Influence of Quality Parameters on Quantities of Pushover Analysis Results

Supriya R Kulkarni* and K S Babu Narayan**
*Research Scholar, National Institute of Technology Surathkal.
Email: supriya101@gmail.com
**Professor, National Institute of Technology Surathkal

Abstract: Pushover analysis is being extensively used for design and performance evaluation of structures under seismic loads. Generation of pushover curve from the analysis of RC structures involves a tremendous amount of computational efforts and analysis results are very sensitive to techniques employed for geometric and material modelling. This analytical investigation presents the influence of variation in materials strengths, effective cover to reinforcement variations and sequence of plastic hinge formations on pushover analysis results in performance evaluation of earthquake resistant design. A single bay single storey RC frame is considered in the present study.

Keywords: Performance based design; Seismic assessment; Geometric modelling; Material modelling; Pushover analysis.

Introduction

Pushover Analysis has been widely used as a tool to gauge the expected performance of a structural system by estimating its strength and deformation capacity in seismic design by means of static inelastic analysis. It is supported by three key concepts: capacity, demand and performance. The capacity is delineated by the capacity curve which shows the structure's capacity to withstand incremental lateral loading. Demand is indicated by the target displacement, representing the maximum displacement that may be expected by the structure during a considered ground motion and, intersection of capacity and demand is portrayed as performance. Based on the FEMA 356 and ATC 40 guidelines, pushover analysis is carried out. Geometric and material modelling capabilities in pushover analysis have been greatly enhanced by techniques that have been redefined and refined to be as close to reality as possible.

Review of Pushover Analysis – State of the Art

The work of Takeda and Sozen[1] where a realistic conceptual model for predicting the dynamic response of a reinforced concrete member has been studied based on a static force displacement relationship which reflects the changes in stiffness for loading and unloading of member is regarded as pioneering in the use of inelastic static analysis. Assumptions that a single mode is dominant and its shape is constant throughout the analysis was proposed and applied in pushover analysis by Gulkan and sozen[2]. Investigations by Helmut Krawinkler and Seneviratna [3] suggested that, a carefully performed pushover analysis would provide great insights to structural aspects that control seismic performance. A response spectrum based pushover procedure was proposed by A.S.Moghdam et al,[4] to obtain seismic response estimates on three types of asymmetrical buildings systems. Chopra and Goel [5] presented modal pushover analysis procedure for estimation of seismic demand and demonstrated the techniques accuracy and practical utility.

Influence of axial load ratio and loading path on plastic hinge length has been investigated by Li Peng and Yi Weijian [6]. Study by P.Poluraju et al [7] indicated that improperly designed and detailed RC frames with strong column weak beams, most of the hinges form in beams and columns have few hinges at limited damage levels. Seismic performance of 5 storied RC residential building according to Moroccan seismic code RPS2000 provisions assessed by M. Mouzzoun et al [8] indicated that the buildings could sustain moderate earthquakes but would be vulnerable to severe earthquake. Sensitivity of pushover curve to material and geometric modelling by comparing the analysis results with that of experimental investigations has been studied by Neena Panandikar (Hede), K.S. Babu Narayan [9].

Wide and varying research attempts to understand structural behavior and to make analysis design, detailing, monitoring and control of structural performance under seismic loads show the tremendous scope and need for refinement of unresolved issues.

This paper presents by the way of illustrations the effect of quality parameters variations like strength of concrete, steel strength, effective cover to reinforcement and variation in sequence of formation of plastic hinge on pushover analysis results and highlights the need for inclusion of sequence of plastic hinge formations in obtaining more meaningful and reliable results.

Details of RC frame subjected to pushover analysis parametric studies

A single bay single storey RC frame as shown in figure 1 is considered for analysis. The reinforcement details and cross sections of the beam and columns have been provided in figure 1b. Commercially available SAP2000 (version-14) has been used as the general finite element software for modelling and analysis. The graphical user interface has been used to create the material and geometric model and properties have been defined accordingly. M3 hinges have been considered as moment effects are predominant in all elements.

