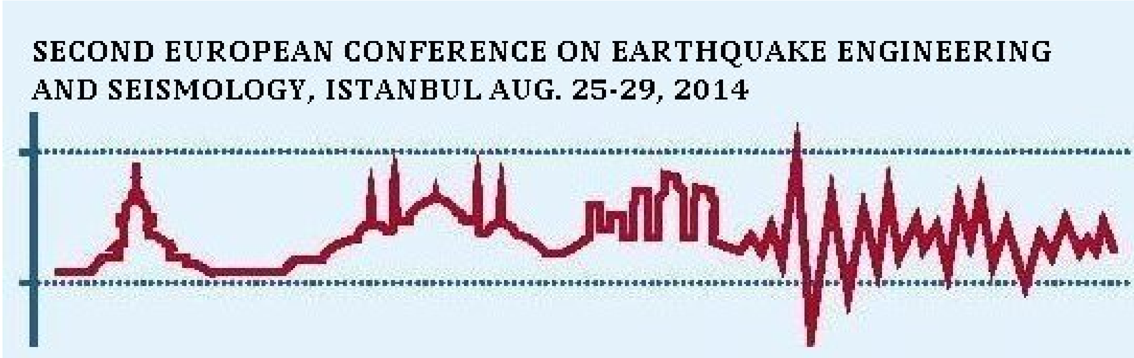

IMPROVEMENT OF ADAPTIVE PUSHOVER PROCEDURE IN PERFORMANCE ASSESSMENT OF STEEL STRUCTURES

A. Aziminejad[1], M. Zare[2], A.S. Moghadam [3]

ABSTRACT

In recent years adaptive pushover analysis proposed to overcome the some weaknesses of traditional pushover procedures. Adaptive pushover could consider the higher modes effects, and the changes in mode shapes due to inelastic behaviour of structures. Past studies showed, adaptive procedure in some cases could improve the ability of nonlinear static procedure in predicting performance of structures, however it extensively rise the complexity of the method and amount of the efforts needed. In this study to overcome these difficulties, simplified methods proposed. In these methods the adaptation of load vectors was limited to few steps. These steps planned when the building experience intensive nonlinear behaviour. The location of these steps through full displacement range, could be identified by considering results of traditional pushover analysis with constant load pattern. To understand the advantages and disadvantages of methods several adaptation procedure was examined. Traditional load adaptations such as force based, drift based, and modified methods such as first mode (mode 1) and story shear adaptive procedure (SAP) were considered. To evaluate accuracy of procedures, each one applied on the SAC group of buildings (i.e. SAC-3, SAC-9 and SAC-20) and the results compared with the nonlinear time history analysis. For nonlinear time history analysis a set of eleven ground motion records, proposed by FEMA 440 [4], applied to the models. The results shows among the examined procedure when the buildings experience extensive nonlinear behaviour, due to increasing of earthquake intensity, the application of SAP method reduced the mean error of response parameters including inter story drift ratio and plastic hinge rotation in compare with traditional pushover procedure, but when earthquake intensity is lower the advantages of adaptive methods over traditional code based procedures decrease.

1- INTRODUCTION

Under the relatively intensive earthquakes, the structural members are generally yielded and behave in nonlinear range, as a result the plastic hinges form in these members. Hinge formation in members will change the total stiffness matrix of the structure and the structure will experience larger displacements and inter story drifts.

The majority of buildings design codes are force based and the equivalent static procedure is the most widely used method in them. The investigations on structural behavior of the building during recent

---

[1] Assistant professor, Islamic azad university, science and research branch, Tehran, Iran, armin.aziminejad@gmail.com

[2] Islamic azad university, science and research branch, Tehran, Iran, mehdizare64@yahoo.com

[3] Assistant professor, International institute of earthquake engineering and seismology, Tehran, Iran moghadam@iiees.ac.ir

earthquakes show that members force and strength should not be considered as a proper criterion for earthquake resistant design of structures and an increase in members' strength does not necessarily mean an increase in the safety (Shaker 2008). Therefore, deformation based seismic design is considered as new methodology for designing the structures and their performance assessment in the new regulations. For the practical development of the performance based design methods, reliable seismic analyzes are needed to be of a high accuracy besides the simplicity. For this reason, nonlinear static analysis has been widely used during the last decade in seismic evaluation of the structures including ASCE41-06 (ASCE/SEI 41-06, 2007), ATC40 (ATC40, 1996) and FEMA273 (FEMA273, 1997) and some of the design regulations including for the assessment and seismic design of the structures.

