Pushover Analysis of RCC building with varying cross sectional area by considering Soil Structure Interaction

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Abstract

This study investigates the effect of increasing the cross-sectional area of structural members on the seismic performance of reinforced concrete (RC) buildings, with particular attention to soil-structure interaction (SSI). The objective is to improve structural behaviour during earthquakes by shifting plastic hinge formations from highly vulnerable zones to safer regions without the need for a complete redesign or advanced structural expertise.

Analyses were conducted on symmetrical mid-rise RC buildings under various soil conditions—fixed base, medium soil, and soft soil. Cross sectional area of structural members are increases from 5% to 20% at the interval of 5% to check hinge failure pattern of overall building. Results indicate that a 5% increase in the cross-sectional area of structural members effectively shifts hinge formations from the Collapse Prevention (CP) performance level to the Immediate Occupancy (IO) zone. The study concludes that a 20% increase in the cross-sectional area is optimal for enhancing seismic performance. The findings underscore the importance of considering SSI in performance-based design and offer a practical approach for improving the earthquake resistance of RC structures without extensive redesign. This work serves as a reference for engineers and researchers focusing on mid-rise RC buildings subjected to seismic forces and varying soil conditions.

Keywords: soil structure interaction, earthquake analysis, hinge formation, change in C/S area.

1. Introduction-

Losses from earthquakes have increased in recent years as compared with previous and the expected losses are significantly higher. It is widely accepted that the current seismic design process has to be modified. Performance-based analysis concepts have been included into a new generation of design and rehabilitation techniques established by the structural engineering community.

Structures are analysed and designed to sustain required seismic demand. Capacity is an combination of strength, stiffness of the structure and its material composition.

FEMA is releasing preliminary standards aimed at enhancing the earthquake resilience of both existing and new buildings. Pushover analysis also known as nonlinear static procedure, based on ATC-40 & FEMA-356 guidelines used by the structural engineering profession to simplify the earthquake analysis.

Capacity spectrum converts multi-story buildings into an equivalent single degree of freedom systems, it depends on performance of the building and it is plotted in the form of graph base share Vs displacement.

This study focused on building capacity by using performance-based analysis. Research is done on how well buildings perform when there is a risk of earthquakes. The structure is first subjected to push over analysis by using fixed based condition and then soil structure interaction cases are applied. This study also aims to determine performance point of the building and number of plastic hinge formations and it describes conditions.

This study deals with earthquake analysis of RC frame by considering fixed base as well as by considering soil structure interaction, various structures are analysed by using fixed base and flexible base conditions two cases for flexible base as soft, medium. For analysis purpose structures are consider as G+5to G+25 at the interval of 5 stories.

Earthquake analysis is done by using pushover analysis and various hinge failure pattern are observed as per zones viz. Collapse prevention zone, Life safety zone, immediate occupancy zone, Operational level zone. Base condition is of structure is very important parameter in case of earthquake analysis base condition as an flexible base gives more accurate results as compared with fixed base condition, so it is need to consider actual soil conditions as per site instead of directly considering fixed base.

Percentage of hinge formation goes on increasing from fixed base to medium soil and medium soil to soft soil, soil structure interaction gives accurate results in case of earthquake analysis as compared with fixed base condition. (4)

This paper says that 54% of Indian land are effected by earthquakes. In case of civil engineering, this phenomenon plays an important role. Structures are made earthquake resistant by incorporating shear wall, bracings, diaphragm and frames which helps to resist building motion. The installation of shear walls transfers earthquake forces very effectively and building can withstand during earthquake ground motion and lateral wind load without deformations.

This paper is on the non-linear static performance of Pushover analysis done by using ETAB software considering shear wall with door and window, openings and without openings on it. Analyse both the uncontrolled and controlled non-linear structural performance.

In this study it is founded that the base shear capacity of structure with shear wall having openings in zigzag manner is 4% lesser as compared with shear wall opening at middle, whereas the displacement demand is 40% more in zigzag manner openings compared with middle openings. (7)

The earthquake analysis of high rise RC building with varying floor are carried out by using pushover analysis, response reduction factor of each model compares with the IS code values. Various earthquake records is considered for modelling purpose and incorporated as per ASCE-16. Building models are analysed as 5, 10, 15 storied in ETAB software. The slab type and height of building depends as per response modification factors, for considered buildings.

