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Innovative Approaches in Seismic Analysis and Design of Multi-Storey Buildings: Integrating Advanced Techniques and Sustainable Solutions

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Abstract: *Pushover analysis, additionally referred to as nonlinear static analysis or the capacity spectrum method, is a method for assessing structural seismic performance. It provides a simple yet effective method for assessing a building's behavior under lateral loads and estimating its capacity to withstand seismic forces. The structural system is subjected to a progressively increasing lateral load pattern in pushover analysis until a predefined displacement or failure criterion is reached. The analysis considers the structure's nonlinear behavior, allowing for the identification of potential weak points and the estimation of overall performance under seismic loads. It's important to note that pushover analysis is typically used for structures designed based on modern design codes that incorporate ductility and energy dissipation capacity. These structures are expected to exhibit ductile behavior during earthquakes, allowing them to absorb and dissipate seismic energy, thus reducing damage and ensuring occupant safety. The specific application of pushover analysis depends on the structural system, building code requirements, and project-specific considerations. Consulting with structural engineers and following the relevant design codes and guidelines is crucial for implementing pushover analysis effectively.*

Keywords: Multi-storey, Pushover analysis, Energy, Building

1. Introduction

The design of the buildings incorporates the resistance to dead load, live load, and seismic load. Following the guidelines specified in IS-456-2000, various load combinations were considered, and the most critical case was taken into account during the building design process.
Dead load primarily consists of the self-weight of the structure, including beams and columns. The self-weight calculations are performed using the STAAD.Pro software, considering the applied dimensions. Additionally, for a slab thickness of 130mm, the floor load is determined based on the unit weight of concrete, which is taken as 3.25 KN/m2. The load from brick infill is considered as a uniform force of 20 KN/m.

Structural Elements: Model the structural elements of the buildings, including columns, beams, slabs, and shear walls. Each element should be assigned with the appropriate section properties, such as dimensions and reinforcement details. Connection Details: Incorporate the connection details between structural elements, such as beam-column connections and slab-column connections. Proper modeling of these connections is important to capture the interaction and redistribution of forces during the pushover analysis. Model the structural elements in STAAD.Pro using appropriate section properties for columns, beams, slabs, and shear walls. Define the cross-sectional dimensions, reinforcement details, and section properties for each element.

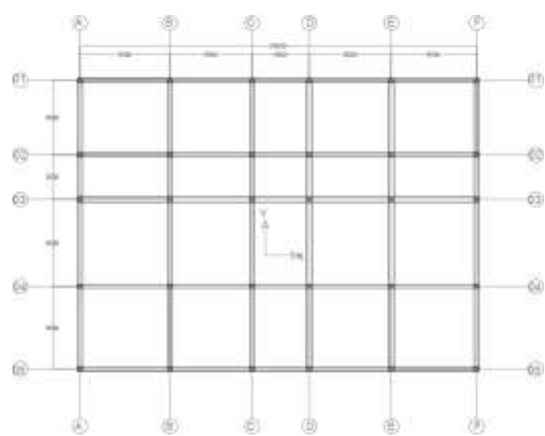

Figure 1.1 showing the plan the building

The building is 24.5n into 18.5m. Its area is 453.25m2 the beams dimensions are taken 300mmx450mm and for columns to be 450mmx450mm. However, for 22 Story building these sections were not adequate and the ground columns collapsed after performing pushover analysis.
So for the 22 story building new dimensions of beams and columns were selected: Beams: 600x800mm
Connection Details: Define the connection details between structural elements, such as beam-column connections and slab-column connections. Incorporate the appropriate connection properties, such as rotational stiffness and shear transfer capacity.
Boundary Conditions: Apply the boundary conditions to represent the support conditions of the buildings. Define fixed supports at the base or any other relevant supports based on the interaction with the foundation.

Seismic Loads: Apply seismic loads based on the design response spectrum for Zone IV. The loads can be determined using the relevant building codes and standards, considering the specific characteristics of the location and the buildings. Apply seismic loads based on the design response spectrum for Zone IV. Define the seismic load parameters in STAAD.Pro, including the peak ground acceleration, damping ratios, and time history data if available.

