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Seismic Response Evaluation of Steel Moment Resisting Frames for Collapse Prevention Level Using a Proposed Modal Pushover Analysis Method

S. Eshghi*, M. M. Maddah, A. R. Garakaninezhad

Research Institute of Structural Engineering, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran.

ABSTRACT: In this paper, a new nonlinear static (pushover) analysis method is presented to evaluate the displacement-based demands of steel moment-resisting frames (MRFs) at the collapse prevention performance level. In this method, the modal pushover responses are integrated using modal combination coefficients, which are calculated from optimization procedures. Two metaheuristic algorithms, including particle swarm optimization and colliding bodies optimization, are utilized for this purpose. In the proposed procedure, the collapse prevention performance level is obtained by a new suggested criterion, which is based on the onset of severe local damages at the structure. This criterion corresponds to occur backward shape in the story capacity curves. The modal combination coefficients are obtained from incremental dynamic analysis (IDA) results of 5, 9, and 11 story steel moment-resisting frames. The optimized modal pushover (OMPA) method is applied to two 9 and 12 story steel MRF buildings. The results showed that the proposed method is easy to implement and is accurate enough to evaluate the displacement-based responses at the CP performance level.

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1- Introduction

Evaluation of displacement-based engineering demand parameters (EDPs) such as inter-story drift ratio profile has great importance in the seismic collapse assessment of structures. Nonlinear static analysis (pushover) methods have been used as approximate approaches for this aim [1]. The previous researches showed that the application of advanced adaptive pushover analysis is complicated and requires time-consuming calculations [2]. In this paper, an alternative method is introduced to produce the inter-story drift profile and the story displacement profile at the collapse prevention (CP) performance level of the mid-rise intermediate moment resisting frames (IMRFs) based on the modal pushover analysis results. Also, in this method, the CP performance level is specified by a novel criterion.

2- Numerical models

In the current study, three 5, 8, and 11-story IMRFs are designed and selected as the reference buildings. The buildings have four 6.0 m bays and 3.1 m in height in each story. The effective seismic mass is attained from the 1.05Dead+1.25Live combination, and the effective seismic weight is obtained from the Dead+Live combination. The modulus of elasticity of steel is assumed 200 GPa, and the beams and columns yield stresses are considered 235 MPa and 350 MPa, respectively. The previous works showed that there is no obvious gain between three-dimensional (3D) and 2D analyses of regular MRFs collapse assessment [3,4]. So, in the current study 2D models have been developed in the OpenSEES program [5,6]. The beams and columns were modeled by elastic beam-column element and plastic hinge rotational springs at member ends that follow the modified IMK model [7]. Also, the panel zones were explicitly modeled using the proposed method by Gupta and Krawinkler [8].

3- Proposed pushover methodology

In the proposed pushover method, the onset of unloading from one story is considered as the CP level of the structure. Unloading from one or more stories of the structure corresponds to occur an extensive failure within the structure. This event is concurrent with a backward form in the story capacity curves in the coordinate of inter-story drift versus story shear.

In this method the EDPs at the CP level can be obtained from the combination of the modal pushover analysis results by a novel modal combination rule according to Eq. (1):

$$EDP_{OMPA} = \sum_{i=1}^{m} \alpha_i EDP_i \tag{1}$$

*Corresponding author's email: s.eshghi@iiees.ac.ir

Where m is the number of considered modes, i is the mode index and α is the modal combination coefficient. The coefficients were calculated using two optimization algorithms of particle swarm optimization (PSO) [9] and colliding bodies optimization (CBO) [10], so the suggested pushover method was named Optimized Modal Pushover Analysis (OMPA). These coefficients were obtained for 3 modes (OMPA-3) and 2 modes (OMPA-2) pushover analysis based on the incremental dynamic analysis (IDA) results of the under-study IMRFs. The IDA analysis was performed by 44 far-field earthquake records of FEMA P695 guideline [11].