Natural periods of floor are considerably different for the same stored buildings. Natural period increases as building heights increase. The flat slab gives highest natural period values and solid slab gives the lowest natural period values. The floor system remarkably changes the seismic base shear coefficient, irrespective of the building height. Different slab systems had different displacement and drift values. Highest displacement is observed in floors having beams without drop in hollow block and flat. This study majorly focused on three type flat slab, solid slab and hollow blocks. (11)

The 4 X 5 bay RC frame is examined for seismic activity. In the combination of seismic hazard and inelastic structural analysis we can find out seismic performance of a structure. Pushover analysis carried out for force-controlled (brittle) and deformation-controlled (ductile) methods to analyse the plastic hinges from pushover curve.

This study shows that considerable yielding in various beams with variable plastic hinge length can sustain in earthquake forces. The plastic hinge, resulting from its brittleness, categorized it in the most critical group when various options for its length behaviour were evaluated during the pushover analysis. In ductile behaviour, structural elements absorb energy in a way that is markedly different from the brittle behaviour observed in the plastic hinge model, and this energy absorption decreases as brittleness increases. (10)

This study shows Seismic Rehabilitation of Buildings and new static push-over analysis algorithm as per the NEHRP Guidelines. G+10 storied steel framed structure with piping racks are consider. 2D & 3D analysis is formulated from this study.

An algorithm incorporated displacement coefficient method, the displacement is given up to the collapse mode through a series of iterative steps. The target displacement, which indicates the amount of displacement that the structure can experience when lateral loads collapse on it. If target displacement exceeds threshold limit either structural members are fail or complete structure gets damaged. (09)

This study aims to find out structural performance of buildings for wind and earthquake effects in combination. Analysis of low and medium-rise RC structures are done by using pushover analysis, it also includes SSI for fixed & flexible base conditions of structure in this flexible base conditions ranges between soft to dense in three soil types. Analysis based on micro me-topological winds with mean value varies from 0.5 to 20 m/s. the current study shows that combined effect of wind and earthquake can affect performance levels.

Elastic and inelastic buildings design base shear performance is reducing proportionally. Results shows that impact of SSI on elastic performance are more correct than inelastic performance. Reduction in yield strength of flexible base structure gives higher displacement in comparison with fixed base condition. (12)

2. Pushover Analysis-

It is a static analysis technique of non-linear, evaluating a structure's seismic performance. A structure is subjected to an incremental lateral loads and its response is observing in terms total base shear Vs roof displacement graph.

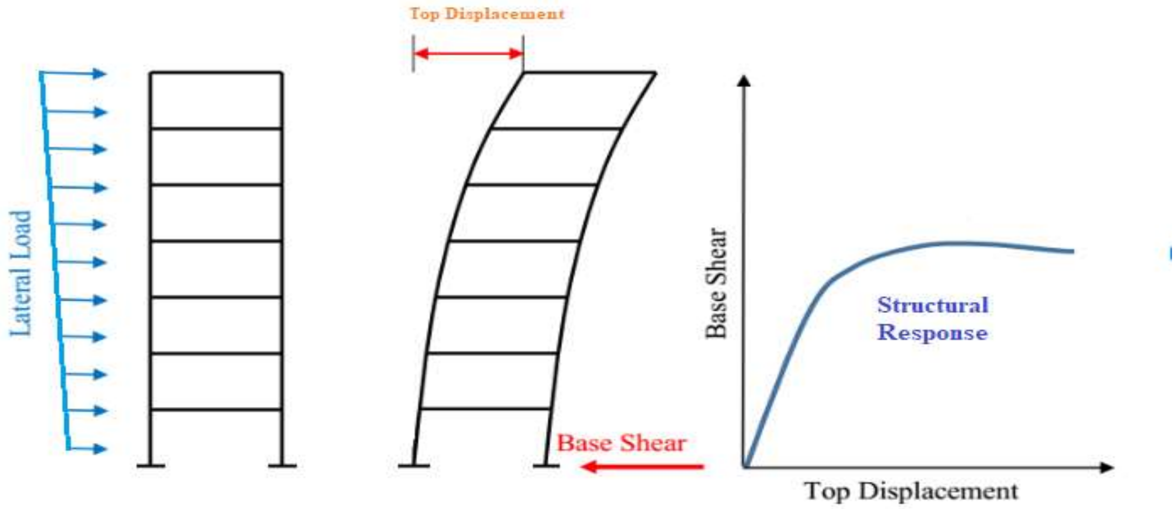


Figure 1. Building Capacity Curve by Pushover Analysis

It is most accurate methods for determining the seismic safety of new or existing structures is pushover analysis, which is widely used in earthquake engineering. There are numerous methods for applying and implementing pushover analysis like (i) variable load patterns, as per FEMA guidelines. (ii) Adaptive load patterns, (iii) force vs. displacement control as per ATC guidelines etc. that will give a capacity curve which would give more accurate seismic behaviour structure.

