PERFOMANCE BASED DESIGN OF RCC BUILDING WITH COST COMPARE AT VARIOUS PERFORMANCE LEVEL

1st AnkurPaghdal 2nd H.B.Patel
1st P.G.Student 2nd Asst. prof.
Civil Engineering
Merchant Institute of Technology, Piludara, Mehsana India,
paghdal_ankur@yahoo.in

Abstract - The present study is an attempt to understand the basic fundamental and procedure of Performance Based Design of R.C.C. building. A Nonlinear Static Analysis (Pushover Analysis) is used to obtain the inelastic deformation capability of building, which depends on hinges formation in various elements of building. The 3-D frame was analysed and designed using IS: 456-2000 and IS: 1893-2002 (Part – I) considering moderate seismic zone. The Result of Nonlinear static analysis show that behaviour of building at various performance level. And calculate cost of building at various performance level and compare with each performance level. The software used for performing performance based design is ETABS 2015.

Keywords- Performance-based seismic design; Buildings Code IS 1893:2000.

I. Introduction (Heading 1)

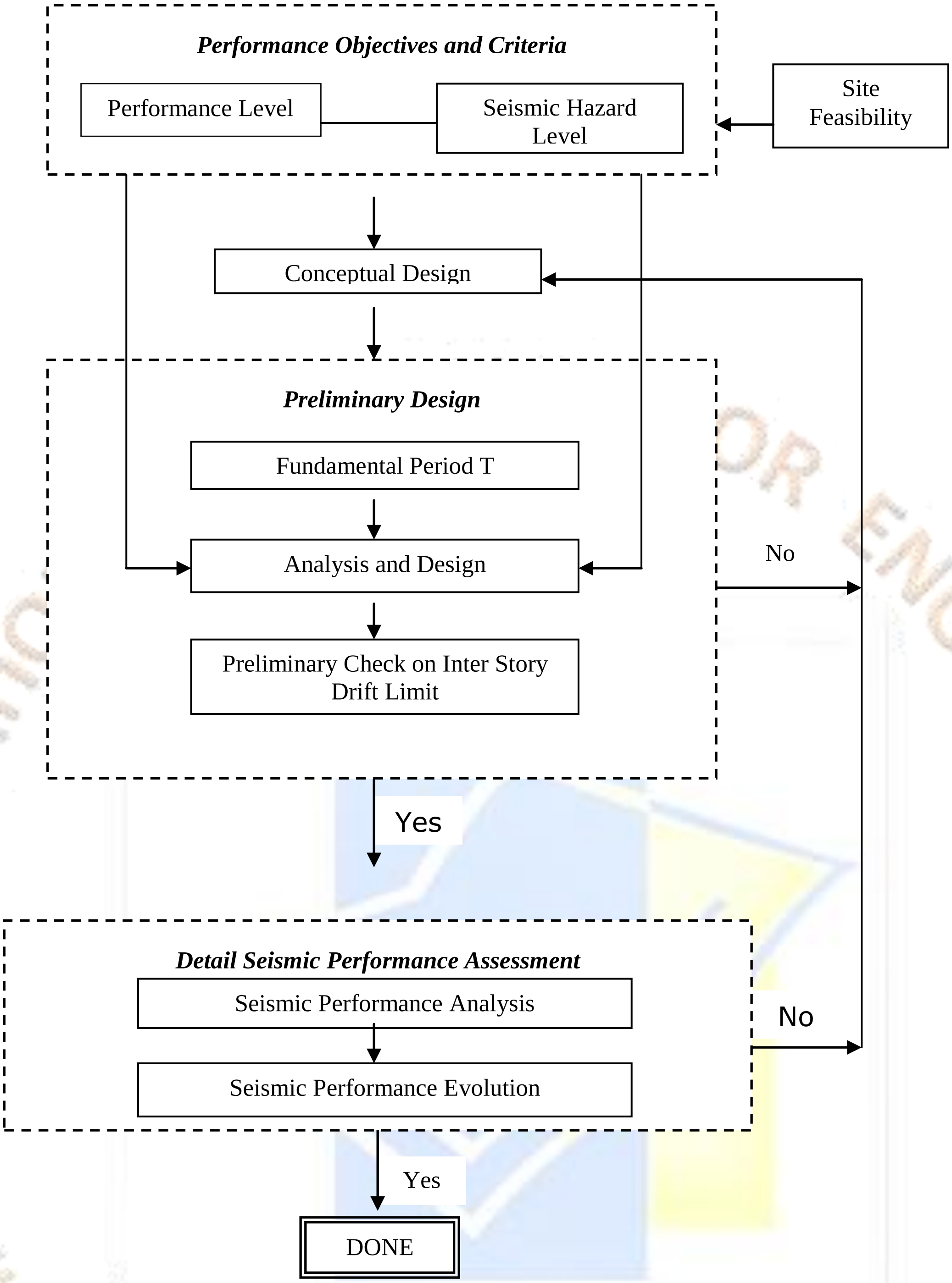
Earthquakes are one of the most destructive forces in nature. The earthquakes cause's major disasters and disruptions compare to the other forces. During last decades several countries of the world, specifically India after Bhuj earthquake took up investigations and implemented methods to reduce the effect of earthquakes. Therefore lesson learnt from past earthquake events and damages caused to several building are given consideration to newly applied methodology. Currently two analysis tools are offered with different levels of complexity; nonlinear static analysis (push over) and nonlinear dynamic analysis (time history). Nonlinear analysis procedures become important in identifying the patterns and levels of damage for a structure's in inelastic behavior and understanding the failure modes of the structure during severe seismic events.

