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Assessment Of Seismic Behavior Of RC Buildings Through Pushover Analysis

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ABSTRACT-This research paper focuses on the Pushover analysis of structures primarily designed to be earthquake-resistant. Specific structural elements are carefully designed to ensure the final building can handle various loads and remain durable and functional throughout its lifespan. The study involves a comparative Pushover analysis of two RCC (Reinforced Cement Concrete) framed structures. Pushover analysis is a static, nonlinear method used to evaluate how a structure behaves under seismic forces, particularly to understand displacement and deformation. This research utilizes ETABS, a widely used structural analysis and design software, commonly adopted in the construction industry for designing buildings.

The main objective of the study is to conduct a comparative analysis using Pushover methodology in ETABS. The paper presents key results such as changes in shear force, bending moment, and deflection. The research also explores the use of simulation tools like ETABS for the analysis and design of buildings with rectangular floor plans, including those with standard vertical profiles and geometrically irregular multi-storey configurations. The overall goal is to assess the behavior, load distribution, and structural stability of the skeletal framework of the building.

I GENERAL INTRODUCTION

Engineering is all about applying innovative designs to overcome real-world challenges. Engineers constantly seek efficient and cost-effective solutions to complete tasks with a focus on achieving maximum effectiveness. This approach contributes to the creation of reliable and long-lasting infrastructure in our everyday lives. In the broader context of engineering and specifically civil engineering structural engineers play a crucial role in the development of a nation. One of the key challenges they face is designing structures that are both economically viable and structurally efficient, ensuring that the final design remains functional and durable throughout its intended lifespan.

This report provides detailed insights into Pushover Analysis, with a focus on its application in seismic load conditions. It explores various aspects of structural design and how they are applied to the construction of complex and critical structures. The analysis and design work presented in this report has been carried out using the ETABS software.

A review of several research papers revealed that when the structure is subjected to Pushover analysis, the target displacement limit is not exceeded, indicating no failure. Hinge formations were primarily observed in the beams, with more hinges developing in the X-direction compared to the Y-direction. These hinges typically formed between the Immediate Occupancy (IO) and Life Safety (LS) performance levels, suggesting that the structure remains in a safe condition.

The analysis showed that lateral loads acting on storeys are higher in seismic Zone III than in Zone II. However, the results for maximum storey displacement and storey drift were found to be nearly the same in both zones. The maximum observed displacement was within the assumed target displacement, confirming that the structure performed well against lateral forces. The building's overall response demonstrated significant resistance to such loads.

Insights from engineers using various analytical methods help in identifying potential structural issues. When evaluating earthquake impacts at a particular location, seismic data from at least the past 50 years is considered to estimate the expected magnitude. This information is used in the design of new buildings to ensure they can endure seismic shocks. Based on analysis results and the increasing demand for structural safety, member cross-sections are adjusted accordingly. The report also details various modifications made to structural properties. Structural engineering, as a broad field, encompasses the construction of diverse structures such as buildings, bridges, and towers. In cases where long spans are required and intermediate supports are not feasible, solutions such as prestressed members or moment-resisting frames are implemented. Moreover, for structures where minimal material use or reduced footprint is desired, applying such technologies proves advantageous.

This research highlights enhancements made to the lateral load-resisting frame system to improve cost-efficiency. Modifications to member dimensions are applied to reduce structural weight and optimize load distribution. The structure's performance under dead load, live load, and seismic load is thoroughly tested to evaluate different design outcomes.

II OBJECTIVE OF THE RESEARCH

Structural design is one of the core principles in the field of engineering. Upon completing an engineering degree, one gains the technical knowledge required for designing and delivering projects. However, executing a project involves much more than theoretical understanding it demands practical knowledge of every aspect, from design codes to planning processes.

It became clear that earning a degree alone wouldn't be sufficient to achieve my career goals in structural engineering. There is a vast range of additional skills and tools to be learned to gain entry into this field with a strong professional profile. Recognizing this, I decided to specialize in one of the leading structural design tools **ETABS**. I enrolled in full-time training to gain in-depth expertise in this software and subsequently chose it as the foundation for my thesis work.

This experience taught me that engineering is incomplete without mastering modern technological tools. Through this research, I learned a great deal and developed practical skills critical to real-world applications.

The main objectives of this research are:

To analyze a reinforced concrete (RC) framed structure under the effect of earthquake loading.

To study the Pushover Analysis results of G+4, G+8, and G+12 storied buildings.

To observe hinge formations at various structural joints.

