(\frac{\delta}{\delta_u}\right)^{\alpha} \frac{dE}{E_c(\delta)} \qquad (2)$$

Where

δ_m is the maximum observed displacement in the member under the ground motion load (obtained from the nonlinear dynamic analysis)

δ_u is the ultimate member displacement under uniformed loading (obtained from incremental lateral load analysis)

f_y is the member's yielding strength (if $Q_y > Q_u$ then Q_y is replaced by Q_u)

E_c (δ) is the hysteretic energy in each cycle for displacement of δ

β is non-negative energy-related strength loss parameter (ranging between 0.1 to 0.15)

δ is the value of the displacement in each vibration cycle

E_h is the cumulative energy absorbed by the hysteresis loops derived by Eq.3.

$$E_h = \sum_{i=1}^{n} E_i \qquad (3)$$

The energy dissipation is defined for a cycle i by the hatched area in Fig. 7, or mathematically by Eq.4.

$$E_i = \int_A^B H.\,dA \qquad (4)$$

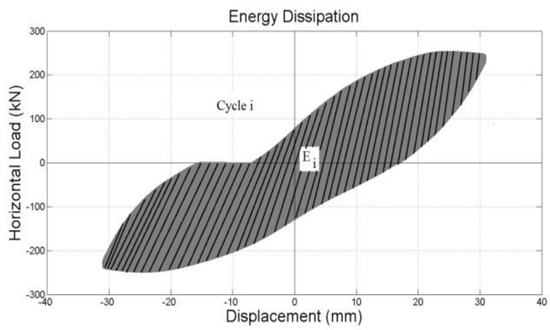


Fig. 7: Energy Dissipation for cycle i

Accordingly, subscripts m, y and u refer to the maximum value achieved, the yield value, and the collapse value respectively. A damage index greater than one means collapse or total damage. Thereby, the structural damage is a function of the response of dE and δ_m which depends on the loading history and the β ,α ,δ_u ,Q_y and Ec (δ) parameters are defined by structural capacity. For example, the DI for one of the plastic hinges in the 6 story model without SSI is calculated for the length link beam (60cm) under the bam record as follows:

$$D = \frac{2.5}{8.9} + \frac{0.12}{2400 * 7.9} * 18802 = 0.399 \approx 0.4$$

5. Introduction of Ground Motions

A complicated but accurate method for investigating non-elastic demands of the structure under the influence of the ground motion records is using the nonlinear time history analysis. The nonlinear dynamic analysis is applicable to all buildings. The results obtained from this method are sensitive to the selected accelerogram for the analysis. In this study, 7 earthquake records are used, 4 of which are near-field and remaining 3 records are far-field ground motions. The characteristics of the records used are presented in Table 6.The basis for selecting earthquake records is the adaptation of the dominate frequency of the earthquake to the frequency of the maim mode of the structure under study. In this case, the most critical condition is obtained to analyse the behaviour of the structure. It should be noted, all records are applied to the base of the models.

Table. 6: Characteristics of the selected earthquakes

NO.	Earthquake	Year	M_w	Station	Field
1	Elcentro	1994	6.46	Calexico Fire Station	Far
2	Kobe	1994	6.9	KJMA	Far
3	Bam	2003	7.51	Bam	Near
4	Kocaeli_Turkey	1999	7.51	Ambarli	Near
5	Northridge-01	1994	6.69	Rinaldi Receiving Station	Near
6	Cape Mendocino	1992	7.01	Petrolia	Near
7	Loma Prieta	1989	6.93	LGPC	Near

First, the ground motions are scaled by dividing their peak ground acceleration (PGA). Then, for the obtained values, response acceleration spectra for 5% damping are provided. Next, the average of the obtained spectra is calculated and compared in the period range of 0.2T and 1.5T. According to standard 2800, the average of SRSS spectrum related to all pairs of components should not be less than10% of 1.3 times of the corresponding value of the design spectrum. The average spectrum of the pairs of components scaled records is shown in Fig. 8.

