Effect of Height of Buildings and Arrangement of Braces On RC Buildings Retrofitted with Steel Knee Braces Based on Incremental Dynamic Analysis (IDA)

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SUMMARY:

In this study, the seismic reliability of Reinforced Concrete (RC) buildings retrofitted using steel knee braces is investigated through Incremental Dynamic Analysis (IDA). As a case study, one, three, five, seven story RC buildings were selected. The effect of using steel knee braces in retrofitting RC buildings is being assessed in two facets: 1-Effect of distributing the steel braces in different spans. For strengthening the RC structures, Knee Bracing Frame (KBF) was applied with four different spatial distributions in the structure. 2-Height effect of buildings. According to the results of first step, RC buildings with different heights were retrofitted with the best arrangement and height effect of buildings on seismic performance of retrofitted frames was assessed. To compare the performance of retrofitted buildings in step one and two with original buildings, IDA curves are drawn.

Keywords: Knee Bracing Frame – Reinforced Concrete Structure – Incremental Dynamic Analysis - OPENSEES

1. INTRODUCTION

Several destructive earthquakes, inflicted various levels of damage upon reinforced concrete buildings all over the world, especially buildings that were built far years ago. The negative consequences of earthquakes made engineers to retrofit existing buildings to prevent damages of probable future earthquakes. One of the main retrofitting approaches is installing new structural element, such as steel knee braces to upgrade the seismic performance of existing undamaged structures before being subjected to a severe earthquake. Although it is common to employ steel braces in steel frames and use shear walls in reinforced concrete structures; in recent years, there have been several studies on use of steel braces in retrofitting RC buildings [Abou-Elfath and Ghobarah, 1995, 2001, Maheri and Sahebi, 1997, Symth et al, 2004, Guneyisi and Altay, 2005, Youssef et al, 2007, Mazzolani, 2008]. In the current study, maximum drift of stories were compared based on data set of seismic response records obtained through incremental dynamic analysis. IDA method has been introduced [Vamvatsikos and Cornell, 2002, 2005].

In this Article, different from the previous studies, as retrofitting approach knee braces were used, and their contribution to seismic performance of a selected RC buildings were investigated. Several scholars have assessed the performance of steel structures with knee braces [Balendra et al, 1987, 1991, Sam et al, 1995, Lotfollahi, 2003, Lotfollahi and Mofid, 2006], but there is a few information about seismic performance of RC structures retrofitted with steel knee braces [Shirazi, 2000, Maheri et al, 2003]. Also several experimental and numerical studies investigating capability of connection between steel and concrete to transferring loads were available in literature [Tasnimi and Masoomi, 1990, Canales and Broseno, 1992, D’Aniello et al, 2006].

2. STRUCTURAL DESIGN

2.1. Base Buildings

In this publication, base RC buildings were not designed properly and have not enough capability to resist during severe earthquakes. All buildings consist of six spans, with typical beams and columns, RC frames with no shear walls. Building that is symmetrical in plan may be chosen for simplicity in the analysis. All buildings were modeled as a series of planar frames connected at each floor level by rigid diaphragms. Therefore, only two dimensional analysis were performed. Fig. 2.1 consists of typical floor of the buildings. Also, elevations of buildings are shown in Fig. 2.2. The buildings were designed for both gravity and seismic loads. The gravity loads consist of dead load and live load. When calculating the dead load, the weight of structural members and masonry walls were included. The live load used was 200 kg/m2 which is typical for an apartment. Other types of loading, such as wind, snow, soil-structure interaction was not considered. Also, the base of columns at the ground floor is assumed to be fixed. Material properties are assumed to be 21MPa for the concrete compressive strength and 240MPa for the yield strength of both longitudinal and transverse reinforcement. In all structures the stories' height is 3.0 meter and the spans' width is 3.0 meter.