Seismic load Calculation for 5 story Building

Eight of a normal floor:
Length of floor = 24.5 m
Width of floor = 18.58 m
Thickness of floor = 0.15 m
Unit weight of floor material = 25 kN/m³
Weight of run of the mill floor = Length x Width x Thickness x Unit weight
= 24.5 m x 18.58 m x 0.15 m x 25 kN/m³
= 1700 kN

Weight, all things considered:

Number of bars in each floor = 5
Number of shafts in the rooftop = 6
Profundity of shaft = 0.3 m
Width of shaft = 0.45 m
Unit weight of shaft material = 25 kN/m³
Weight of all shafts = ((Number of pillars in each floor x Load of bar) + (Number of shafts in the rooftop x Load of bar))
= ((5 x 24.5 m + 6 x 18.5 m) x 0.3 m x 0.45 m x 25 kN/m³)
= 788 kN

Weight of sections in the principal floor:

Number of segments in the principal floor = 30
Length of segment = 4.2 m
Width of segment = 0.45 m
Profundity of segment = 0.45 m
Unit weight of section material = 25 kN/m³
Weight of sections in the primary floor = Number of segments in the main floor x Length x Width x Profundity x Unit weight
= 30 x 4.2 m x 0.45 m x 0.45 m x 25 kN/m³
= 638 kN

Weight of sections in different floors:
Number of sections in each floor (aside from the main floor) = 30
Length of section = 4 m
Width of section = 0.45 m

Profundity of section = 0.45 m
Unit weight of section material = 25 kN/m³
Weight of sections in different floors = Number of segments in each floor x Length x Width x Profundity x Unit weight
= 30 x 4 m x 0.45 m x 0.45 m x 25 kN/m³
= 607.5 kN

Table 1

item	**Quantity**	**Calculation**	**Weight (kN)**
Weight of typical floor	1	24.5 m x 18.58 m x 0.15 m x 25 kN/m³	1700
Weight of all beams	1	((5 x 24.5 m + 6 x 18.5 m) x 0.3 m x 0.45 m x 25 kN/m³)	788
Weight of columns in 1st floor	1	30 x 4.2 m x 0.45 m x 0.45 m x 25 kN/m³	638
Weight of columns in other floors	4	30 x 4 m x 0.45 m x 0.45 m x 25 kN/m³	607.5
Live load on a typical floor	0	24.5 m x 18.5 m x (3 kN/m² - 3 kN/m²) x 0.5	0
Weight of brick infill at 1st floor	1	(5 x 24.5 m + 6 x 18.5 m) x 4.2 m x 0.12 m x 20 kN/m³	2354
Weight of brick infill in other floors	4	(5 x 24.5 m + 6 x 18.5 m) x 4 m x 0.12 m x 20 kN/m³	2242

Loadings:
Apply gravity loads to represent the structure's self-weight as well as any additional dead and live loads. These loads must be distributed accurately in accordance with the building's design codes and standards. Using STAAD.Pro's loading capabilities, apply gravity loads to the structure. Define the structure's self-weight, as well as any additional dead and live loads required by the design.

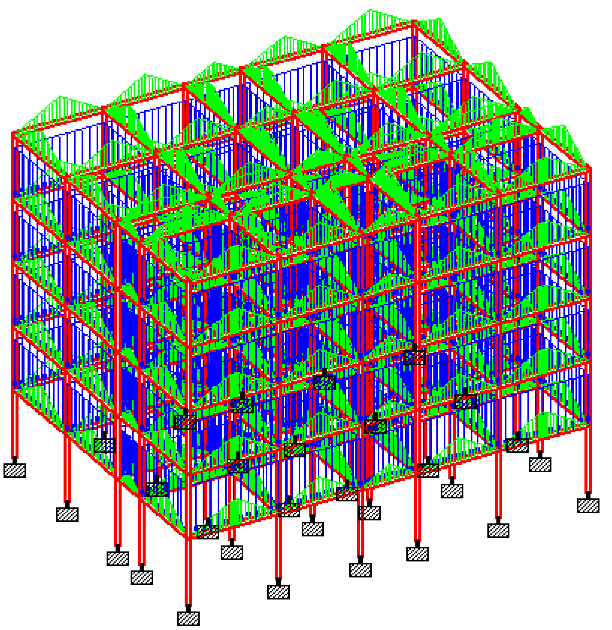

Figure 2 demonstrating the impact of the block infill load on the beams

With a concrete slab thickness of 130mm, the floor load is calculated as follows, and the figure below depicts the structure with the implemented floor load.
$0.13*25=3.25KN/m^2$

