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Innovative study of Performance Based Seismic Design Method for RCM R Frames with Vertical Geometric Irregularity

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Abstract: *A performance-based seismic design (PBSD) method is aimed at controlling the structural damage based on precise estimations of proper response parameters. PBSD method evaluates the performance of a building frame for any seismic hazard, the building may experience. This paper gives a comparison between Performance based Seismic design and conventional design method (using I.S 1893; 2002) for irregular RC building frames (10 storey) and evaluates performance using pushover and Time History analysis*.

Keywords- *Performance based seismic design (PBSD), response parameters; Performance based plastic design (PBPD), RC building, and Performance evaluation*.

I. INTRODUCTION

Earthquakes have the potential for causing the greatest damages, among all the natural hazards. Since earthquake forces are random in nature & unpredictable, need of some sophisticated methods to analyze our structures for these forces. Performance based design can relate to a new dimension in the seismic design philosophy. We need to carefully understand and model the earthquake forces to study the actual behavior of structure so that structure faces a controlled damage. India has witnessed more than 690 earthquakes of Richter magnitude (‘*M*’) greater than 5 during 1828 to 2010. Damage survey reports show that life and property losses occur in urban and semi-urban areas. It is uneconomical to design a building so as not to suffer any damage during strong earthquake. An engineering approach aims for achieving balance in cost and performance through controlled damage. The goal of performance-based seismic design is to ensure that performance objectives are satisfied. A successful conceptual design could hopefully reduce the impact of uncertainties on the real structural behaviour.

1.1 Current status of seismic design procedure and its weakness

Current seismic design practice around the world is carried by elastic method even though it is acknowledged that the buildings undergo large deformations in inelastic range when subjected to large earthquakes. As a result in seismic activity, there may be severe yielding and buckling of structural members and connections, can be unevenly and widely distributed in the structure designed by elastic methods. This may result in rather undesirable and unpredictable response, total collapse, or difficult and costly repair work at best.[1] There is need for more direct design methods that would fit in the framework of PBSD and produce structures that would perform as desired.
Major weaknesses of current seismic procedure:

- Increasing base shear to reduce damage is not reliable since past earthquakes have results of total collapse due to local column failure.
- Upper story failures in buildings are not justified by elastic method which assumes lateral force distribution which does not account for nonlinear behaviour of the structure.
- Earthquake changes stiffness of the members due to cracking of concrete and yielding of steel and proportioning of members according to elastic analysis leads to major failures.
- Materials like Reinforced Concrete have hysteretic (pinched) behaviour which is not accounted.

Many studies have shown the column undergo yielding if it is designed as per capacity approach, inelastic behaviour of the column are not considered.

II. Performance Based Seismic Design of Reinforced Moment Resistant Frames

Reinforced Concrete Building stock in India is mainly classified from low to medium rise buildings. Approach of I.S 1893,2002 is in tune with typical code practice followed by many other countries. In spite of knowing drawbacks of force based seismic design procedures, the practice is in vogue due to its simplicity and non-availability of the alternative. We can use guidelines given by FEMA and ATC documents by modifying them for Indian condition. An outline of the step-by-step Performance-Based Seismic Design (PBSD) procedure is given in the following.[1]

2.1 Design procedure

An outline of the step-by-step Performance-Based Seismic Design (PBSD) procedure is given in the following.
1. Initially desired yield mechanism is selected.
2. Fundamental period 'T' of the structure is estimated, along with yielding drift 'θy'.[2]
3. Determine inelastic spectral acceleration
4. Calculate the ductility reduction factor and the structural ductility factor.

With the assumed yield drift 'θy' for different structural systems from tables in ASCE (2006)the energy modification factor, 'γ' , depends on the structural ductility factor ('μ_s') and the ductility reduction factor (' R_μ') and can be obtained from the following relationship.:[3]

$$\gamma = \frac{2\mu_s - 1}{R_\mu^2} \tag{2.1}$$

To consider the hysteretic (degradation of strength and stiffness) behavior, the coefficient 'C_2' (modification factor) is determined which represents the effect of pinched shape of hysteretic loops, stiffness degradation, and strength deterioration on the maximum displacement response according to FEMA 356. Ductility reduction factor 'R_μ' and energy modification factor 'γ' can be calculated as follows:

$$\theta u = \frac{\theta t}{C\,2} \qquad \mu_s = \frac{\theta u}{\theta y} \qquad \gamma = \frac{2\mu_s - 1}{R_\mu^2} \tag{2.2}$$