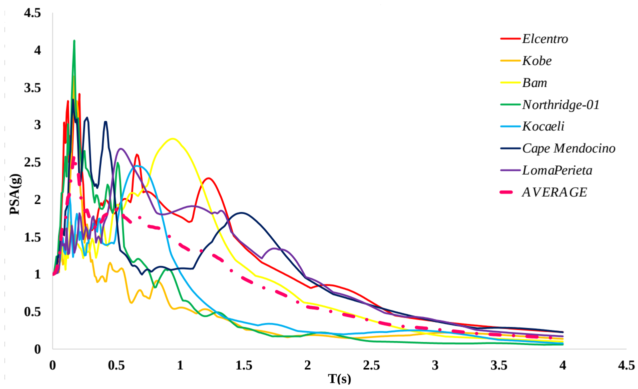


Fig. 8: Design Spectrum and the average of the scaled spectra

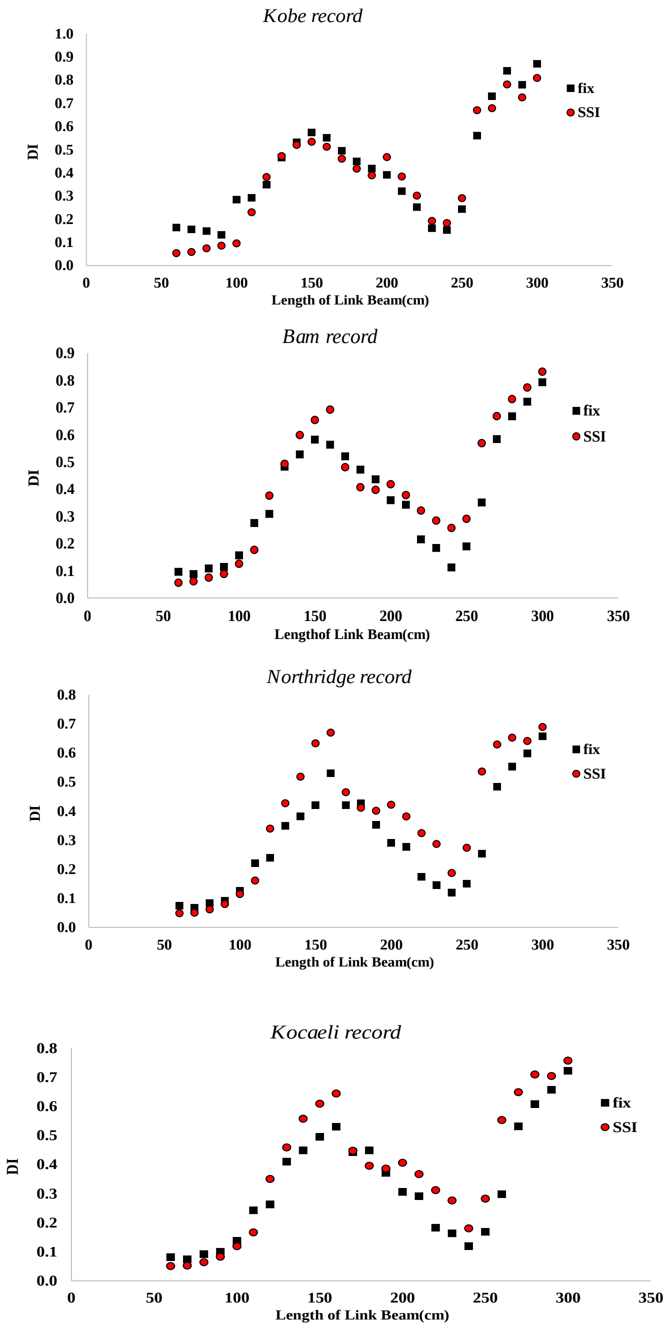
In this paper, dynamic time-history analysis has been conducted to assess the effects of link beam length and SSI on the damage index of the EBF system. This is one of the innovations in this article.

