PUSHOVER ANALYSIS OF RC BUILDING: COMPARATIVE STUDY ON SEISMIC ZONES OF INDIA

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ABSTRACT
Non-linear analysis is necessary to evaluate the seismic demand of the proposed or existing structure, as linear analysis is inadequate in assessing the seismic demand under severe earthquakes. In this article non-linear static analysis (pushover analysis) has been done to understand the behavior of G+9 multistoried residential building located in different seismic zones (II, III, IV, V) of India having similar geometrical properties using SAP2000. The behavior of multistoried building has been investigated in terms of force-displacement relationships, inelastic behavior of structure and sequential hinge formations etc. Plastic hinge formation gives real behavior of the structure. From the analysis results, it was observed that, when the zone varies from II to V, base shear, displacement and time period has been increased gradually, indicating the severity of seismic activity. In this analysis, firstly hinges were formed in beams and then in columns at ground floor of structure. The hinge formation propagates from ground floor to middle floor columns and then finally to the upper floor columns. The propagation of hinges from lower stories to upper stories leads to collapse of structure. Results indicate that, the damage in a building is limited and columns at the lower stories can be retrofitted based on the importance of the structure.

Key words: Non-Linear Analysis, Seismic Zones, Seismic Demand, Plastic Hinge, Inelastic Behavior.

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1. INTRODUCTION
Most of the structures are vulnerable to lateral loads, especially to seismic loads which are dynamic in nature and highly unpredictable. Past earthquakes also show that many structures susceptible to seismic loads are collapsed and damaged severely. Future earthquakes are unavoidable as 60% of land area is susceptible to seismic hazards in India. Safe design practices and quality control in construction can decrease the damage of life and property. Earthquake analysis and design principles are developed due to the earthquake consequences and damage of the structures. Earthquake analysis methods are divided into following four categories:

- Seismic coefficient method (Equivalent linear static analysis)
- Response spectrum method (Linear dynamic analysis)
- Pushover method (Non-linear static analysis)
- Time history analysis (Non-linear dynamic analysis)

Linear static analysis or seismic coefficient method is a conventional elastic design method which doesn't give realistic values when the earthquake is severe. Non-linear analysis is necessary to capture the response of structures under moderate to extreme earthquakes. Non-linear dynamic analysis (Time history analysis) requires site specific ground motion studies. The evaluations of dynamic earthquake parameters are inevitable and on the other hand it is computational, complex, time consuming and not feasible for most of the practical applications.

Pushover method of analysis can be used for proposed or existing building to evaluate the performance in terms of seismic or lateral forces and deformation demands. This method is widely adopted for its proportionality nature with the concepts of Performance Based Seismic Design (PBSD) [1]. Therefore, pushover analysis is a practical means of PBSD. High level analysis procedures are required to design the structure according to PBSD. Recent seismic design codes and guidelines give the design procedures for nonlinear and dynamic analysis [2-4]. Pushover analysis considers inelastic response characteristics and it can be used to estimate the seismic demands imposed on the structure during seismic excitation. Inelastic or Non-linear behavior of structure during seismic excitation is directly addressed by the pushover analysis.

Non-linear static procedures (NSP) can be applied to structures in many methods, which are Capacity Spectrum Method (CSM) [2], Displacement Coefficient Method (DCM) [3] and Modal Pushover Analysis (MPA) [5]. Minor changes in the analytical procedures had been applied by many researchers [6, 7]. The performance, yielding effects and the accuracy in applying pushover analysis to RC structures are captured, analyzed and studied. Structural Analysis Program, SAP2000 manual [8] explains the basic and the complete set of modeling and analysis features. This manual also helps in understanding the assumptions and procedures used in SAP2000. IS 1893 (Part 1): 2002 [9] is the important code generally used in seismic design. IS 1893 code provides the important information like zone factor, soil properties and importance of the building based on the location which intern helps in calculating the seismic coefficient of the structure. It also provides the empirical expressions in estimating the fundamental natural period based on the type of building.

