Seismic Response of Performance Base Designed Building: A Review

Sarosh Sheikh 1, S S Sanghai2* and Abhijeet Nardey3

1PG Scholar, Department of Civil Engineering, G.H. Raisoni College of engineering, Nagpur, India
2,3Civil Engineering Faculty, G.H. Raisoni College of engineering, Nagpur, India
1saroshsheikh123@gmail.com

Abstract: A review on Performance Based Plastic Design method (PBPD) for RCC building has been presented in this paper with detailed manner. The first is the study of Performance Based Plastic Design method relating with IS code method. And then secondly review includes the research gap that is to apply this method on Irregular Buildings and to observe the efficiency of Design and Cost analysis comparing to IS code recommendations. When a Structure is designed by IS Code (IS 456: 2000) recommendations, it satisfies the strength as well as serviceability standards. But when an earthquake hits the structure, it leads to collapse which leads to loss of life as well as property. A Recently developed PBPD method can be a promising & efficient seismic design approach as it counteract total collapse of structure. This method is becoming popular due to its total collapse prevention. The paper addressed the relevant examination of provisions as specified in the appropriate design standard and software-based finite element analysis conducted by various authors, as well as a review of the problem, in order to reach a meaningful conclusion for the study. Also, a suggestion for the scope of future development is to study the Design as well as Cost efficiency of Performance Based Plastic Design of Various Irregular RCC buildings which will be a new or important aspect of the study. Despite the fact that fewer papers have been published in this area than in others, this report covers a broad range of research efforts and progress into the New Performance based Plastic Design method & seismic behavior of irregular buildings, demonstrating the field's growing interest.

Keywords: Performance Based Plastic Design, Non-Linear Analysis, Target displacement, Irregular structures Ductility Factor.

List of symbols

| Symbol | Description |
|--------|-------------|
| R      | Reduction factor |
| Rμ     | Ductility Reduction Factor |
| Sa     | Elastic Design Spectral Acceleration Value |
| SDS    | Design spectral Response Acceleration Parameter at short periods (5% damped) |
| DS1    | Design spectral Response Acceleration Parameter at period of 1 sec (5% damped) |
| μ      | Ductility Factor |
| Z      | Zone factors |
| Tn     | Time Period |
| Ci     | Seismic Response Coefficient |
| C2     | Modification Factor of Target Design |
| Drift (FEMA 440) |
| Fi     | Lateral Force at level i |
| Fn     | Lateral Force at the Top-Level n of the Structure |
| F_L    | Total Required Lateral Force |
| g      | Acceleration due to Gravity |
| h      | Height, Total Height of the Structure |
| l      | Occupancy Factor (ASCE 7-05) |
| L      | Span Length |
| L'     | Distance Between Plastic Hinges in |
1. Introduction

To control structural deformation & damage there are various methods suggested, Performance Based Design method (PBPD) is one among them. PBPD method is established on “STRONG COLUMN-WEAK BEAM” concept [1]. PBPD method is an empirically formulae-based method that works on pre targeted drift and yield target, which plays vital role in this method. Method includes calculation of design base shear by lateral which thrusts the structure up to required lateral drift and energy demand.

In general practise, the normal designed structure is meant for max limiting forces and therefore it is checked for the limiting max forces and limiting checks are done as per criteria given in IS codes [7]. But in this Force-based method the seismic strength of structure is calculated by elastic design spectrum. With reference to ductility factor (μ), Design strength is calculated. Reduction factor (R) modifies the elastic strength for design base shear. The method has the assumption that structural stiffness will not be affected as design strength reduces from elastic strength. The main focus of the study is to work out the Reduction Factor R, and to determine the failures observed in PBPD method [9]. First of all, lateral forces are calculated which is based on Elastic spectra from IS 1893: 2016 [10] from which design spectral acceleration, (Sa) is obtained for time period “Tn”. The Ductility factor (μ) is calculated as the ratio of Max displacement to yield displacement. When value of ductility factor is unity than its elastic response & when ductility factor is more than 1, it will be an inelastic in nature.