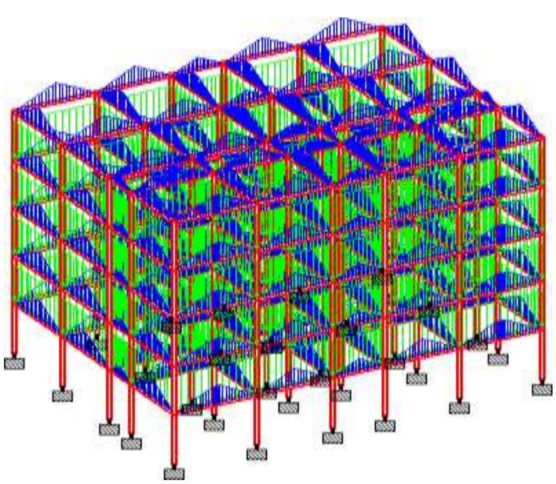

Figure 3 demonstrating the impact of the floor weight on the concrete slabs

The live load on the roof was 3KN/m2 and the remaining floors were 4KN/m2. The graphical representations below depict the structure's live load.

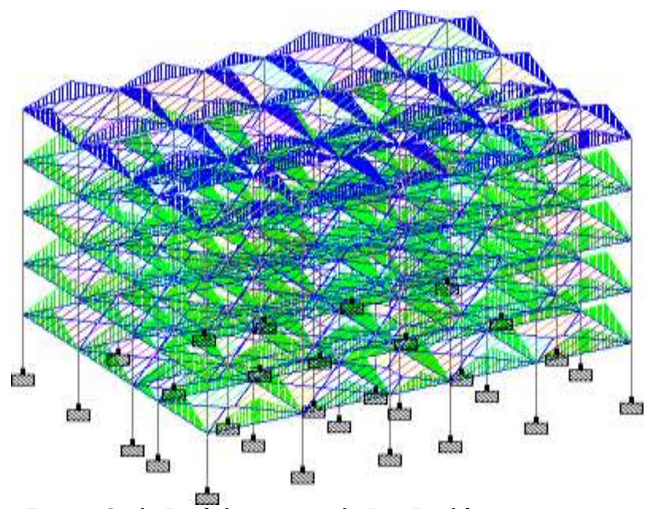

Figure 4 On the Roof, demonstrates the Live Load functioning

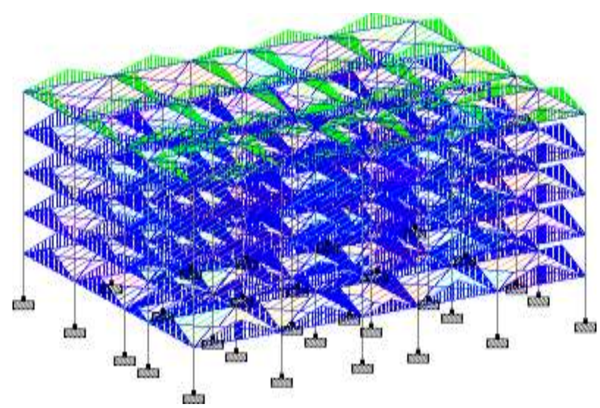

Figure 5 illustrates the live Load acting from 1^{st} floor to the 4^{th}

The information below are from STAAD Pro after section characteristics and loads have been tasked them with:

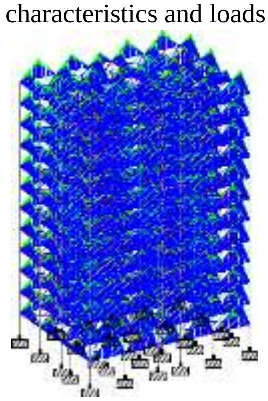

Figure 6 demonstrating live load functioning building

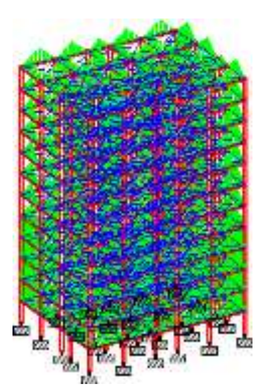

Figure 7 display self-weight on 12 level structure on 12 story

2. Performance Based Evaluation

The pushover analysis methodology is widely used to define the displacement-based response of non-linear structures. It is commonly used in seismic performance evaluation because it provides an accurate estimate of the structure's capacity.