2. BUILDING MODELLING, ANALYSIS AND DESIGN
A G+9 reinforced concrete building is modelled, analysed and studied. The study is carried out in all the seismic zones of India and conclusions are drawn. The input data required for the design of G+9 building are presented in the tables below. Table 1 show the building details such as plan size, total height of the building, floor height and location details such as zone, soil type etc. The factors such as importance factor, response reduction factor values are taken
from IS 1893 (Part 1): 2002. Table 2 shows the material properties and section properties. Table 3 shows the loading details on the building for designing.

**Table 1** General building and location details

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan size</td>
<td>20 × 20</td>
</tr>
<tr>
<td>Building height</td>
<td>31m</td>
</tr>
<tr>
<td>Type of structure</td>
<td>Multi storey RC frame (G+9)</td>
</tr>
<tr>
<td>Zone</td>
<td>All Seismic Zones of India (i.e., Zone II, III, IV, V)</td>
</tr>
<tr>
<td>Soil type</td>
<td>Type II (medium soil)</td>
</tr>
<tr>
<td>Damping</td>
<td>5%</td>
</tr>
<tr>
<td>Storey height</td>
<td>Ground floor 4m, remaining floors 3m.</td>
</tr>
<tr>
<td>Bay width</td>
<td>4m</td>
</tr>
<tr>
<td>Bays in x and y directions</td>
<td>5</td>
</tr>
<tr>
<td>Support Conditions</td>
<td>Fixed</td>
</tr>
<tr>
<td>Importance Factor, I</td>
<td>1</td>
</tr>
<tr>
<td>Response Reduction Factor, R</td>
<td>5 (SMRF)</td>
</tr>
</tbody>
</table>

**Table 2** Details of materials and section properties

<table>
<thead>
<tr>
<th>Part</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam</td>
<td>300mm×600mm</td>
</tr>
<tr>
<td>Column</td>
<td>600mm×600mm</td>
</tr>
<tr>
<td>Slab</td>
<td>125mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>$f_{ck} = 25$ MPa, Density = 25 kN/m$^3$</td>
</tr>
<tr>
<td>Steel</td>
<td>$f_{y} = 415$ MPa</td>
</tr>
<tr>
<td>Brick</td>
<td>Density = 20 kN/m$^3$</td>
</tr>
</tbody>
</table>

**Table 3** Loading details for the design

<table>
<thead>
<tr>
<th>Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imposed load</td>
<td>3.0 kN/m$^2$</td>
</tr>
<tr>
<td>Floor finishes load</td>
<td>1.0kN/m$^2$</td>
</tr>
<tr>
<td>Wall load on beams</td>
<td>18.5 kN/m</td>
</tr>
<tr>
<td>Equivalent lateral loads</td>
<td>According to IS 1893 (Part I):2002 [12]</td>
</tr>
</tbody>
</table>

3 PUSHER ANALYSIS

A lateral load of certain shape is applied on the created modal and analysed. The shape of the lateral load may be inverted triangular, parabolic or uniform. Building is pushed in one horizontal direction and the behaviour of the building is studied in the form of top deflection. The lateral load intensity is gradually increased in a controlled manner such that plastic hinges formation and failures in structural elements are recorded. Proportion of applied force on each floor is constant, only its magnitude is increased gradually.

3.1. PUSHER ANALYSIS PROCEDURE

1. Create a 3D model by defining and assigning the material properties and frame sections such as beams, columns, and slab. Fig. 1. Shows building modal details such as (a) plan, (b) elevation and (c) isometric view of the reinforced concrete structure.
2. Assign end (length) offsets, insertion point, diaphragms to the considered building. Fig. 2 shows the plan with end offsets and Fig. 3 shows the 3D geometric modal with insertion point on the top centre.

**Figure 1** Building Modal Details
3. Define and assign the load cases such as dead, live, floor finishes, wall, earthquake loads and modify them as per IS 1893:2002.