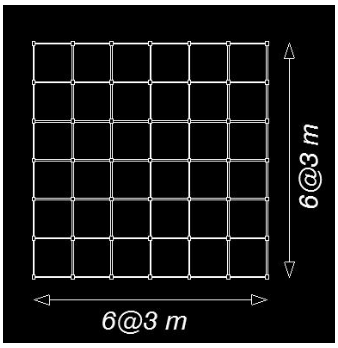

Figure 2.1. Layout for plan of the original building

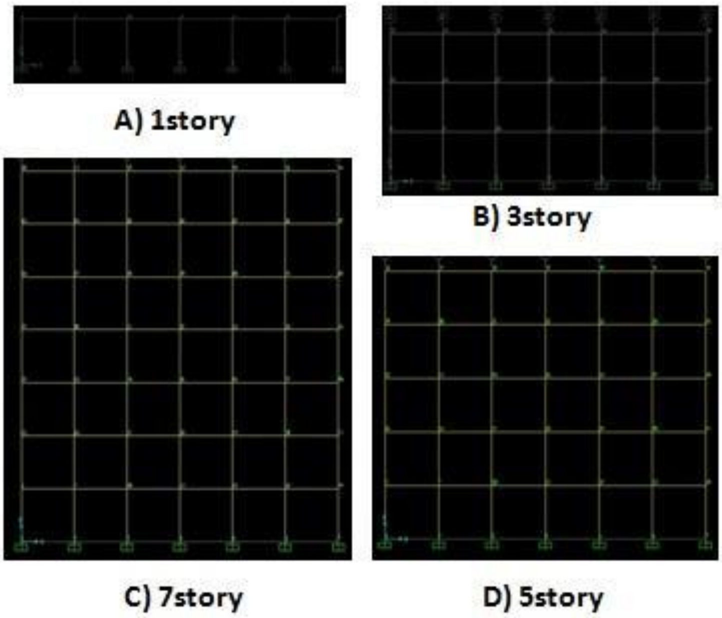

Figure 2.2. Elevation of (A) 1story (B) 3story (C) 7story (D) 5story original buildings

Dimensions of beams and columns, also amount of used reinforcements in buildings were shown in Figure 2.3. All dimensions are in mm. Concrete cover is 40mm.

