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Performance-based seismic evaluation methods for the estimation of inelastic deformation demands

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Abstract. The article presents experimental research and comparison of two performance-based seismic evaluation methods: nonlinear static procedure (NSP) / pushover analysis (PoA) and nonlinear time history analysis. It is established that nonlinear static procedure is good enough for prediction of plastic hinges localization, but difference between methods results is more than 15 % with a lack of seismic resistance.

1 Introduction

Performance-based method is focused on performance required in use for the business processes and the needs of the users, and then on the evaluations and verification of building assets result. It is the modern approach to earthquake resistant design.

Time history analysis is a rigorous numerical method by integrating differential equation of motion directly. Full time history give the response of a structure over time during and after the dynamic loads application represented by accelerogram (Fig. 1).

Nonlinear static analysis using pushover procedures are becoming increasingly common in engineering practice for building structures seismic evaluation. Seismic demands are computed by nonlinear static analysis of the structure, which is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. The purpose of pushover analysis is to estimate the expected performance of a structural system by evaluating its strength and deformation demands under seismic loads by means of a static nonlinear analysis, and comparing these demands to available capacities at the targeted performance levels. The result of the structure analysis is a Base Shear-Displacement diagram, the global force-displacement curve or capacity curve of the structure (Fig.2). This capacity curve provides valuable information about the response of the structure because it approximates how it will behave after exceeding its elastic limit. The capacity curve has several characteristic points which are represented in Fig 3.

Comparing two methods for seismic analysis its clear seems the time-history analisys is relatively more time consuming and costly.