Performance based design is modern approach to earthquake resistant design. The purpose of Performance-Base Design (PBD) is given to realistic assessment of how a structure will perform when subjected to either particular or generalized earthquake ground motion. It is assumed that the structure components able to resist earthquake ground motion by yielding in to inelastic range, absorbing energy and acting in a ductile manner. Normally, this method depends on each country's condition in economy, technical level and regional seismic intensity. But recently performance based design method is consider more effective one worldwide including Japan and China.

Structural engineers are interested in the performance of buildings during earthquakes to verify assumptions and adequacy of the buildings. Earthquake gives an opportunity to structural designer to check its design methodology with certain assumptions. All this information is useful to for design new structures.

II. DESIGNFLOWCHART

Fig. 1 illustrates the flowchart for the performance-based seismic design of new buildings. Topics in Fig. 1 except those illustrated with dotted lines will be discussed in the following sections.



III. PERFORMANCE BASED DESIGN

In the performance-based design approach, acceptability criteria are established in term of performance level or damage levels for a specified earthquake ground motion. As per current performance-based design practice, consider the structure are capable to resisting minor earthquake without significant damage, moderate earthquakes with repairable damage and major earthquakes without collapse.

1. STATIC NONLINEAR ANALYSIS

Nonlinear Static (Pushover) Analysis is a procedure where a building model is subjected to increasing load in one direction. The Pushover Analysis consists of the application of gravity loads and a respective lateral load pattern until the building collapsed or a specified displacement is reached. The frames were subjected to gravity analysis and simultaneous lateral loading. In all cases, lateral forces were applied monotonically in a step-by-step manner. The applied lateral forces were proportional to the product of mass and the first mode shape amplitude at each story level under consideration. Pushover analysis procedure explicitly addresses the nonlinear behavior of the structure. Pushover analysis provides information about failure mechanism, failure modes, ductility demand, displacement capacity and stability of the structure. However Pushover Analysis gives a reasonably, accurate estimate for strength of the structural frame, assuming that its element do not fail due to secondary effect before the inelastic mechanism occurs. In more frequent case of sequential yielding the estimates of displacements corresponding to the base shear near the formation of inelastic mechanism are not typically accurate.

Nevertheless, in most cases the simple bilinear force-displacement (moment-curvature) relationship represents an acceptable approximation considering all the uncertainties involved in seismic design.