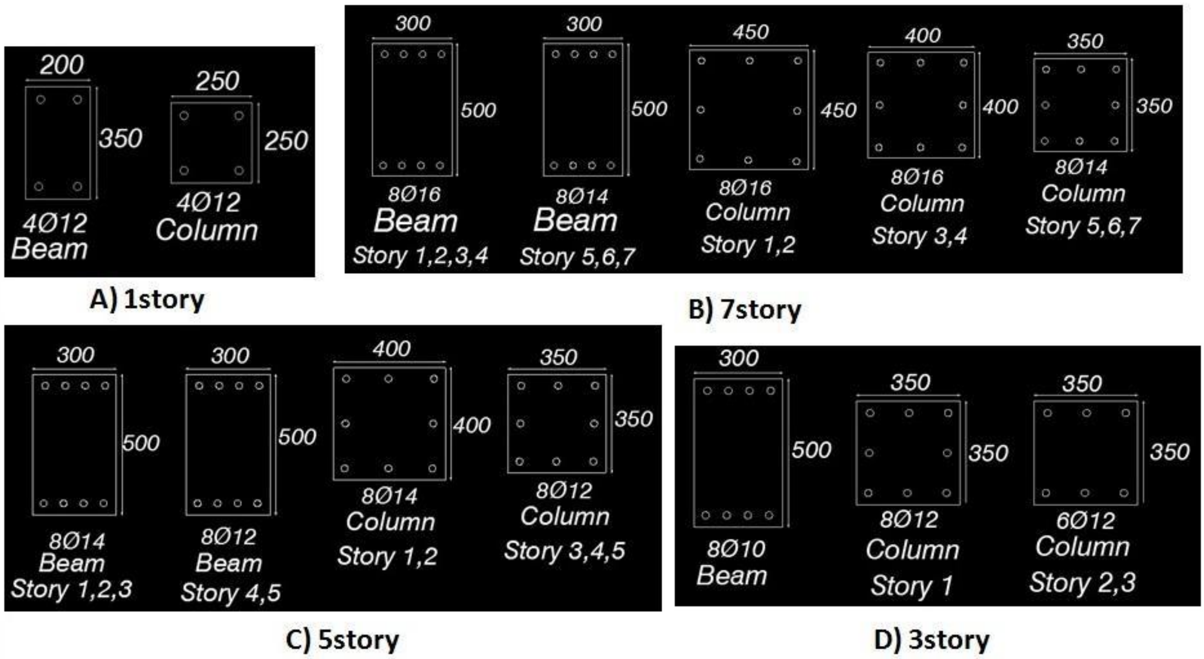

Figure 2.3. Section of beams and columns (in mm) in (A) 1story (B) 7story (C) 5story (D) 3story buildings

2.2. Retrofitted Buildings

2.2.1. Step One: Choosing Best Arrangement of Braces

It is important to develop effective and economic seismic retrofitting systems for upgrading the seismic performance of RC buildings before being subjected to a severe earthquake. In this study knee braces were used in order to improve seismic behavior of RC buildings. At the first time, Balendra (1991) used this brace to retrofit one story steel frame which is shown in Fig.2.4. This kind of brace has two fundamental parts: diagonal member and knee member. The diagonal members are sufficiently strong despite buckling, which provides lateral stiffness. The knee members usually are chosen box section to absorb energy by plastic hinge deformation; thus this kind of braces has appropriate stiffness under lateral loads and further has high energy absorption features. The knee members are designed to absorb earthquake energy and plastic hinges are formed in the middle and both ends. In the meantime, other members experience fewer forces and remain in elastic zone. In fact, knee member function is similar to a fuse. In addition, after the earthquake, changing this knee member is easily possible and buildings can be retrofitted after the earthquake by utilizing this method. Box 60*60*4 mm was chosen for knee members. Diagonal members should be strong enough not to buckle before formation of plastic hinges in the knee member. Augmenting size of brace will increase lateral stiffness of structure until a special boundary; after that limit, increasing the size of brace will slightly affect the stiffness of frame. All braces are typical, which were used Box100*100*4 mm. The young modulus of steel is E=200,000 MPa and the steel yield stress is f_y=240 MPa.
Proportion of h/H should not be more than 0.3 to provide sufficient lateral stiffness to control the drift in order to prevent any structural or non-structural damage during earthquake. Also, to prevent acting brace in shear mode h/H should not be less than 0.2. In this article, proportion of b/B and h=/H is equal to 2. /9.

According to the Shirazi's investigations (2000), the best geometry which provides maximum lateral stiffness has these characteristics:

1. Brace should be along with the intersection of beam and column

2. Diagonal member should divide knee member into two equal length (b / B = h / H)

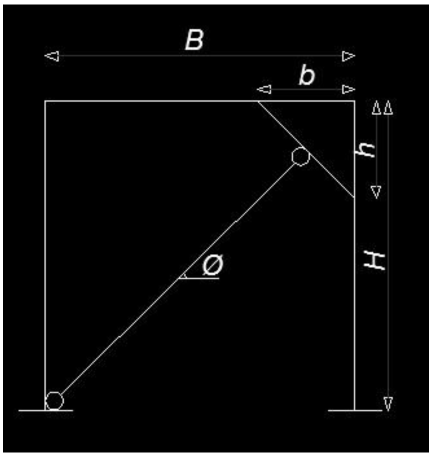

Figure 2.4. One story frame retrofitted by knee brace

In the current study, the knee bracing systems were used, and the spatial distribution of braces over the height of buildings was investigated to achieve the greatest performance with the same quantity of used steel braces. In order to enhance seismic performance of the base building, four different retrofitting cases were designed. In these settings various is the distribution of braces over the spans as shown in Fig. 2.5. Steel members used in all settings have the same length and characteristic.