Nonlinear static analysis has numerous advantages compared with the linear static analysis. Using this method, valuable information of the structural response can be obtained that could not be achieved using the linear static analyzes. The implementation of this method is very simple and easy in comparison with the nonlinear dynamic analysis. Despite the numerous advantages of the conventional Pushover analyzes, deficiencies are still found in these methods including not considering the changes in the modes due to inelastic behavior, not considering the reduction of the structure strength stiffness during earthquake cycles and inability in considering the effects of higher modes. Due to the numerous advantages of the Pushover analysis method and its simplicity, great efforts have been made to resolve these deficiencies. Hence, different Pushover methods have been proposed to incorporate the effects of higher modes and changes in the modal characteristics of the structure due to damages a structure sustain during earthquake excitations. Adaptive load pattern Pushover method is among such improved methods in which the loading pattern is adapted through several steps based on instantaneous modal characteristics of the structure. In this paper, to simplify and improve these methods the adaptation of load vectors was limited to few steps. These steps planned when the building experience nonlinear behaviour. The location of these steps through full displacement range, identified by considering results of traditional pushover analysis with constant load pattern. To understand the advantages and disadvantages of methods several adaptation procedure was examined. Traditional load adaptations such as force based, drift based, and modified methods such as first mode (mode 1) and story shear adaptive procedure (SAP) were considered. To assess accuracy of procedures, each one applied on the SAC group of buildings (i.e. SAC-3, SAC-9 and SAC-20) and the results compared with the nonlinear time history analysis. For nonlinear dynamic analysis a suit of eleven earthquakes records was used. It is worth mentioning that SAP 2000 software was used for all the nonlinear dynamic and adaptive and non-adaptive static analyzes.

2- PUSHOVER ANALYSIS

Although the nonlinear dynamic time history analysis is the best and most accurate method to analyze and assess the seismic behavior of the structures, the nonlinear static (Pushover) analysis is recommended by the valid instructions and regulations of the seismic improvement of the buildings due to simplicity of application and result interpretation. Pushover nonlinear static analysis is based on relating the characteristics of a structure with multiple degrees of freedom to a structure with 1 degree of freedom.

In these methods, the effects of material nonlinearity are considered directly during structural analysis. The structural model is put under an incremental lateral load to get to a target displacement so that the displacement of the control point (i.e. mass center of the building roof) gets to a specific amount or the building becomes unstable. Sequence of fractures, plastic joints and damages to the structural members can be easily presented during the process. Target displacement in these methods considered to be equal to the maximum probable displacement which building undergo under the probable earthquake excitation. To evaluate the performance of the structure using the Pushover analysis, structural members plastic deformation are checked when building reached to the target displacement during the analysis procedure.

It is assumed in Pushover analysis method that the response of a building can be estimated accurately by a single degree of freedom model. It means that the dynamic response of a system with multiple degrees of freedom is predictable by using a single dominant mode (i.e. the first mode).

This Dominant mode shape, $\{\phi\}$ is assumed to be unchanged during the analysis regardless of the plastic deformations of the members. The lateral load pattern is determined based on the assumed dominant mode shape and the following equation.

$$\{f\} = [m] \times \{\phi\} \tag{1}$$

In this equation [m] is the mass matrix of the system with multiple degrees of freedom, $\{\phi\}$ is the assumed dominant mode shape and {f} is the lateral load pattern.
Target displacement in the Pushover analysis should be an approximate of the maximum expected deformation under the probable earthquake. This displacement can be estimated by using single degree of freedom approximation in which the nonlinear effects are considered by using some displacement amplification factors. In this regard, several methods have been developed such as the capacity spectrum method (ATC40, 1996) and coefficients method (FEMA356, 2000).

2- ADAPTIVE PUSHOVER METHOD

One of the main disadvantages of the conventional nonlinear static methods in the current Regulations and codes is that a constant lateral load pattern is applied during the analysis and changes in modal characteristics of the structure could not be considered. So when the structure behave in the nonlinear range and accordingly, modes and stiffness matrix of the structure is changed, the analysis is still continued with the original lateral load pattern with no changes. Therefore, in order to overcome the aforementioned deficiencies, some researchers have proposed the Adaptive load pattern in recent years. In these methods, applied loading pattern is changed and adapted relative to the modal characteristics of the structure at each loading stage. It means unlike the conventional Pushover methods in which the structure is pushed through a single step and a constant load pattern to get the target displacement, in the Adaptive Pushover analysis the structure is pushed to the target displacement using multiple steps and a new load pattern (which is calculated using the modal characteristics of the structure in the same step) is applied at each step.
In this paper, two new methods namely SAP (Story Shear-based Adaptive Pushover) analysis and Code A-lateral load distribution-based Adaptive Pushover analysis have been evaluated.
To simplify process, and based on this fact that in initial steps structure behave dominantly in linear range, the adaption of lateral load was limited in some selected steps which structure experience extensive nonlinear deformation. To recognize these steps, first a non-adaptive push over analysis was performed, then using the resultant performance curve, the adaption steps was carefully determined. It is worth mentioning that the obtained loading pattern at each adaption step is kept constant up to the next adaption step.

3- DESCRIPTION OF THE ADAPTIVE PUSHOVER METHODS USED IN THIS STUDY

To evaluate the efficiency of the Adaptive loading pattern push over methods they should be analytically applied to the structures and the results should be compared with the results of other push over methods and nonlinear time history dynamic analysis. Pushover methods used in this study are divided into two categories of constant and Adaptive loading patterns. In the first category, the loading patterns proportional to the first mode of the structure (M1), the rectangular loading pattern and equivalent static load pattern of the Code have been used.
In the second category, adaptive loading pattern push-over methods based on story shear, the first mode of the structure, lateral load distribution of the code, relative displacement of the stories as well as force-based adaptive push-over method are used. All of these methods will be described in continue, separately.