Based on pushover analysis, the state of building damage measured by using the drift and displacement of building and it is distributed in various performance levels like Operational level, Immediate Occupancy (IO) level, Life Safety (LS) level and Collapse Prevention (CP) level. The selection of post-earthquake category depends on the building's condition and the severity of damage. [4]

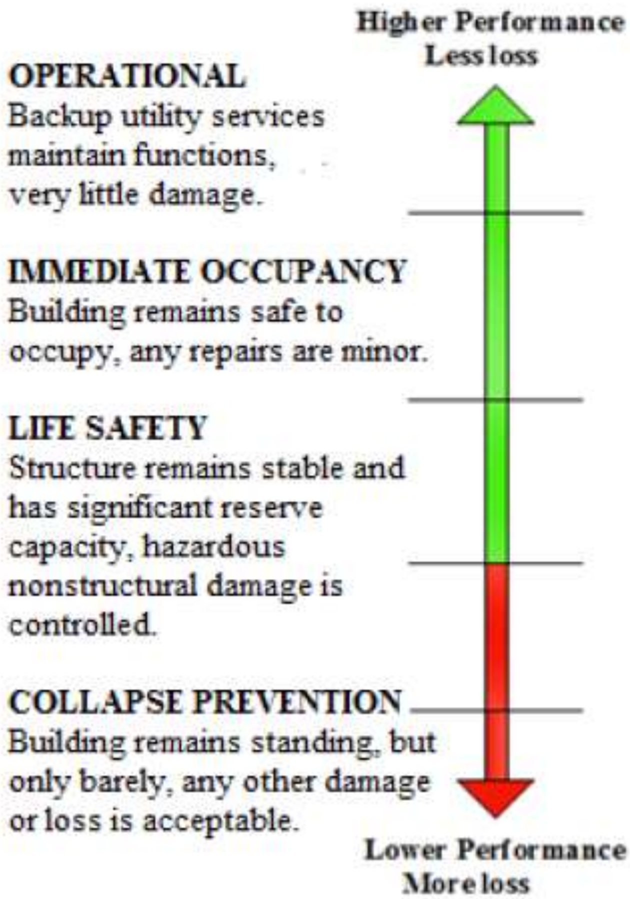


Figure 2. Building Performance Level

2.1 Winkler approach-

The Winkler approach describes the soil system with discrete, tightly spaced, independent mutually, linearly acting elastic springs. It shows that the soil condition effects can be taken into account by considering springs of specified stiffness.

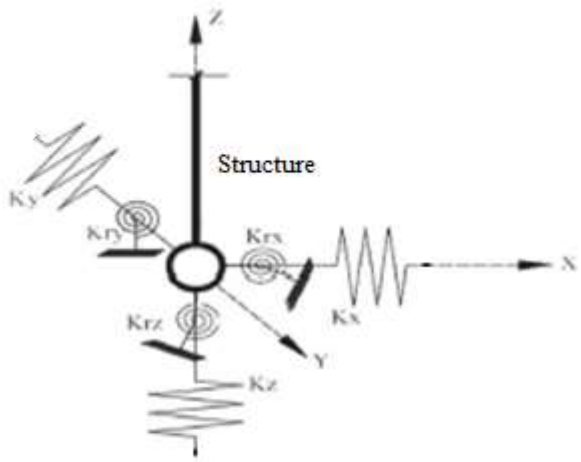


Figure 3. Six DOF for Soil Spring

Spring stiffness are calculated by using formulas given by Gazetas, G. Formulas and charts for impedances of surface and embedded foundations [01].

3. Methodology-

This study is quantitative in nature and analysis is done by using computer software, the methodology focuses on the capacity spectrum method through pushover analysis. It offers a very thorough analysis of how seismic demand is decreased with increasing displacement. The three main components capacity, demand and performance must be determined by simplified nonlinear analysis procedures using pushover analysis.