This method is one of the simplest possible analytical tools for determining the main characteristics of non-linear structural behavior under monotonically increasing static load. It is based on several simplified assumptions and does not pretend to be very accurate. Comprehensive nonlinear analysis will be more accurate but computationally very time consuming and not suitable for design purpose as compared to simple pushover analysis. Nevertheless this method can provide fair estimates of several parameters that cannot be provide fair estimates of several parameters that cannot be predicted by elastic analysis and which represent a basis for the evaluation of structural behavior during strong earthquakes.

Three dimensional static analyses are performed in a step by step fashion in which the possibility of formation of inelastic hinges in a member is checked in each step. If no element reaches its inelastic moment capacity, then load applied is incremented and analysis is performed for new load case. Whenever, any element reaches its inelastic moment capacity, inelastic hinges is introduced in that element. Now, new analysis is performed on this structure with new earthquake load distribution, as earthquake load distribution will depend on the structural properties. Checking is done for inelastic moment capacity of other elements and plastic hinge is introduced when element reaches its inelastic moment capacity. Load required for formation of plastic hinge in elements were considered as the event. This procedure is repeated until inelastic mechanism is formed in the entire structure that leads to collapse of structure. The collapse load corresponds to the load required for final event to occur.

Two types of pushover are:

1. **Force controlled**

Used when load is known and structure is desired to support this load, means for gravity load on structure used force controlled.

2. **Displacement controlled**

Used when load is unknown but displacement is known and structure is desired to lose their strength and become unstable, means for lateral load on structure used displacement controlled.

Three main steps involved in this analysis procedure.

I. Capacity of building – Representation of the structure’s ability to resist a force
II. Demand curve – Representation of earthquake ground motion
III.Performance point – Intersection point of demand curve and capacity curve

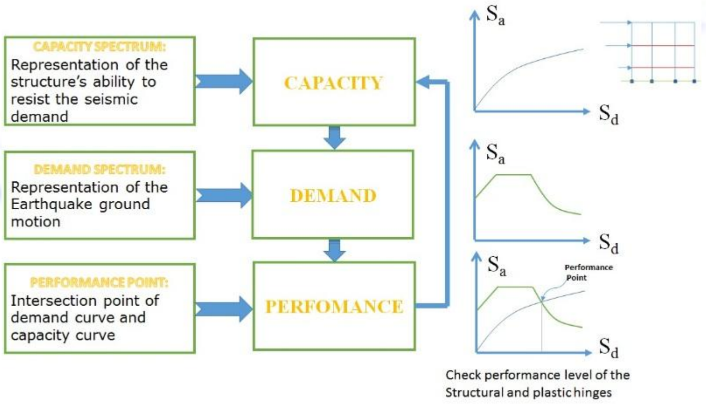
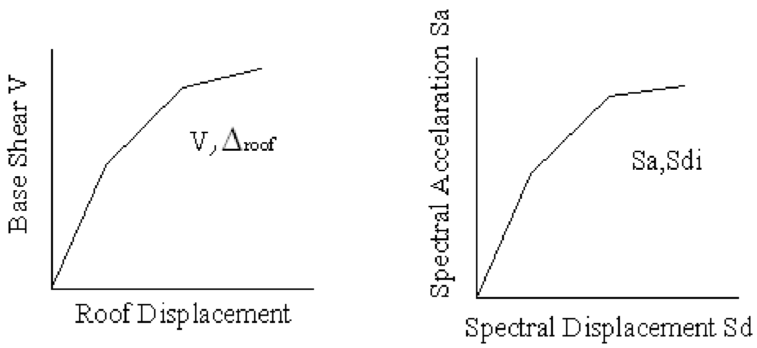


Fig.3.1 (a) Capacity curve (b) Demand Spectra Curve (c) performance point



Capacity Curve Capacity Spectrum

Fig. 3.2Capacity spectrum conversion

To convert a response spectrum from the standard $S_a$vs T format found in the building code to ADRS format, it is necessary to determine the value of $S_{di}$for each point on the curve, where the $S_{ai}$and T meets. This can achieved using Eq. 4.1.