5. Determine actual lateral forces

Shear distribution factor for the respective story factor for the respective story is calculated by using following equation:

$$\frac{V_i}{V_n} = \beta_i = \left(\frac{\sum_{j=1}^{n} w_j h_j}{w_n h_n}\right)^{0.75T^{-0.2}} \tag{2.3}$$

V_i = shear force at i[th] level ; β_i = Shear distribution factor at ith level
w_j = Seismic weight atlevel j; h_j = height of level j from the base

w_n = Seismic weight at top level ; h_n = height of roof level from the base

Then, the lateral force at level i, Fi , can be obtained as:

$$F_i = (\beta_i - \beta_{i+1}).V_n \tag{2.4}$$

F_i = Lateral force at ith levl ;V_n = Story shear at roof level;V_y = Design base shear

Substituting the values of V_n we get following equation:

$$F_i = (\beta_i - \beta_{i+1})\left(\frac{w_n h_n}{\sum_{j=1}^{n} w_j h_j}\right)^{0.75T^{-0.2}}.V_y \tag{2.5}$$

6. Design of designated yielding and Non-designated yielding members.

For Reinforced Concrete moment frames, beams are designed as Designated Yielding members because of strength contribution from slabs and non-rectangular beam shapes (ie, T shape beam), as well as the use of different amounts of top and bottom reinforcement, plastic moments in positive and negative direction of DYM may be different:

$$\sum_{i=1}^{n} F_i h_i\,\theta_p = 2.M_{pc}\theta_p + \sum_{i=1}^{n} \beta_i.(M_{pb-positive} + M_{pb-negative})\gamma_i$$

$$\sum_{i=1}^{n} F_i h_i\,\theta_p = 2.\sum_{i=1}^{n} F_i h_i\,\theta_p + \sum_{i=1}^{n}(1+x)\beta_i.(M_{pb-positive})\gamma_i \tag{2.6}$$

$$\beta_i(M_{pb-positive}) = \beta_i \frac{\sum_{i=1}^{n} F_i h_i - 2M_{pc}}{(1+x)\sum_{i=1}^{n}\beta_i \frac{L}{L'_i}} \tag{2.7}$$

Where x is the ratio of the absolute value of negative Bending moment to positive Bending moment. Members that are not designated to yield (Non-DYM), such as columns in, must be designed to resist the combination of factored gravity loads and maximum expected strength of the DYM by accounting for reasonable strain-hardening and material over strength. The columns must be designed for maximum expected forces by including gravity loads on beams and columns and by considering a reasonable extent of strain-hardening and material over strength in the beam plastic hinges.

$$M_p = \xi M_{pb} = 1.25.M_{pb} \quad (2.8)$$

III. Performance Based Seismic Design of Reinforced Concrete Moment Resistant Irregular Frame

To study the effect of vertical Geometric Irregularity we have compared two 10 storey frames with one step and two step setbacks with conventional and Performance based Seismic design method. Following are the three frame models considered for the study. Basic Dimensions for the frames and general design parameters were taken commonly as .Type of frame: Moment Resistant frame,Size of Column = 350 x 350mm, Size of Beam = 350 x 500 mm, Thickness of Slab = 125mm thick Wall thickness = 150mm, Floor Finish = 1 KN/m2 ,Live load at all floor levels = 2 KN/m^2,Zone III, Medium type of soil.

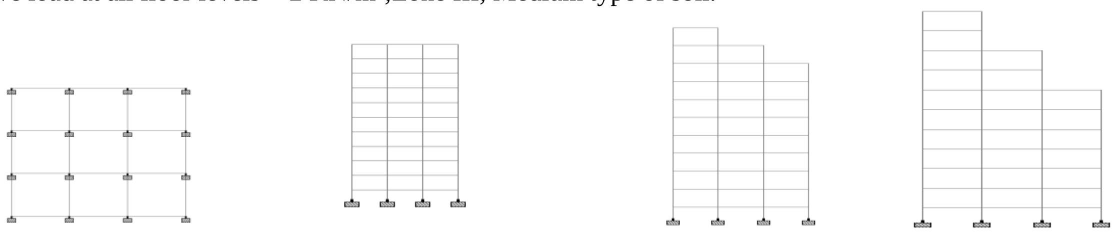


Fig 3.1 Plan and Elevation of 10 storied regular and irregular frames considered for study

3.1 Redesign of the frames by Performance based seismic design method

The same frames were designed considering plastic method of design which is described in above chapter. All the three frames had same basic seismic parameters which are calculated according to normal procedure.