3-1 FIRST MODE-BASED ADAPTIVE PUSHOVER ANALYSIS METHOD (A-M1)

In this method, the lateral loading pattern is proportional to the Mode-1 of the structure that is adapted at each step. This method takes into account the softening of the capacity curve due to reduction of the structure stiffness. This will change the modes (FEMA440, 2005). The loading pattern used in this method is presented using Eq.(2).

$$F_i = \phi_i \tag{2}$$

3-2 FORCE-BASED ADAPTIVE PUSHOVER ANALYSIS METHOD (FAP)

Antoniu and Pinho (2002) developed the proposed method by Elnashai and evaluated its application in a number of reinforced concrete structures. In the proposed method, lateral load distribution pattern is not fixed and is adapted continuously according to mode shapes and modal coefficients resulted from modal analysis at each loading step.

Algorithm of the force-based adaptive push-over method can be classified into four stages (Antoniou et al., 2002).

1. Determination of the nominal load vector P_0
2. Calculation of the load coefficient λ
3. Calculation of the normalized modal vector $\overline{F}$
4. Adapting the loading vector

3-3 DRIFT-BASED ADAPTIVE PUSHOVER ANALYSIS METHOD (DRAP)

Antoniou and Pinho (2004) proposed Relative Drift-based Adaptive Pushover method. In this method the scaled normal displacement modal vector is used for determination of the lateral load pattern at each stage of the analysis. In each step inter-story drift is calculated by using proper modal combination rule such as the SRSS method (Antoniou and Pinho, 2004). Total displacement of each story is also obtained by adding the relative displacement of the story and lower stories.

3-4 STORY SHEAR-BASED ADAPTIVE PUSHOVER ANALYSIS METHOD (SAP)

This method is based on the non-adaptive Pushover procedure proposed in FEMA 440 known as SRSS method with some modifications. In this method story shear of each modes calculated, and combined using SRSS rule in each adaption step. The absolute subtraction of the shears of each story and the upper story is used to obtain the lateral load pattern of the story.

In this method, in order to determine the lateral load pattern at each step, $\overline{f_i}$ vector is used. First, according to Eq. (3). Modal lateral force is obtained at each story using the mass of the stories (M_i), mode shapes (ϕ_{ij}) and spectral acceleration (S_a).

$$F_{ij} = M_i \phi_{ij} S_a(j) \tag{3}$$

Then using these lateral forces, story shear for each mode could be calculated using Eq.(4).

$$V_{ij} = \sum_{k=i}^{k=n} F_{kj} \tag{4}$$

Modal shear forces of each story obtained using SRSS combination rule Eq.(5)

$$V_i = \sqrt{\sum_{j=1}^{n} \left(V_{ij}\right)^2} \tag{5}$$

Then, the applied force to each story is obtained from the absolute value of the difference between shear forces of that story and the upper story Eq.(6).

$$f_i = \left| V_i - V_{i+1} \right| \tag{6}$$

Finally, f_i force vector is converted into normalized force vector of $\overline{f_i}$ by using Eq.(7).

$$\overline{f_i} = \frac{f_i}{\sum_{i=1}^{n} f_i} \tag{7}$$

3-5 CODE LATERAL LOAD DISTRIBUTION-BASED ADAPTIVE PUSHOVER ANALYSIS METHOD (CODE-A)

This method is based on lateral load distribution of linear static procedure proposed by FEMA356. This method calculate the fundamental period of the structure at each adaption step of the analysis and using Eq. (8) and Eq.(9) lateral load pattern will be obtained at each step of the analysis.

$$K=0.5T+0.75 \tag{8}$$

$$F_i = \frac{w_i h_i^k}{\sum_{j=1}^{n} w_j h_j^k} \tag{9}$$

In Eq. (8) and Eq. (9) T is the fundamental period of structure, F_i is the lateral force of the i*th* story, n is the number of stories, w_i and w_j are the weight of i*th* and j*th* stories, respectively, and h_i and h_j are the height of i*th* and j*th* stories.

4- SELECTED EARTHQUAKES

In this study, eleven earthquake records propsed in FEMA 440 for nonlinear dynamic analyzes have been used. These records were selected among Pacific Earthquake Engineering Research Center (PEER) database which is the collection of more than 50 intensive earthquakes with magnitudes of 8 <Ms <5.5 and the closest distance to the fault of between 8 to 20 km. Characteristics of the eleven selected records are listed in the Table.1. (FEMA440, 2005).

It is worth mentioning that in this research, average acceleration spectrum of 11 mentioned earthquakes is used in calculation of the load pattern in the Shear-based and Force-based Adaptive Pushover analyzes. Also average displacement spectrum of 11 earthquakes is used in calculation of the load pattern in the drift-based Adaptive Pushover analysis.

