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Performance Based Seismic Design of RCC Building

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Abstract: ***The performance-based seismic design approach enable us to design new structures more economically and to assess existing structures more realistically. In addition, it is possible to develop and validate by advanced simulation innovative solutions that make step change improvements to the financial viability of a project. The reduced material consumption that results from the adoption of this approach also makes a positive contribution to the sustainability of new developments. The promise of performance-based seismic engineering is to produce structures with predictable seismic performance. Conventional 'code based' design is unsuitable for high-rise buildings as has been recognized in Japan and China for many years. Performance based seismic design explicitly evaluates how building is likely to perform in given potential hazard. In performance based design identifying and assessing performance capability of building in an integral part of design process, and guide the many decisions that must be made. Present study based on performance based seismic design synthesis and non-linear analysis of multi-storey RCC building. Performance based seismic design synthesis is an iterative process, begins with selection of performance objective followed by development of preliminary design, an assessment as to whether or not the design meets the performance objective and finally redesign and reassessment, if required until desired performance level is achieved. In this paper work will be carried out for performance based seismic design of multi-storey (G+5) RCC building. Once design is complete, non-linear analysis is carried out to study seismic performance then it's compared with seismic performance of building designed with conventional code provisions.***

Keywords: Performance Based Seismic Design, Non-Linear Analysis, Cost Effective Design.

1. Introduction

Earthquake resistant design of building in India is carried out as per guideline given in code IS1893:2002. According to this guideline base shear is computed based on perceived maximum seismic risk characterized by maximum considered earthquake, importance of building and reduction in demand depending on perceived seismic damage of the structure. The computed base shear force in then distributed to floor levels which depends on amount of mass present at story level and its height. Building is then analyzed under lateral force vector which gives design forces and moments for design earthquake. These forces and moments are combined with forces and moments due to dead and live loads according to load combinations to give design forces and moments in structural members. It was recognized that a frame building would perform better under seismic attack if it could be assured that plastic hinges only occur in beams rather than in column(Bean mechanism), and the shear strength of member exceeded the shear corresponding to flexural strength. This can be identified as true start of performance based seismic design, where the overall performance of building is controlled as function of design process. Performance based seismic design synthesis is an iterative process, begins with selection of performance objective followed by development of preliminary design, an assessment as to whether or not the design meets the performance objective and finally redesign and reassessment, if required until desired performance level is achieved.

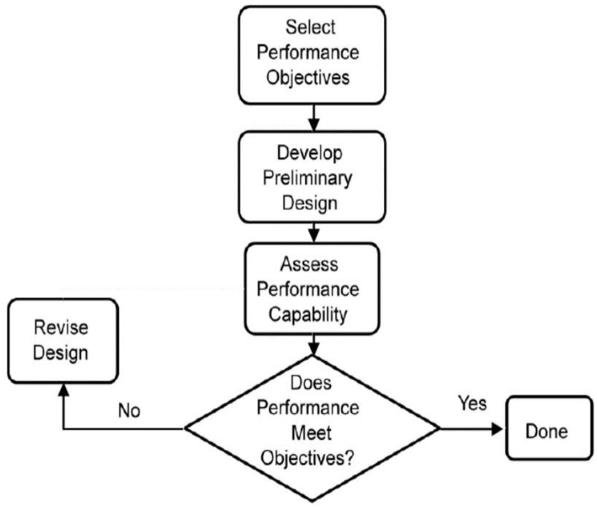

Fig. 1, Performance Based Seismic Design[5]

Preliminary design can be carried out by direct displacement based seismic design [DDBD] of MJN Priestley *et al.* [9] takes care of design drift under considered seismic risk. ñUnified approach to performance based seismic designò [UPBD] of Sing and Choudhury [10] which theoretically calculates depth of beam to satisfy the inter-story drift and target performance level. Calculated beam depth is then used in preliminary design which is carried out by DDBD. Seismic evaluation is carried out using pushover analysis.

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2. Performance Based Seismic Design Procedure for RCC frame

The step by step PBD procedure is summarized as follows.

2.1. Performance Objective

It is a coupling of expected performance level with level of seismic ground motion. A performance level describes a limiting damaging condition that may be considered for given building. Seismic ground motion is a function of the location of the building with respect to site-specific geological characteristic.

2.2. Preliminary design by direct displacement based design

Step 1. MDOF to ESDOF

The first stage of design process is to represent the multi-degree of freedom(MDOF) structure by equivalent single degree of freedom structure(ESDOF) modelling the first inelastic mode of response using substitute structure concept.