6. Results

6.1. Evaluation of the Optimum Length of the LB

In this part, DI values for link beams with different length shave been investigated for a 6-story structure with 5-m bays under 7 ground motion records with and without considering the SSI effects. For each earthquake record, the damage indices with and without considering the SSI are determined. The results of this part have been presented in Figs. 9. Average of results according to the optimum length of the link beam is presented in Fig 10. As can be seen, the DI values in shorter lengths of the link beam are less compared to the longer lengths. In the event of Kobe earthquake, the optimum length for the DI was found to be 90 cm, and as the length of the link beam increases, the DI value grows leading to maximum value in the length of 150 cm. Then, trend of variations in DI starts descending and in

240 cm, the minimum value among maximum lengths for the link beam is obtained. After that, the DI value rises again with the increasing of the length of the link beam. For Elcentro Earthquake, 60 cm was found to be the optimum length for the Park-Ang DI. Then, as the length of the link beam increases, the DI value grows and reaches its maximum value in the length of 150 cm again, and the descending damage index occurs in longer link beams. In 240 cm the least possible value for damage index is among the longer link beams. Then the damage index value rises again with the increasing of the length of the link beam. The results of the damage index for Bam earthquake is the same as the other two except that the minimum value of the damage index for the structure with braced system is at 240 cm of the link beam.



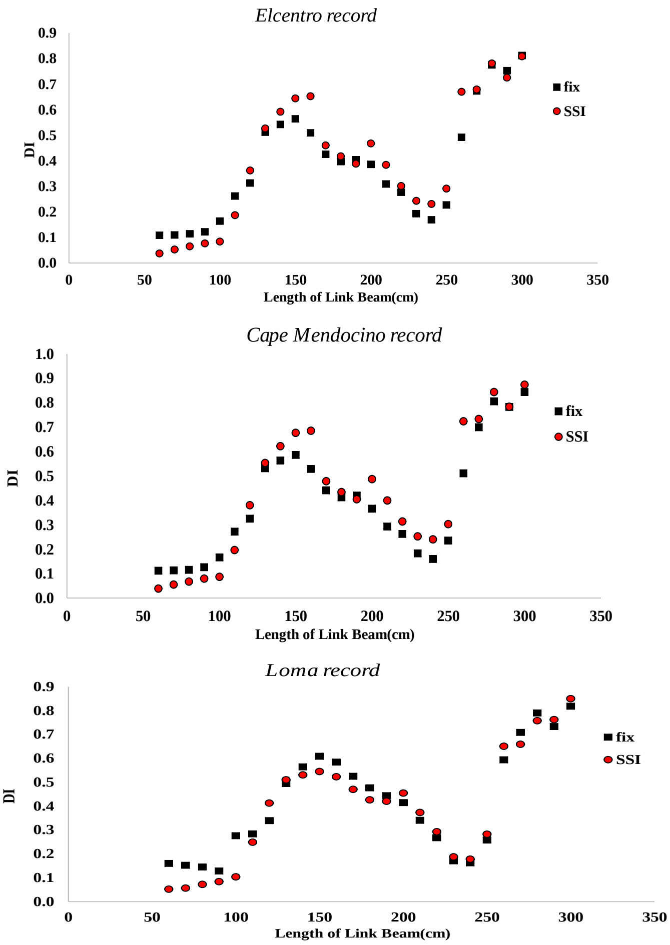


Fig. 9: DI Values (According to the Optimum Length of the Link Beam)