Given the risk level of ASCE 7-10 Code (ASCE 7-10, 2010) to have a proper comparison between the nonlinear dynamic and static analyses' results, eleven selected accelerograms were scaled to the spectrum of this Code for the western part of the United States. To investigate the effect of earthquake intensity on the proposed methods' performance, two scale factors including the Code's scale factor (S.F=1.93) and the twice the code's scale factor (S.F=3.86) were considered. Figure 2 shows the average spectrum of the selected earthquakes before and after scaling in compare with ASCE 7-10's design spectrum.

Table 1. Characteristics of the eleven selected records (FEMA440, 2005)

#	Identifier	Earthquake	Date	Magnitude	Station Location (Number)	PGA (g)	PGV (cm/sec)
1	ICC000	Superstitn	11-24-87	Ms=6.6	El Centro Imp. Co.Cent(01335)	0.358	46.4
2	LOS000	Northridge	1-17-94	Ms=6.7	Canyon Country-W Lost Cany(90057)	0.41	43
3	G02090	Loma Prieta	10-18-89	Ms=7.1	Gilroy Array #2 (47380)	0.322	39.1
4	TCU122N	Chi-Chi,Taiwan	9-20-99	Ms=7.6	(TCU122)	0.261	34
5	G03090	Loma Prieta	10-18-89	Ms=7.1	Gilroy Array #3 (47381)	0.367	44.7
6	CNP196	Northridge	1-17-94	Ms=6.7	Canoga Park-Topanga Can(90053)	0.42	60.8
7	CHY101W	Chi-Chi,Taiwan	9-20-99	Ms=7.6	(CHY101)	0.353	70.6
8	ICC090	Superstitn	11-24-87	Ms=6.6	El Centro Imp. Co.Cent(01335)	0.258	40.9
9	CNP106	Northridge	1-17-94	Ms=6.7	Canoga Park-Topanga Can(90053)	0.356	32.1
10	E02140	Imperial Valley	10-15-79	Ms=6.9	El Centro Array #2 (5115)	0.315	31.5
11	E11230	Imperial Valley	10-15-79	Ms=6.9	El Centro Array #11 (5058)	0.38	42.1

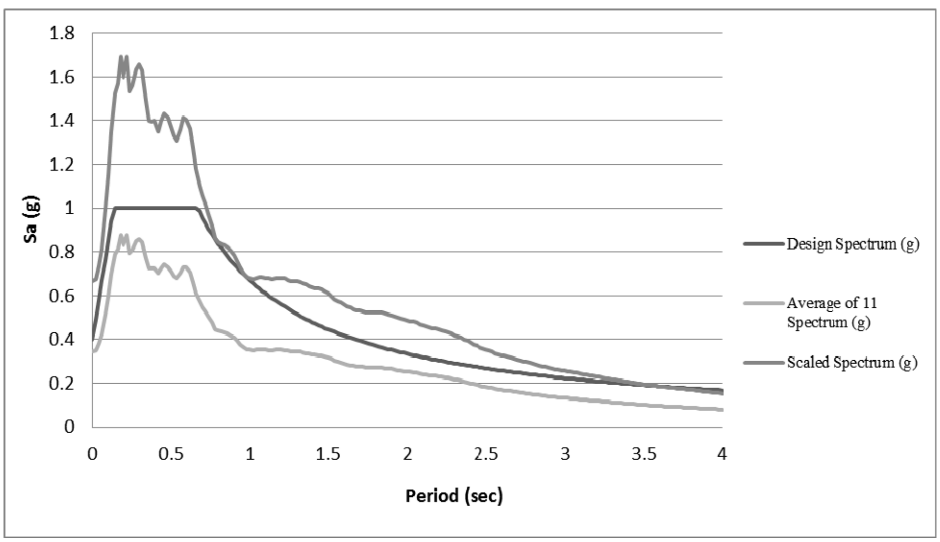

Figure 2. Average spectrum of the selected earthquakes before and after scaling versus the design spectrum of the ASCE 7-10 Code

5- DETERMINATION OF THE TARGET DISPLACEMENT

To evaluate the performance of the Adaptive Pushover methods, no approximate method is used in determination of the target displacement. To this goal, first nonlinear dynamic analyzes were applied on models using selected records. Nonlinear dynyamic analysis conducted using SAP2000 software. Then the maximum roof displacement of models were determined and the average value was used as target displacement for nonlinear static analyzes. It should be noted that target displacements were calculated for each of the three SAC group structures and for each earthquake intensity, separately.

6- STRUCTURAL MODELS

Structural models studied in this paper include short, medium and high rise structures of the SAC group in the Los Angeles called SAC3, SAC9 and SAC20. SAC3, SAC9 and SAC20 are 3, 9 and 20 story buildings with resistant steel perimeter moment frames, respectively that were designed by Consulting Engineers for Phase II of the SAC group research project. Seismic considerations of UBC1994 Code for Los Angeles area are considered in designing these structures (Ohtori et al., 2003). Many researchers have used these buildings as base buildings for their researches. Two-dimensional models were used in this study and only one moment-resistant frame in north-south direction of the building is modeled.As a sample selected frame of the SAC3 building is shown in figures 3.