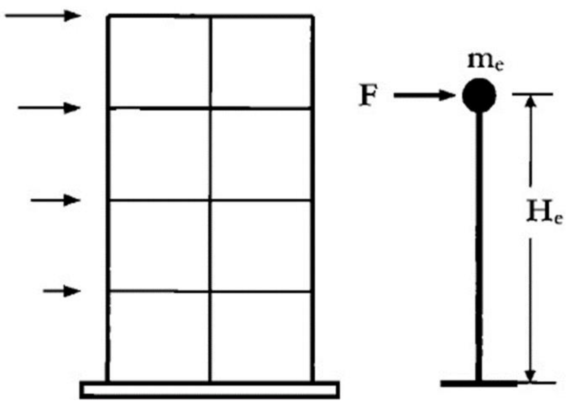

Fig. 2, Substitute Structure Concept, MDOF to ESDOF [9]

$$\Delta_d = \frac{\sum_{i=1}^{i=n} m_i \Delta_i^2}{\sum_{i=1}^{i=n} m_i \Delta_i}$$ é é .. (1)

$$m_e = \frac{\sum_{i=1}^{i=n} m_i \Delta_i}{\Delta_d}$$ é é .. (2)

$$H_e = \frac{\sum_{i=1}^{i=n} m_i \Delta_i H_i}{\sum_{i=1}^{i=n} m_i \Delta_i}$$ é é .. (3)

Here, mi, hi and &Δ_i are respectively the mass, height from base and displacement for i[th] storey &Δ_d is target displacement, m_e is equivalent mass, H_e is the effective height of the ESDOF system.

Step- 2. Design story Displacement

The target displacement shape and amplitude of MDOF structure on the base of performance level consideration (Drift limit and inelastic rotation in beam) in calculated. The design displacement of frame are related to normalized inelastic mode shape δ_i where i=1 to n are the story and displacement æ$_c$ of the critical story by the relationship.

$$\Delta_i = \delta_i \frac{\Delta_c}{\delta_c}$$ é é .. (4)

Normalized inelastic mode shape is given as

For nÒ $\delta_i = \frac{H_i}{H_n}$

For n> $\delta_i = \frac{H_i}{H_n} \times \{1 - \frac{H_i}{4H_n}\}$ é é .. (5)

Step 3. Design Displacement Ductility

The SDOF design displacement ductility factor is related to equivalent yield displacement Δ_y.

$$\mu = \frac{\Delta_d}{\Delta_y}$$ é é .. (6)

Yield displacement Δ_y is given as

$$\Delta_y = \theta_y * H_e$$ é é .. (7)

$$\theta_y = 0.5\varepsilon_y \frac{L_b}{h_b}$$

Step 4. Equivalent viscous damping

Equivalent viscous damping is given by elastic damping and hysteresis damping

$$\xi_{eq} = 0.05 + 0.565\left(\frac{\mu - 1}{\mu\pi}\right)$$ é (8)

Step 5. Effective period of substitute structure

The effective time period (T_e) is obtained from Displacement spectra. Influence of ductility can be represented by equivalent viscous damping or directly by inelastic displacement spectra. Hence displacement spectrum corresponding to the curve of damping ξ is derived for Indian seismicity, structure located in soft soil as shown in fig.3. This conversion of IS1893 acceleration spectrum is carried out using guideline given in DBD12, modal code for direct displacement based seismic design. Effective period is carried out using target design displacement Δ_d.

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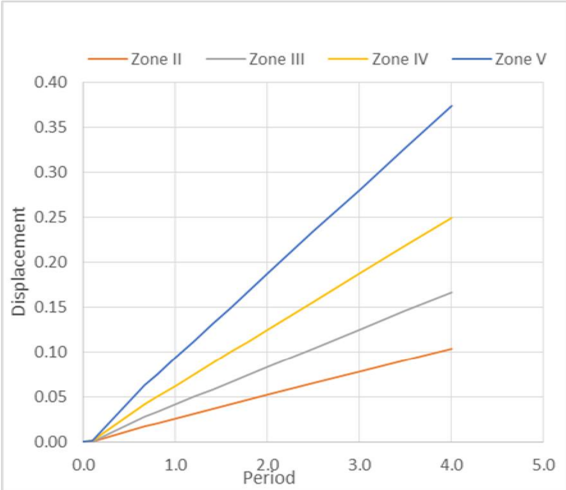

