CFRP-RETROFITTING OF REINFORCEDCONCRETE FRAMES CONSIDERINGNONLINEAR SOIL-STRUCTURE INTERACTION

MahboobehYARAHMADI
M.Sc. of Earthquake Engineering, Shiraz University of Technology, Shiraz, Iran
m.yarahmadi@sutech.ac.ir

AbdolHosseinBAGHLANI
Assistant Professor, Shiraz University of Technology, Shiraz,Iran
baghlani@sutech.ac.ir

BehtashJAVIDSHARIFI
Construction Superintendent, Fars Regional Electricity Company, Shiraz, Iran
b.javidsharifi@sutech.ac.ir

Keywords:CFRP, Soil-Structure Interaction, Pushover Analysis, Life Safety, Retrofit

ABSTRACT

New and existing structures should always satisfy the necessities of their contemporary codes. Continuous changes in design codes make it inevitable for existing structures to need to be rehabilitated every now and then so that they can fulfil the least expectable duty they are meant to. The method of analysis and results fetched from these analyses depend strictly on the shape and height of the structure. High-rise structures do not yield appropriate results in case analysed with ordinary pushover analysis and the best method of analysis for such buildings is to go through time-history responses. In this study, two frames of different heights are inspected and analysed in order to be retrofitted with CFRP, once considering nonlinear SSI and once supposing the supports to be placed on rigid ground. This phenomenon is assumed to exist in order to make the results as exact as possible. It is observed that for all cases SSI results in less expenditure, while causes the structure to behave rather differently from what it is expected. The place of plastic hinges may also vary when the nonlinear SSI is possible.

INTRODUCTION

To adjust existing structures with necessities of new versions of codes for safety of buildings against earthquake, several common methods can be taken up. One relatively economic and easy-to-perform way is making use of FRP composites, CFRP's to be exact. The reason of choosing this specific type of material is its reasonable price, accessibility in the region in addition to its proper workability. Structures need to technically satisfy regulations in local codes in order to be reliable and deemed safe in case an earthquake in the region happens.

In this work of study, two frames, namely a 5-story and an 8-story reinforced concrete (RC) frame, are inspected and analysed under pushover loading based on the Iranian no.360 Code of Retrofitting of Existing Structures. Plastic hinges are observed and tried to be retrofitted. Pushover curves and their bilinear representations are depicted in Fig. 1.

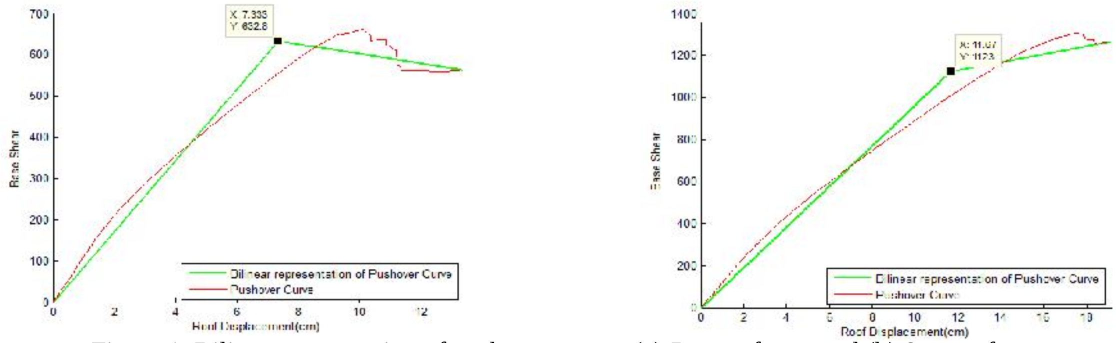


Figure 1. Bilinear presentation of pushover curves (a) 5-story frame and (b) 8-story frame

Eq.(1) fromthe Iranian no.360 Code of Retrofitting of Existing Structures is made use of to calculate target displacements of the structures in order for pushover analyses:

$$S_t = C_0 C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g \tag{1}$$

Terms of the equation, which are calculated based on physical and dynamic characteristics of each frame using equations in the mentioned code, are presented in Tables 1 and 2. S_t, which is the target displacement, is the amount the control point of the structure should be pushed in order for plastic hinges to be recorded.