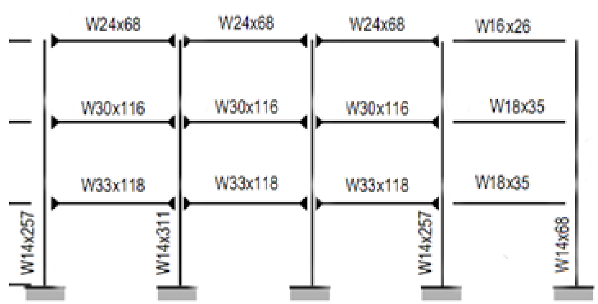

Figure 3. Frame model of the SAC3 building

7- THE ANALITICAL RESULTS

To evaluate performance of different nonlinear addaptive procedures, response parameters such as displacement responses, inter-story drift, shear and overturning moment of the stories, obtained from these Pushover methods and compared to values obtained from the average of the maximum responses of the nonlinear dynamic analyzes. In addition to these parameters, rotation of the beam plastic hinges has been also studied before and after increasing the intensity of earthquakes.
In order to compare the accuracy of different Pushover methods in estimation of the responses, nonlinear dynamic analysis result is used as an accurate answer. In this regard, error index introduced by FEMA440 is used for different methods according to Eq.(10). The index is defined as follows (FEMA440, 2005).

$$Error\ (\%) = 100 \times \left| \frac{R_{NTHA} - R_{PUSH}}{R_{NTHA}} \right| \tag{10}$$

Where R_{NTHA} is the nonlinear dynamic analysis response under consideration and R_{PUSH} is nonlinear static analysis response. The closer the error index to the zero, means the less the Pushover method error is compared to the nonlinear dynamic analysis, and the more accurate results can obtain frrom the pushover method.
In order to better compare the results of the proposed nonlinear static analyzes, average displacement error, relative displacement, shear and overturning moment of the stories for each of the structures are plotted in percentages.

The first parameter examined in this study is displacement of the stories. Accordingly, maximum displacement response of the stories obtained by using different Pushover methods were compared to the average of maximum displacement response of the stories obtained by using nonlinear dynamic analyzes and results are shown in diagram 1. In this diagram M1, code and rectangular are classical non adaptive pushover methods with lateral load pattern of first mode, rectangular and equivalent static respectively the other results obtained from adaptive procedures which introduced in previous sections. Considering the average error diagram of the stories' displacement (diagram 1) it is observed that by increasing the height of the SAC group structures, the error using M1, A-M1, Rectangular and

DRAP Pushover methods was increased so that in M1 method a dramatic average error increase was observed by changing from SAC9 structure to SAC20 one . On the other hand Application of SAP method to SAC20 structure yielded a very proper approximation and decreased the error of the Code method by 82% and reduced the average displacement error of stories to 1.44%. However for this response parameters the results of SAP methods were less accurate for shorter models in compare with results obtained from conventional non adaptive procedures.

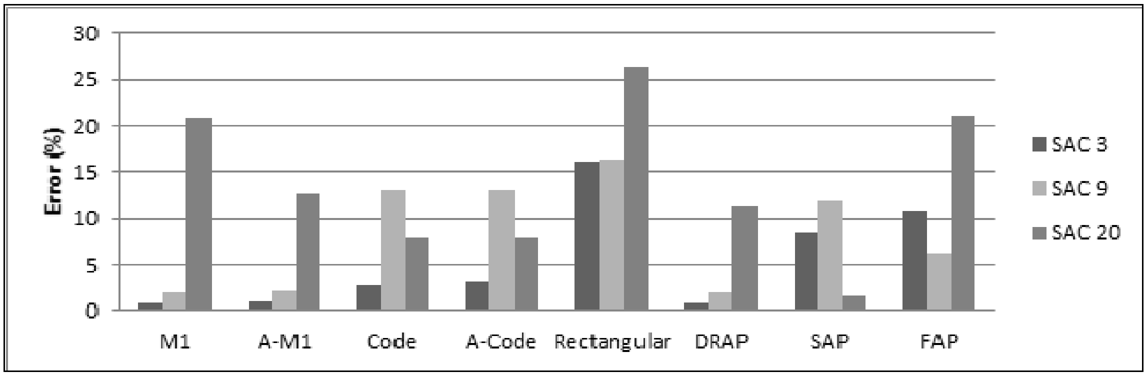

Diagram 1. Average displacement error of the stories for the studied nonlinear static methods (%)

Diagram 2 shows the average drift error of the stories in percent for the studied nonlinear static methods. As can be seen from this diagram, the most accurate results for the relative displacement of the stories is obtained using DRAP method with the average error percentages of 2.7 and 6.42 for SAC3 and SAC9 buildings, respectively. The best result for SAC20 building was also obtained using SAP Adaptive Pushover method so that decreased the error by 62% comparing to Code method. As shown in diagram 3, by comparing M1 and Code methods with A-M1 and A-Code ones, it can be indicated that in three and nine-story structures, using Adaptive loading pattern insignificantly improved the results. But for the twenty-story structure, adapting the loading pattern using A-M1 method increased the performance accuracy of this method by 25% compared to M1 method.