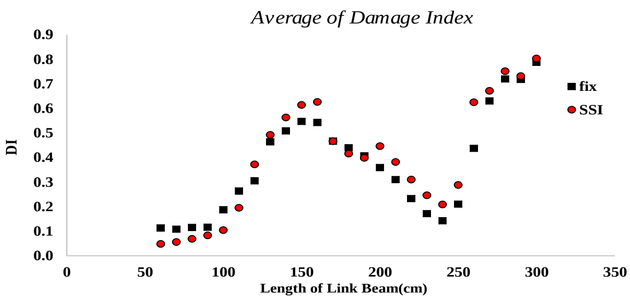
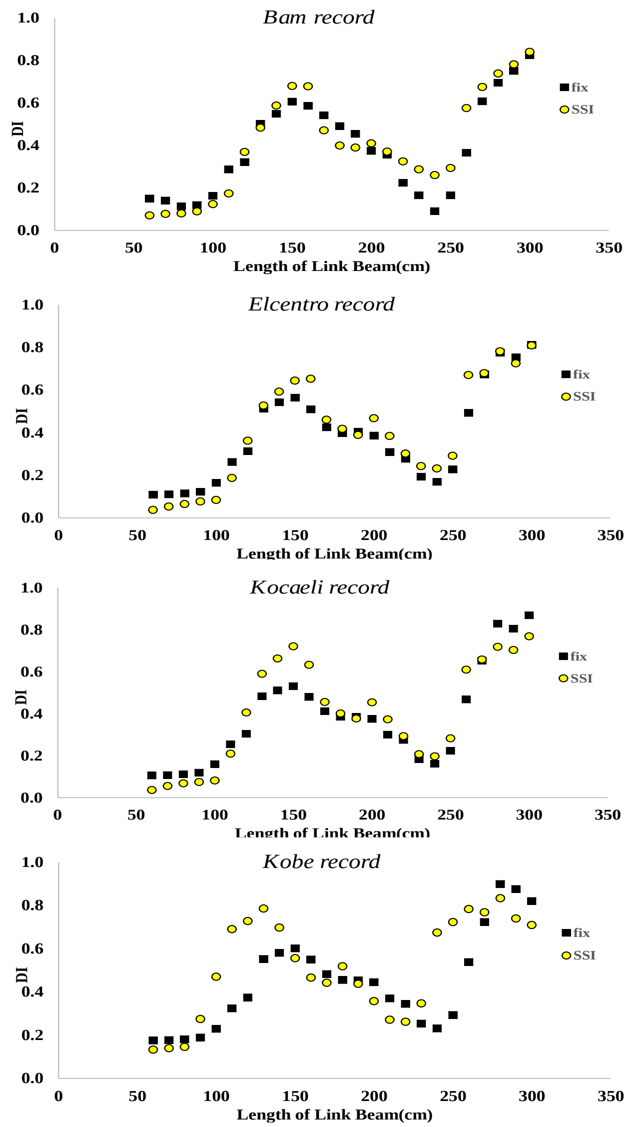


Fig. 10: Average of DI Values (According to the Optimum Length of the Link Beam)

Considering the SSI effects, total changes applied on the value of the eccentric frame's DI and different link beam lengths has shown different effects. In Kobe earthquake, for lengths of smaller than 110 cm considering the SSI causes a decrease in the value of the DI and in the other lengths, it is in accordance with the fixed base state. In lengths of over 260 cm, considering the SSI causes a negligible drop in the value of the DI. In Elcentro earthquake, for lengths of smaller than 110 cm, considering the SSI causes a decrease in the value of the DI, but in the other lengths it increases until in 160 cm, the value of DI while considering the SI, is more compared to other lengths. Taking the SSI into account for lengths smaller than 110 cm, reduces the DI values but in longer link beams it leads to an increase in the damage index. The lengths between 220 and 240 cm of link beam exhibit the minimum DI values for the structure. The optimal numerical value for the design of the link beam is in the specified range. The basis for determining the optimal length of link beam is the minimization of the Damage Index (DI).

6.2. Assessment of the effect of frame's primary design in selecting the optimum LB length

In this part, DI values in different link beam lengths for a 6 story structure with 5 m bays has been assessed. The primary length assigned to the link beam in designing and defining the geometrical characteristics of the sections is 240 cm. The effect of the geometrical characteristics of the sections on the optimum length of the link beam is recognized by evaluating the results of the damage index for this 6 story steel frame. The results of this section are shown in Figs. 11. Average of results, according to the frame's primary design is presented in Fig 12.