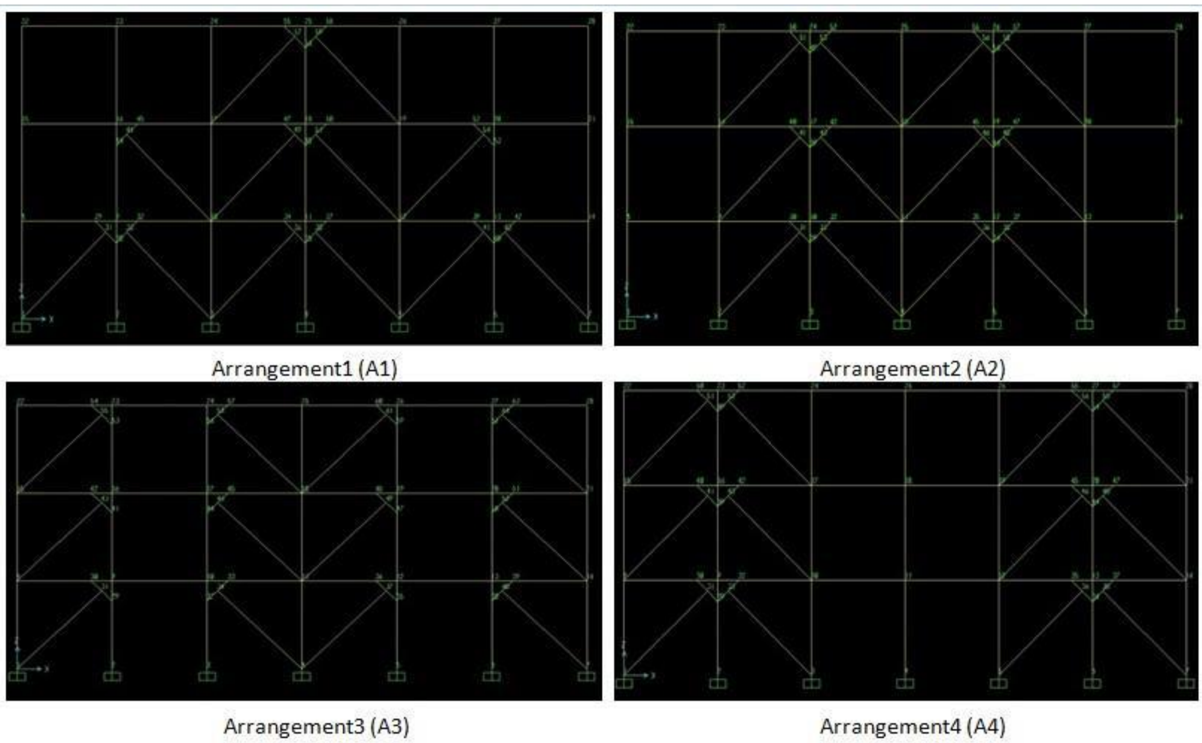

Figure 2.5. Layout of braced frames with different distribution of braces

2.2.2. Step Two: Height Effect of Buildings on Capability of Retrofitting

According to the result of step one, which will be reported in section 4.1, the best arrangement of building was selected. In this step, braces are going to assemble on the structures with different height. Four different retrofitting cases were designed. In these settings various is the height of buildings as shown in Fig. 2.6