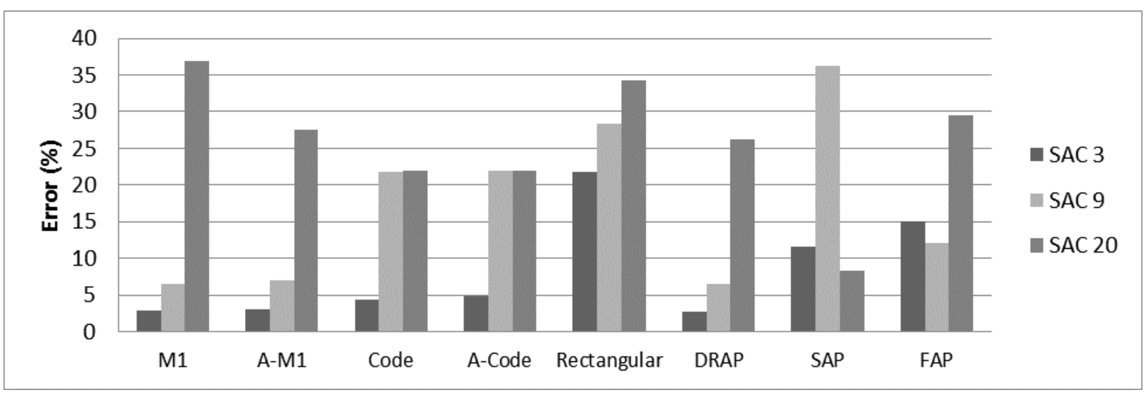

Diagram 2. Average drift error of the stories for the studied nonlinear static methods (%)

To investigate the performance of Adaptive Pushover methods by increasing the earthquake intensity, relative displacements of the stories before and after increasing the earthquake intensity were compared. The average relative displacement error of the stories, before and after increasing the earthquake intensity is shown in diagrams 3 and 4 for SAC9 and SAC20 structures, respectively. As mentioned before, in order to increase the intensity of earthquakes, the scale factor resulted from scaling the earthquake records (S.F = 1.93) was doubled (S.F=3.86). The effect of increasing the scale

factor (earthquake intensity) is separately shown in diagrams 3 and 4 for both structures. According to diagram 3, M1 and Code methods provided similar results in comparison to A-M1 and A-Code methods so that in Code and A-Code methods by increasing the earthquake intensity, no change was observed in performance accuracy of the method. But in M1 and A-M1 methods by increasing the earthquake intensity, the error rate was increased from 7.01% to 25.26%. Also, in Rectangular, DRAP and FAP methods by increasing the earthquake intensity, average relative displacement error of the stories was increased so that in Rectangular method it was increased from 28.28% to 45.54%, in DRAP method from 6.42% to 24.49% and in FAP method from 12.14% to 33.47%.
The important point is that by increasing the earthquake intensity and extending the nonlinear behavior of SAC9 structure, SAP method decreased the average relative displacement error of the stories by 52% and reduced the error rate from 36.16% to 17.06%.
According to diagram 4, in SAC20 structure, despite the slight decrease in the accuracy of SAP method by increasing the earthquake intensity, it still yields the lowest error rate (9.74%).

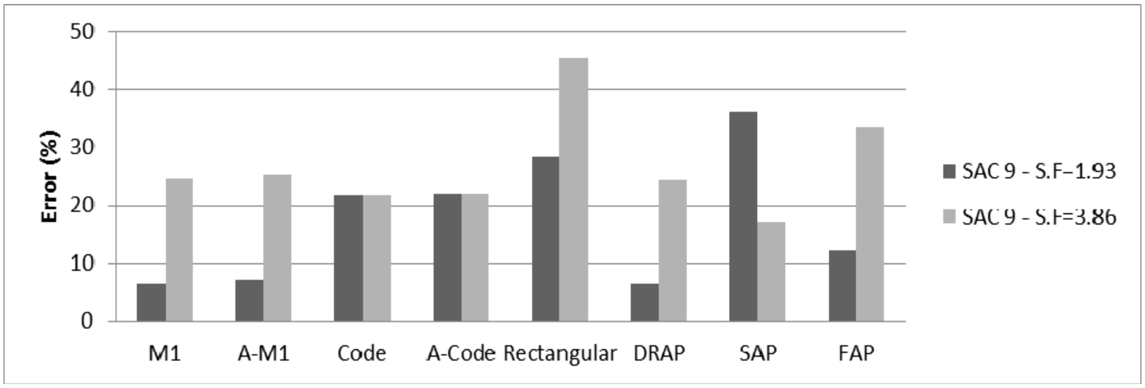

Diagram 3. Average drift error of the SAC9 structure stories in percent for the studied nonlinear static methods (before and after increasing the earthquake intensity)