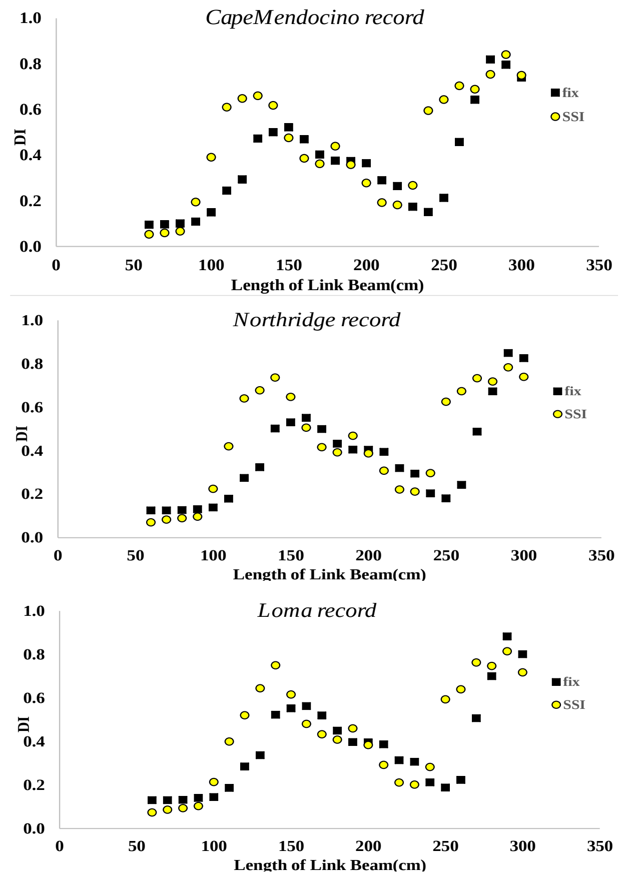


Fig. 11: DI Values(According to frame's primary design)

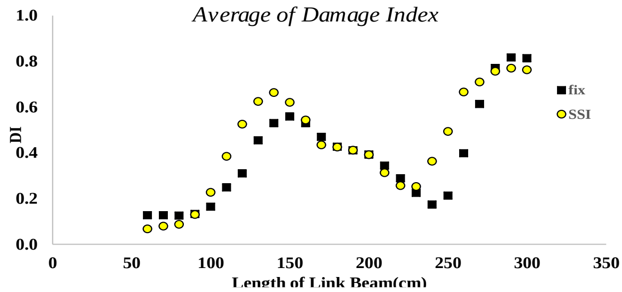
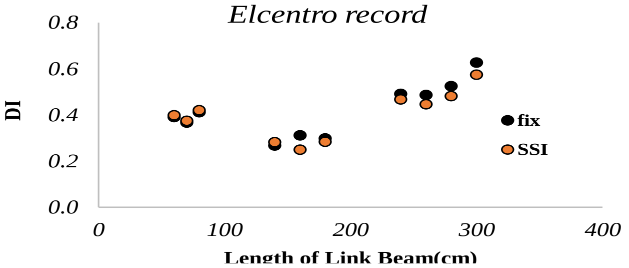


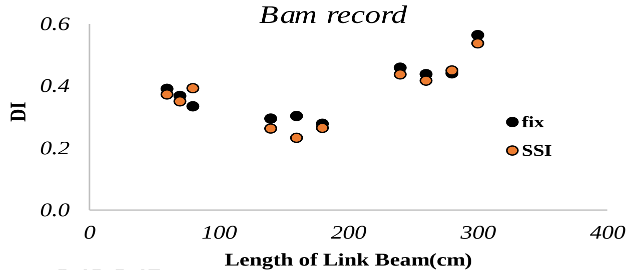
Fig. 12: Average of DI Values (According to frame's primary design)

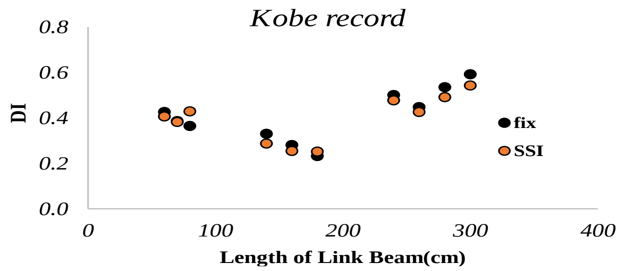
6.3. Assessment of the effect of the ratio of the LB length to the bay's length in selecting the optimum link beam length

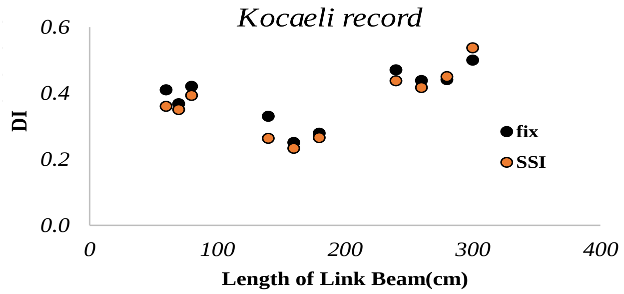
Regarding the fact that the link beam's behavior is affected by the ratio of the length of it to the length of the bay has also been investigated. To examine this subject, a 6 story frame with 6 m bays has been modeled and the primary length of the link beam is considered 240 cm for designing. The results of this section are shown in Figs.13. Average of results, according to the ratio of the link beam's length to the bay's length is presented in Fig 14.