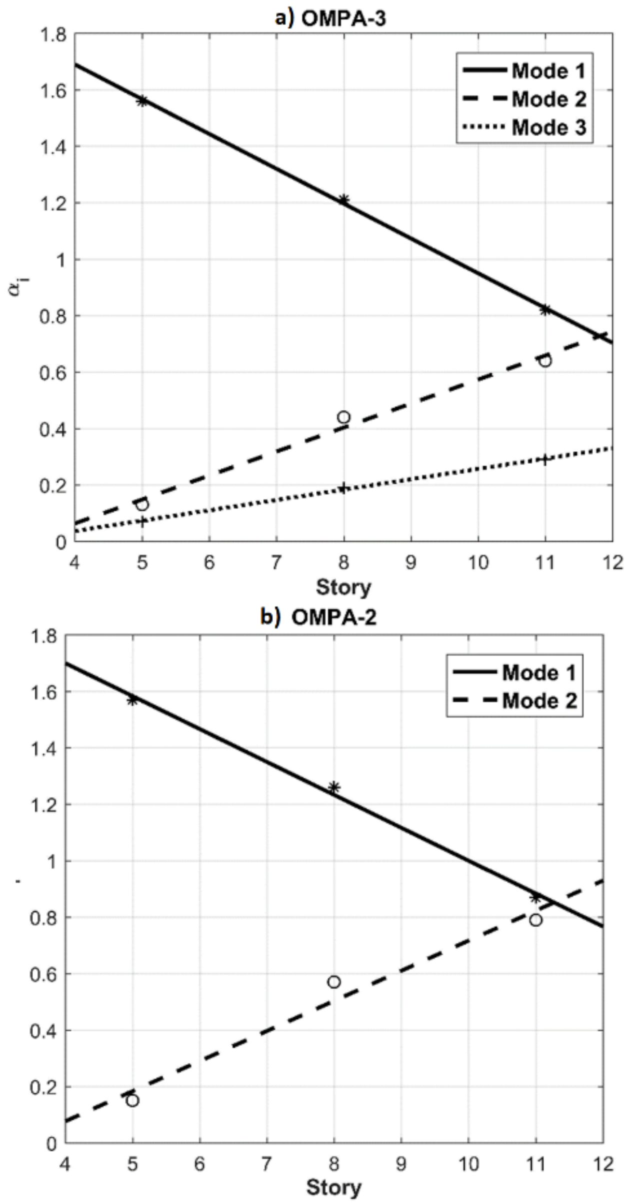

Fig. 1. The resulted αi coefficient values in terms of Story number: a) OMPA by 3 modes, b) OMPA by 2 modes.

Table 1. Obtained values for a and b constants.

	OMPA-3			OMPA-2	
	Mode 1	**Mode 2**	**Mode 3**	**Mode 1**	**Mode 2**
a	-0.123	0.085	0.037	-0.117	0.107
b	2.183	-0.277	-0.110	2.167	-0.350

A simple equation for α_i as a function of story numbers (N) is derived by performing optimization and fitting process as Eq. (2):

$$\alpha_i = a_i N + b_i \quad (2)$$

Where a and b are constant values which are presented in Table 1 and Fig. 1.

A summary of the OMPA steps is presented below:

1. Determine the mass matrix $[M]$ and the mode shapes $\{\phi_i\}$ (i=1,2,3).
2. Perform modal pushover analysis by load patterns of $S_i=[M].\{\phi_i\}$.
3. Determine the CP level displacements, $\delta_{CP,i}$, based on the story capacity curves by the proposed criterion.
4. Evaluating EDP_i at each $\delta_{CP,i}$.
5. Compute the α_i ratios based on the story number (N) by Eq. (2).
6. Determine the EDPs at the CP level by Eq. (1).

4- Results and Discussion

The proposed pushover method is validated based on two 9-story and 12-story IMRF models. The accuracy of the OMPA method is compared with the other pushover methods in Table 2. Also, the results of the 12-story frame are presented in Fig. 2.

5- Conclusion

The results showed that it is sufficient to consider only two modes for the suggested combination rule. Also, the OMPA method presented high accuracy in evaluating the inter-story drift profile and story displacement profile at the CP level of mid-rise regular steel IMRFs.

Table 2. The error values of pushover methods in comparison with the IDA results for the 9 and 12-story frames

Story	Profile	Mode 1	SRSS-2	SRSS-3	OMPA-2	OMPA-3
9	**Drift**	15.2%	6.5%	6.7%	4.1%	4.0%
	Disp	8.0%	8.0%	7.6%	5.0%	5.2%
12	**Drift**	15.2%	6.5%	6.7%	4.1%	4.0%
	Disp	8.0%	8.0%	7.6%	5.0%	5.2%

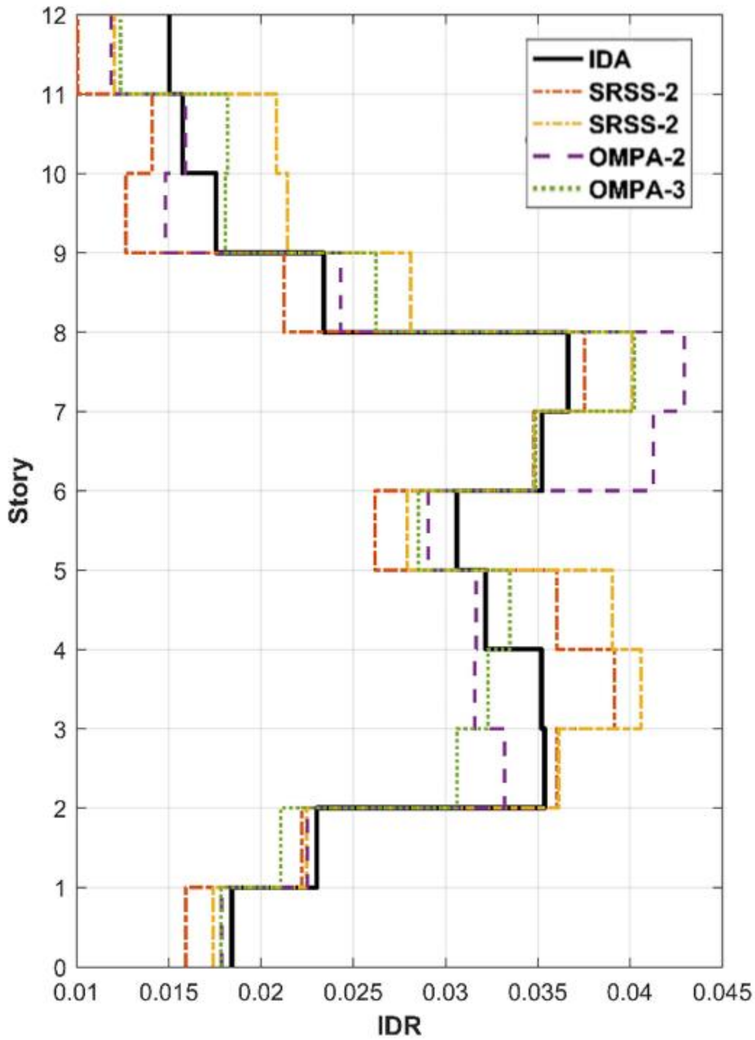

Fig. 2. Inter-story drift profiles of 12 story model.

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