Fig.3 Displacement spectra at MCE for damping ဒ

Step 6. Effective stiffness of substitute structure

The effective stiffness of ESDOF system at maximum displacement can be found by inverting normal equation for period of SDOF oscillator. It is given as F/Δ_d.

$$K_e = \frac{4\pi^2 m_e}{T_e^2} \quad \text{é é .. (9)}$$

Step 7. Design base shear force

It is found from substitute structure

$$F = V_{base} = K_e * \Delta_d \quad \text{é .. (10)}$$

This base shear is vertically distributed to floor levels as given below

The design is done with expected strength of material for load combination given below.

DL+LL

DL+LL±EL_X

DL+LL±EL_Y é .. (11)

Where DL, LL stands for Dead Load, Live Load and EL_X, EL_Y stands for Earthquake Load along X and Y-direction.

Step 8. Capacity Design

Capacity design is carried out to ensure weak-beam strong-column such that at every beam column joint columns to beams capacity ratio shall not be less than 1.3. Columns are ensured to behave as elastic member. In the general DDBD, bottom ground storey columns are designed to behave as elastic members. Shear failure of beams are also avoided. The column sizes are restricted in way that the maximum steel in columns is 4%. Nominal reinforcement of beam was taken as 0.32% at each face for ductile behavior.

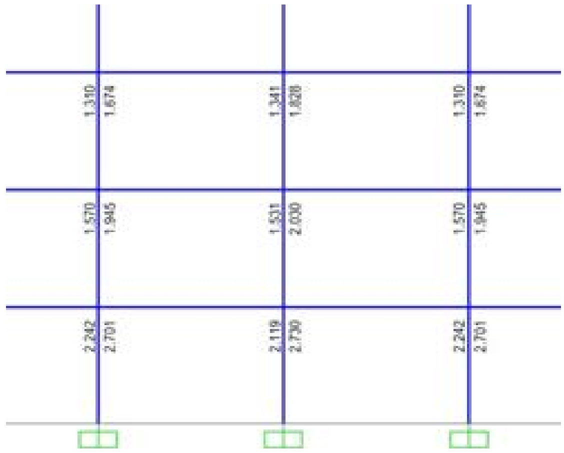

Fig.4 Capacity design, × M_CÓ1.3× M_B

Step 9. Seismic Evaluation

Designed building are subjected to nonlinear static analysis for evaluation of performance point. The performance level of building is noted from the type of plastic hinge formed in frame member. Pushover analysis is carried out using SAP2000 V17 obtained performance level of buildings designed with Indian standard and performance based seismic design philosophy are shown in results.

3. Comparison between performance based seismic design and India codal seismic design philosophy

Here preliminary design of PBSD has been carried out using DDBD and India seismic design using IS1893:2002. DDBD uses expected material strength while Indian design uses characteristic strength for design purpose. DDBD uses constant frame beam section for particular frame while IS may use different beam section as it is force based. Load combination used in DDBD are as written in eq. 11 while IS uses 1.5(DL+LL), 1.2(DL+LL±EL), 1.5(DL±EL), 0.9DL±1.5EL where DL, stands for dead load, LL for live load, EL for seismic load along frame.

4. Design and Evaluation work

For seismic performance comparison between PBSD and IS, two buildings have been designed with both philosophyŝs. Both building carries live load 4kN/m^2 at floor level and seismic risk of zone V (India), plan of building is as shown below in fig.5. IS seismic design is carried out as per IS1893:2002 and PBSD is carried out by DDBD as preliminary design. DDBD is carried out as explained above. Six storey buildings designed with IS and PBD are represented by IS6 and PBD6 respectively.

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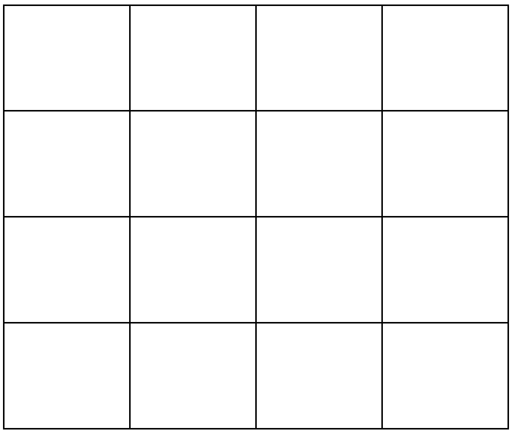

Fig.5 Building Plan,
4 bays in each direction, 4m each.