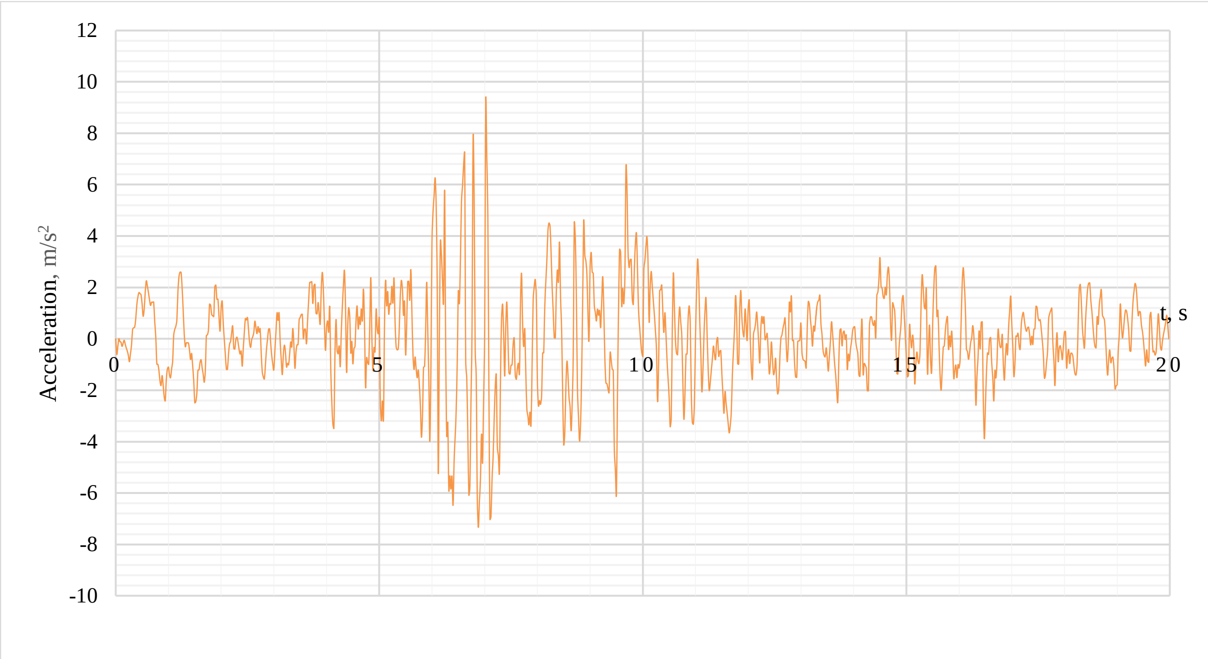

Figure 1. Accelerogramm radial component of the 1978 Tabas, Iran, Earthquake

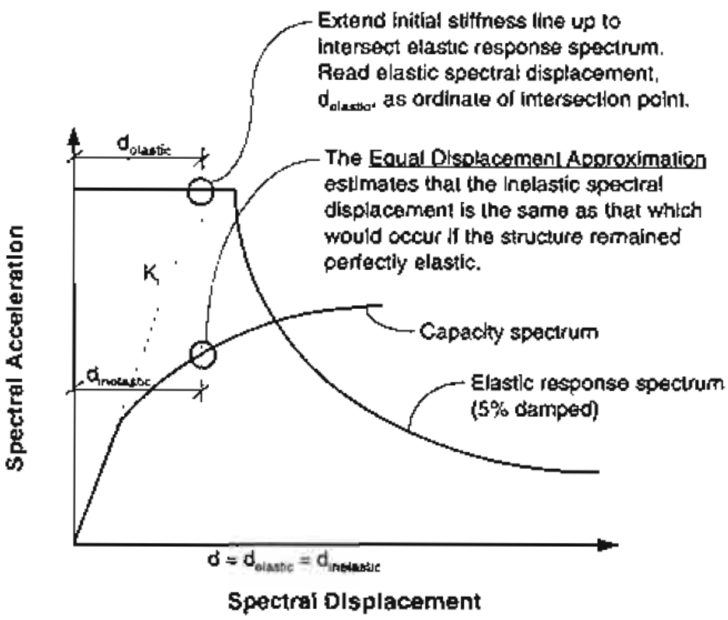

Figure 2. Targert displacement estimation using nonlinear static method (ATC-40)

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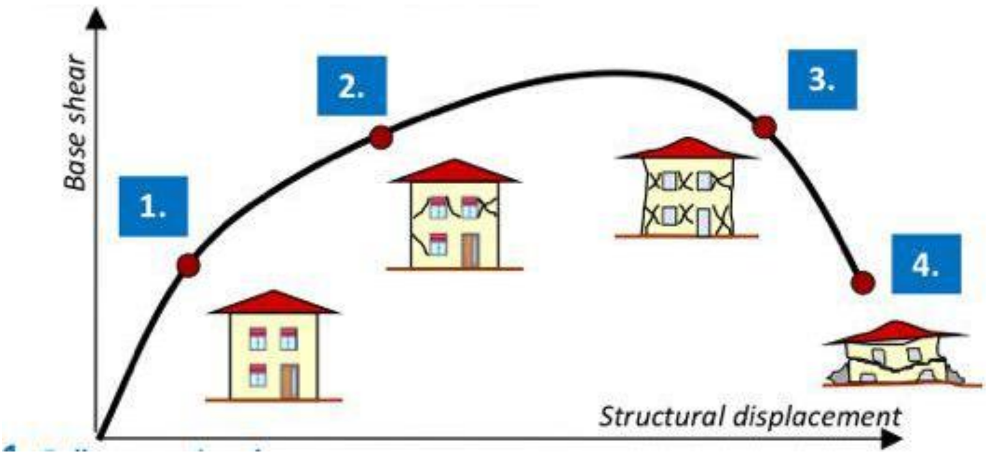

Figure 3. Capacity curve characteristic points:

1. Fully operational: Continuous service. Negligible structural and nonstructural damage. 2. Operational: Most operations and functions can resume immediately. Structure safe for occupancy. Essential operations protected, non-essential operations disrupted. Repair required to restore some non-essential services. Damage is light. 3. Life Safety: Damage is moderate, but structure remains stabl. Selected building systems, features, or contents may be protected from damage. Life safety is generally protected. Building may be evacuated following earthquake. Repair possible, but may be economically impractical. 4. Near Collapse: Damage severe, but structural collapse prevented. Nonstructural elements may fall. Repair generally not possible

2 Problem statement

Three masses 9-meters high column was selected as representative case study to carry out the performance-based seismic methods evaluation.