Table 1. Needed parameters to calculate target displacement of the 5-story frame
(Iranian Code of Retrofitting of Existing Structures no.360)

	δt (cm)	Sa	C2	C1	C0	Ti	Cm	Vy(KN)
Primary structure (no SSI)	13.3	0.56	1	1.02	1.4	0.78	0.9	604
Primary structure (SSI)	14	0.55	1	1.02	1.4	0.81	0.9	604
Retrofitted structure (no SSI)	12.5	0.56	1	1.003	1.4	0.78	0.9	1070
Retrofitted structure (SSI)	13	0.55	1	1.003	1.4	0.81	0.9	1055

Table 2. Needed parameters to calculate target displacement of the 8-story frame
(Iranian Code of Retrofitting of Existing Structures no.360)

	δ_t (cm)	S_a	C_2	C_1	C_0	T_i	C_m	V_y(KN)
Primary structure (no SSI)	19	0.48	1	1	1.46	0.98	0.9	604
Primary structure (SSI)	20	0.46	1	1	1.46	1.04	0.9	604
Retrofitted structure (no SSI)	19	0.48	1	1	1.46	0.98	0.9	1070
Retrofitted structure (SSI)	19.5	0.46	1	1	1.46	1.04	0.9	1055

The two frames are shown schematically in Fig. 2.