The reinforced concrete structural members are design as per IS 456-2000 and earthquake forces consider as per IS 1893-2002. The structure is situated in ZONE V, the materials used are Fe500 for the steel reinforcement and grade of concrete is M30.

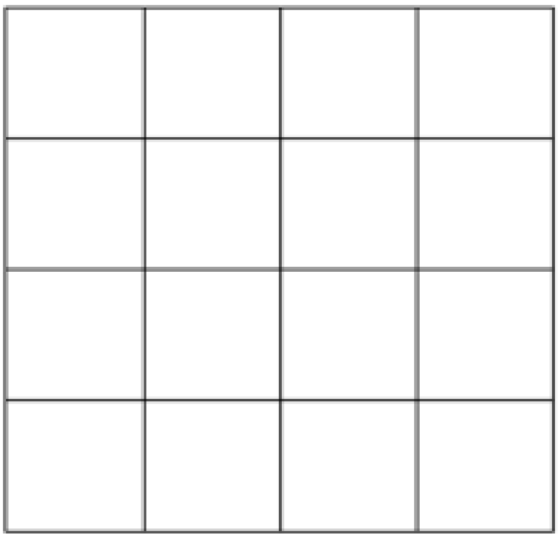


Figure 4. G+9 Building Plan

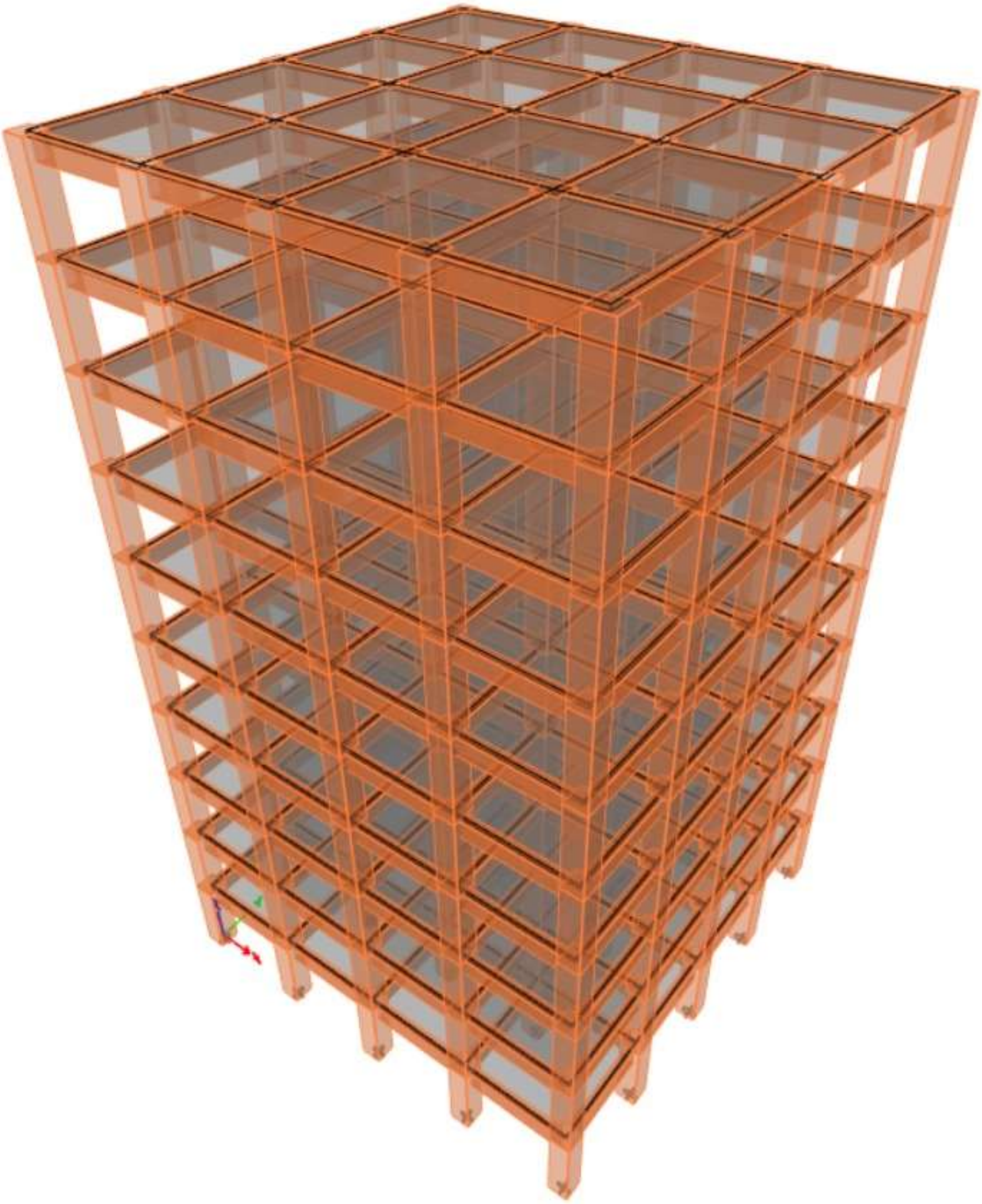


Figure 5. G+9 Building Elevation

Several structures are examined in this study for fixed and flexible base conditions, flexible base are classified as medium soil. G+9 storey building designed according to IS 456-2000, cross section area of beams and columns are increased by 5%, 10%, 15% and 20%.

Table 1. Structural Components of Building

Structural members	**Beam**	**Column**
Dimension	300x400	500x500

Spring stiffness formulas are calculated by using formulas based on soil strata beneath structure, foundation details etc. [4].

Table 2. Spring Stiffness's for Medium Soil

Spring Stiffness (kN/m)	
Vertical direction	82617.19
Lateral Horizontal direction	82617.19
longitudinal Horizontal direction	111135.42