To compare pushover curves for each building configuration.

To investigate storey drift, monitored displacement, and other response parameters under the same loading but with different building geometries.

III MOTIVATION OF THE PRESENT RESEARCH

Structural engineers constantly seek ways to optimize their designs and maximize the efficiency of structural systems. They frequently modify structural elements to achieve suitable load distribution and aim to minimize material usage, thereby creating cost-effective and resource-efficient buildings.

To achieve innovation and significant improvements, designs are often made visually striking and structurally complex. Modifications are introduced from time to time when a design meets all the required criteria and adheres to applicable design codes and standards. Additionally, researchers continue to experiment and evolve existing methods to obtain new outcomes and compare them with current ones.

If a design is deemed appropriate and complies with structural norms, it undergoes a thorough review process. Experts then assess its feasibility in detail, and if it meets all necessary benchmarks, approval for its implementation is granted.

I chose this topic for my research due to my strong interest in structural design and my desire to gain a deeper understanding of the design process. This study not only enhanced my knowledge in the field but also introduced me to several essential tools used to validate and analyze structural behavior. Through this journey, I discovered that this is currently one of the most relevant and widely researched topics, both at prestigious institutions like the IITs and internationally.

IV OVERVIEW OF THE METHODOLOGY

This research involves examining various parameters to uncover the facts we aimed to explore. The methodology used must be well-established and practically applicable. Therefore, ETABS was selected for this study, as it is widely adopted in the field of structural analysis and design today. Additionally, expert support is readily available in case of any technical difficulties during the process.

A brief background of the software tools used in structural design and analysis is provided below. In this field, several software programs are commonly utilized, such as:

- ETABS
- SAP
- SAFE
- ANSYS
- STAAD PRO
- STAAD FOUNDATION
- STAAD RCDC

Most architecture alternatives run in parallel with ETABS 'cloud services and display the findings in simple graphical side-by - side comparisons. Model for high seismic regions or daily environments, using an application of the Finite Elements. Optimize the BIM concrete and steel workflows with complete incorporation of physical and air.

A. INTRODUCTION TO ETABS

The innovative and advanced ETABS is the ultimate integrated software package for structural analysis and design. Built on over 40 years of continuous research and development, the latest version of ETABS offers unmatched 3D object-based modelling and visualization tools. It provides exceptionally fast linear and nonlinear analytical capabilities, along with advanced and comprehensive design features for a wide range of materials. Additionally, ETABS presents intuitive graphic displays, reports, and schematic drawings that allow users to quickly and efficiently interpret and obtain analysis and design results.

ETABS covers every phase of the engineering design process, from the initial design creation to the generation of schematic drawings. The model development process has never been simpler intuitive drawing commands enable quick generation of floor plans and elevation frames. CAD drawings can be directly imported into ETABS models or used as templates for overlaying ETABS objects. The advanced 64-bit SAP solver provides rapid analysis of large and complex models, supporting nonlinear modeling techniques such as construction sequencing and time-dependent effects (e.g., creep and shrinkage).

Structural analysis software plays a crucial role in performing seismic calculations for building foundations. In today's modern era where computers are an integral part of every aspect of life relying solely on traditional textbook methods for analytical development, though still important, is no longer sufficient. The field of construction and design has become so competitive and advanced that the use of computer software has become essential. This section introduces the structural analysis software ETABS, which has become a key tool in modern structural engineering.

V MODELLING OF STRUCTURE

Model creation is a fundamental step in the process of obtaining accurate results for any construction project. It involves developing structural components such as beams, columns, and slabs. The modeling process must be precise, with accurate dimensions to ensure reliability. Once the structural model is generated, it provides a clear representation of the building's entire framework. With the help of this model, engineers can identify critical load-bearing areas and better understand the structural behavior and type of the building.

A structural engineer can make necessary modifications efficiently without wasting resources or labor by utilizing the structural model. Beams and columns are positioned strategically to ensure a smooth and systematic flow of loads, maintaining the building's structural integrity and functionality.

VI ANALYSIS RESULTS

A. BENDING MOMENT DIAGRAM.

The key parameter for determining the amount of reinforcement required in a beam is the bending moment. It provides insight into the magnitude and effect of loads acting on a specific structural member. The maximum bending moment in a member guides the necessary reinforcement design. Bending moment, defined as the force multiplied by the perpendicular distance at a given point or section, is a crucial factor in structural analysis. As illustrated in Figure 1, beams are subjected to uniformly distributed loads, evidenced by the parabolic shape of the bending moment diagram. If a beam's cross-section is smaller than required, failure may occur at points of maximum bending. Therefore, additional reinforcement is provided in areas subjected to higher loads and greater bending moments.