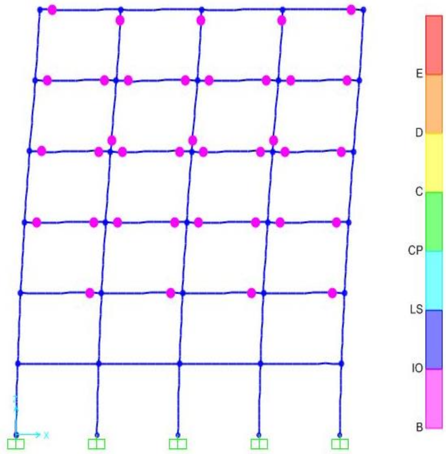

Fig.8 IS6, Pushover Hinges at DBE

5. Results

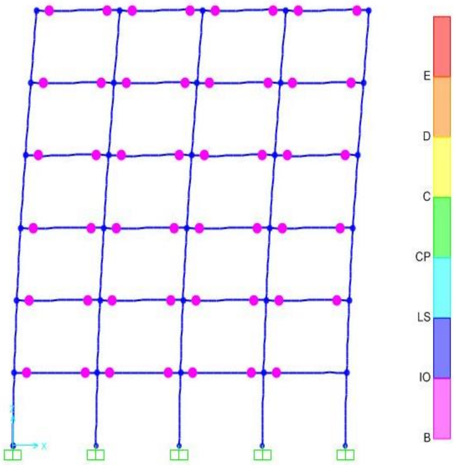

Fig.6 PBD6, Pushover Hinges at DBE

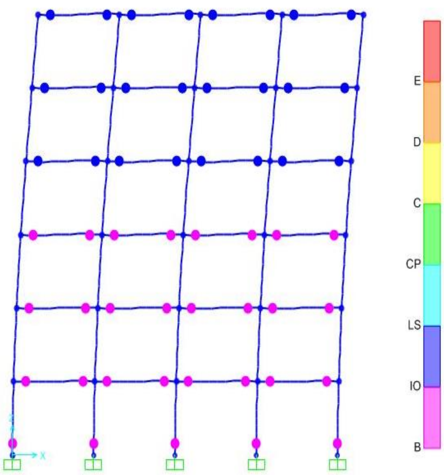

Fig.7 PBD6, Pushover Hinges at MCE

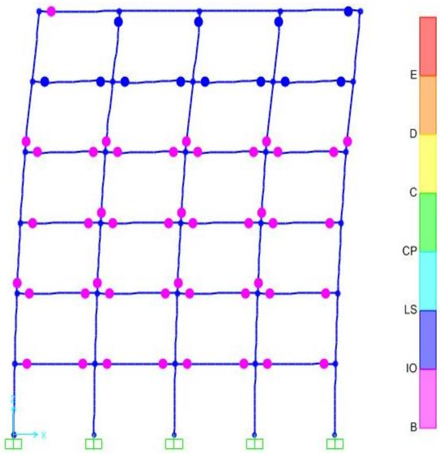

Fig.9 IS6, Pushover Hinges at MCE

Table 1, Member Performance Level at seismic risk

Building	Member Performance Level at seismic risk of DBE		Member Performance Level at seismic risk of MCE	
	Beam	Column	Beam	Column
IS6	B-IO	B-IO	IO-LS	IO-LS
PBD6	B-IO	---------	IO-LS	---------

6. Conclusion

Performance based seismic design of RCC building has been carried out. Direct displacement based seismic design approach has been used to carry out Performance based design. A theoretically developed beams depth on the basis of unified approach to performance based seismic design has been calculated first for specific performance level. Rest of design procedure is in line with direct displacement based seismic design. Drift and performance combination considered were CP with 3% drift for performance based design. Performance evaluation has been carried out through pushover analysis. Result have been presented. It has been found that performance based design method can be used to design frame building with any desired drift and member performance level. Result shows member performance levels, following conclusions are made.

1. For building designed with performance based design under design basis earthquake and maximum considered earthquake, column performance is elastic, while in IS code method it is B-IO and IO-LS respectively. It concludes that capacity design is necessary with column beam capacity ratio 1.3.
2. Hinge formation locations have been observed. It shows that, in performance based design hinge formation in beams is uniform as compared to IS code design. It concludes that distribution of lateral strength is more rational in performance based design than IS code design method.

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