Reduction factor (R) from (IS 1893: 2016), Zone factors “Z” from (clause 6.4.2, IS 1893: 2016) & importance factor “[I” from (clause 6.4.2, IS 1893: 2016) is applied for the calculation of total base shear “Vb”. As Reduction factor (R) for all type of structure falls in defined category is same, therefore it doesn’t anticipate the exact elastic behavior of the structure. Zone factor (Z) proposes design forces as per zones categorized in the country and data available for previous earthquake history. Based on functional use of structure importance factor is used [7]. Elements used for design forces are mostly supported engineering judgement so we will say that current code is sort of assumptive [4]. Due to which structure behaves large deformation.
2. Literature Review

Eeri (2000) introduced “N2 Method”, a traditional nonlinear method of analysis of structure [1]. The method integrated the pushover analysis of MDOF modal with spectrum analysis of SDOF system. In the paper comparison has been presented between N2 method and both FEMA 273 and ATC 40 nonlinear static analysis procedures and derivation is explained. This method was proposed to eliminate the iterative process of analysis. The method showed reasonable matching of the results provided the structure oscillation predominantly in first mode.

Goel, liao et al. (2010) [2] given a review on Performance Based Plastic Design (PBPD) method to adopt it for seismic design. Paper explains whole procedure in detailed manner to achieve yield mechanism by plastic design & proposed the base shear equations for hazard level (s). 20-storey steel and RCC moment frames was to analyzed by PBPD method. Inelastic static and dynamic analysis results revealed that frame developed Strong column sway mechanism and also ductility demand and storey drift was within target. Method showed excellent outcome comparing to more iterative inelastic time-history analyses.

Liao & Subhash C. Goel (2012) [3] introduced the Performance Based Design method (PBPD) for the first time on the seismic resistant RCC moment frame of 4,8,12, & 20 storey. The RC frame was analyzed & designed by PBPD method. Paper shows that selected drift and targeted yield being two main elements of the tactic which determine expected structural damage. As the method is direct approach based, so the base shear calculation is also modified. For seismic design of existing structures, work energy-based equation was applied. Research Paper concluded that PBPD method gives more than expected results and more advantageous for tall frames.

Sahoo and Chao (2010) [4] used PBPD method to design Buckling restrained braced frames. PBPD method was applied to style Buckling restrained braced frames. PBPD method could also be an immediate approach method, as nonlinear behavior and key performance are already selected in the beginning of the method, so no iteration required in this method. Three high rise buildings were designed, and seismic analysis was performed using nonlinear time history. The seismic analysis was done using forty different ground motions with MCE and DBE hazard levels. The study shows the tactic gives economical design compared to usual code-based design. It conjointly meant performance goal in terms of yield displacement and target drift.

Sejal Dalal, Vasanwala (2012) [5] compared the factors such as lateral force, stability, and costing by analysis as well as design of Steel Moment Resisting frame by PBPD method and Elastic Design (ED) method regarding. Push over Analysis and Time history analysis for six ground motions was adopted for seismic evaluation using the SAP2000 software. Ist the MRF was designed by elastic approach following the UBC94 codes and analysed by Pushover Analysis. The Time history analysis of MRF was done using six completely different ground motions. Same MRF was conjointly designed by Performance based mostly plastic analysis (PBPD) and analyzed by Time history method. Author recommends with the study, PBPD methodology supports the “Strong column - Weak beam” conception, is better resulting compared to the elastic style methodology in terms of the optimum capability utilization.

Dalal, Vasanwala (2012) in comparison the overall performance of moment resisting frames (MRF) designed by using overall Performance-based plastic analysis with MRF designed with the aid of conventional limit state method proposed in Indian preferred codes (IS800:2007). Elastic design was used to design the steel moment resisting frame, which was then followed by performance-based plastic design. Elastic design method was used to quantify lateral forces, and structural participants were designed for elastic beam-columns mainly using limit state design by Philosophical considerations. And for PBPD method, lateral forces are calculated based on inelastic spectral acceleration using reduction factors. In this paper author also explained the step-by-step process of designing steel MRF by elastic approach and performance-based plastic analysis (PBPD) with reference to (IS800:2007). Based on proven outcomes, the author recommends the PBPD technique over the Elastic design approach in terms of protection and average financial system.
Urvesh A Shah, Dr. Sejal P Dalal (2015) [6] presented a paper on design of L-shaped RCC frame using Performance Based Plastic Design. This paper has cleared the concept PBPD design method for Indian Engineers by designing 15 story L-shaped RCC frame. Engineers are unsure how to achieve the desired goals of monitoring drifts, distribution, and degree of inelastic deformation because they lack guidance. According to the report, lateral forces were higher than the code-specified lateral force distribution, resulting in more conservative result and better efficiency. As opposed to beams that meet the “strong column-weak beam” criterion, columns are built for higher moments. Failure occurs only at predetermined beam locations, not in columns, preventing the total failure of the structure and increasing life protection.