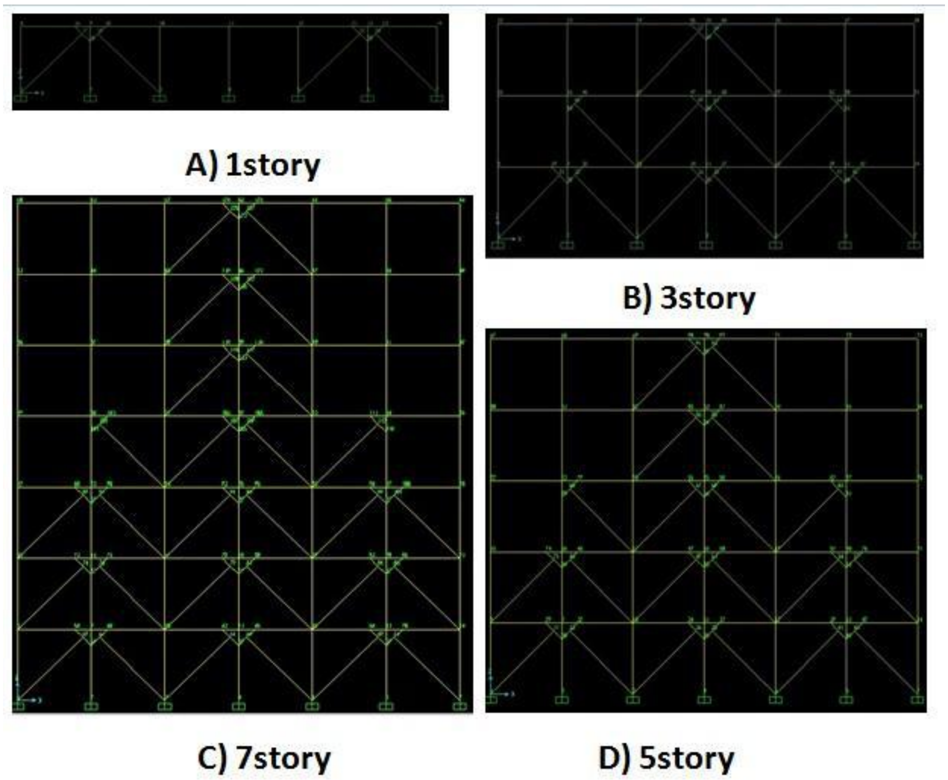

Figure 2.6. Layout of (A) 1story (B) 3story (C) 7story (D) 5story braced frames

3. MODELING AND INPUT GROUND MOTION

All these buildings were built in OpenSees software. Before conducting incremental dynamic analysis, the periods of free vibration of the first mode of the original and retrofitted frames are compared to result of primary design in SAP2000 software to ensure the accuracy of models which are listed in Table 1&2. MRF is an abbreviation of Moment Resisting Frame. As expected, the braced frames have higher stiffness and therefore shorter fundamental period than the base frame.

Table 1. Periods of Free Vibration of Base and Braced Frames in Step1

Type of retrofitting	Arrangement1	Arrangement 2	Arrangement 3	Arrangement 4	MRF
1^{st} mode period (Sec)	0.345	0.387	0.397	0.368	0.545

Table 2. Periods of Free Vibration of Base and Braced Frames in Step2

Story Numbers	1Story		3Story		5Story		7Story	
1^{st} mode period (Sec)	Braced	MRF	Braced	MRF	Braced	MRF	Braced	MRF
	0.184	0.353	0.355	0.545	0.536	0.710	0.700	0.886

According to "**Quantification of Building Seismic Performance Factors**" [FEMA P695, 2009], for IDA method, twenty two records of earthquake are needed. All models were built in OpenSees software, and 22 ground motions with different scale factors were imposed to each structure. Name and specification of records are available in FEMA P695. Since models are two dimensional, stronger component of records was imposed to structures.

4. SEISMIC RESPONSE ANALYSIS

The seismic response of the original and retrofitted structures was evaluated by means of IDA analysis. To draw IDA curves, each record has been scaled from 0.1Sa(T1, 0.05) to 1.0Sa(T1, 0.05), results of OpenSees processing were recorded. Each record has an IDA curve; for assessing the performance of structures, average of all records was used.

4.1. Effect of Distribution of Braces

Quantities of maximum drift of stories for each structure due to all records are shown in Fig. 4.1. Base is shown with MRF, and KBF is an abbreviation of Knee Braces Frame.