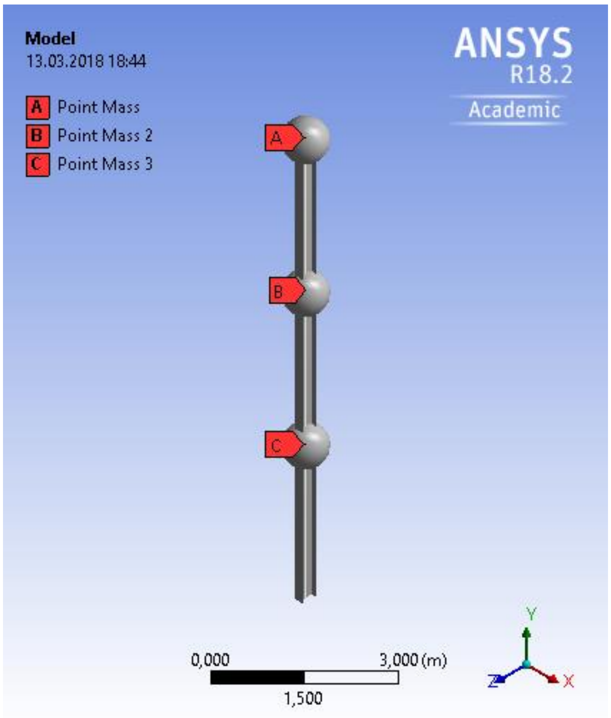

Figure 4. Dynamic model general view

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As a construction material structural steel was chosen. Stress-strain diagram is shown on Fig. 5. To describe the non-linear behavior of the system elements the model of Bilinear Kinematic Hardening has been adopted. The diagrams of steel deformation under tension and compression are the same. The yield surface is described by the Von-Mises criterion and is a cylinder whose axis coincides with the axis of hydrostatic compression in the axes of the main stresses (Fig. 6). Damping parameters were calculated based on 1st and 3rd natural vibration frequency. Dynamic model characteristics are shown in Table 1.

The seismic excitation used for nonlinear time history and pushover evaluations is defined by a set of three strong ground motions:

1. Iran, 1978 г. (Erthq. 1);
2. El Centro, USA (California), 1979 г. (Erthq. 2);
3. Duzce, Turkey, 1999 г. (Erthq. 3).

Accelerogram records were taken from [14].

Table 1. Dynamic model characteristics

№	Nomination	Value		
		Erthq. 1	Erthq. 2	Erthq. 3
1	Cross-section, *mm*	*I-beam 300(h)x200(b)x15(b_f)x8(b_w)*		
2	Height, *mm*	*9000*		
3	Young modulus, *Pa*	$2e^{11}$		
4	Yield point, *MPa*	*270*		
5	Tangential modulus, *MPa*	$5.361e^{3}$		
6	Masses $m_a = m_b = m_c$, *kg*	*3000*	*10000*	*7000*
7	1st natural vibration frequency f_1, *Hz*	*0.853*	*0.45094*	*0.5637*
8	2nd natural vibration frequency f_1, *Hz*	*5.397*	*2.8677*	*3.5813*
9	3rd natural vibration frequency f_1, *Hz*	*13.799*	*7.3161*	*9.1411*
10	Damping parameter α_R, s^{-1}	*0.241*	*0.507*	*0.328794*
11	Damping parameter β_R, *s*	*0.00052*	*0.00234*	*0.001616*