Table 3.1 Seismic parameters considered for design

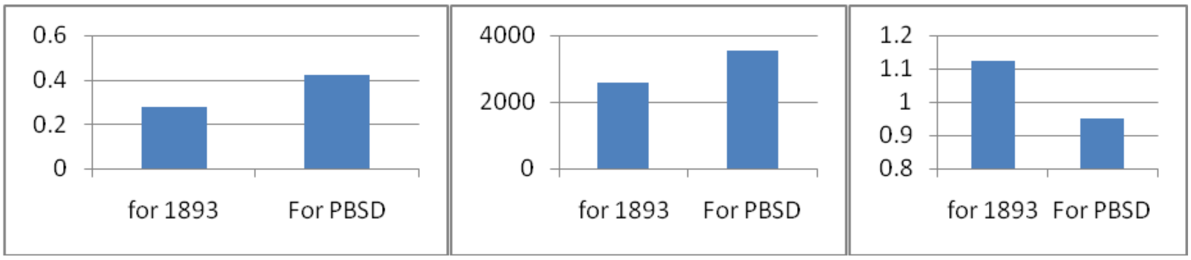
Seismic zone factor '*Z*'	0.16
Soil Profile Type	Type 2 Medium
Importance factor, '*I*'	1
Sa Inelastic	0.1875 g
'*T*'	0.8s
Yield drift ratio 'θ_y'	0.5%
Target drift ratio 'θ_u'	2%
Inelastic drift ratio '$(\theta_u - \theta_y)$'	1.5%
Ductility factor	4
Reduction Factor due to Ductility '$R\mu$'	4
Energy Modification Factor 'γ'	0.43
Design Base shear	816.832

3.2Comparative evaluation of 10 story irregular frames (with one and two step setback) with respect to I.S 1893-2002 and PBSD method

It is clear that in PBSD method performance point (intersection of demand and capacity curves) shifts due to extra confined steel which is normally incorporated in design. Hence provision for extra ductility is avoided since this care is already taken while designing.

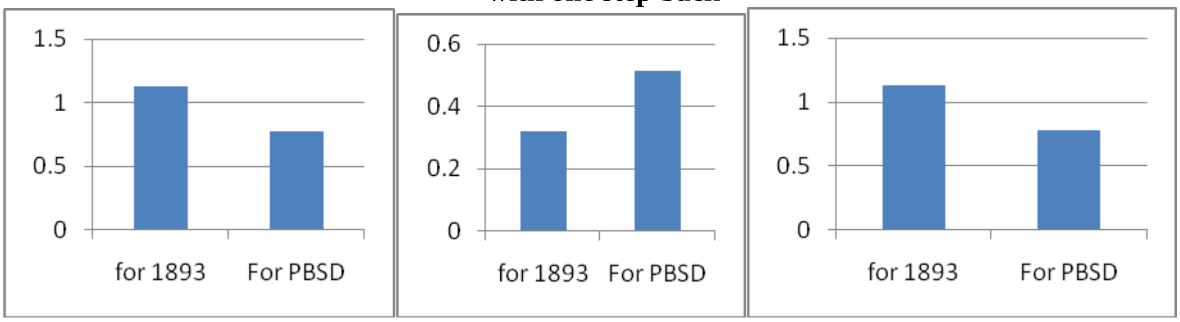
Table 3.2 Performance point comparison for Irregular frame with one and two step setback

Type of frame	Performance point parameters	I.S 1893 method	PBSD method
Irregular frame with one step setback	Base shear *vs* Displacement	2575	3535
	Spectral acceleration *vs* Spectral displacement	0.278	0.421
	Effective Time	1.122	0.951
Irregular frame with two step setback	Base shear *vs* Displacement	2770	3990
	Spectral acceleration *vs* Spectral displacement	0.32	0.514
	Effective Time	1.13	0.78



Performance point (V ,D) Performance point (Sa,Sd) Performance point (T effective)

Fig 3.2 Push over curve comparison for I.S 1893 method ad PBSD method for irregular frame with one step back