4. Load combinations are defined as per Indian code IS 456-2000 and linear static analysis is carried initially.

5. After linear static analysis we have to assign two load cases. Firstly gravity load case then pushover load case is assigned to the structure.

6. As explained in FEMA-356 and as per ATC-40, SAP 2000 provides default hinge properties such that for beams shear ($V_2$) and flexural ($M_3$) hinge and for columns axial force and bending moments ($P, M_2, M_3$).

7. Finally non-linear static or pushover analysis is carried out and the results were obtained in the form of capacity curve (pushover curve), demand curve and performance point.

### 3.2. HINGE FORMATION

Under pushover load or incrementally increased lateral loads, gradual yielding of structural elements would occur. Yield in structural elements experience a change in stiffness of structure as shown in Fig. 4. Plastic hinge (yielding) formation sequence in the structural elements can be studied by this force deflection curve. Fig. 4 shows the structure behaviour based on the hinge formations in beams and columns. The points shown in the Fig. 4 explains different states. If the hinge is formed in between A to B then the hinge is in elastic state. The structure remains elastic from A to B. If the hinge is formed in between B to IO then it is below immediate occupancy state. At this state, the structure can be occupied immediately with minor non-structural element repair works. Structural elements did not fail. If hinge is formed in between IO (Immediate Occupancy) to LS (Life Safety) then the life of the structure is safe but repair works are to be done and rehabilitation methods are applied if necessary. If the hinges are formed in between LS (Life Safety) to CP (Collapse Prevention) then the structural elements are damaged but structure won’t collapse. At this state building needs rehabilitation works and sometimes retrofitting methods should be implemented based on the level of failure. If the hinges are formed in between CP (Collapse Prevention) to C (Ultimate Capacity) then the structure crosses its ultimate strength. At point B, yielding starts and structure enters into non-linear range. If hinge is in between C (ultimate capacity) to D (residual strength) then the structural elements drop the load and there is reduction in load carrying capacity. The load carrying capacity of structure increases from point B to C and then suddenly drops to D. If the hinge falls at D or beyond D then there will be no increase in load carrying capacity, however...
the structure continues to deform. If the hinges are formed beyond the E, then the structure will collapse [10].

![Force - Displacement curve](image)

**Fig. 4** Force - Displacement curve

(Habibullah and Stephen, 1998)

### 3.3. EVALUATION OF PERFORMANCE POINT

The final outputs of the analysis are in terms of demand and capacity (pushover) curves. The intersection point of both the curves is called performance point. If the performance point is near the elastic range, then the structure is safe and it offers good resistance with lot of reserve strength as shown in Fig. 5(a). If the performance point is away from the elastic or linear range then the structure remains with very little reserve strength as shown in Fig. 5(b) and behaves very poor when the seismic loads are imposed on the structure. Retrofitting methods are to be implemented to avoid the major damages and sudden collapse in a structure [11].

![Safe design vs Unsafe design](image)

**Figure 5** (Kadid and Boumrkik, 2008)

### 4. RESULTS AND DISCUSSIONS

Figs. 6 through 9 shows, the comparison of performance point in all the zones (zone II to V) for the considered building. Performance point is explained in the form of Spectral displacement Vs Spectral acceleration graphs. Performance point gives the global behaviour of the building. The results will obtain in the form of capacity and demand curves. Formation of plastic hinges gives real behaviour of structure and their elements. Capacity curve was shown in green colour where as demand curve was shown in black colour. The intersecting point of both the curves gives performance point. Hinges are mostly formed in beams and very few are
formed in columns which follow the weak beam and strong column concept. The performance point changes from LINEARITY to IO to LS level as zone considerations from ZONE II to ZONE V.