$$S_{di} = \frac{T_i^2}{4\pi} S_{ai} g \qquad \ldots . (4.1)$$

Standard demand response spectra contain a range of spectral acceleration and a second range of constant spectral velocity (S_v). Spectral acceleration and displacement at period T_i are given by;

$$S_{ai} g = \frac{2\pi}{T_i} S_v \text{, and } S_{di} = \frac{T_i}{2\pi} S_v \qquad \ldots . (4.2)$$

$$S_{ai} = \frac{V_i / w}{\alpha_i}$$

$$S_{di} = \frac{\delta}{PF_1 \times \phi_{1.roof}}$$

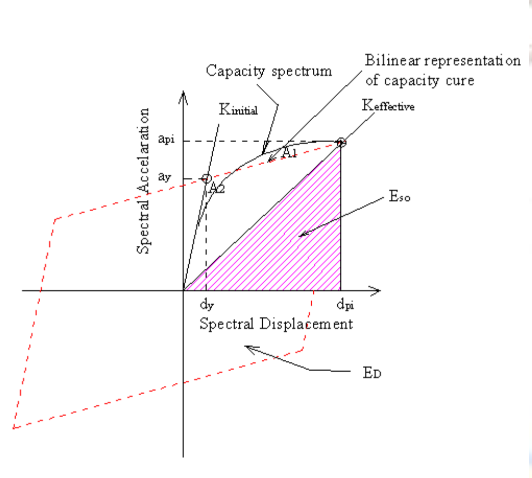


Fig. 3.3Derivation of energy dissipated by damping

IV. Procedure to obtain performance point

Procedure C:

Reduce Seismic Demand by adding Damping: Adding damping will reduce the demand as there will be more energy dissipation. This will bring down the demand curve as shown in Fig. 4.1

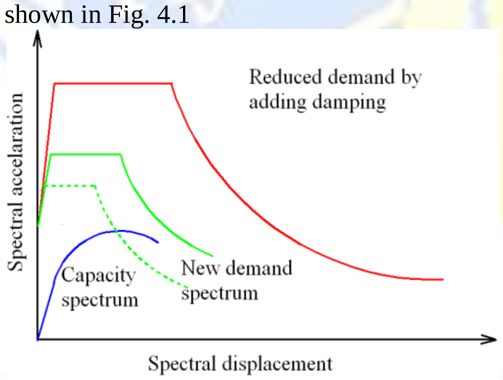


Fig. 4.1Obtaining performance point by adding damping

Performance point on capacity and demand curve

Above three procedures are described in ATC-40 to find the performance point. The most transparent is the Procedure 'C'. To find the performance point using

Procedure 'C' the following steps are followed:

1. Damped response spectrum (5% damping) appropriate for the site for the hazard level required for the performance objective is developed and converted to ADRS format using Eq.4.1 and 4.2.
2. The capacity curve as obtained from the nonlinear analysis is converted to a capacity spectrum using Eq. 4.3 and Eq. 4.4.
3. A trial performance point api, dpi is selected. This may be done using the equal displacement approximation (trial and error method to find maximum hysteresis loop area based on engineering judgment) as shown in Fig. 3.20.
4. The reduced demand spectrum is plotted together with the capacity spectrum in ADRS format.
5. A bilinear representation of capacity spectrum is developed such that the area under the capacity spectrum and the bilinear representation is the same. Bilinear representation depend on selection of starting point api,dpi and ending point ay,dy.

6. If the reduced demand spectrum intersects the capacity spectrum at api,dpi or if the intersection point dp is within 5% of dpi, then this point represents the performance point.

7. If the intersection point does not lie within acceptable tolerance (5% of dpi or other) then select another point and repeat steps 4 to 7. The intersection point obtained in step 6 can be used as starting point for the next iteration.

The above procedure is represented graphically in Fig 4.2.