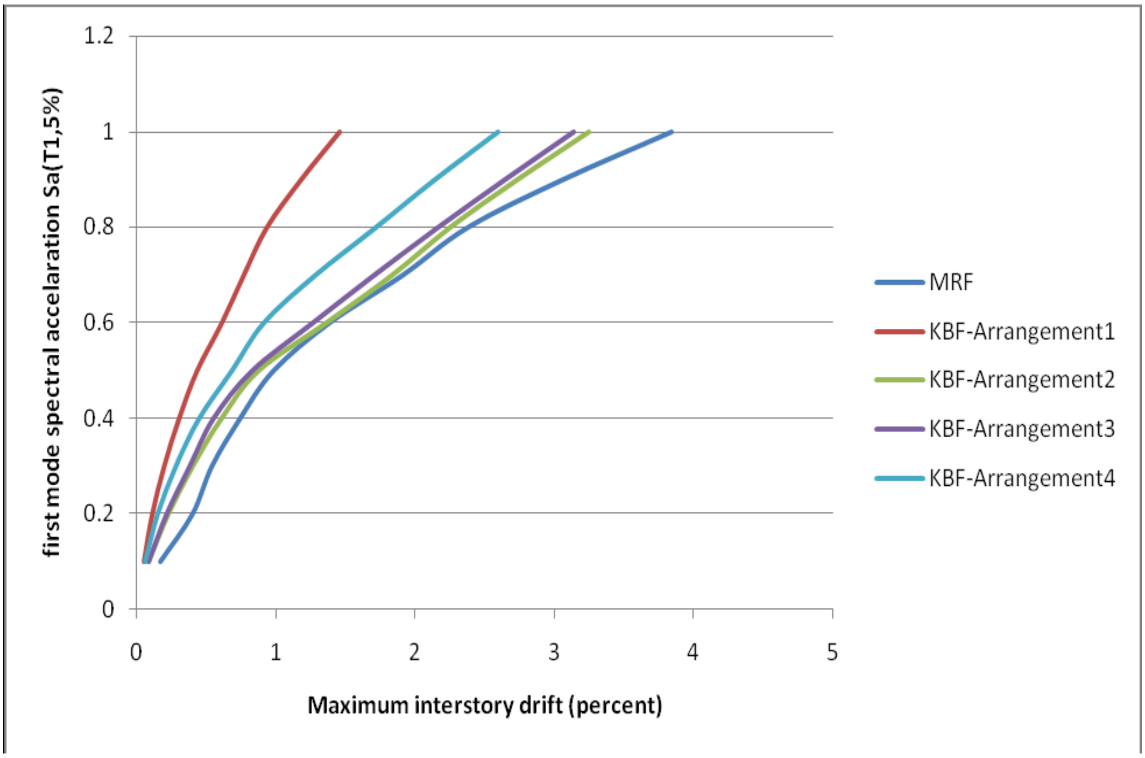

Figure 4.1. IDA curves for 3story buildings with different arrangement of braces

4.2. Height Effect of Buildings

IDA curves for original and retrofitted frames of one, three, five, seven story building were shown in Fig.4.2. to Fig.4.5.