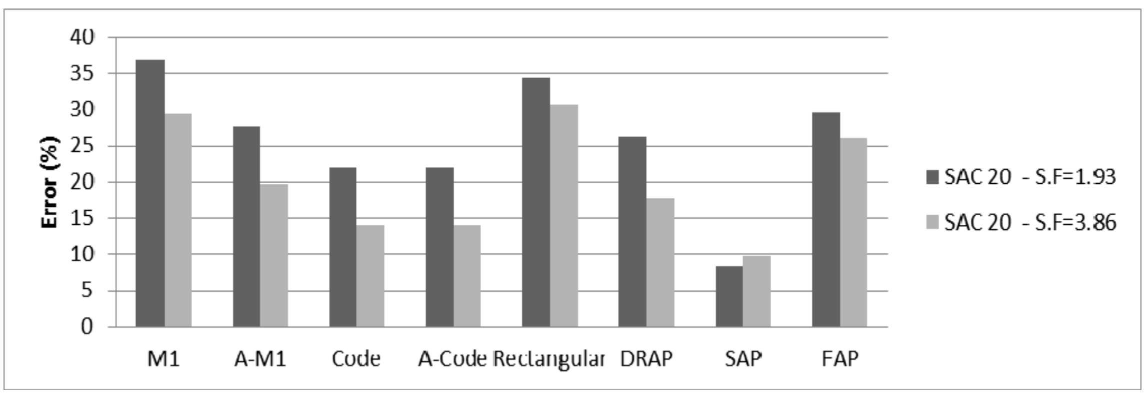

Diagram 4. Average drift error of the SAC20 structure stories in percent for the studied nonlinear static methods (before and after increasing the earthquake intensity)

An important parameter for evaluating structural performance is plastic hinge rotation, to evaluate the effect of increasing the earthquake intensity on the accuracy of the studied Pushover methods, the maximum rotation of the beam plastic hinges obtained using different Pushover methods were compared with average of the maximum nonlinear dynamic analyses' responses. To better understand the change of this parameter, responses before and after increasing the intensity of the earthquakes has been put together in a diagram.
Rotation error rates of the beam plastic hinges of SAC9 and SAC20 structures obtained by using the studied Pushover methods are shown in diagrams 5 and 6.
By having a review on diagram 5 it is indicated that by increasing the earthquake intensity, error rate in estimating the rotation of the beam plastic hinges has been increased in all methods except for

Rectangular and SAP methods. The results of Code and A-Code methods slightly changed before and after increasing the earthquake intensity and presented almost the same results. Comparison of M1 and A-M1 methods also indicated that both these methods perform similarly in predicting amount of plastic hinge rotation in beams. FAP and SAP methods, with an error rate of 2.78% and 40.66%, respectively showed the highest and lowest accuracy before the scale factor being doubled. By increasing the scale factor performance of SAP method was improved and has the best results after rectangular and FAP methods. When the scale factor was doubled, Rectangular and Code methods having error rates of 1.43% and 42.19% were the most and least accurate methods.

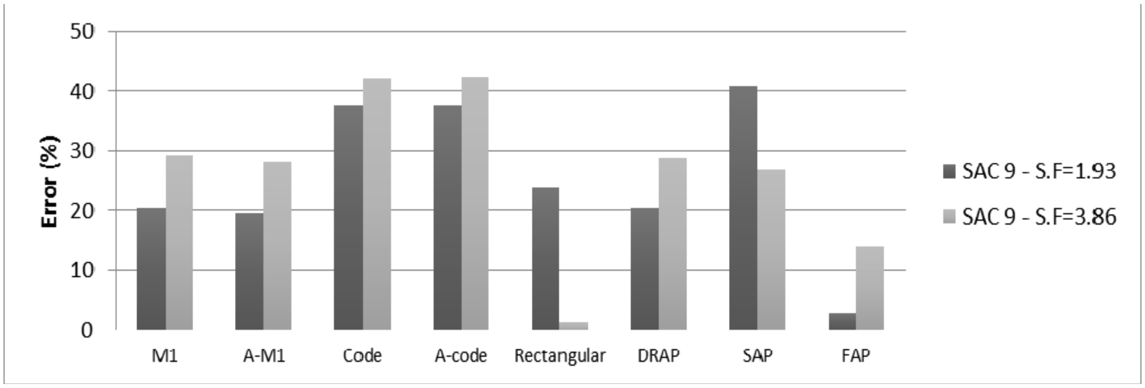

Diagram 5. Plastic Rotation error rate of the beam plastic hinges of SAC9 structure for the studied nonlinear static methods (%) (Before and after increasing the earthquake intensity)

As it is obvious from diagram 6, the performance of all the methods by further entering the structure to the nonlinear zone is improved except in Code and SAP methods. This is obviously observed in the results of M1, Rectangular and FAP methods. Despite the unacceptable results of these three methods before increasing the intensity of earthquake, by increasing the nonlinear behavior of SAC20 structure, results' accuracy of these methods significantly increased. Before increasing the earthquake intensity, SAP method by having 21.64% error, and after increasing the earthquake intensity, M1 method by having 1.74% error showed the best performances. Adapting the loading pattern in A-M1 method improved its results compared to M1 method before doubling the scale factor, but after doubling the scale factor and increasing the earthquake intensity, results' accuracy of this method was decreased compared to M1 method.