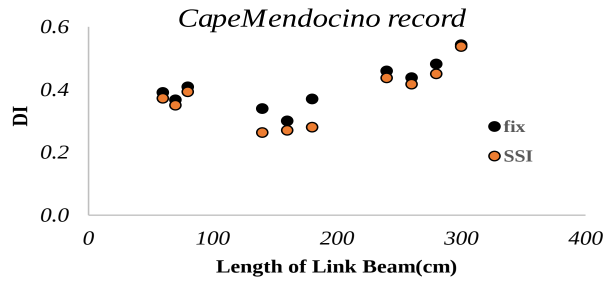
Figures 15 to 17 show the damage index for different lengths of the link beam and the frame span, without considering the effect of soil interaction, for different records studied. Also, figures 18 to 20 exhibit the damage index for different conditions under the effect of seven earthquake records with soil-structure interaction effect. Comparing the results, it is observed that the change in span length, compared to the change in link beam length, will have a much greater effect in determining the damage index. So, in both cases with and without considering the soil-structure interaction effects, with changing the length of the link beam, the damage index does not changed much, but by changing the length of the span, a general change in the pattern of damage index is observed.

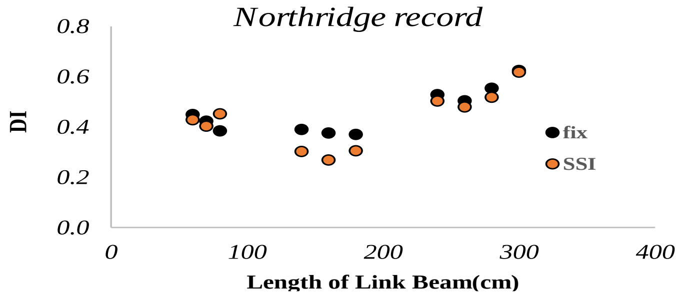












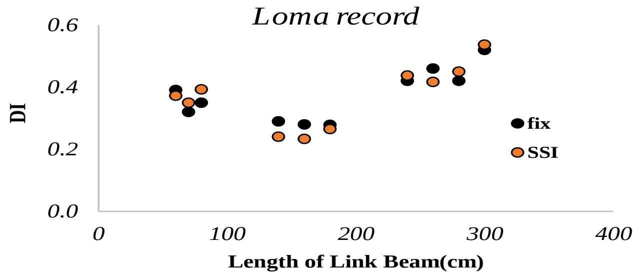


Fig. 13: DI Values(According to ratio of the link beam's length to the bay's length)

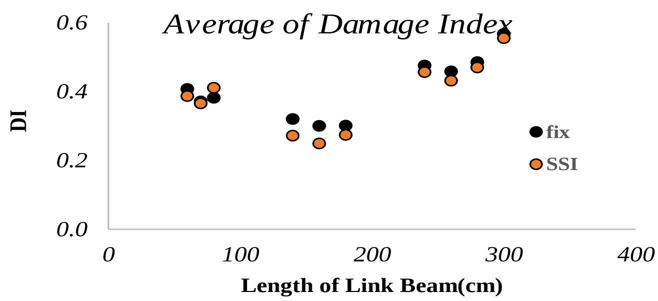


Fig. 14: Average of DI Values (According to ratio of the link beam's length to the bay's length)

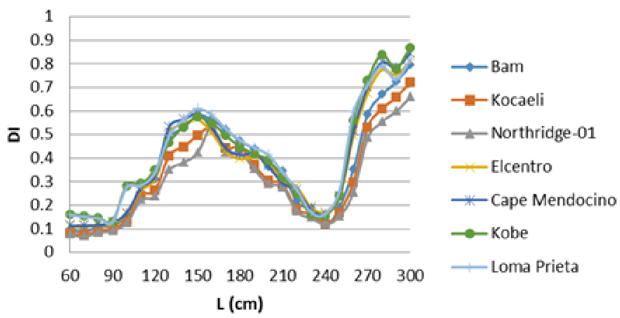


Fig. 15: DI Values versus Length (Fixed Base: L=60cm , Bay=5m)