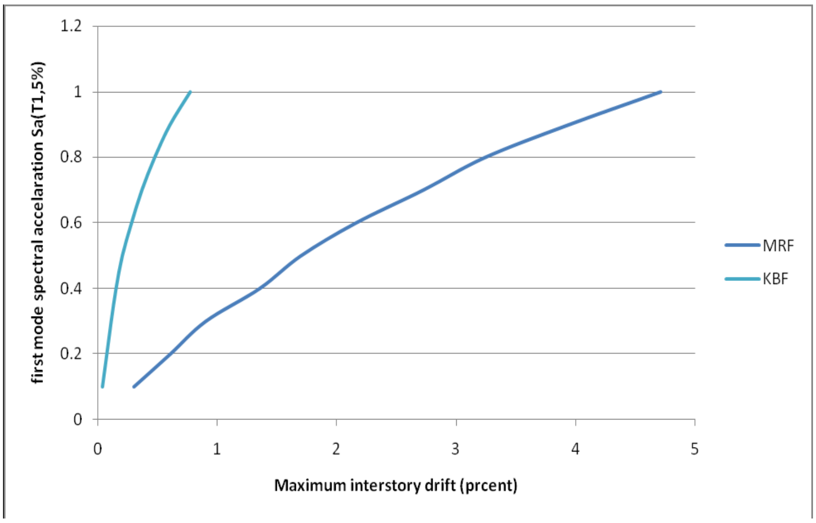

Figure 4.2. IDA curves for 1story Moment Resisting Frame and Knee Braced Frame

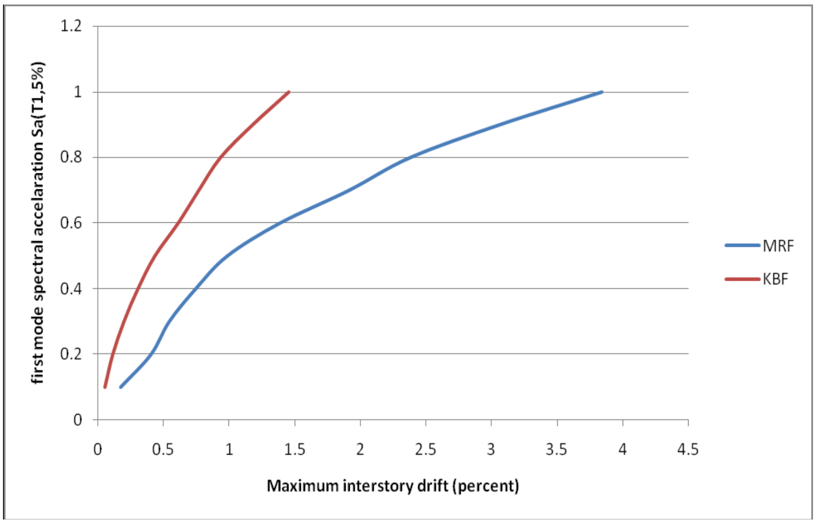

Figure 4.3. IDA curves for 3story Moment Resisting Frame and Knee Braced Frame

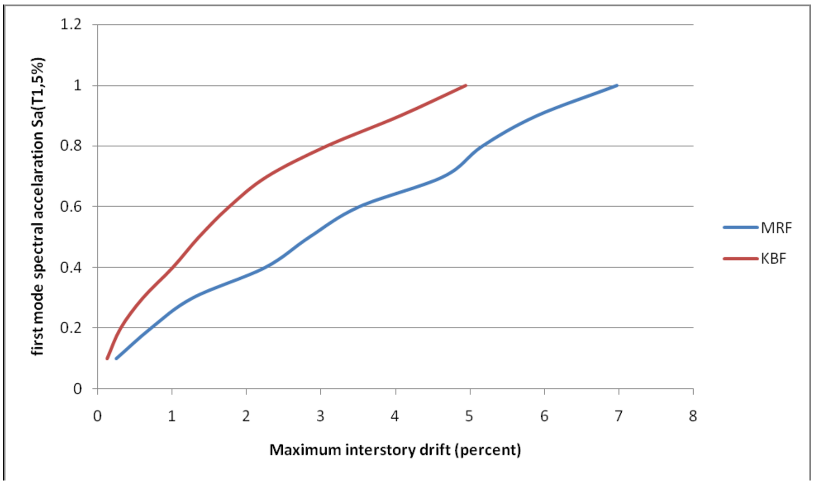

Figure 4.4. IDA curves for 5story Moment Resisting Frame and Knee Braced Frame

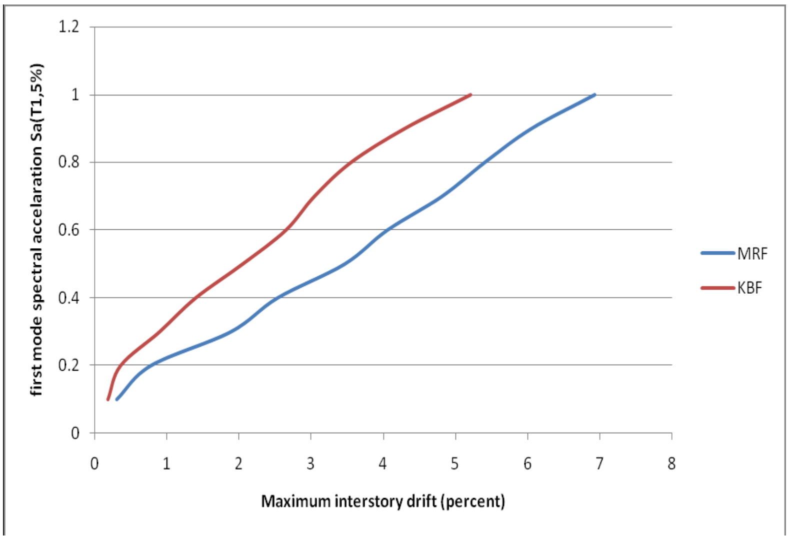

Figure 4.5. IDA curves for 7story Moment Resisting Frame and Knee Braced Frame

According to above results, reduction of maximum drift in retrofitted buildings in compare to original ones were shown in Fig. 4.6.

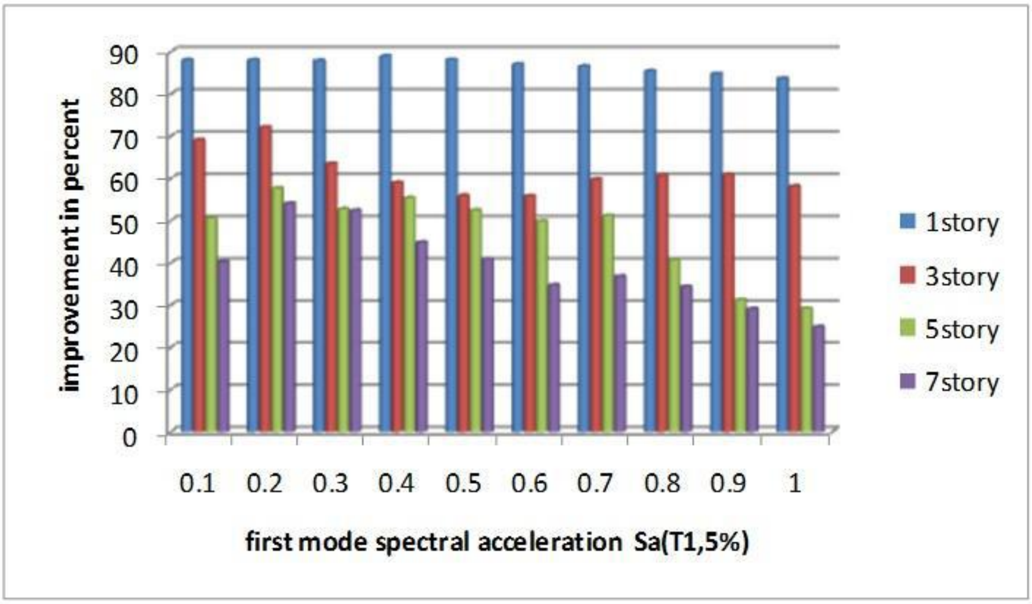

Figure 4.6. Reduction of drift due to using knee braces

5. CONCLUSION

This paper represents performance of RC buildings before and after retrofitting with steel knee braces based on incremental dynamic analysis. According to the results of section 4.1. first and fourth type of distributing (A1, A4) effectively decrease drifts of stories which A1 is so much better. Among rests of structures, distribution of knee brace slightly affects the seismic reliability of the braced frames. According to the results of section 4.2. generally improvement of seismic performance of buildings due to retrofitting with knee braces, has a reverse relation with the height of structures. So, for short-rise or mid-rise structures this kind of retrofitting is logical, but, in high-rise buildings, knee brace can not improve seismic performance of structures very well and using them is not economical.

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