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RESEARCH ARTICLE

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# A STUDY ON THE PERFORMANCE BASED DESIGN OF REGULAR AND IRREGULAR R.C. FRAMED BUILDINGS

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## ABSTRACT

Performance – based design is an iterative procedure that begins with the choice of performance objectives, followed by the improvement of a beginning design, an evaluation is to taken whether or not the building meets the performance objective, and finally redesign and re-evaluation has to be done until the performance level is reached. To meet the performance based design an effective tool i.e., Non Linear Static Analysis (named as Pushover Analysis) is used. In the present work a seven storey both regular and irregular reinforced concrete building is situated in Zone V, is taken for the purpose of study. Inter Storey Drift, Diaphragm Displacement, are the desired performance levels is considered in this work, and analysis is to be done by considering various cases under design based Earthquake and finally the performance objective for both the buildings (regular, irregular) is achieved when the size of beams and columns are increased and when the shear wall is introduced in the building. This analysis is performed by using SAP2000, ETABS.

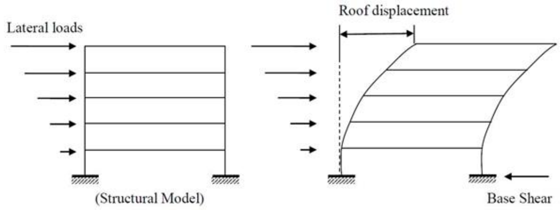
## INTRODUCTION

Structures on the earth are generally subjected to two types of forces, one is vertical forces and another one is lateral forces. All the structures are primarily designed for gravitational loads/ force equal to mass times its gravity in the vertical direction. Because of the normal factor of safety used in the design specifications, most structures tend to be sufficiently protected.

When a structure is subjected to ground motions during earthquake two types of loads are considered i.e., static and dynamic. Static loads are constant with time whereas Dynamic loads are time varying, most structures are designed with assumption by considering all loads are static, but in practical case structures is rarely subjected to dynamic loads, consideration of dynamic loads in analysis makes the solution is time consuming and more complicated. This aspect of neglecting these forces may cause of disaster, particularly in case of building subjected to lateral loads there are different methods of analysis which provides different degrees of accuracy.

## PUSHOVER ANALYSIS

Pushover analysis is of two types, (i) Force controlled or (ii) Displacement controlled. In the force control, the total lateral force is applied to the structure in small increments. In the displacement control, the displacement of the top storey of the structure is incremented step by step, such that the required horizontal force pushes the structure laterally. The distance through which the structure is pushed, is proportional to the fundamental horizontal translational mode of the structure.



**Static Approximations in the Pushover Analysis**

## REVIEW

Madan, D. Das & A. Hashmi[15] (2014) studied the development of a fundamental approach for performance based seismic design of masonry in filled frames with minimum number of trials is an important objective.

Dhileep. M et al. (2011)[7] explained the practical difficulties associated with the non linear direct numerical integration of the equations of motion leads to the use of non linear static pushover analysis of structures.

R. K. Goel and A. K. Chopra (2001)[5] presented an improved Direct Displacement-Based Design Procedure for Performance-Based seismic design of structures.

Naeim *et. al*.(2001)[18] described the seismic performance of buildings and performance objectives to define the state of the building following a design earthquake.

Ghobarah (2001)[11] reviewed the reliability of performance based design in earthquake engineering, need of multiple performances, and hazard levels for future seismic design practice.

J. B. Mander (2001)[16] reviewed from an historical perspective past and current developments in earthquake engineered structures.

Gupta and Kunnath (2001)[12] investigated the FEMA-356 procedures and offered a new procedure called Adaptive Pushover Procedure (APM) to account for the higher mode effects and to overcome the shortcomings of the FEMA-356 procedure.

Chang and Kim (1994)[4] investigated a 20-story building with a soft story by nonlinear time-history and nonlinear pushover analysis.