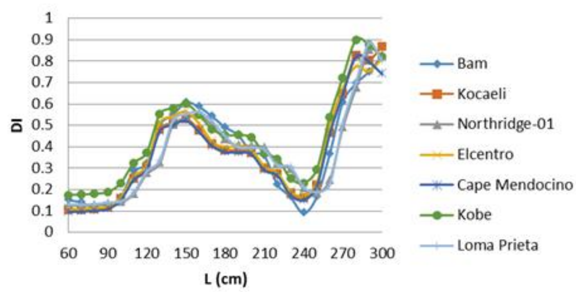


Fig. 16: DI Values versus Length (Fixed Base: L=240cm , Bay=5m)

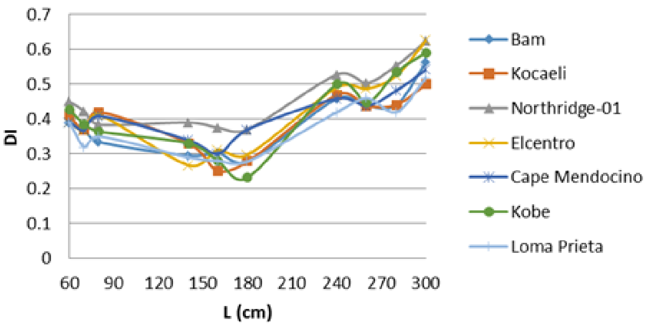


Fig. 17: DI Values versus Length (Fixed Base: L=240cm , Bay=6m)

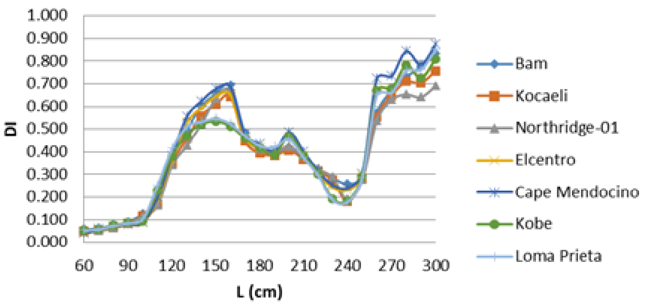


Fig. 18: DI Values versus Length (Flexible Base: L=60cm , Bay=5m)

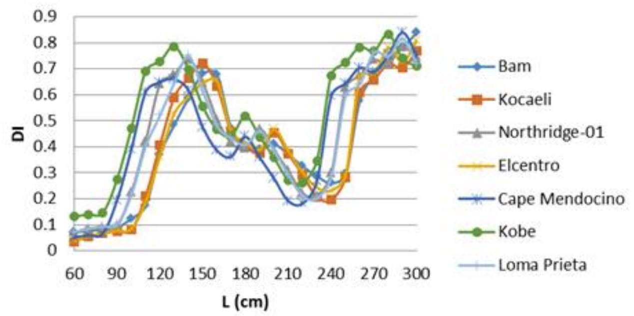


Fig. 19: DI Values versus Length (Flexible Base: L=240cm , Bay=5m)

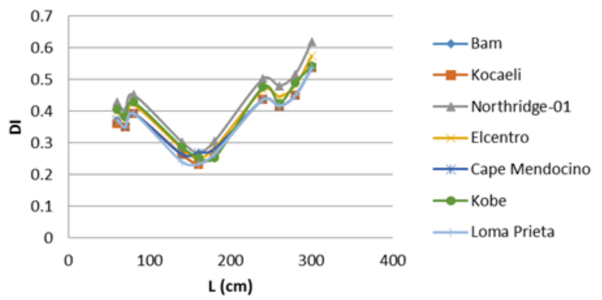


Fig. 20: DI Values versus Length (Flexible Base: L=240cm , Bay=6m)

Tables 7 and 8 show the numerical values of the damage index for different lengths of the link beam. Examining the average results, it is observed that in conditions where the effects of soil interaction have been neglected, with a 75% increase in link beam length, a 7.4% increase in damage index, and with 16.7% increase in span length, a 33% decrease in damage index can be observed. Also, considering the soil interaction effects, with increasing the length of the link beam from 0.6m to 2.4 m, we see a 1.23% increase in damage index, and also with an increase of one meter of span length, we see a 25.8% decrease in damage index. Considering the effect of soil interaction under the condition that the length of the link beam is 0.6 m and the length of the span is 5m, the damage index has increased by 1.74%. Change in the condition where the length of the link beam is 2.4 m and the span length is 5 m, the damage index decreases by 4.5% and when the length of the link beam is 2.4 m and the length of the span is 6m, we will see a 2.3% decrease in the damage index**.**