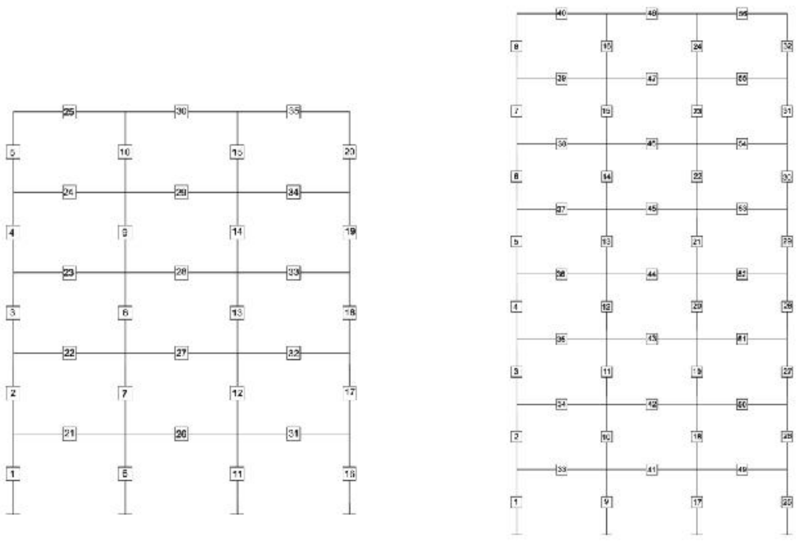


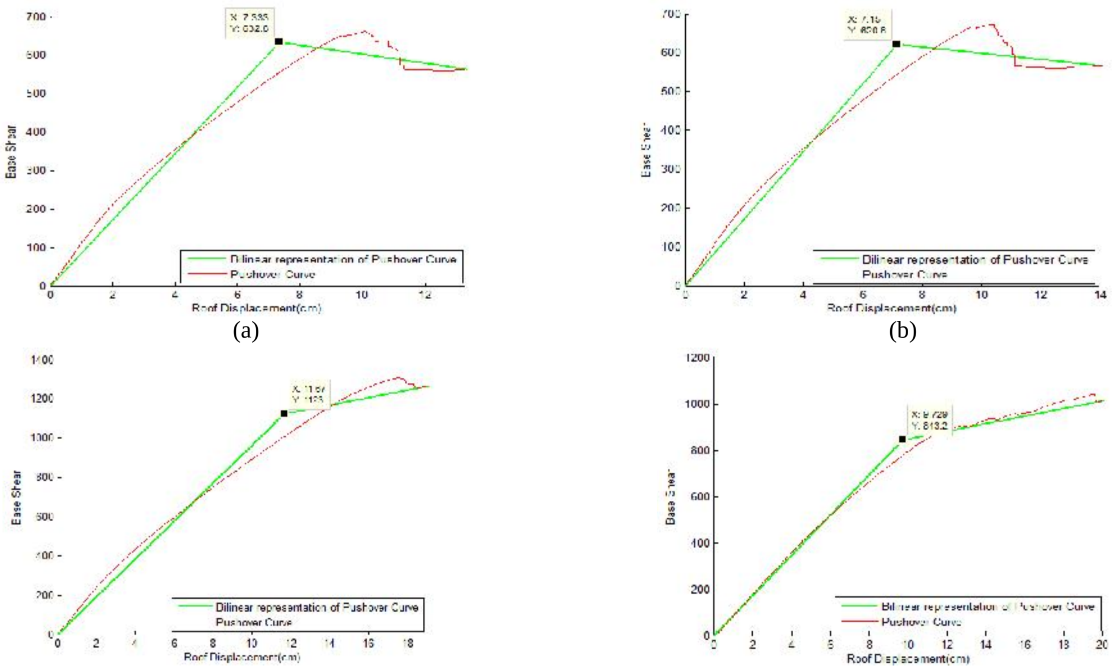
Figure 2. Schematic views of the frames

Section properties for the 8-story frame in order to carry out a dynamic time-history analysis are presented in Table 4.

Table 4. Cross section properties for the 8-story frame

Section	b	H	d	d’	A_{st}	A_s	A_s’	Shear steel spacing
A-A	600	600	540	60	16φ25	-	-	150
B-B	600	600	540	60	16φ18	-	-	150
C-C	500	500	440	60	16φ16	-	-	125
D-D	500	500	440	60	-	6φ25	4φ25	100
E-E	500	500	440	60	-	6φ22	4φ22	100
F-F	500	500	440	60	-	6φ18	3φ18	100

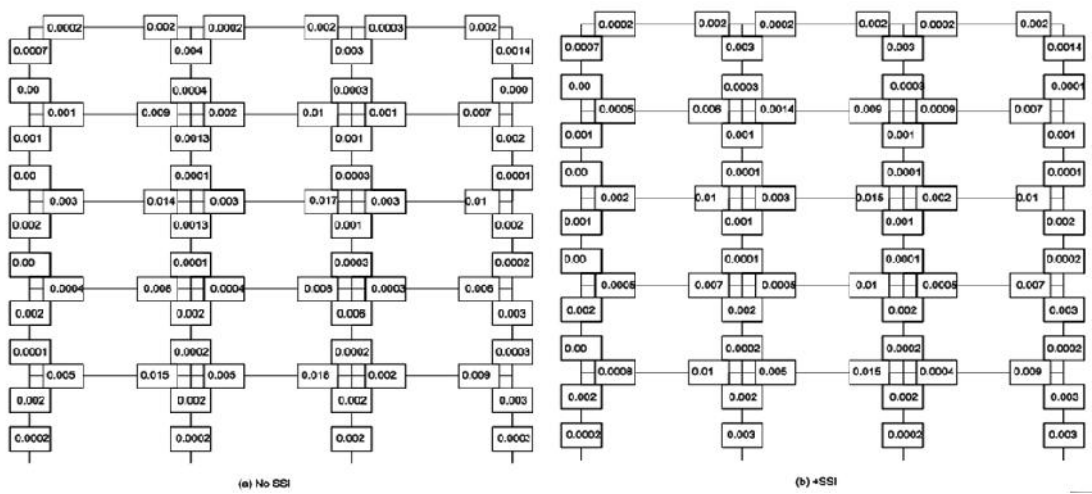
Bilinear representations of pushover curves for both frames before retrofitting with and without SSI are shown in Fig. 3.



(a) (b)
(c) (d)

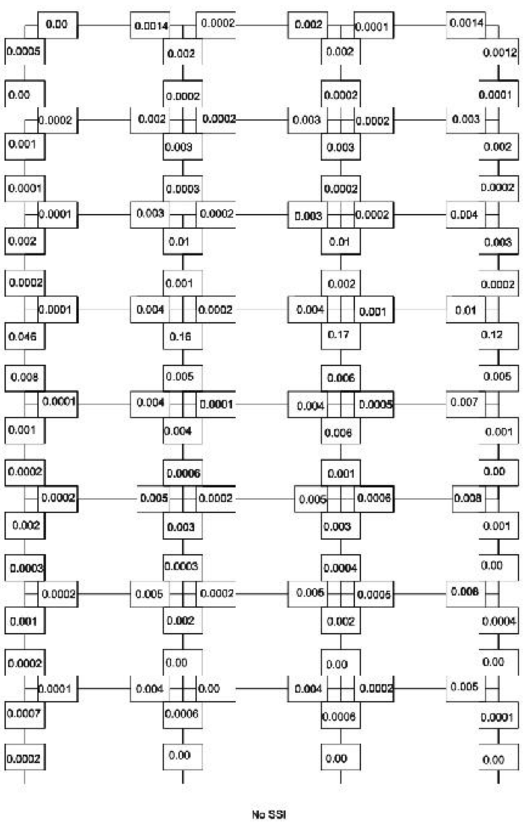
Figure 3. Bilinear representation of pushover curves before retrofitting (a) 5-story frame, no SSI, (b) 5-story frame nonlinear SSI, (c) 8-story frame, no SSI, (d) 8-story frame nonlinear SSI