## SEISMIC ANALYSIS PROCEDURE

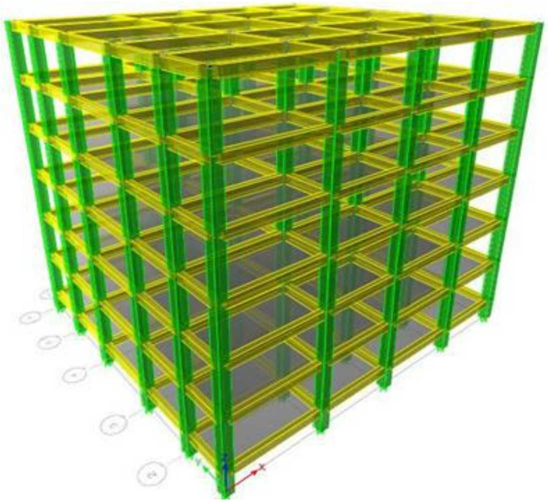
**Seismic Weight :** The seismic weight of the each floor is its full dead load plus appropriate amount of specified imposed load. While computing the seismic weight of the each floor, weight of columns, weight of walls in a storey shall be equally distributed to the floors above and below the story.

**Design Seismic Base Shear :** It is the total design lateral force to the base of the structure. In other words it is the seismic base shear ($V_b$) along any principal direction is determined by the following expression:

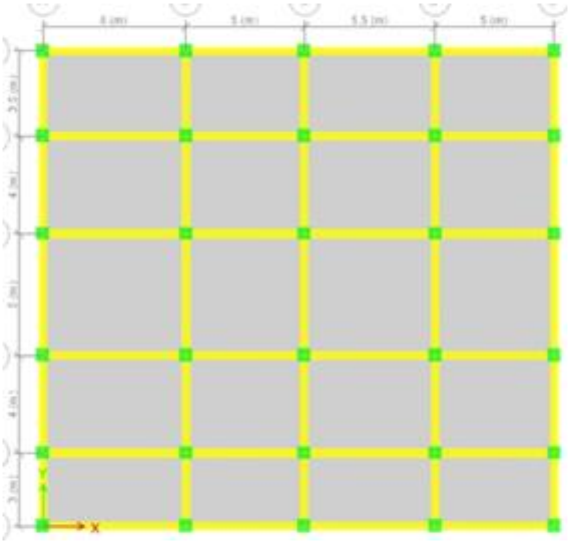
$V_b = A_h W$

Where W is the total seismic weight of the structure.

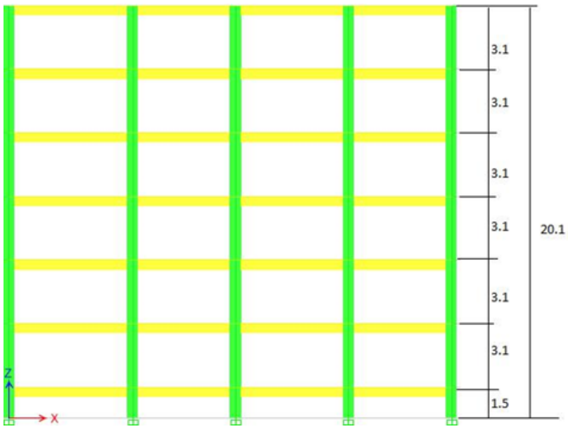
## REGULAR BUILDING



**3D View of Symmetrical Building**



**Plan of Symmetrical Building.**



Elevation of Symmetrical Building

**Loads Considered**

The following loads were considered for the analysis of the building. The loadswere taken in accordance with IS code.

- Live Load on Floors = 3.5 kN/$m^2$ (Imposed Load)
- Live Load on Roof = 1.5 kN/$m^2$
- Floor Finishes on Floor = 1 kN/$m^2$
- Roof Finishes on Roof = 1 kN/$m^2$

**Sectional Properties of Frame Elements**

The section properties of frame elements for basic structure are taken as follows:

- Beams = 300×500 mm
- Columns = 450×550 mm
- Thickness of Slab = 125 mm
- Thickness of External Wall = 230 mm
- Thickness of Internal Wall = 150 mm

**Calculation of Seismic Weight of Structure**

As per the code provisions, the percentage of design live load to be considered for the calculation of earthquake force is 25% for the floors if that load is less than 3kN/$m^2$, 50% for load is more than 3kN/$m^2$. And no live load needs to be considered for the roof.