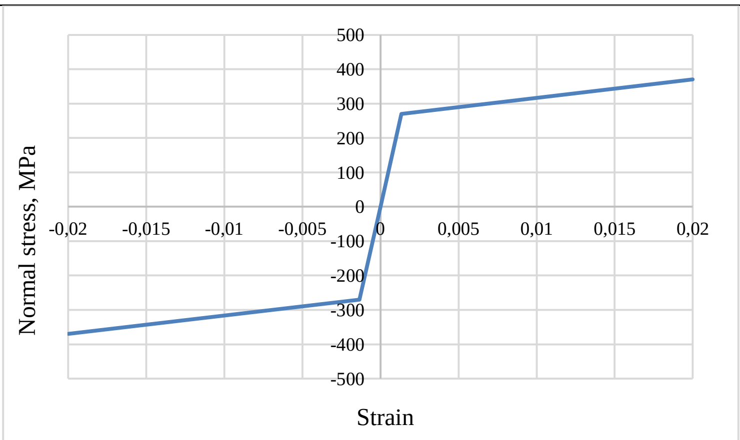

Figure 5. Stress-strain diagram of steel

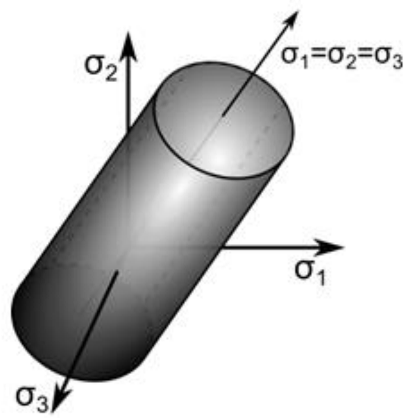

Figure 6. Von-Mises yield surface in the axes of the main stresses

3 Results

Seismic response were estimated by following parametrs set :
– Nodes horizontal displacements;
– Maximum bending moment ;
– Maximum shear forces.

Figures 7-9 show the top point horizontal displacement, bending moments and shear forces near the anchorage obtained from nonlinear time history analyses of Iran eathquaqe ground motions, respectively.

For the nonlinear static procedure «Pushover» module of software package Lira 10.6 were used. The characteristic point was obtained according to grapho-analytical method described in [3].

Numerical simulation results are summarized in Table 2.

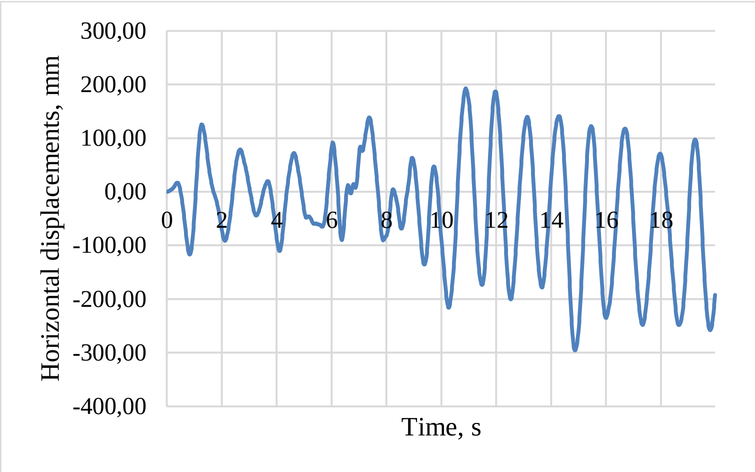

Figure 7. Horizontal displacements of the top point under seismic impact Erthq.1 [Δ_{max} = -295.70 mm at t = 14.88 s]

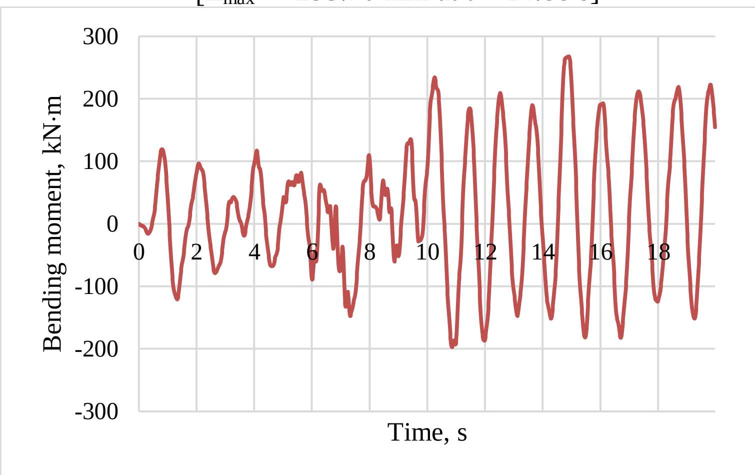

Figure 8. Bending moment near the anchorage under seismic impact Erthq.1 [M_{max} = 267.38 kN·m at t = 14.91 s]