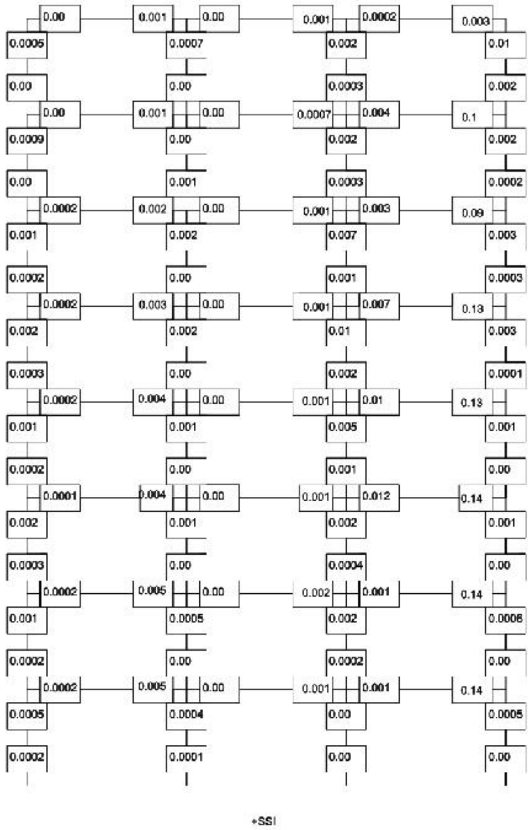
Rotations of elements with and without SSI are shown in Fig. 4 and Fig. 5. It should be noted that for the 5-story frame pushover analysis and for the 8-story frame time-history analysis are carried out.



(a) (b)

Figure 4. Rotations of the elements of the 5-story frame before retrofitting (a) no SSI, (b) nonlinear SSI

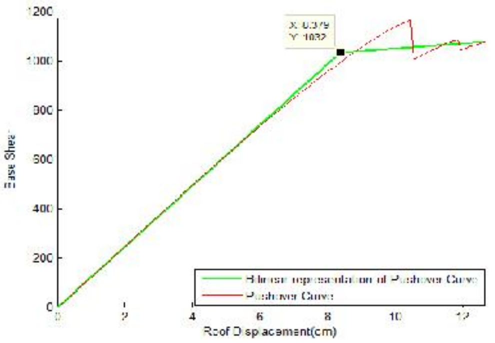




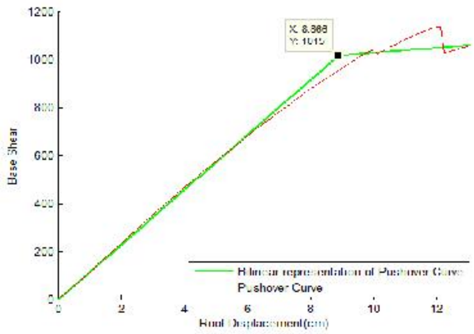
(a) (b)

Figure 5. Rotations of the elementsof the 8-story frame before retrofitting (a) no SSI, (b) nonlinear SSI

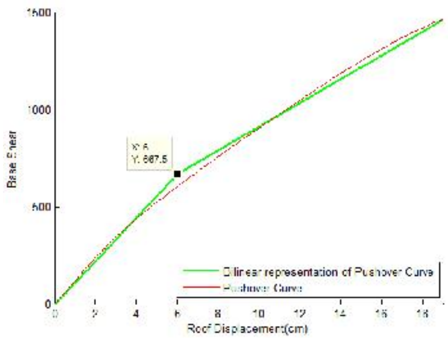
After the structures are retrofitted, pushover curves along with their bilinear estimations are drawn as shown in Fig. 6.