Pushover analysis entails applying lateral loads to the structure in a step-by-step fashion. These loads cause plastic hinges to form at critical sections, resulting in force redistribution and the formation of failure mechanisms. This procedure establishes a non-linear relationship between the applied lateral force and the structure's deformation, which is typically represented by a capacity curve. The capacity curve depicts the base shear (lateral force) versus roof displacement and illustrates the structure's load-carrying capacity before failure.

It is critical to note that the design base shear, as determined by seismic design codes such as IS 1893, should always be less than the base shear obtained from the pushover curve. This ensures a sufficient safety factor and that the structure is designed to withstand anticipated loading conditions.

The performance objectives in seismic design can vary depending on economic factors and the sensitivity of the structure. The European code FEMA 356 includes recommendations for performance goals such as.

1. Life Safety under Design Basis Earthquake (DBE): During the seismic event taken into account in the building's design basis, the structure should maintain its integrity and ensure the safety of the occupants.
2. Maximum Considered Earthquake (MCE) Collapse Prevention: The structure should have enough capacity to prevent collapse and maintain stability during a more severe earthquake, known as the maximum considered earthquake.

2.1 The following are the objectives of performance-based evaluation in structural engineering:

1. Safety: Ensuring occupant safety and reducing the risk of structural failure during extreme events such as earthquakes, windstorms, or other hazardous conditions.
2. Assessing: structural reliability and robustness by evaluating the structure's ability to resist loads and maintain its integrity under various scenarios.
3. Evaluating: the structure's functionality and operational capability during and after a disruptive event to ensure it can continue to serve its intended purpose.
4. Damage: limitation is the process of limiting the extent and severity of structural damage in order to prevent progressive collapse and reduce the need for expensive repairs or reconstruction.
5. Resilience: Increasing the structure's ability to withstand and recover from extreme events, reducing downtime and facilitating a quick return to routine.
6. Cost-effectiveness: Enhancing design and retrofitting strategies to achieve the desired level of performance within practical cost constraints, taking into account the trade-off between the initial expenditure and future advantages.
7. Sustainability: integrating aspects of sustainability into the design and assessment process, such as reducing environmental impact and resource consumption.
8. Code Compliance: Ensuring that relevant construction rules, norms, and guidelines are followed in order to meet the minimum safety requirements and ensure that the structure meets the specified performance criteria.

2.2 Performance based design versus Force based design

In the field of structural engineering, two distinct methods—force-based design and performance-based design—are employed to guarantee the performance and safety of structures, particularly in the context of seismic design. Let's examine each strategy in greater detail:

Force-Based Design:

1. Relies on specific design criteria and code provisions.
2. Focuses on meeting predetermined force levels based on code requirements.
3. Assumes simplified linear elastic behavior of the structure.
4. Ensures minimum safety requirements and provides a reasonable level of protection.
5. May not capture the true behavior and response of structures under severe or unusual loading conditions.
6. Provides a straightforward and widely adopted method for structural design.

Performance-Based Design:

1. Takes a comprehensive approach to structural design.
2. Evaluates the behavior and response of the structure using advanced analysis techniques.
3. Considers non-linear effects, material behavior, and component interaction.
4. Aims to achieve desired performance objectives

under different seismic events.

5. Allows for a tailored design approach based on the specific characteristics of the structure.
6. Enhances resilience, optimizes design, and reduces the potential for unexpected damage.
7. Requires a more detailed understanding of the structure's behavior and advanced analysis techniques.
8. Involves a collaborative design process and coordination between stakeholders.

The choice between force-based design and performance-based design depends on project requirements, design complexity, desired performance levels, and available resources and expertise.

3. The Results of the Pushover Analysis

3.1 Overview

Pushover Analysis was used on the 5, 12, and 22 storey structures that were developed. Each of the structural elements, including the beams, columns, slabs, and brick infill, was given the proper self-weight. The load combinations were used in accordance with the requirements stated in IS 1893-2002. Up until the moment of collapse, the structures were gradually subjected to lateral stresses. The research produced a number of curves, which are succinctly explained here to emphasise their importance.
To comprehend the structural behaviour under lateral stresses, many curves were created. These curves offer important information on how the building reacts to and performs during seismic occurrences. Let's examine the important curves that the study produced.
The capacity curve, commonly referred to as the pushover curve, is a graph showing the relationship between base shear and roof displacement. It depicts the building's ability to withstand lateral stresses and demonstrates how the structure reacts as displacement rises. The curve represents the greatest force that a structure can bear before failing.

