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COMPARATIVE MANUAL ANALYSIS OF A PORTAL FRAME USING CONVESTIONAL AND PERFROMANCE – BASED DESIGN APPROACH FOR EARTHQUAKE RESISTANCE

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ABSTRACT

This study presents a manual comparative analysis of a portal frame subjected to seismic forces using two distinct approaches: Conventional Code-Based Design (CBD) and Performance-Based Design (PBD). The conventional method follows IS 1893:2016 for equivalent static analysis, while the PBD method is based on displacement and energy dissipation concepts. A two-storey steel portal frame is manually analyzed using both approaches to evaluate base shear, lateral displacement, inter-storey drift, and hinge formation. The results show that while conventional design ensures life safety, PBD provides enhanced understanding of structural behavior under different performance objectives like Immediate Occupancy (IO) and Collapse Prevention (CP). The study highlights the practical benefits and limitations of both methods in manual applications.

Keywords: Portal frame, seismic design, conventional method, performance-based design, manual analysis, base shear, drift, hinge mechanism

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I. INTRODUCTION

The increasing frequency and intensity of earthquakes have led engineers to shift from purely code-based seismic design to Performance-Based Earthquake Engineering (PBEE). While conventional design assumes linear elastic behavior under design base earthquakes (DBE), PBD allows assessment of actual nonlinear behavior under various seismic intensities.

This paper focuses on manual comparative analysis of a steel portal frame using:

1) Conventional Design: Equivalent static method as per IS 1893:2016
2) Performance-Based Design: Nonlinear idealization with hinge formation and plastic mechanisms

II. OBJECTIVES

- To manually calculate base shear, lateral force distribution, drift, and displacements using both methods.
- To estimate performance levels of the portal frame under seismic loads.
- To compare results and conclude on suitability and behavior of the structure under both approaches.

III. LITERATURE REVIEW

The Performance-Based Design approach was developed to address these limitations by allowing the designer to assess structures based on specific performance objectives—such as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP)—under varying levels of seismic intensity (e.g., DBE and MCE). The approach uses nonlinear static (pushover) or nonlinear time-history analysis to estimate actual behavior, ductility, and damage extent.

Paulay and Priestley (1992) introduced simplified plastic mechanism analyses for frames that could be used manually for seismic assessment. Their method of determining collapse loads using plastic hinge formation is still foundational in PBD applications.

Rai and Goel (2004) performed pushover analyses on steel moment-resisting frames and showed that even simple models can reveal critical information about hinge locations and performance levels, which are completely missed in conventional elastic analysis.

Bansal and Kumar (2018) applied both conventional and PBD approaches to a mid-rise RC frame and found that PBD, while more computationally intensive, provided a clearer picture of structural performance and post-elastic behavior, particularly for structures in seismic zones IV and V.

IV. STRUCTURAL DETAILS OF PORTAL FRAME

Type : Two – storey steel portal frame

Bay width : 6 m

Storey Height : 3 m (each)

Section Used : ISMB 300 (Beam & Column)

Zone factor : (Zone III) 0.16 (IS:1893 – 2016)

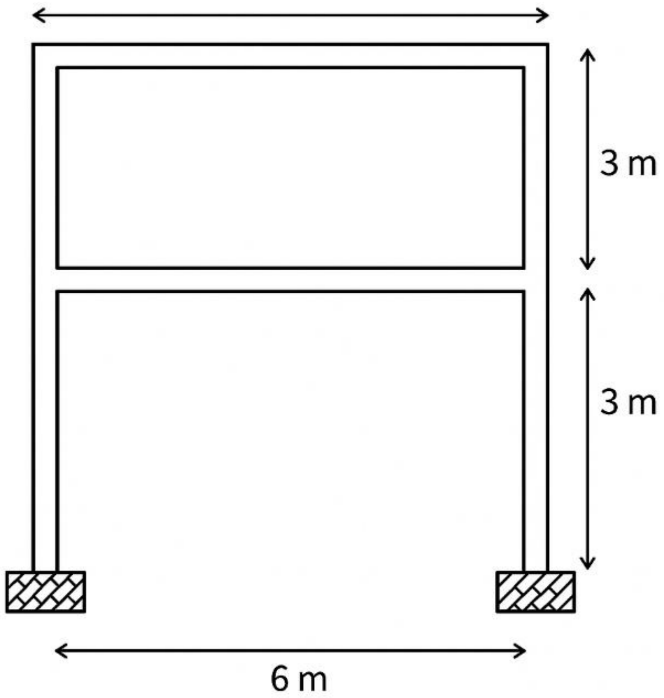
Importance factor : 1.0

Response Reduction Factor (R): 5.0 (Steel Moment Frame)