S. S. Qammer, S. P. Dalal, and P. D. Dalal (2018) [7] performed analysis and design of 4,8,12, & 15 storied building by PBPD method attuned with IS Code. Design lateral forces were calculated by referring IS 1893:2016. Nonlinear static push over analysis was used for seismic performance evaluation. Parameters for comparison were (a) Push Over Curves (b) story Displacement and bury story drift magnitude relation and (c) Response Reduction issue. Results explicit that Response Reduction numbers were bigger than IS 1893:2016 such value that satisfies the performance of PBPD methodology.

J. K. Shah and S. P. Dalal (2018) [8] compared the Performance Based Plastic Design (PBPD) and Force Based Design (FBD) methods for designing 5,10, and 15-story Zipper Braced Frames. The use of Pushover analysis (a) Deformation and Capability, (b) Response Reduction Factor, and (c) Failure Pattern were used to compare the studies. The FBD method was incorporated as per the guidelines of IS 1893:2016. Results indicated better performance of PBPD frames concerning to deformation and capacity. Hinges were seen in the columns & response reduction factor values PBPD frames was found higher than FBD frames. It was observed that seismic performance of PBPD frames is better than FBD frames especially for taller heights.

Sejal P Dalal and Khyati Vaidya [10] compared the seismic efficiency and cost of five, ten, and fifteen-story steel Concentrically Braced Frames (CBF) designed using the performance-based totally plastic design (PBPD) method and the force-based design (FBD) method. The frames were compared using the following parameters: lateral load distribution, contributor design parts, seismic performance, and cost. As a result, the lateral load distribution in PBPD frames became more real, and the column parts of PBPD frames were found to be heavier. Due to the fact that PBPD is built for a higher ductility problem, the brace parts are lighter than FBD frames. In terms of cost, we can assume that the PBPD approach is not cost-effective for low-rise structures since parts are heavier; however, it is cost-effective for high upward thrust or taller systems.

3. **PBPD Methodology**

- **Calculation of Lateral Forces.**

  **Step 1. Target Drift & Yield Drift Selection.**

  - First step toward PBPD method is to select predetermined drift ($\theta_{max}$) and yield mechanism ($\theta_y$) [1]. Inelastic drift ($p$) is the difference between the predetermined flow ($max$) and the yield mechanism ($y$) in goal drift [2]. Liao & Goel (2012) [3] advised to alter target float ($\theta_{max}$) through dividing C2 factor as per FEMA 440 to account the pinched hysteretic conduct of RCC body. C2 issue for higher term ($T > \text{approx. zero.6}$) is almost same to 1. C2 for lower time period is more than 1 which decreases($\theta_{max}$) but will increase base shear.
Figure 1. Moment resistant frame with beam plastic hinges has a predetermined yield mechanism (Goel and Chao)

Step 2. Design Spectral Acceleration

IS 1893: 2016[5] gives the design acceleration coefficient, ‘Sa / g’ similar to term ‘T’ for 5% damping for exclusive soils that is for MCE [7]. In PBPD, ‘Sa / g’ is reduced to Design Basis Earthquake (DBE) by considering zone factor “(Sa / g x Z / 2)” [2]. Fajfar (2000) [1] suggested that Design Spectral Acceleration can be reduced by taking “Sa_{inelastic}” which is based on Reduction factor (R).

\[ S_{a_{inelastic}} = \frac{S_a}{R_u} \]

By the suggestion of Vidic et. Al (1994) Reduction factor can be calculated in accordance with ductility factor (μ).

\[ R_u = (\mu - 1) \frac{T}{T_c} + 1 \quad (T < T_c) \]

\[ R_u = \mu \quad (T > T_c) \quad \ldots \ldots \quad (1) \]

- The characteristic time period (Tc) for medium stiff soil is 0.55 seconds (IS 1893: 2016).
- For structures with T greater than 0.55 sec, the values of T and R are the same. The structure with T of less than 0.55 seconds has a lower R value [7].