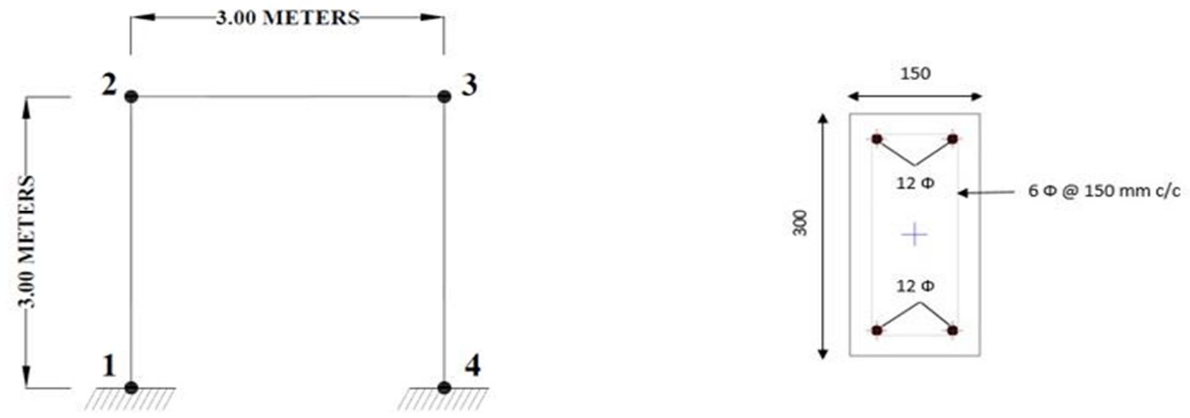

Figure 1. Details of single bay single storey RC frame

Analysis Results and Discussions

Effect of variation in material strengths and detailing on pushover analysis results

To show the influence of material strength and effective cover variations, pushover analysis is carried out on RC frame wherein five values of steel strength (fs) (350,380,415,445,475 MPa), five values of concrete strength (fc) (17, 18.5, 20, 21.5 and 23 MPa) and effective cover (dc) (25, 30, and 35) central being adopted in design, higher and lower values accounting for 15% variations have been considered. Analysis results have been presented in Tables 1 to 3.

Table 1.Pushover Analysis Results for Effective Cover 25mm

f_c / f_s	17		18.5		20		21.5		23	
	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)
350	0.018716	43.294	0.018507	43.384	0.018323	43.467	0.018069	43.526	0.018008	43.619
380	0.019138	46.937	0.018941	47.078	0.018741	47.171	0.018561	47.259	0.018399	47.342
415	0.038578	51.006	0.01943	51.223	0.019227	51.461	0.019033	51.579	0.018856	51.672
445	0.03914	54.378	0.038892	54.632	0.038517	54.835	0.019413	55.058	0.019238	55.289
475	0.040194	58.079	0.039441	58.227	0.033196	58.227	0.03987	58.464	0.038536	58.732

Table 2. Pushover Analysis Results for Effective Cover 30mm

f_c / f_s	17		18.5		20		21.5		23	
	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)
350	0.018544	42.695	0.018336	42.843	0.01814	42.933	0.018093	42.823	0.017949	42.842
380	0.019015	46.248	0.018779	46.387	0.018569	46.523	0.018471	46.433	0.018319	46.58
415	0.038154	50.142	0.019255	50.358	0.019055	50.594	0.018887	50.244	0.018732	50.499
445	0.038943	53.591	0.038484	53.661	0.038009	53.922	0.019248	53.551	0.01908	53.793
475	0.039511	57.111	0.039213	57.265	0.038742	57.416	0.038542	56.893	0.020632	57.117

Table 3. Pushover Analysis Results for Effective Cover 35mm

f_c / f_s	17		18.5		20		21.5		23	
	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)	Disp (m)	Base Shear (kN)
350	0.018417	41.451	0.018193	41.755	0.018	41.863	0.017856	42.182	0.017708	42.398
380	0.0188	44.713	0.018593	44.979	0.018438	45.181	0.01824	45.431	0.018108	45.813
415	0.019436	48.478	0.019427	48.73	0.01884	48.959	0.018686	49.215	0.018543	49.475
445	0.037523	51.807	0.03696	51.941	0.019284	52.188	0.019184	52.506	0.019027	52.759
475	0.038878	55.236	0.03765	55.414	0.037534	55.617	0.03696	55.777	0.019634	55.999

For the effective cover of 30mm and strength of concrete as M17, the displacement varies from 0.018544m to 0.039511m with 15% variation in steel strength and the corresponding base shears are 42.695kN and 57.111kN respectively. It has been discovered from the table that there's significant modification in displacement and base shear for varied strength of the steel however there's a negligible modification discovered for varied concrete strengths. This continues in an exceedingly similar pattern for little changes with the cover to reinforcement. Thus it's been thought-about that the probable modification in acquirement with relation to cover to the reinforcement features a terribly tiny role with respect to displacement and strength. Figure 2 which shows the pushover curves for material variations shows the variations in steel strength has a major effect on push over results of the frame whereas the concrete grade has negligible effect.