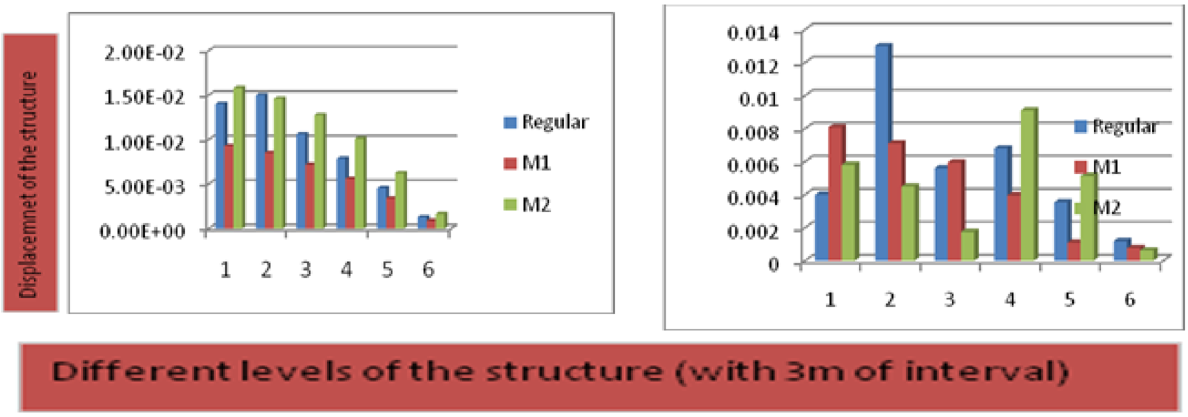
Performance point (V ,D) Performance point (Sa,Sd) Performance point (T effective)

Fig 3.3 Push over curve comparison for I.S 1893 method ad PBSD method for irregular frame with two step back

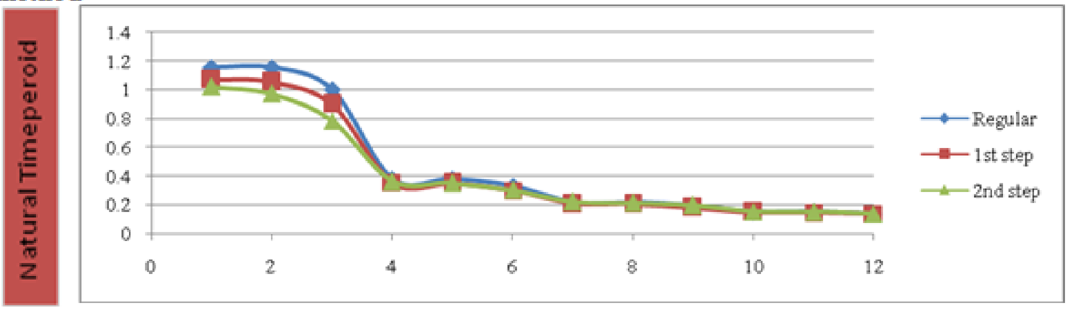
3.3 Time History Analysis

We have considered 4 standard ground motions(Superstition Hills1987 (Brawley), Imperial Valley, 1940(El Centro), 1989 Loma Prieta (Corralitos Station), 1994 Northridge (Santa Monica City Hall), Imperial Valley, 1940 (El Centro) Intensity factor=2.0). These ground motions are taken considering their maximum intensity and peak ground acceleration. After performing the time history analysis the major aspect considered is displacement.[8]

Fig 3.4 Comparative summarization of the three frames designed by 1893; 2002 and PBSD method



method



No of mode shapes

Fig 3.5 Time period and mode shape variation Curve for frames designed by PBSD method

For irregular frame with two step setback at top it is seen that the time period decreases initially up to 4th mode and then follows same trend as that of other irregular frame and regular frame. This indicates that for irregular frame, if designed by PBSD method it is more efficient than conventional I.S.1893; 2002 method.

IV. Conclusion

Performance Based Seismic Design involves distribution of lateral forces according to new distribution factor which is defined on basis of real ground motion. This gives proper proportioning and designing of the frame members. Basic difference between regular and irregular frame design is for upper storey the calculations for base shear decreases due to asymmetry. For the irregular frame with two step setback when designed by PBSD method the displacement is lowest after time history analysis compared to the irregular frame with one step setback and regular frame. This proves the degree of reliability of Performance based seismic design method whereas displacement is more in case of conventional method design. Time period is one of the effective means to check the reliability of PBSD method. Time period for the irregular frame with two step setback is lowest than other two frames.

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