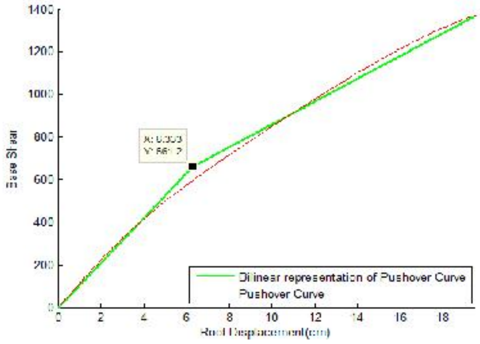
(a)



(b)



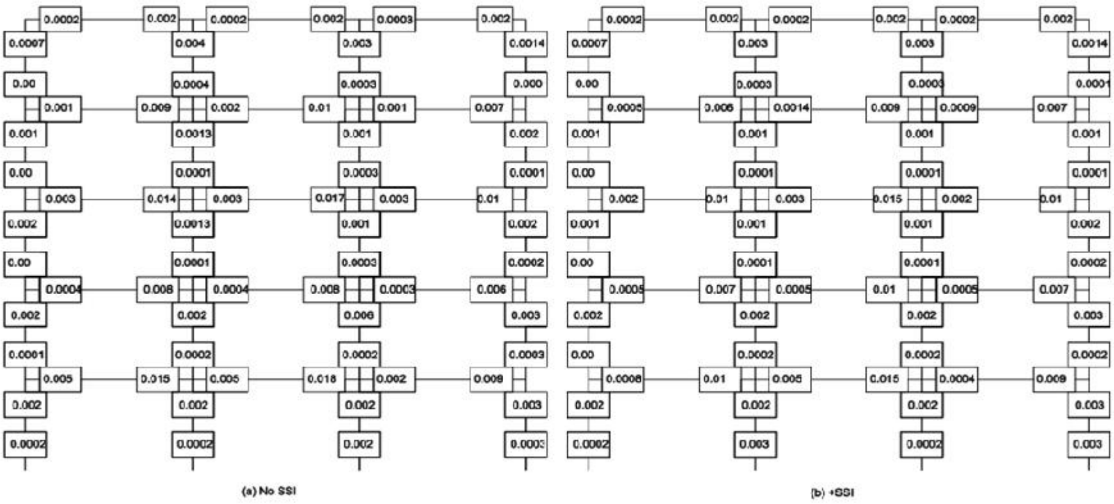
(c)



(d)

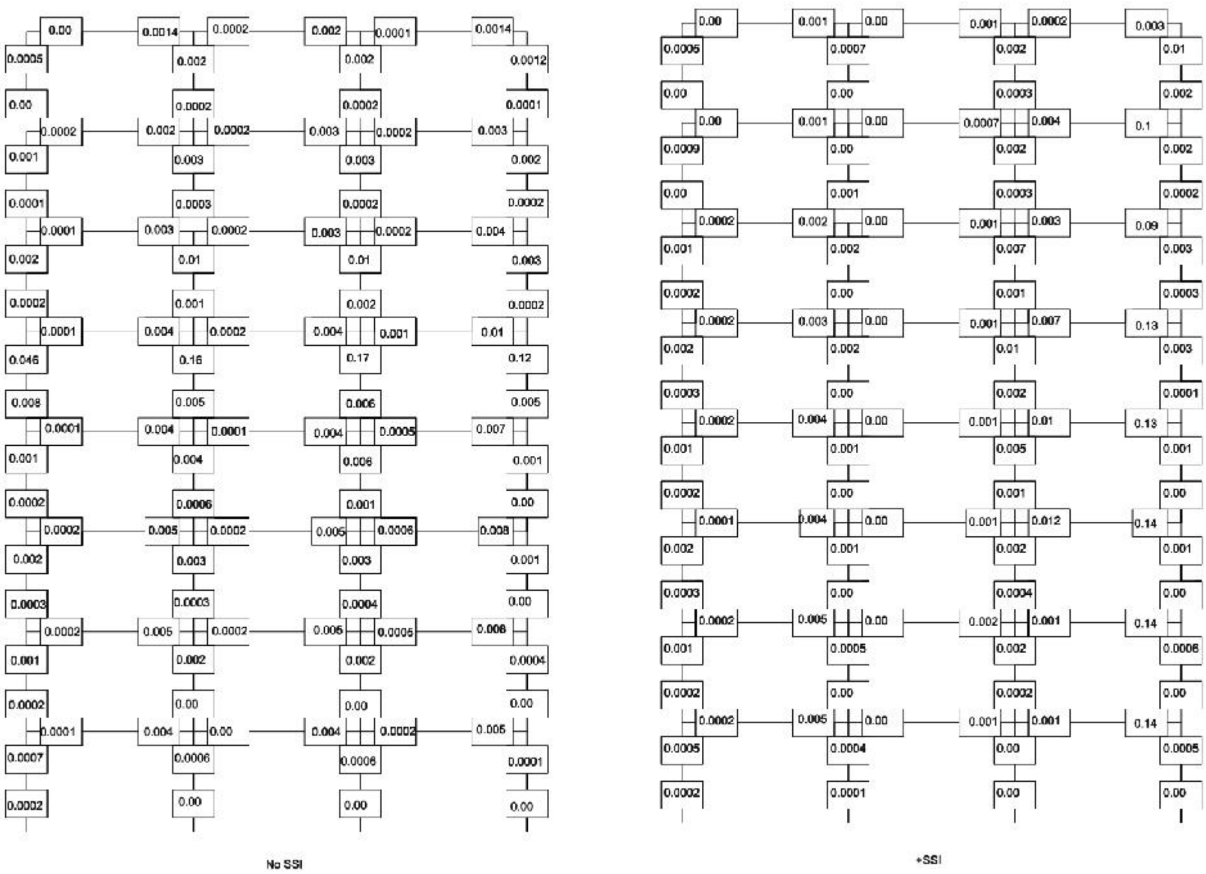
Figure 6. Bilinear representation of pushover curves after retrofitting (a) 5-story frame, no SSI, (b) 5-story frame nonlinear SSI, (c) 8-story frame, no SSI, (d) 8-story frame nonlinear SSI