longitudinal Rocking direction	121611.43
lateral Rocking direction	125804.93
Torsional	21443.24

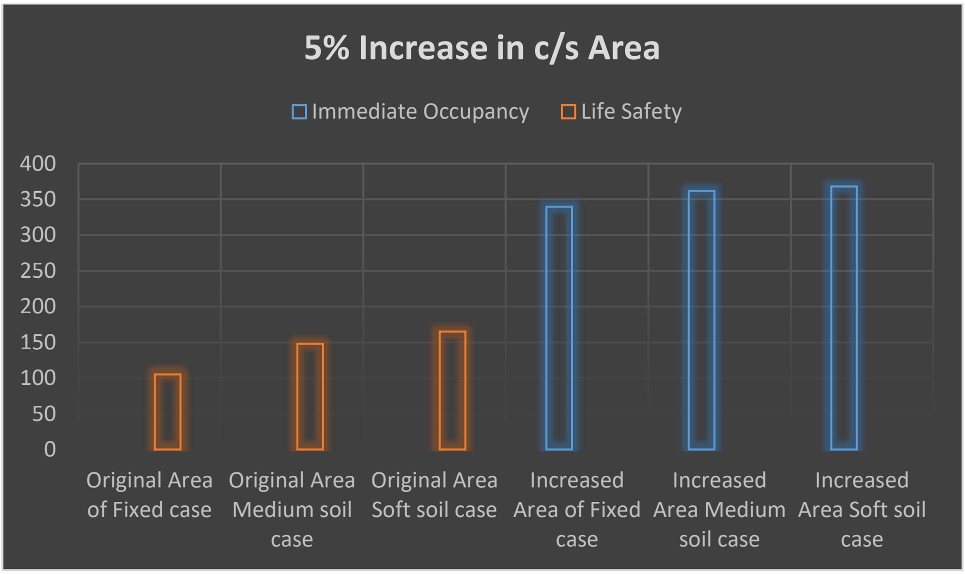
4. Result and Discussion-

Analysis and comparison are done on fixed based condition and flexible base condition with variable cross sectional area of structural members. Performance of structure are observed from number of hinges as shown in following graphs.

4.1 Building with Original C/S Area Compared with 5% Increased C/S Area-

As original cross sectional area of structural members are increased by 5% in case of fixed base, medium soil and soft soil condition number of hinge formation in collapse prevention zone shifted into immediate occupancy zone, as fixed base condition changes into medium soil condition number of hinge formation gets increased by 6.47% and in case of soft soil it increases by 8.23% as compared with fixed base.

This gives number hinge formation in collapse prevention zone which is most vulnerable zone shifts into immediate occupancy zone which is less vulnerable zones for various earthquake events.