**1. Roof Seismic Weight:** Slab Load = [ (21.5×19.5) × 25 + (1×1) + (1.5 × 0.25) ] = 1311.531 kN

Parapet Wall = { [ (2×21.5) + (2×19.5) ] ×0.23} × 20 × (_______) = 480.93 kN

Lateral Directions Beams = [ (6+5+5.5+5) ×6 ] × (0.5×0.3) × 25 = 483.75 kN Transverse Direction Beams = [ (19.5×5) × (0.5×0.3) ×25 ] = 365.625 kN

Columns = (0.55×0.45×25) ×30×______) = 236.67 kN

Total Load on Roof = 2878.506 kN

**2. Weight of Storey (6,5,4,3,2):**Slab = [(21.5×19.5) ×0.125×25]+(1×1)+(3.5×0.5) =1312.9 kN

Internal Wall = [(4×21.5 +3×19.5) ×0.15×20] × (3.1-0.55) = 1105.4 kN External Wall = [2× (21.5 + 19.5) ×0.23×20] × (3.1-0.55) = 961.86 kN Lateral Direction Beams = 483.75 kN

Transverse Direction = 365.625 kN

Columns = 2×236.67 = 473.34 kN Total Load on Storey = 4702.875 kN

3. **Ground Floor:**

Slab = 1312.9 kN

Internal wall = -----= 552.7 kN

External Wall = -----= 480.93 kN

Lateral Direction Beams = 483.75 kN

Transverse Direction = 365.625 kN

Columns = 236.67 kN

Total Load on Ground floor = 3432.575 kN

**Load Details**

| | Dead Load | Live Load | Total Load |
|---|---|---|---|
| **Storey** | **(kN)** | **(kN)** | **(kN)** |
| 7 | 2878.13 | 0.375 | 2878.51 |
| 6 | 4701.13 | 1.75 | 4702.88 |
| 5 | 4701.13 | 1.75 | 4702.88 |
| 4 | 4701.13 | 1.75 | 4702.88 |
| 3 | 4701.13 | 1.75 | 4702.88 |
| 2 | 4701.13 | 1.75 | 4702.88 |
| 1 | 3430.83 | 1.75 | 3432.58 |
| **Total Load** | **29814.9** | **10.875** | **29825.5** |

**Load Combinations :** As per (IS 1893 (Part 1) : 2002, clause 6.3.1.2)

1.5 (D.L + L.L) = 44738.184 kN

1.2 (D.L + L.L + E.$Q_X$) = 35790.54 kN 0.9 D.L + 1.5 E.$Q_X$ = 26833.12 kN

1.5 (D.L + E.$Q_X$) = 44721.87 kN

**Seismic Specifications and Calculation of Base Shear**

Zone Factor (Z) = 0.36

Importance Factor (I) = 1.5

Response Reduction Factor (R) = 5

Time Period (T) = = 0.4096 sec

Medium soil $S_a/g$ = 2.5

Horizontal Seismic Coefficient (Ah) =----------= 0.135

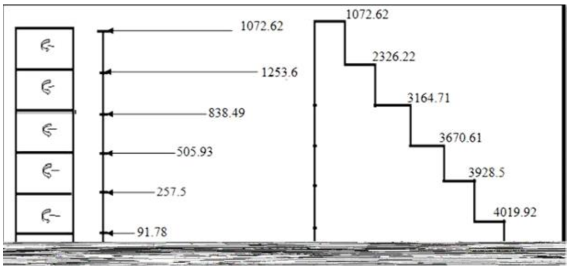
Base hear $V_b$ = (0.135× 29825.456) = 4026.4 kN

## Design Lateral Force

$$Q_i = \frac{V_h W_i h_i^2}{\Sigma W_i h_i^2}$$

### Calculation of Lateral Loads and Base Shear

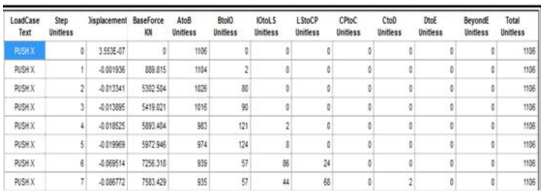
| | Wi | hi | Wi hi2 | $\frac{W_i h_i^2}{\Sigma W_i h_{i2}}$ | Qi | Vb |
|---|---|---|---|---|---|---|
| | (kN) | (m) | $\times 10^3$ | | (kN) | (kN) |
| 7 | 2878.51 | 20.1 | 1162.94 | 0.266 | 1071.62 | 1072.62 |
| 6 | 4702.88 | 17 | 1359.13 | 0.311 | 1253.6 | 2326.22 |
| 5 | 4702.88 | 13.9 | 908.64 | 0.208 | 838.49 | 3164.71 |
| 4 | 4702.88 | 10.8 | 548.54 | 0.125 | 505.93 | 3670.61 |
| 3 | 4702.88 | 7.7 | 278.83 | 0.06 | 257.5 | 3928.51 |
| 2 | 4702.88 | 4.6 | 99.51 | 0.02 | 91.78 | 4019.92 |
| 1 | 3432.27 | 1.5 | 7.723 | 1.76 $\times 10^3$ | 7.18 | 4026.9 |



(a) Lumped Mass Diagram, (b) Applied Inverted Triangular Loading, (c) Base Shear.