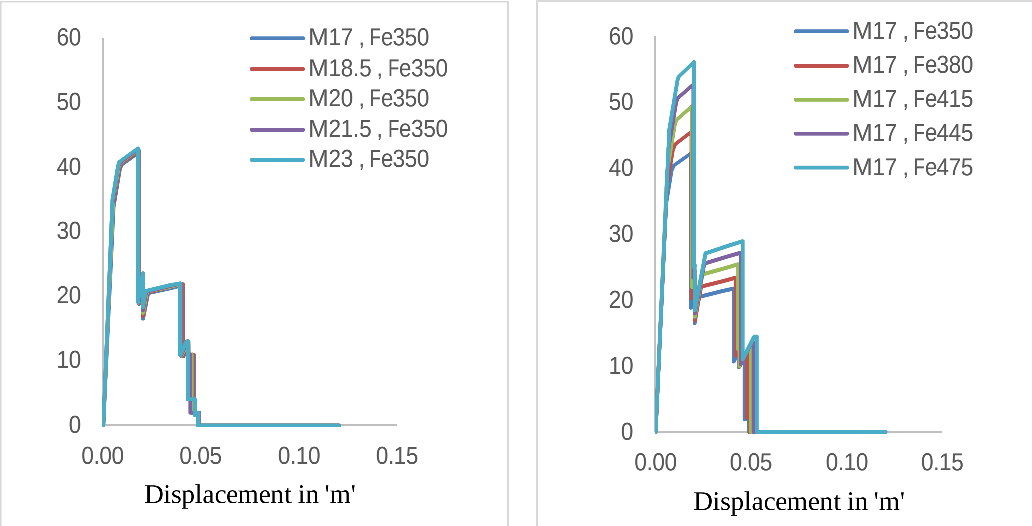

Figure 2. Pushover curves for material variations for the effective cover of 25mm

Effect of plastic hinge formation sequence on pushover analysis results

Pushover analysis necessarily being an exercise to trace structural behavior and understand load deformation characteristics, stiffness degradation, ductility and deformation accommodation consideration of hinge formation sequence and its influence on analysis results is of prime importance. Due to uncertainties in material strength and tolerances in detailing many hinge formation sequences are possible leading to a set of pushover curves.

The frame in figure 1 has been investigated by modelling beams and columns as assemblages of 12 finite elements each and to generate different hinge sequences, weaker elements have been deliberately created at potential plastic hinge locations. To show the influence of sequence of plastic hinge formation on base shear and displacements, the pushover analysis results for first 6 sequences are presented as shown in table 4.

Table 4. Pushover analysis results for sequence variations

Sl No	Sequence series	Base Shear (kN)	Displacement (m)
1	1432	48.992	0.050238
2	1423	45.314	0.047463
3	1243	36.402	0.015835
4	1324	35.462	0.013686
5	1342	35.529	0.013701
6	1234	30.426	0.015663

It can be observed that the displacement and base shear varies for every sequence of hinge formation. The minimum displacement obtained is 0.013686m and the corresponding base shear is 35.462kN for hinge sequence 1324 and maximum displacement is 0.050238m with base shear of 48.992kN for hinge sequence 1432. Figure 3 shows pushover curves for all the 6 sequence of hinge formations. The pushover analysis results obtained from all different sequences of hinge formations have the displacement values between these ranges, and that they are all distinctive. This clearly indicates the influence of sequence of hinge formation on pushover analysis results, particularly on displacement characteristics. It's additionally determined that the bottom shear variations are freelance of changes in displacement characteristics. Observations are reliable with assumptions in plastic theory and style, whereby collapse load is invariant to hinge formation sequence. One amongst the doable reasons for variations in base shear results is attributable to the strength parameter variations.