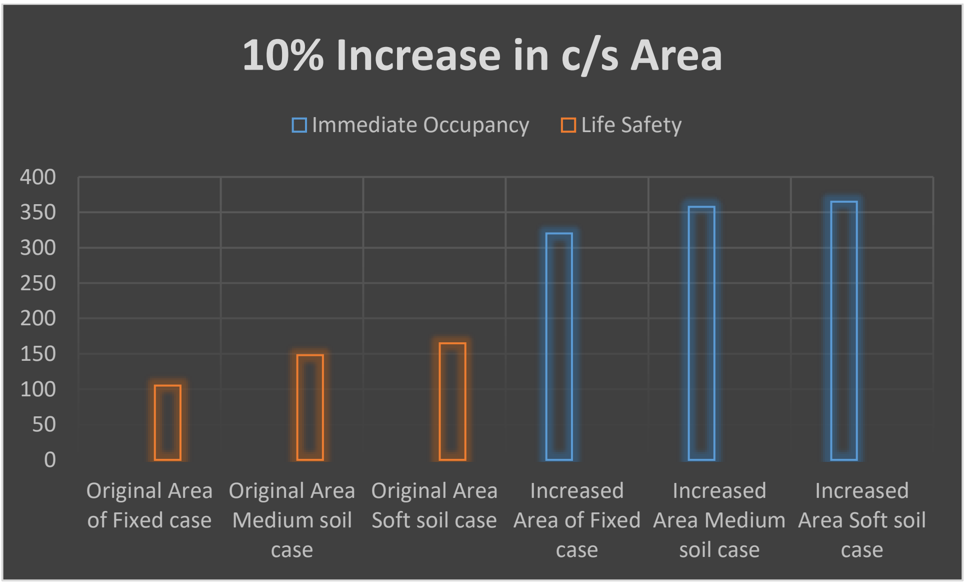


Graph 1. Increase in Structural Member's C/S Area by 5%

4.2 Building with Original C/S Area Compared with 10% Increased C/S Area-

As original cross sectional area of structural members is increased by 10% in case of fixed base, medium soil and soft soil condition number of hinge formation in collapse prevention zone shifted into immediate occupancy zone, as fixed base condition changes into medium soil condition number of hinge formation gets increased by 11.87% and in case of soft soil it increases by 14.06% as compared with fixed base.

This gives number hinge formation in collapse prevention zone which is most vulnerable zone shifts into immediate occupancy zone which is less vulnerable zones for various earthquake events.

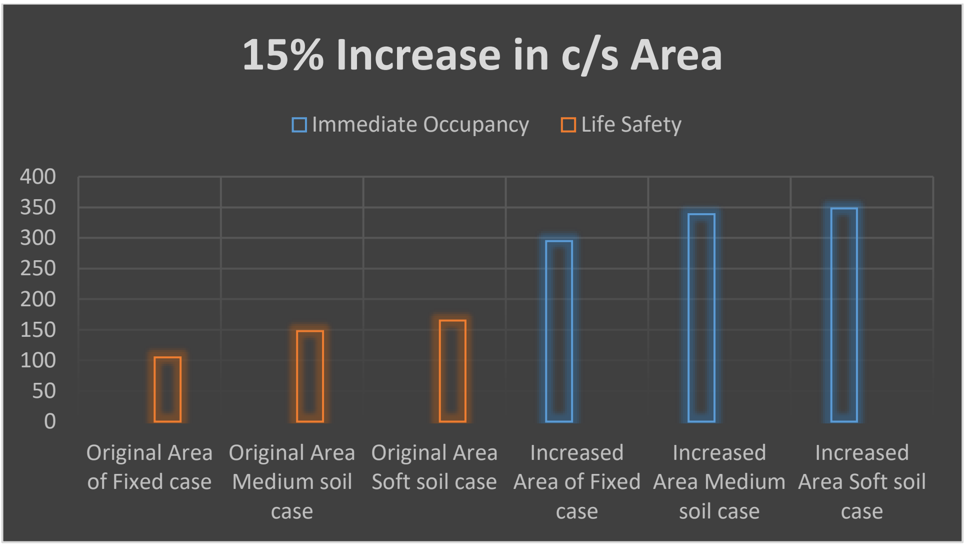


Graph 2. Increase in Structural Member's C/S Area by 10%

4.3 Building with Original C/S Area Compared with 15% Increased C/S Area-

As original cross sectional area of structural members is increased by 15% in case of fixed base, medium soil and soft soil condition number of hinge formation in collapse prevention zone shifted into immediate occupancy zone, as fixed base condition changes into medium soil condition number of hinge formation gets increased by 14.91% and in case of soft soil it increases by 17.96% as compared with fixed base.