**Figure 6** Spectral Acceleration Vs Spectral Displacement (Zone – II)

**Figure 7** Spectral Acceleration Vs. Spectral Displacement (Zone – III)
4.1. COMPARISON OF RESULTS

Performance of the structure with respect to the performance points is compared in terms of maximum base shear and total lateral displacement. Fig. 13 shows the comparison of maximum base shear and total lateral displacements. Remaining parameters like time periods, damping ratios, spectral acceleration and spectral displacement are also compared in all the zones. Table 4 shows the different parameters considered and their analysis results in different zones. Fig. 10 is a graph showing the comparative results for base shear in all the seismic zones of India. From Fig.10 we can say that as the seismic zone increases from II to V, base shear also increases. The variation of maximum lateral displacements with the variation of seismic zones
was shown in Fig 11 and the maximum time periods for all the considered seismic zones were shown in Fig.12.

Table 4 Comparison of Performance Parameters

<table>
<thead>
<tr>
<th>Indian Seismic Zone</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral acceleration (m/sec²)</td>
<td>0.085</td>
<td>0.122</td>
<td>0.143</td>
<td>0.158</td>
</tr>
<tr>
<td>Spectral displacement (m)</td>
<td>0.013</td>
<td>0.020</td>
<td>0.028</td>
<td>0.044</td>
</tr>
<tr>
<td>Damping ratio</td>
<td>0.050</td>
<td>0.069</td>
<td>0.120</td>
<td>0.152</td>
</tr>
<tr>
<td>Base shear (kN)</td>
<td>2257.479</td>
<td>3242.988</td>
<td>3872.402</td>
<td>4346.706</td>
</tr>
<tr>
<td>Time period (sec)</td>
<td>0.796</td>
<td>0.821</td>
<td>0.892</td>
<td>1.009</td>
</tr>
<tr>
<td>Displacement (m)</td>
<td>0.017</td>
<td>0.026</td>
<td>0.035</td>
<td>0.054</td>
</tr>
</tbody>
</table>

Figure 10 Comparison of maximum base shear of different zones

Figure 11 Comparison of maximum displacement of different zones

Figure 12 Comparison of maximum time period of different zones

Figure 13 Comparison of maximum base shear and maximum displacement

Structural behaviour was explained based on the sequence of formation of hinges. Hinge formation in a building of different zones has been obtained and observed. Figs. 14, 15, and 16 reveal the hinge formation patterns. From the Figs. 14 through 16, it is observed that the hinge formation patterns are similar in all zones. At first plastic hinges were formed at beam ends and at base level of lower storey columns, then hinge formation propagates to middle and upper
stories. The yielding in the upper storey columns continues. Most of the hinges are formed at B, IO, and LS levels. For each zone hinge patterns at two stages were considered. One is at DBE (Design Based Earthquake) and other is at MCE (Maximum Considered Earthquake). Fig. 15 shows that for Zones III & IV the hinge formations at DBE, MCE are similar. From the results we can conclude that, the structure is very limitedly exposed to damage and the columns at the lower storey needed to be retrofit based on the importance of the building.

Figure 14 Hinge Patterns in the building at Zone – II

Figure 15 Hinge patterns in the building at Zone III & IV
5. CONCLUSIONS
The following conclusions are drawn from the non-linear static analysis:

1. As it go from zone II to V seismic demand increases.
2. Global behaviour of the structure is significant to resist the lateral loads but there are local failures in columns which are not desirable.
3. The performance point changes from LINEARITY to IO, to LS level as zone considered from ZONE II to ZONE V.
4. As the Seismic Zone changes from II to V total storey drift, maximum base shear and time periods are increased gradually.
5. The performance point for different zones are as follow:
   • Zone II, it is in linear state that is in between A to B.
   • Zone III, it is at point B.
   • Zone IV, it is beyond point B which is in nonlinear state.
   • Zone V, it is in nonlinear state which is near to IO level.
6. Observations from the analysis results show that all hinges formed in the structure are within collapse prevention (CP) level for the design based earthquake (DBE).
7. Finally results indicate that, the damage in building is limited and columns at the lower storey need to be retrofitted based on the importance of the structure.

REFERENCES