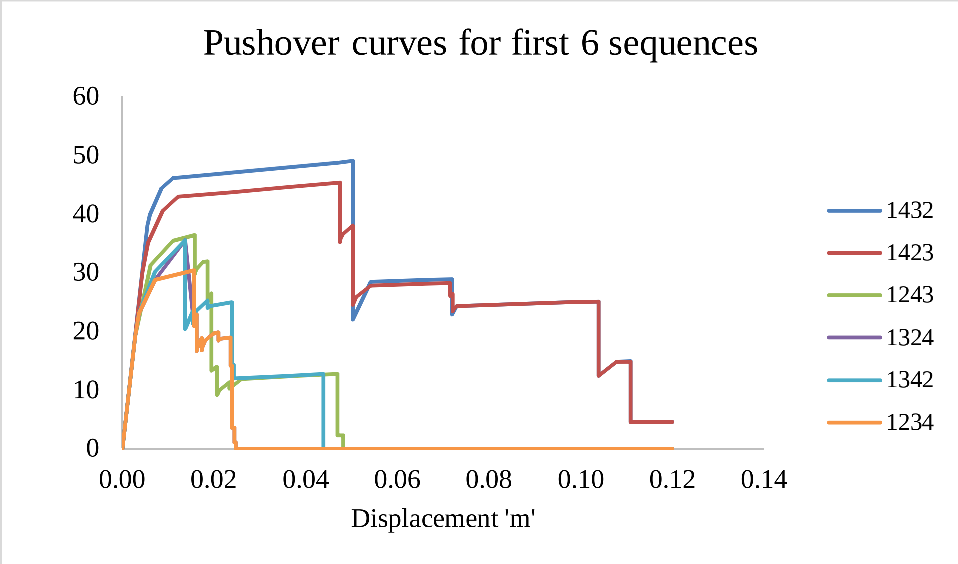

Figure 3. Pushover curves for first 6 sequences

Conclusions

Variations in strength characteristics of material and quality of workmanship quantifiable in terms of errors in dimensions of structural elements and reinforcement placement alters pushover analysis results. As has been illustrated variation of plus or minus 15% in strengths, base shear ranges in + 15%. This is expected as the sections are all under reinforced and as the variation in cover is very limited, variation in strengths are also insignificant. The range of variation in displacements is very significant being -5% to +110% indicating modelling techniques should address by inclusion of these uncertainties.

Investigations on influence of hinge formation sequence on analysis results clearly indicate that changes in displacement can be to the tune of +267% due to uncertainties in material quality and workmanship (while base shear shows an increase of 38%). This is too significant, hence can never be ignored. More realistic evaluation of performance becomes possible only when sequence of plastic hinge formation issue is considered and addressed.

References

[1] Takeda, T., Sozen, M.A. and Neilsoen, N.N, “Reinforced concrete response to simulated earthquakes”, Journal of Structural Division., 96(12), 1970, 2557-2573

[2] Gulkan, P. and Sozen, M.A, “Inelastic response of reinforced concrete structures to earthquake ground motion.” Journal of the American Concrete Institute., 71, 1974, 601-609.

[3] Krawinkler Helmut and Seneviratana G.D.P.K, “Pros and cons of pushover analysis of seismic performance evaluation.” Engineering structures. 20, (4-6),1998,452-464

[4] Moghdam. A.S and Tso W.K, “Pushover analysis for asymmetric and set back multi story buildings”, 12WCEE, 2000, pp.1-8

[5] Chopra, A.K, “Dynamics of structures, theory and applications to earthquake engineering.” Prentice Hall of India Pvt. Ltd., New Delhi. 2001.

[6] Peng. Li and Weijian. Yi, “Experimental and analytical studies on the confinement effect of transverse reinforcement in concrete columns under cyclic loading”, The 14th World Conference On Earthquake Engineering, Beijing, China, October 2008,

[7] Poluraju P, Durgabhavani T, Mounika K, Nageswari M, Soni Priya K, “Non-Linear pushover analysis of flatslab building by using SAP2000”, International Journal of Recent Technology and Engineering, Vol. 1, April 2012.

[8] Mouzzoun M, Moustachi O, Taleb A and Jalal S, “seismic performance assessment of reinforced concrete buildings using pushover analysis”, IOSR – JMCE, Vol. 5, Feb 2013, pp. 44-49.

[9] Hede Neena and Babu Narayan K.S, “Sensitivity of pushover curve to material and geometric modelling- an analytical investigation”, Structures, Elsevier, 2014, pp. 91-97.