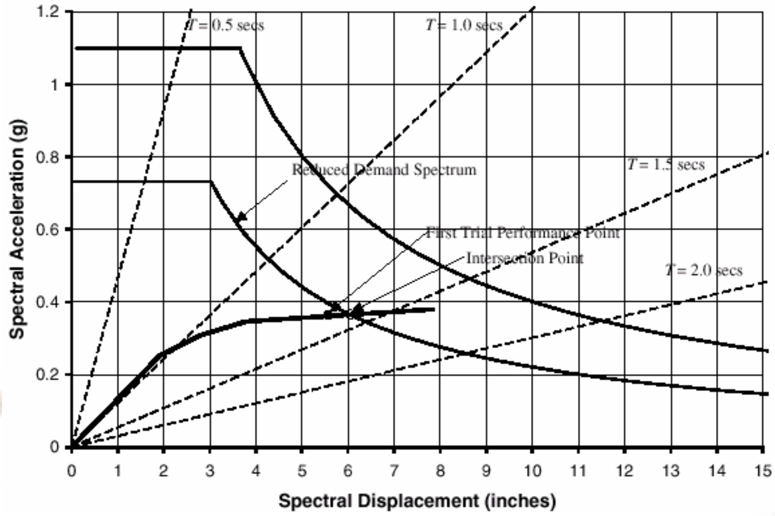


Fig 4.2 Performance point evaluation by procedure ‘C’

V. DETERMINATION OF MOMENT, CURVATURE AND ROTATION

. Under lateral load, the structures dissipate energy under severely imposed deformations through critical regions of the members, often termed as “plastic hinges”. Location of plastic hinges in the structures is important, because plastic hinges cause excessive deformation. In plastic hinges regions, rotations of the member is very high which leads to failure.

The [illegible] are.

$$k = \left[(p_t + p_t')^2 n^2 + 2\left(p_t + \frac{p_t' d'}{d} \right) n \right]^{1/2} - (p_t + p_t')n \quad \text{. . . . (5.5)}$$

$$M_y = A_s \; f_y \; jd \quad \text{. . . . (5.6)}$$

$$\phi_y = \frac{f_y / E_s}{d(1-k)} \quad \text{. . . . (5.7)}$$

The ultimate curvature and moment of doubly reinforced section are given by following equation.

$$a = \frac{A_s \; f_y - A_s' \, f_y}{0.85 f_c' b} \quad \text{. . . . (5.8)}$$

$$M_u = 0.85 \, f_c' \, a b \left(d - \frac{a}{2} \right) + A_s' \; f_s' (d - d') \quad \text{. . . . (5.9)}$$

$$\phi_u = \frac{\varepsilon_c}{c}$$

VI. PUSHOVER ANALYSIS CONSIDERING SITE SPECIFIC RESPONSE SPECTRA

The procedure of assigning dead and live load case, different load combinations, defining mass source, and assigning the rigid diaphragms to all storeys are same as Time history analysis method, explained in section 5.5. The procedure to define and to assign Response spectra load case for analysis of building is illustrated as follows:

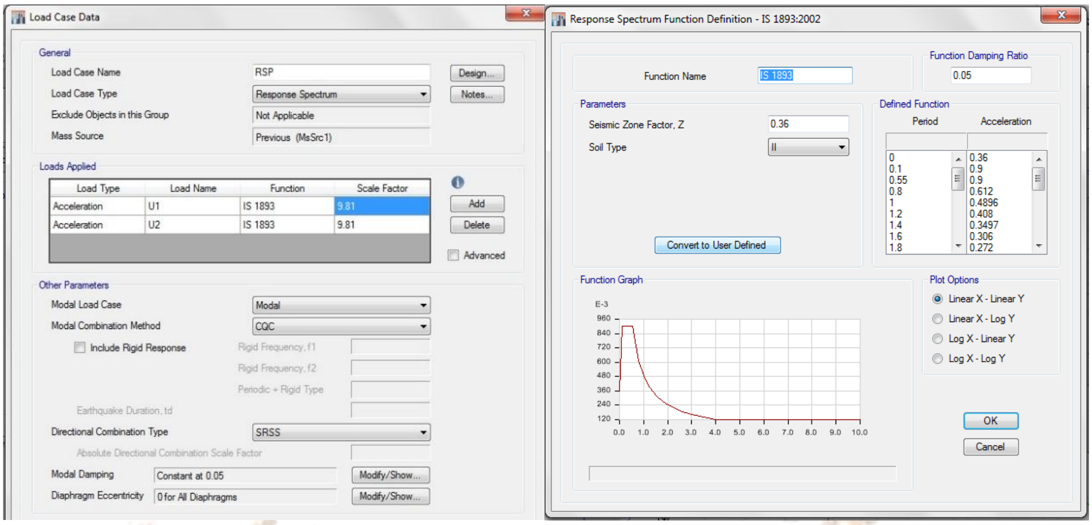


Fig.6.1 Response Spectra Graphs

After completing the above steps, **Run analysis** command is used to carry out the analysis of building. After the analysis is performed various results are displayed. The results are obtained in the form of shear forces, axial forces, bending moments, story shear forces and base shear in graphical and tabular form.

LATERAL FORCE FOR PUSHOVER ANALYSIS

Lateral forces and vertical downward forces are considered during the analysis and design of building structures. Vertical force or gravity force can be easily calculated. But lateral force is randomly generated on the building during the earthquake and so it is difficult to calculate. Many codes give different lateral load distribution pattern for earthquake design, but still it is not realistic for all types of building structures. It is accurate only if the applied pattern of loads induces a pattern of deformation in the structure that is similar to that which will be induced during the earthquake ground motion.

The effect of acceleration time history and site specific response spectra analysis on lateral load pattern is discussed in this section.A three dimensional reinforced concrete (RC) frame structure is considered for pushover analysis. All beam sizes are 250×500 mm and column sizes are given in Table 5.3. The slab thickness is considered as 150 mm. The loading considered on building are:

- 3 kN/m^2 live load
- 3 kN/m^2 super imposed dead load for partition wall
- 1 kN/m^2 floor finish load
- 12.5 kN/m for periphery wall

Story height is taken 3m. Material properties are assumed as M25 concrete and Fe 415 longitudinal and transverse reinforcement. Parametric study is carried out considering force in X-Direction.

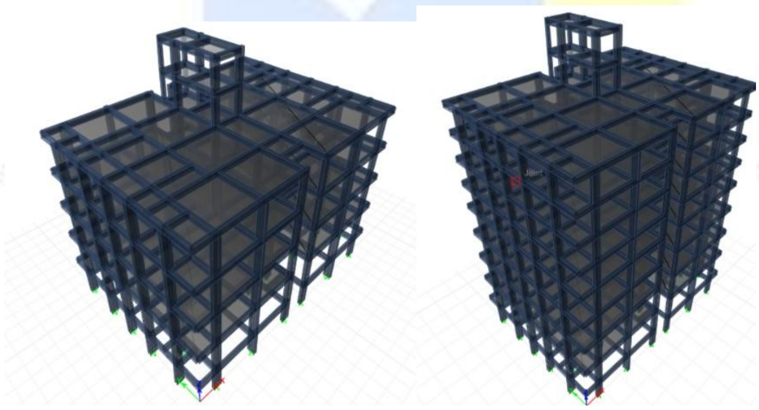


Fig.6.1 3D of 3-story building and 7- story building.

Lateral forces at each story level is calculated considering Site specific response spectra using ETABS software and the resulting force distribution along the height of structure is compared for each case.

Comparison of cost at various level is find out of various performance level is exceeding,

3 story building of cost is 3.4 million in Zone III and 3.9 in zone IV.
7 story building of cost is 5.3 million in zone III and 6.0 million in Zone Iv.

VII. CONCLUSIONS

The interior frames of 4- and 7-story buildings wereconsidered in pushover analyses to represent low- and mediumrisereinforced concrete (RC) buildings for study. Beam andcolumn elements are modeled as nonlinear frame elements withlumped plasticity by defining plastic hinges at both ends of the beams and columns. The frames were modeled with default and user-defined hinge properties to study possible differences in the results of pushover analyses. The following findings were observed:

1.The base shear capacity of models with the default hinges and with the user-defined hinges for different plastic hinge length and transverse reinforcement spacing are similar; the variation in the base shear capacity is less than 5%. Thus, the base shear capacity does not depend on whether the default or user-defined hinge properties are used.