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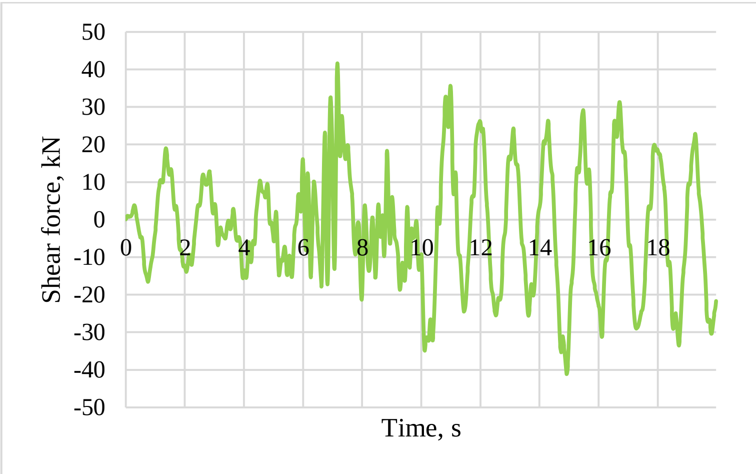

Figure 9. Shear force near the anchorage under seismic impact Erthq.1
[$Q_{max,1}$ = -41.19 kN at t = 14.92 s / $Q_{max,2}$ = -41.64 kN at t = 7.17 s]

Table 2. Analysis result comparison

№	Nomination	Value					
		Erthq.1		Erthq.2		Erthq.3	
1	Top point maximum horizontal deformation, *mm*	*-295.70* *-204.34*	*-30.9%*	*-282.15* *-274.21*	*-2.81%*	*-268.25* *-226.54*	*-15.55%*
2	Middle point maximum horizontal deformation, *mm*	*-163.80* *-108.23*	*-33.9%*	*-151.84* *-144.61*	*-4.76%*	*-140.87* *-119.72*	*-15.01%*
3	Lower point maximum horizontal deformation, *mm*	*-55.10* *-31.86*	*-42.2%*	*-46.79* *-44.38*	*-5.15%*	*-46.55* *-35.23*	*-24.32%*
4	Maximum bending moment near the anchorage, *kN·m*	*267.38* *235.24*	*-12.0%*	*270.3* *275.63*	*1.93%*	*271.54* *244.07*	*-10.12%*
5	Maximum shaer force near the anchorage, *кН*	*41.19* *31.43*	*-23.7%*	*43.73* *36.786*	*-15.8%*	*43.68* *32.58*	*-25.41%*

1. Numerator – nonlinear time history analysis; , denominator – nonlinear static procedure
2. Accuracy with a sign «-» means seismic resistance lack

Conclusions

We can draw the following conclusions based on the completed research:

– Maximum horizontal displacements values differ by more than 10%. The difference between the horizontal displacements of the system nodes with decreasing height increases. The maximum difference of results is about 42%.

– The plastic hinges formation and structural failure are identical for different methods of seismic estimation.

– Seismic resistance lack in the nonlinear static procedure estimation is caused by the underestimation of higher vibration modes.

– Traditional Pushover analysis performed on the 1st vibration mode can only be used for low-rise buildings and low structures.

– To assess the high-rise buildings and structures seismic resistance modification of the non-linear static method are needed in terms of the distribution of inertial forces of the system taking into account the required number of higher vibration modes.

– New method development are needed to combine the inertial forces or the analysis results for each of the natural vibration forms for NSP, constructing a capacity curve and method for characteristic point searching. The obtained by new proposed method results_ should be verified_by the results obtained by the nonlinear time history analysis.

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