Table. 7: DI Values for Fixed Base

Records	L=60 cm, Bay=5 m		L=240 cm, Bay=5 m		L=240 cm, Bay=6 m	
	DI-max	DI-min	DI-max	DI-min	DI-max	DI-min
	L (cm)	L (cm)	L (cm)	L (cm)	L (cm)	L (cm)
Bam	0.794	0.087	0.825	0.090	0.564	0.278
	300	70	300	240	300	180
Kocaeli	0.722	0.074	0.869	0.105	0.500	0.250
	300	70	300	60	300	180
Northridge-01	0.657	0.068	0.849	0.125	0.624	0.370
	300	70	290	60,70	300	180
Elcentro	0.812	0.108	0.812	0.108	0.626	0.267
	300	60	300	60	300	140
Cape Mendocino	0.844	0.113	0.819	0.095	0.542	0.300
	300	60	280	60	300	160
Kobe	0.870	0.132	0.899	0.175	0.591	0.232
	300	90	280	60	300	180
Loma Prieta	0.818	0.128	0.883	0.130	0.520	0.278
	300	90	290	60,70	300	180
Average	0.788	0.101	0.851	0.118	0.567	0.282
	300	90	290	60,70	300	180

Table. 8: DI values considering SSI Effects

Records	L=60 cm, Bay=5 m		L=240 cm, Bay=5 m		L=240 cm, Bay=6 m	
	DI-max	DI-min	DI-max	DI-min	DI-max	DI-min
	L (cm)	L (cm)	L (cm)	L (cm)	L (cm)	L (cm)
Bam	0.831	0.056	0.840	0.07	0.537	0.233
	300	60	300	60	300	160
Kocaeli	0.757	0.050	0.768	0.035	0.537	0.233
	300	60	300	60	300	160
Northridge-	0.688	0.048	0.783	0.070	0.617	0.267

01	300	60	290	60	300	160
Elcentro	0.809	0.037	0.809	0.037	0.574	0.249
	300	60	300	60	300	160
Cape Mendocino	0.873	0.038	0.84	0.052	0.537	0.263
	300	60	290	60	300	140
Kobe	0.809	0.053	0.833	0.132	0.542	0.251
	300	60	280	60	300	180
Loma Prieta	0.849	0.051	0.814	0.072	0.537	0.233
	300	60	290	60	300	160
Average	0.802	0.047	0.812	0.067	0.554	0.247
	300	60	290	60	300	160

7. Conclusion

To evaluate the optimum damage index (DI) in the eccentrically braced frames (EBFs), the three Kobe, Elcentro and Bam earthquakes have been applied to link beams with different lengths and the frames have been modeled with and without considering the soil-structure interaction (SSI) effects. Accordingly, the following results are obtained based on evaluation of Park-Ang damage index values:

1. The DI value for a 6-story frame for Kobe earthquake in the length of 90 cm without considering the SSI and in 60 cm with considering the SSI, indicates the minimum values which are equal to 0.12 and 0.06, respectively.
2. In the longer links, the minimum value of DI for two states of with and without SSI, occurred in 240 cm which are equal to 0.13 and 0.14, respectively.
3. The optimum DI of the El centro earthquake for both with and without SSI, happened in the length of 60 cm which is equal to 0.022 and 0.105, respectively. In longer links, the DI value for 240 cm shows the minimum value which is equal to 0.18 without accounting for SSI effects and 0.215 SSI is included.
4. In Bam earthquake the minimum DI value happened in 240 cm when excluding the SSI which is equal to 0.102 and this occurred in the length of 60 cm when considering the soil-structure interaction which is 0.075.
5. In general, link beam lengths smaller than 110 cm have the minimum DI value and lengths between 140 and 180 cm and also those over 260 cm show the maximum DI value in a structure with 5 m bays. Thus, based on the observed results, it is clear that if a longer link beam is to be used, the lengths between 220 and 240 cm exhibit the minimum DI values for the structure.

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