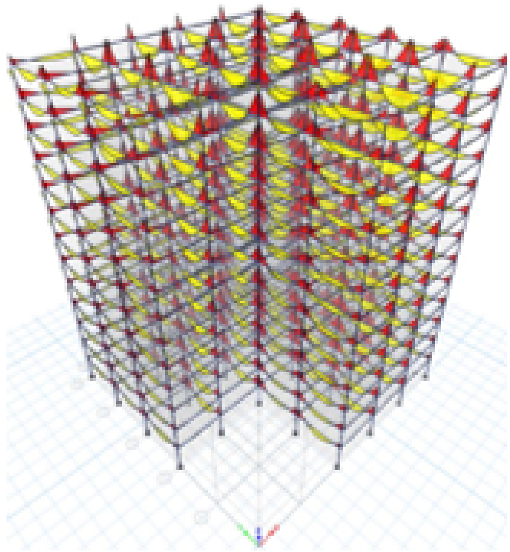

Fig 1: Bending Moment Diagram of G+ 12 Irregular building.

Above high-rise **3D structural frame** with a regular grid layout. Consists of **moment-resisting frames** or **braced frames**, modeled in reinforced concrete. Multiple bays in **both X and Y directions**, suggesting a symmetric or semi-symmetric floor plan. These colors represent **relative displacement magnitudes** or **mode shape deformations**. The deformation pattern increases with height, typical of mode shapes or pushover displacements. The structure is visualizing **first mode vibration** (fundamental mode), or a **pushover analysis result**. The exaggerated deformation helps identify **soft stories**, **torsional behavior**, or **lateral displacement concentration**. The uniform color, spread across levels suggests reasonably **uniform stiffness**, though red zones toward corners might imply higher drift or flexibility. The **grid plane at the base** suggests a regular foundation grid system. The small 3D axis (bottom center) confirms **global X, Y, Z directions** for reference.

This visualization shows:

How the structure **responds to dynamic loads**.

Detect **irregularities** in stiffness, mass, or geometry.

and **design validation or retrofitting**.

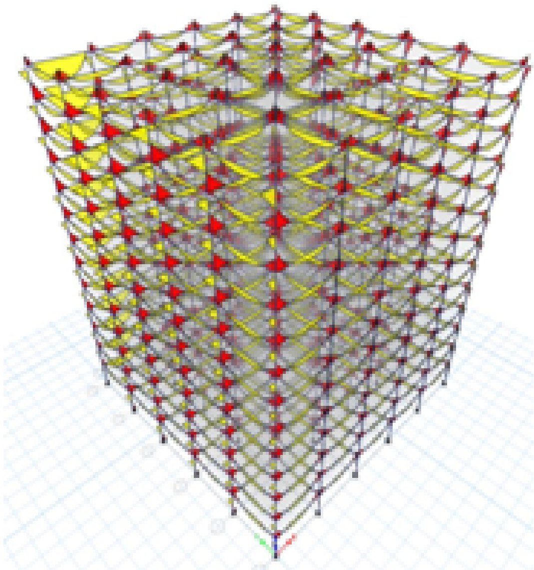

Fig 2: Bending Moment Diagram of G+ 12 regular building.

From fig 1 and fig 2 we can clearly observe that bending moment result will be greater in case of irregular structures as compared to regular structures. So, we must always give preference to regular geometry of building.

The **bending moment** which represents the internal forces resisting structural deformation—tends to be **higher in irregular structures** due to their discontinuities, asymmetric load distribution, and varying stiffness across different sections. Here's a deeper breakdown:

Bending Moments are Higher in Irregular Structures because of following points:

1. Uneven Load Distribution: Irregular buildings often have asymmetric layouts or varying story heights, leading to uneven force distribution throughout the structure.
2. Sudden Changes in Stiffness: Features like setbacks, overhangs, or irregular floor plans create localized stiffness variations, causing abrupt force transitions.
3. Torsional Effects: Irregularities introduce torsion, where the building experiences rotational forces due to unbalanced mass or load distribution, increasing bending moments in structural elements.
4. Seismic Performance Issues: During earthquakes, irregular structures exhibit higher stress concentrations, amplifying bending moments in beams and columns, which can weaken the structural integrity over time.