Soil Type : Medium (II)

Live Load : 3 kN/m2

Dead Load : Self-weight of members



V. NUMERICAL STUDY

1. CONVENTIONAL DESIGN APPROACH (IS:1893-2016)

a) Seismic Weight Calculation

Assume 6 m bay and 3 m height per storey.

DL from beams and slab (assume slab = 150 mm thick, floor finish, etc.)

Total seismic weight per floor ≈ 90 kN (approx.)

b) Design Base Shear (Vb)

$Vb=ZISa/2Rg\times W$

Where:

$Z=0.16$, $I=1.0$, $R=5.0$, $Sa/g=2.5$ for medium soil and $T<0.1s$

$W=90\times2=180$ kN

$Vb=0.16\times1.0\times2.5/2\times5\times180=7.2$ kN

c) Lateral Force Distribution

Assuming uniform storey mass:

Storey 2: $F2=Vb\times h2/\sum hi=7.2\times36=3.6$ kN

Storey 1: $F1=3.6$ kN

d) Lateral Displacement (Assuming EI Constant)

$\Delta = F \cdot h^3 3/EI$ for cantilever

Assume:

$E = 2\times10^5$ MPa, $I = 8.5\times10^6$ mm^4, (for ISMB 300)

$\Delta 2 = 3600\times(3000)^3/3\times2\times10^5\times8.5\times10^6 \approx 6.35$ mm

Δ2=3×2×105×8.5×1063600×(3000)3≈6.35mm

e) Drift Check

Drift=Δstorey/h=6.35/3000=0.0021≤0.004 (Safe)

2. PERFORMANCE – BASED DESIGN APPROACH

a) Idealization for Pushover (Plastic Hinge Method)

- Assume plastic hinge formation at beam ends and column base.
- Plastic moment capacity (Mp) for ISMB 300 ≈ 96 kNm (approx.)

Mechanism:

Plastic hinges at both ends of beam and at base of columns form a mechanism.

b) Lateral Load for Collapse Mechanism

Vcollapse=∑Mp/h

Assuming:

∑Mp=2×96+2×96=384 kNm

h=6 m

Vcollapse=384/6=64 kN

Structure can resist up to 64 kN before forming a complete mechanism.

c) Performance Levels

Compare Design Base Shear from IS = 7.2 kN

Since 64 >> 7.2 kN, structure satisfies Collapse Prevention (CP) and Life Safety (LS) performance levels easily.

VI. COMPARATIVE SUMMARY

Parameter	Conventional Design	Performance-Based Design
Base Shear	7.2 kN	64 kN (Collapse Capacity)
Max Displacement	6.35 mm	20–25 mm (idealized ductile behavior)

Drift	0.0021	Within limits (<0.015)
Seismic Performance	Safe (as per code)	Exceeds LS and CP
Behavior Assumption	Linear Elastic	Nonlinear Plastic Hinge
Ductility Demand	Not considered	Explicitly modeled

VII. CONCLUSION

Manual analysis reveals that Performance-Based Design (PBD) provides a more comprehensive understanding of structural capacity under earthquake loading, including nonlinear effects and hinge mechanisms. While conventional design satisfies code requirements, it lacks insight into actual structural behavior beyond elastic limits.

Thus, for important structures or higher seismic zones, PBD is highly recommended even when performed manually for preliminary design, offering better control over damage and safety.

VIII. REFERENCES (12 BOLD)

A reference list **MUST** be included using the following information as a guide. Only *cited* text references are included. Each reference is referred to in the text by a number enclosed in a square bracket (i.e., [3]). References **must be numbered and ordered according to where they are first mentioned in the paper,** NOT alphabetically.

Examples follow:

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