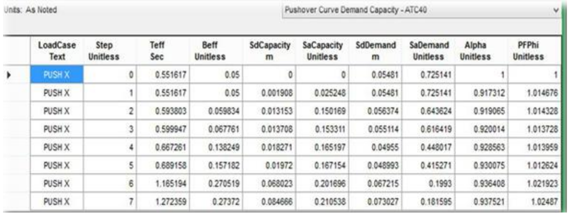

Static Nonlinear Case: PUSH X
Plot Type: Resultant Base Shear vs Monitored Displacement
Units: KN, m, C
Current Plot Parameters: VDPO1

Pushover Curve for Basic Structure



| LoadCase Text | Step Unitless | Displacement | BaseForce KN | AtoB Unitless | BtoIO Unitless | IOtoLS Unitless | LStoCP Unitless | CPtoC Unitless | CtoD Unitless | DtoE Unitless | BeyondE Unitless | Total Unitless |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PUSH X | 0 | 3.553E-07 | 0 | 1106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 1 | -0.001936 | 889.815 | 1104 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 2 | -0.013341 | 5302.504 | 1026 | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 3 | -0.013895 | 5419.021 | 1016 | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 4 | -0.018525 | 5893.404 | 983 | 121 | 2 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 5 | -0.019969 | 5972.946 | 974 | 124 | 8 | 0 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 6 | -0.069514 | 7256.318 | 939 | 57 | 86 | 24 | 0 | 0 | 0 | 0 | 1106 |
| PUSH X | 7 | -0.086772 | 7583.429 | 935 | 57 | 44 | 68 | 0 | 2 | 0 | 0 | 1106 |

Capacity Spectrum Curve for Basic Structures


Units: As Noted
Pushover Curve Demand Capacity - ATC40

| LoadCase Text | Step Unitless | Teff Sec | Beff Unitless | SdCapacity m | SaCapacity Unitless | SdDemand m | SaDemand Unitless | Alpha Unitless | PFPhi Unitless |
|---|---|---|---|---|---|---|---|---|---|
| PUSH X | 0 | 0.551617 | 0.05 | 0 | 0 | 0.05481 | 0.725141 | 1 | 1 |
| PUSH X | 1 | 0.551617 | 0.05 | 0.001908 | 0.025248 | 0.05481 | 0.725141 | 0.917312 | 1.014676 |
| PUSH X | 2 | 0.593803 | 0.059834 | 0.013153 | 0.150169 | 0.056374 | 0.643624 | 0.919065 | 1.014328 |
| PUSH X | 3 | 0.599947 | 0.067761 | 0.013708 | 0.153311 | 0.055114 | 0.616419 | 0.920014 | 1.013728 |
| PUSH X | 4 | 0.667261 | 0.138249 | 0.018271 | 0.165197 | 0.04955 | 0.448017 | 0.928563 | 1.013959 |
| PUSH X | 5 | 0.689158 | 0.157182 | 0.01972 | 0.167154 | 0.048993 | 0.415271 | 0.930075 | 1.012624 |
| PUSH X | 6 | 1.165194 | 0.270519 | 0.068023 | 0.201696 | 0.067215 | 0.1993 | 0.936408 | 1.021923 |
| PUSH X | 7 | 1.272359 | 0.27372 | 0.084666 | 0.210538 | 0.073027 | 0.181595 | 0.937521 | 1.02487 |