The Pushover Curve plots the lateral force acting on the structure against the displacement of the roof. It demonstrates the gradual buildup of force as the structure is pushed laterally. At crucial points, plastic hinges form, and the pressures progressively redistribute, developing the collapse process.
Drift Curve: The Drift Curve depicts the lateral displacement of each floor with respect to the base or the story drift. It displays the building's deformation pattern as lateral stresses increase. The curve detects possible trouble spots and assesses the building's deformation performance.

3.2 G+4 RCC Building's Pushover analysis

The Pushover curve, which depicts the connection between base shear and lateral displacement of the building, is shown in Figure 1. It is clear that the building is safe for the specified earthquake level since its base shear capacity is much larger than its design base shear.
The construction of plastic hinges in the building's 3D model is seen in Figures 2 and 3.
These hinges show the transfer of forces during the pushover analysis and appear at crucial portions.

Table 1 summarizes the key parameters of the performance point for the G+4 building.

1	Base shear	2679.179	(KN)
2	Spectral Acceleration, Sa	0.488	(m/s)
3	Effective time period, Teff	0.823	(s)
4	Roof displacement	0.108	(m)
5	Spectral displacement, Sd	0.082	(m)
6	Effective damping, βeff	0.189	

It includes the base shear, roof displacement, spectral acceleration (Sa), spectral displacement (Sd), effective time period (Teff), and effective damping (βeff). These values provide important insights into the building's response under seismic forces.
The total lateral force applied on the structure at the ultimate capacity point is represented as base shear (in KN). The base shear in this scenario is computed to be 2679.179 KN. This figure represents the maximum force that the structure can endure before deforming significantly.

Roof displacement (in metres): This is the horizontal displacement or distortion of the structure's roof. The reported value of 0.108 metres is the amount of movement experienced by the roof during the seismic event. This displacement is normally calculated in relation to the roof's initial location.

3.3 The G+11 RCC Structure's Pushover Analysis

The Pushover curve, as depicted in the illustration, depicts the connection between the building's base shear and lateral displacement. KN and metres are the units for base reaction and displacement, respectively. The highest measured node displacement is 0.43m.
According to the Pushover Curve, the building has a much larger base shear capability than the planned base

shear. The capacity derived from the plot is 4800KN, whereas the design base shear, marked as VB, was determined to be 4364KN. This signifies that the building's performance is adequate for the specified earthquake level.
In summary, the Pushover study shows that the building has a larger base shear capacity than the design requires. This signifies that the structure is well-prepared for

Table 2 summarizes the key parameters of the performance point for the G+11 building.

Base shear(KN)	4415.444
Spectral Acceleration, Sa (m/s)	0.14
Effective time period, Teff (s)	1.986
Roof displacement (m)	0.166
Spectral displacement, Sd (m)	0.137
Effective damping, βeff	0.17

4 Conclusions

Finally, the chat discussion shed light on the use of pushover analysis to assess the seismic performance of multi-story reinforced concrete buildings. The following are the important results and conclusions obtained from the discussion:

1. Pushover analysis appears to be a straightforward approach for analysing the response of the structure to earthquake stresses of both existing and new structures.
2. The study examined three separate RC structures and concluded that well-designed structures with suitable sections and strengthening elements that follow to standard codes perform better under seismic loads.
3. The structural simulation and evaluation approach began with designing the structure in STAAD Pro, which was then exported to SAP2000 for non-linear static analysis. Plastic hinges were assigned to the beams in accordance with FEMA 356 criteria.
4. The selected pushover analysis approach necessitated providing lateral pressures to the control node, which were computed after accounting for the columns at both ends. The building model was then examined and the results were discussed.
5. The materials employed in the structure of the building have a significant influence on the performance of pushover studies. Compliance with design rules, as well as suitable material selection, are crucial for achieving maximum seismic resistance.

5 Future Scope

The future scope of the research on "Seismic Analysis and Design Considerations for Multi-Storey Buildings: A Comprehensive Study" includes:
Investigation of advanced analysis techniques: Explore advanced analysis methods such as nonlinear time history analysis, performance-based design, or hybrid simulation to further enhance the understanding of the seismic behavior of multi-storey buildings.
Incorporation of soil-structure interaction: Consider the interaction between the building and the underlying soil to capture the realistic response of the structure under seismic forces. This would involve studying the soil properties, foundation design, and their influence on the overall building behavior

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