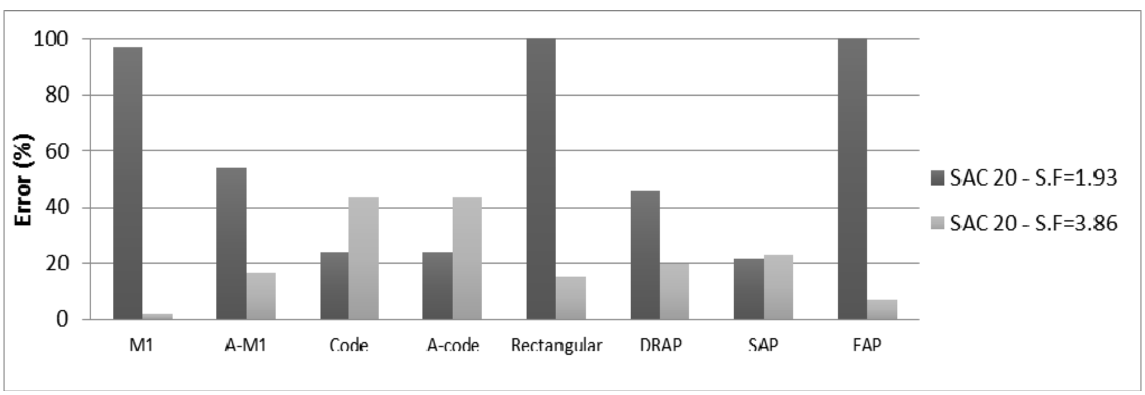

Diagram 6. Plastic Rotation error rate of the beam plastic hinges of SAC20 structure for the studied nonlinear static methods (%) (Before and after increasing the earthquake intensity)

8- CONCLUSIONS

In the present study, the nonlinear static Adaptive method was evaluated and modified. The method was simplified as much as possible and the number of correction steps of the lateral load pattern was reduced. In addition to the conventional adapting patterns and methods, modified patterns and methods and SAP, Mode-1 and Code-based Adaptive methods were proposed. By comparing the results of these methods and the results of the nonlinear dynamical analysis in the range of studied models and studies, the following conclusions are presented.

1. Reducing the number of steps in adapting lateral load and limiting the steps in parts with intensive nonlinear behavior will decrease the volume of calculations and simplify the performance of the method, while maintaining the accuracy.
2. Using shear-based Adaptive SAP method increased the evaluation accuracy of all the responses including relative displacement of the story, deformation of the story, in medium to high rise structures compared to other methods. Improvement of the results and error decrease of these structures was increased by increasing the earthquake intensity and nonlinear behavior of the structure.
3. In evaluation of the plastic hinges' rotation, SAP Adaptive method is of proper accuracy and in medium to high intensity earthquakes is of the same accuracies.
4. In SAC20 structure, M1-based lateral loading pattern Adapting method (A-M1) decreased the error rate of displacement, relative displacement, shear and overturning moment of the stories compared to Mode 1-based constant loading pattern method (M1). But in SAC3 and SAC9 structures Adaptive A-M1 method has no advantage and the results very almost the same.
5. Average error rate of displacement, relative displacement of the stories by using DRAP method was lower than FAP method for all the three SAC Group structures and the accuracy of this method was higher than Force-based loading pattern method.
6. Using Adaptive methods in short structures will significantly improve the results and use of conventional Code methods arise recommended.

REFERENCES

Antoniou S and Pinho R (2004) "*Develoment And Verification Of A Dispiacement-Based Adaptive Pushover Procedure*", Journal of Earthquake Engineering, Vol 8, No 5, pp 643-661

Antoniou S, Rovithakis A and Pinho R (2002) "*Development And Verification Of A Fully Adaptive Pushover Procedure*", Proceedings Twelfth European Conference on Earthquake Engineering, London, UK, Paper No 822

ASCE (2010) "Minimum Design Loads for Buildings and Other Structures", ASCE/SEI 7-10, American Society of Civil Engineers, Reston, Virginia

ASCE/SEI (2007) "Seismic Rehabilitation of Existing Buildings", ASCE/SEI 41-06, American Society of Civil Engineers, Reston, Virginia

ATC (1996) "Seismic Evaluation And Retrofit Of Concrete Buildings", Vol I, ATC 40, Applied Technology Council, Redwood City

FEMA (2005) "Improvement of Nonlinear Static Seismic Analysis Procedures", ATC-55 Project, FEMA 440, Federal Emergency Management Agency, Washington, D.C

FEMA (2000) "Prestandard and Commentary for thd Seismic Rehabilitation of Buildings", FEMA 356, Federal Emergency Management Agency, Washington, D.C

FEMA (1997) "NEHRP Guidelines For The Seismic Rehabilitation Of The Buildings", FEMA 273, Federal Emergency Management Agency, Washington, D.C

Gupta B and Kunnath SK (2000) "*Adaptive Spectra-Based Pushover Procedure For Seismic Evaluation Of Structures*", Earthquake Spectra, 16(2). Pp. 367-391

Ohtori Y, Christenson RE, Spencer BF and Dyke SJ (2003) "*Benchmark Problems In Seismically Excited Nonlinear Buildings*", Journal of Engineering Mechanics, ASCE, 129, to appear, http://cee.uiuc.edu/sstl/

Shakeri K (2008) "Adaptive Modal Pushover Analysis For Seismic Assessment Of Structures", Ph.D Thesis, University Of Science And Technology, Iran, Tehran