This gives number hinge formation in collapse prevention zone which is most vulnerable zone shifts into immediate occupancy zone which is less vulnerable zones for various earthquake events.

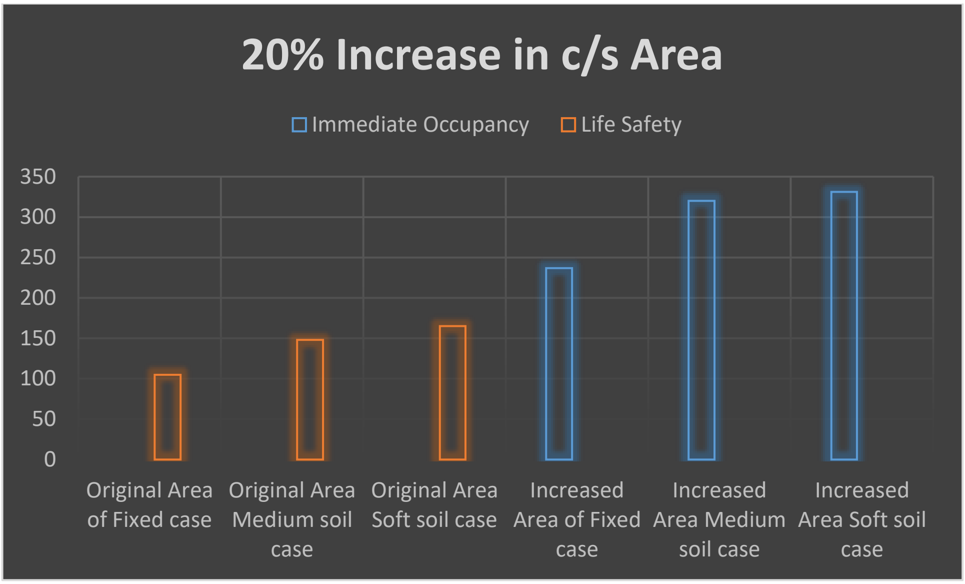


Graph 3. Increase in Structural Member's C/S Area by 15%

4.4 Building with Original C/S Area Compared with 20% Increased C/S Area-

As original cross sectional area of structural members is increased by 15% in case of fixed base, medium soil and soft soil condition number of hinge formation in collapse prevention zone shifted into immediate occupancy zone, as fixed base condition changes into medium soil condition number of hinge formation gets increased by 19.85% and in case of soft soil it increases by 23.96% as compared with fixed base condition.

This shows that number hinge formation in collapse prevention zone which is most vulnerable zone shifts into immediate occupancy zone which is less vulnerable zones for various earthquake events.



Graph 1. Increase in Structural Member's C/S Area by 20%

5. Conclusion-

Increase in cross sectional area of structural members improves building performance in case of earthquake forces, by increasing c/s area of structural members hinge formations from vulnerable zones can get shifted into less vulnerable zones. No need to redesign the complete structure or required skills. Following conclusions are drawn from results.

- For increase in 5% of the c/s area of structural member's number, hinge failures from collapse prevention zone shifts into immediate occupancy zone which is in safer zone.
- For fixed base condition, by increasing 20% c/s area of structural member's number of hinge formation gets reduced by 43.46% in immediate occupancy zone.
- For medium soil condition, by increasing 20% c/s area of structural member's number of hinge formation gets reduced by 13.10% in immediate occupancy zone.
- For soft soil condition, by increasing 20% c/s area of structural member's number of hinge formation gets reduced by 11.18% in immediate occupancy zone.
- Number of hinge formation increases as end condition changes from fixed base condition to medium soil, varying in between 7% to 19% and for fixed base to soft soil, varying in between 9% to 23%.
- As per study 20% is the optimum increase in percentage of c/s area which gives most effective results.

Symmetrical RC structures are analysed in this study. Moreover, study was exclusively conducted for change in cross sectional area of structural members along with soil structure interaction. The present study can be used as reference material for midrise RC buildings considering soil structure interaction.

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