2. Plastic hinge length ($L\ p$) has considerable effects on the displacement capacity of the frames. Comparisons show that there is a variation of about 30% in displacement capacities due to $L\ p$.

3. Displacement capacity depends on the amount of transverse reinforcement at the potential hinge regions. Comparisons clearly point out that an increase in the amount of transverse reinforcement improves the displacement capacity. The improvement is more effective for smaller spacing. For example, reducing the spacing from 200 mm to 100 mm provides an increase of up to 40% in the displacement capacity, while reducing the spacing from 200 mm to 150 mm provides an increase of only 12% for the 3-story frame.

4. Comparison of hinging patterns indicates that both models with default hinges (Case A) and the user-defined hinges (Case B3) estimate plastic hinge formation at the yielding state quite well. However, there are significant differences in the hinging patterns at the ultimate state. Although the hinge locations seem to be consistent, the model with default hinges emphasizes a ductile beam mechanism in which the columns are stronger than the beams; damage or failure occurs at the beams.

5. The orientation and the axial load level of the columns cannot be taken into account properly by the default-hinge properties. Based on the observations in the hinging patterns, it is apparent that the user-defined hinge model is more successful in capturing the hinging mechanism compared to the model with default hinges.

6. Although the capacity curve for the default-hinge model is reasonable for modern code compliant buildings, it may not be suitable for others. Considering that most existing buildings in India and some other countries do not conform to requirements of modern code detailing, the use of default hinges needs special care.

This study is carried out to investigate the possible differences between pushover analyses of the default-hinge and user-defined hinge models. The observations clearly show that the user-defined hinge model is better than the default-hinge model in reflecting nonlinear behavior compatible with element properties. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should definitely avoid the misuse of default-hinge properties.

This optimization methodology provides a powerful computer-based technique for performance based design of multi-storey RC building structures. The proposed optimization methodology provides a good basis for more comprehensive performance-based optimization of structures as more accurate nonlinear pushover procedures taking into account the higher mode effects are developed and multiple levels of performance criteria and design objectives are to be simultaneously considered.

VIII. REFERENCES

1. Federal Emergency Management Agency (FEMA)-356, “Prestandard and Commentary for the Seismic Rehabilitation of Building”, FEMA 356/November 2000, Building Seismic Safety Council, Washington, D.C., 2000.
2. Applied Technology Council (ATC)-40, “Seismic Evolution and Retrofit of Concrete Building”, Report No.SSC 96-01, Volume I, Applied Technology Council, California, November,1996.
3. Federal Emergency Management Agency (FEMA)-273, “NEHRP Guidelines for the Seismic Rehabilitation of Buildings”, Building Seismic Safety Council, Washington, D.C., October 1997.
4. Indian Standard Code 456-2000 Plain And Reinforced Concrete -Code Of Practice
5. Indian Standard Code 1893- Criteria For Earthquake Resistant Design Of Structures
6. Andreas J. Kappos and Georgios Panagopoulos, “Performance-Based Seismic Design of 3D R/C Buildings Using Inelastic Static and Dynamic Analysis procedures”, *ISET Journal of earthquake Technology*, Paper No. 444, Vol. 41, No.1, March 2004 pp.141-158.
7. Park R., and Paulay T., Reinforced Concrete structure, Wiley-Interscience, 1974.
8. Mehmet Inel, HayriBaytanOzmen, “Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings”, paper of science direct ,Department of Civil Engineering, Pamukkale University, Denizli, Turkey. 2007 pp 1494-1502.
9. Performance-based seismic design of structures: a direct displacement-based approach
   Engineering Structures 25 (2003) 1803–1813 QiangXue∗, Cheng-Chung Chen *Sinotech Engineering Consultants Inc., 171 Nanking East Road Sec. 5, Taipei 105, Taiwan* Received 22 June 2002; received in revised form 19 May 2003; accepted 1 August 2003
10. Push-over analysis for performance-based seismic design R. Hasan, L. Xu, D.E. Grierson Department of Civil Engineering, University of Waterloo, Waterloo, Ont., Canada N2L 3G1 Received 6August 2001; accepted 22 July 2002 Science Direct