Capacity Spectrum Curve Data for Basic Structures

### Comparison of Performance Properties

| Particulars | Basic Structure | Case 1 | Case 2 | Case 3 | Remarks |
|---|---|---|---|---|---|
| Roof Displacement (mm) | 61.4 | 45.1 | 21.2 | 28.7 | Increase in size of frame elements in case 2 and Insertion of shear wall as in case 3 increases the performance of the building with sufficient decrease in roof displacement. |
| % change in Roof Displacement | - | -26.54 | -65.47 | -53.25 | |
| Maximum Base Shear * (kN) | 5767.016 | 10355.812 | 14350.635 | 417382.284 | |
| Lateral Drift Ratio (LDR) Δ/H | 0.00305 | 0.00224 | 0.00212 | 0.00105 | |
| Acceptable LDR | 0.025 | 0.025 | 0.025 | 0.025 | |
| Performance Point ( Base Shear (kN), Displacement (mm)) | (5567.833, 66) | (8791.366, 45) | (11140.129, 37) | (29852.33, 2.6e-3) | |

### Performance Based Design

### Target Roof Lateral Displacement Ratios at Various Performance Levels

| Performance level | Operational | Immediate Occupancy | Life-Safety | Collapse Prevention |
|---|---|---|---|---|
| Lateral Drift ratio (δ/h) % | 0.37 | 0.7 | 2.0 | 4 |

Where, δ is Lateral Roof Displacement and, h is the total height of the Building

Performance based design objective for MCE is met by the above case and they are listed below.

Case 1 – Increasing reinforcement for various frame elements.

Case 2 – Increasing the size of beams and columns along with their reinforcement. Case 3 – introducing shear wall

The performance objective for DBE is met after performing various iterations and performance level, (after performing Pushover Analysis) lies in Immediate Occupancy level i.e., roof displacement of building is 0.7% of total height of building.

Target Roof Displacement = 0.007 × 20.1 = 0.1407m = 140.7mm

The maximum roof displacement obtained after pushover analysis for case: Case 1 less than the target roof displacement (140.7mm). Design thus obtained is subjected to DBE (Design Basis Earthquake) so that the structural damage is limited to Grade 2 (slight structural damage, moderate non – structural damage) in order to ensure Immediate Occupancy.

If in case any of the above cases exceeds the target roof displacement (140.7mm) the design thus obtained is subjected to triangular loading corresponding to MCE (Maximum Considered Earthquake) so that the structural damage is limited to Grade 3 (moderate structural damage, heavy non – structural damage) in order to ensure Life Safety i.e., roof displacement of building is 2.0% of total height of the building.

New Target Roof Displacement for M.C.E = 0.02 × 20.1 = 0.402m = 402 mm

Then the design horizontal seismic coefficient $A_h$ for a structure under MCE is determined by the following expressions:

$$(A_h) = \frac{}{}\,\frac{}{}\,\frac{}{} = 2 \times 0.135 = 0.27$$

This is two times as that for DBE. Hence the triangular loading obtained.

The shear is 3024.3 × 2 = 6048.6 kN.

## CONCLUSION

The principle advantage of the performance Based Seismic Engineering (PBSE) is that the choice of performance goals lies within the owner who can decide the acceptable damage state. The engineer can also convey to the owner a better understanding of the expected damage state. PBSE does not eliminate the risks associated with uncertainties in ground motions, material properties, element behaviour or geotechnical properties. However, it provides a new technique to remove unnecessary conservatism for same parameter and discover unidentified deficiencies for others. If implemented correctly and competently, PBSE can produce a design that is more reliable than traditional procedures. One very useful characteristic of the ATC – 40 and FEMA 273/356 documents is that they provide a step by step approach for PBSE. This is an important first step towards a building code implementation of performance based design.

Based on the present study the following conclusions can be drawn

1. The performance objective for both the buildings (regular, irregular) is achieved when the size of beams and columns is increased with reinforcement (case 2) and when introducing the shear wall (case 3) for both regular and irregular.
2. Damaged control is within Grade II, Lateral roof displacement (21.2 in case 2 and 28.7 in case 3 both cases are less than 140.7 mm in irregular structure) and inter storey drift ratio are within limit (0.01 for case 2 and case 3).
3. In both regular and irregular buildings, only change in reinforcement in beams and columns are not enough to increase their performance. A suitable combination of increasing reinforcement is necessary for achieving performance point.
4. The performance based seismic design obtained by above procedure satisfies the acceptance criteria for immediate occupancy and life safety limit states for various intensities of earthquakes.

Thus it is conformed that performance based seismic design gives a structure with better seismic load carrying capacity, thereby achieving the objective of performance as well as economy and there is certainly room for further improvement in the above mentioned method.

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