Step 3. Shear Distribution Factor Calculation (\( \beta_i \))

\[ \beta_i = \frac{V_i}{V_n} \]

\[ \beta = \left( \sum_{i} \frac{w_i h_i}{w_i h_n} \right)^{0.75} \]

\[ \beta = \left( \sum_{i} \frac{w_i h_i}{w_i h_n} \right)^{0.75} \]

\[ \ldots \ldots \quad (2) \]

Step 4. Base Shear Calculation (V)

\[ \frac{V_y}{W} = \frac{-\alpha + (2 + 4yS^2)}{2} \quad (3) \]
\[
\alpha = \left( \sum_{i=1}^{n} \beta_i \right) h_t \times \left( \sum_{i=1}^{n} w_i h_i \right) ^{0.75 T^{0.2}} \times \frac{\sqrt{0.8 \pi^2}}{T^2 g}
\]  

(4)

**Note:** If the structure's force deformation behavior differs from that of an elastic plastic structure, change \(V\) by modifying & changing it.

*Step 5. Beam – Column moment Calculation:*

- **PBPD analysis for RCC frame is adopted with the aid of the idea that hinge can be forming in beam at distance 0.1L to zero.2 L from face of column. Moments for beams are calculated by using equation of equilibrium [6].**

**Beam Moments Calculation**

- **As factor 1.1 is used to design lateral forces for the optimal plastic moment \(M_{pc}\) of the column, it is assumed that no soft storey mechanisms will occur.**

- **Every story's required beam moment capability is determined using the plastic style method [8]., which assumes that moment intensity (Mu) equals moments from lateral forces (iM_{pb}) [8].**

\[
\beta M_{pb} = \beta \times \frac{\sum_{i=1}^{n} F_i h_i - 2 M_p}{2 \sum_{i=1}^{n} \beta (T_r) i}
\]

(5)

**Column Moments Calculation**

- **As the frame limits its target drift, shear force and bending moments are reached up to its maximum strength (VRBS)I and (M_{pr})i. It’s supposed that Column at base reaches its most capability and also the leveling lateral forces are evaluated by equation of equilibrium of column.**

\[
\sum_{i=1}^{n} \left( M_{pr_i} \right) + \sum_{i=1}^{n} \left( V_{RBS_i} h_i \right) + \frac{d_i}{2} + M = \sum_{i=1}^{n} \alpha_i h_i + M_{pc}
\]

(6)

\[
\alpha_i = \frac{\beta_i - \beta_{i+1}}{\sum_{i=1}^{n} \left( \beta_i - \beta_{i+1} \right)}
\]

(7)

**Note:** \(\sum M_{pr}\) and \(M_{pc}\) values are doubled for interior columns to find FL. The design of beam and column for above moments and shear values is done as per IS 456:2000[9].

**Figure 2. Beam- Column Calculation**
4. Gap Study
Construction of contemporary high-rise structures began to address a variety of demands, including population growth, high land costs, and even to display a company’s financial standing in the case of corporate buildings [17]. There is a paucity of land for separate parking areas in major cities. To address this issue, buildings are being developed with many parking floors within the same structure, as well as opulent structures with amenities such as a swimming pool and gym. Irregular Structure is the name given to this sort of structure. The structure’s Earthquake characteristics alter as a result of these contemporary provisions.

The study’s major goal is to create and test a seismic design approach for RC Irregular Building that could build buildings with predictable and intended seismic performance. To enhance the PBPD approach and expand its applicability to reinforced concrete structures, a comprehensive research effort is required. Design and functional constraints in the construction of building systems frequently put particular form demands on the structural engineer, resulting in structural systems with irregularities in geometry, stiffness, or mass. When such structures are built in a seismically active area, the engineer must have a thorough understanding of the seismic response of such irregular structures as well as reliable guidelines for developing a safe, cost-effective, and reliable structural design that accounts for such irregularity during inelastic response [18]. Because of its functional and aesthetic concerns, these irregular structures are fairly widespread all over the world. According to all the reviews, it is observed that there is a scope of work for Design and Analysis of Irregular Building by Performance Based Plastic Design method and Comparison of Results constraints including Cost as well as Performance Efficiency. As a result, we will attempt to compute the seismic forces operating on the irregular structure using Indian Standard codes and the Performance Based Plastic Design approach, as well as perform a dynamic analysis of the chosen structure using various factors.