After the structure is retrofitted the rotations must be controlled so that no more critical points exist in the structure. Fig. 7 and Fig. 8 represent post-retrofitting rotations of the elements.



(a) (b)

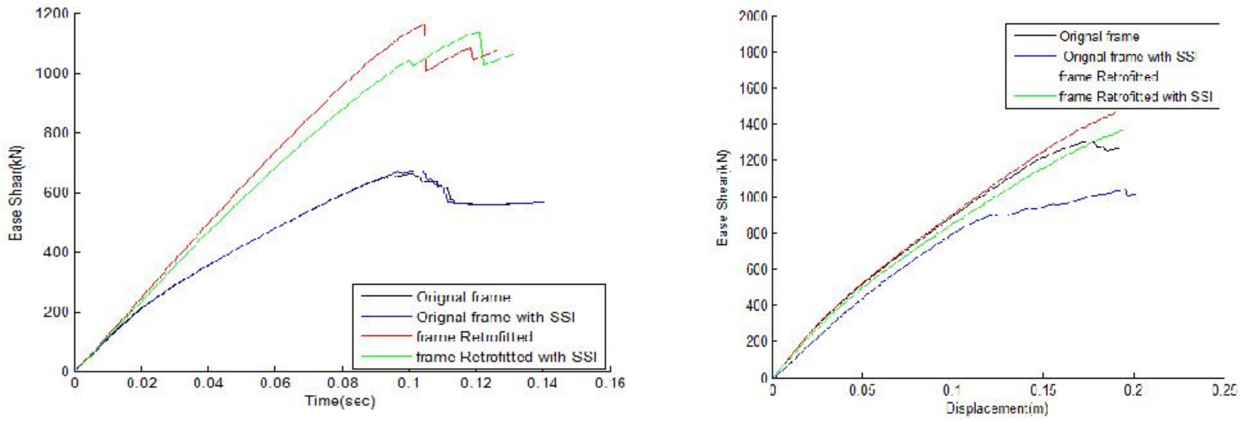
Figure 7. Rotations of the elements of the 5-story frame after retrofitting (a) no SSI, (b) nonlinear SSI



(a) (b)

Figure 8. Rotations of the elements of the 8-story frame after retrofitting (a) no SSI, (b) nonlinear SSI