5. Irregular Structures:
Building irregularities come in a variety of shapes and sizes, depending on their location and scope, but they are generally split into two categories: plan irregularities and vertical irregularities [15]. Some major Irregularities are discussed below:

5.1. Plan Irregularities:

5.1.1. Torsional Irregularity
When the maximum storey drift, computed with design eccentricity, at one end of the structure traverse to an axis is more than 1.2 times the average of storey drift at both ends of the structure, torsional irregularity is considered to exist. When a structure has torsional irregularity, the overturning moment can rise suddenly [16]. As a result, the effect of irregularity is a critical factor to consider during the design of a structure.

5.1.2. Re-entrant corners
Re-entrant corners are found in the plan configuration of a structure and its lateral force resisting system when both projections of the structure beyond the re-entrant corner are greater than 15% of the plan dimension.

5.1.3. Diaphragm discontinuity
Diaphragms with abrupt discontinuous or varying stiffness, such as those with cut-out or open areas greater than 50% of the gross enclosed diagram area, or more than 50% changes in effective diaphragm stiffness from one storey to the next [16].
5.2. Vertical Irregularity

5.2.1. Stiffness Irregularity

a. Soft storey: A soft storey has lateral stiffness that is less than 70% of the storey above it or less than 80% of the average lateral stiffness of the three storeys above it.

b. Extreme Soft Storey: The lateral stiffness of a soft storey is less than 60% of that of the storey above, or less than 70% of the average stiffness of the three storeys above. Buildings on stilts, for example, will fall into this category.

5.2.2. Mass Irregularity:

When the effective mass of one storey exceeds 150 percent of the effective mass of an adjacent storey, mass irregularities are considered to exist. The effective mass is the real mass, which includes the floor's dead weight as well as the weight of partitions and equipment. Increased lateral inertial forces, reduced ductility of vertical load resisting elements, and increased tendency to collapse due to the P-effect can all be caused by excess mass [16]. Irregularities in mass distribution in the vertical and horizontal planes can lead to erratic behavior and complicated dynamics. In the case of heavy masses in upper floors, the Centre of gravity is shifted above the base.

5.2.3. Vertical Geometric Irregularity

When the horizontal dimension of the lateral force resisting system in one storey is more than 150 percent that of an adjacent storey, geometric irregularity exists. A vertical re-entrant corner can also be visualized as a setback. The general solution to a setback problem is total seismic separation in plan through a separation section, allowing the portion of the building to vibrate freely [16].

5.2.4. Discontinuity in capacity - Weak Storey

The total strength of all seismic force resisting elements that share the storey shear in the considered direction is referred to as the storey lateral strength. The lateral strength of a weak storey is less than 80% of the lateral strength of the storey above it.
6. **Need of Study.**

The study will compare irregular RCC buildings designed using the Performance Based Plastic Design method to IS Code provisions. The study's main focus is on building design efficiency and cost evaluation. As perfect regularity is an idealization that rarely occurs, real structures are almost always irregular. In recent years, a lot of research has gone into studying the seismic response of asymmetric structures and improving seismic code torsional provisions. But research on Specially “Performance based plastic Design method applied to irregular structures and their comparison on Seismic Design and Cost Calculation are very rarely seen. And the study will be a guidance to structural engineers for such type Structures.

7. **Conclusions**

The PBPD method is a direct technique design method that uses pre-selected target drift and targeted yield as main aim targets to assess the magnitude and distribution of impending structural damage [8]. To obtain the intended yield mechanism and behavior, plastic design is applied to the body individuals and relations [8]. Design base shear calculated by using PBPD approach is much less as compared to IS 1893:2016 provisions (mainly for better storied frames) as design spectral acceleration numbers is directly decreased by ductility element. Response reduction thing values found to be greater than the IS 1893:2016 detailed cost which displays enhanced margins in opposition to dynamic instability [6]. The lateral loads are found to be evenly distributed. The structure is designed for the Life safety performance level in terms of drift achieved. Failure occurs more effectively at predetermined beam locations rather than in columns, preventing the entire structure from collapsing and increasing life protection [10]. After studying the papers its concluded that Columns are designed for better moments in comparison to beam. The PBPD approach is not cost-effective for structures with low upward thrust, but it is cost-effective for systems with high upward thrust or that are taller [10].

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