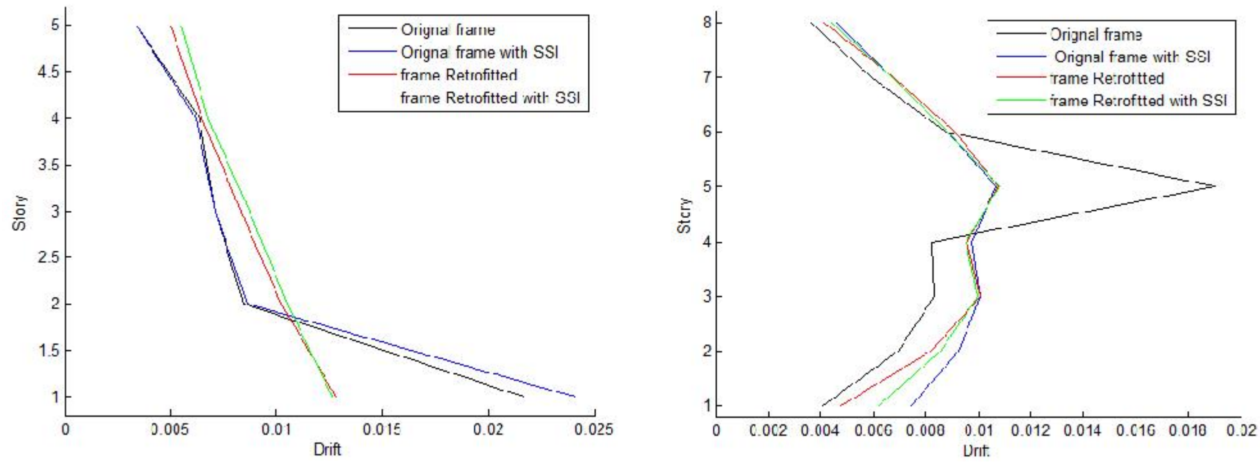
Base shears of the structures versus control point displacement are drawn and presented in Fig. 9.



(a) (b)

Figure 9. Base shears in the primary and retrofitted frames with and without nonlinear SSI, (a) the 5-story frame, (b) the 8-story frame

Recorded story drifts before and after the performance of retrofitting are illustrated in Fig. 10.



(a) (b)

Figure 10. Peak story drifts in the primary and retrofitted structures with and without SSI, (a) the 5-story frame, (b)the 8-story frame

CONCLUSIONS

Two reinforced concrete structures, namely a 5-story and an 8-story were analysed in order to be seismically retrofitted. Pushover analysis was carried out for the 5-story frame while for the 8-story one time-history analyses were performed. Under pushover analyses, results of the retrofitting and costs are as presented in Tables 5 and 6.

Table 5. Area and cost of CFRP required for retrofitting of the frame

Analysis	CFRP area needed	Cost (I.R. rials)
The 5-story frame		
Pushover (no SSI)	254	381000000
Pushover (SSI)	229	343500000
The 8-story frame		
Pushover (no SSI)	66	99000000
Pushover (SSI)	24	36000000

Table 6. Number of CFRP layers needed

Element numbers	Pushover (no SSI)	Pushover (SSI)
The 5-story frame		
1, 16	1	1
2, 17	1	1
3, 18	1	1
4, 19	1	1
5, 20	1	1
6, 11	1	1
7, 12	1	1
8, 13	1	1
9, 14	1	1
10, 15	-	-
21, 26, 31	5	4
22, 27, 32	2	2
The 8-story frame		
13, 21	2	1
14, 22	1	1
35, 43, 51	1	-

It is important to remind that as mentioned earlier, for the 8-story frame at least one time-history analysis is necessary which was further than the scope of this work. The results of such retrofitting are presented in a parallel work.

ACKNOWLEDEMENTS

Authors wish to thank professor S. Mohasseb from Tehran University, Tehran, for his very valuable comments on using FRP for the retrofitting of structures. This study was carried out under the support of Shiraz University of Technology for the proceedings of the 7th International Conference on Seismology & Earthquake Engineering. Reviewers are to be thanked gratefully for their insight into the matter and their kind remarks.

REFERENCES

Chopra AK (1995)Dynamics of structures (Vol. 3): Prentice Hall New Jersey

El-Amoury Tand Ghobarah A (2005)Retrofit of RC frames using FRP jacketing or steel bracing. JSEE, 7(2), 83-94

Rao RV, Savsani VJ and Vakharia DP (2011) Teaching-learning-based optimization: A novel method for constrained mechanical design optimization problems

Raychowdhury P (2008) nonlinear winkler-based shallow foundation model for performance assessment of seismically loaded structures. ProQuest

Terzaghi (1943) K., Theoretical soil mechanics

The Iranian Code of Retrofitting of Existing Structures no.360

Zou X, Teng J-G, De Lorenzis L and Xia S (2007).Optimal performance-based design of FRP jackets for seismic retrofit of reinforced concrete frames. Composites Part B: Engineering, 38(5), 584-597