Advantages of Regular Geometry in Buildings

- **Uniform Load Distribution**: More predictable behavior under gravity and lateral forces, reducing stress points.
- **Efficient Material Use**: Regular structures require **less reinforcement** since forces are better managed, leading to cost-effective construction.
- **Enhanced Structural Stability**: Symmetrical geometry minimizes unwanted torsional effects, improving seismic resilience.
- **Simplified Design & Analysis**: Structural calculations and software simulations (like **ETABS and STAAD Pro**, which you're skilled at using) work more efficiently with regular structures.

Design Considerations

If an irregular geometry is unavoidable (for functional or aesthetic reasons), engineers can:

i. Use reinforced shear walls to balance stiffness variations.
ii. Optimize column layouts to minimize load imbalances.
iii. Employ base isolators or dampers to reduce dynamic stress concentrations.

B. BASE SHEAR VS DISPLACEMENT.

One of the primary challenges in achieving an efficient structural design is controlling deflection. Deflection occurs due to the loads applied to a structure, and it is the responsibility of a structural engineer to minimize it within acceptable limits. According to IS 456:2000, the permissible deflection for a structural member should not exceed L/250 (mm), where *L* is the effective span of the member. Adhering to this guideline ensures both safety and serviceability of the structure.

Monitored Displacement (mm)	Base Shear (kN)
-106.07	1.3597
-96	1.3
-84	1.15
-72	1
-60	0.85
-48	0.7
-36	0.55
-24	0.4
-12	0.2
0	0

Table 1: Result values of Base Shear vs Displacement

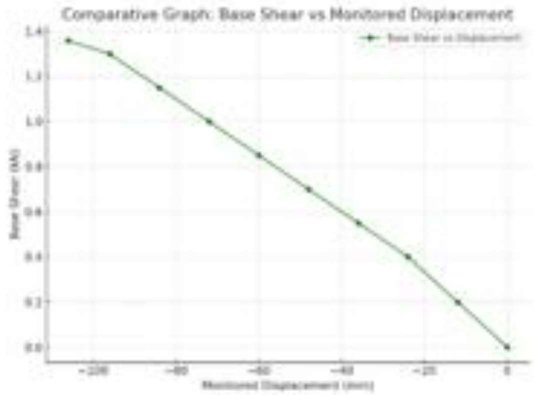

Fig 3: Base Shear vs Displacement (G+12).

It is evident that maximum deflection typically occurs in high-rise buildings; however, it can be reduced by introducing a column at mid-span or by modifying the cross-sectional properties of structural members. As illustrated in Figure 4, displacement increases with the rise in base shear. Base shear is a result of lateral forces acting on the structure, such as those caused by wind or seismic activity. When a larger portion of the building is in contact with the ground, the magnitude of base shear tends to be higher.

Deflection is evaluated based on load combinations, and it typically occurs in two directions: vertical and horizontal. Vertical deflection results from gravity-induced loads, such as the self-weight of the structure and live loads. On the other hand, horizontal deflection is caused by lateral forces, commonly referred to as earthquake or seismic loads.

C. AXIAL FORCE DETAILS.

Axial force refers to the load that columns transmit along their length. It results from the cumulative effect of various forces including live load, dead load, seismic load, floor finish load, and the self-weight of structural elements like beams and columns. These forces are transferred vertically through beams into the columns and then carried down to the foundation and ultimately to the underlying soil strata. For efficient load transfer, it is essential that columns are well-integrated with floor beams to maintain a continuous load path. However, in this particular study, some columns were deliberately omitted near the staircase area to optimize spatial efficiency and enhance usable space.

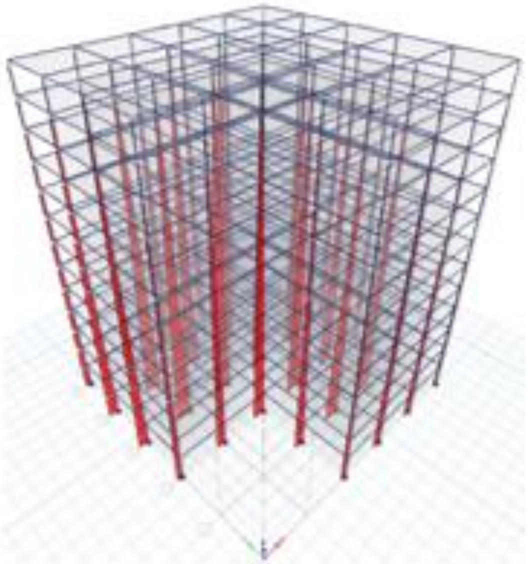

Fig 4(a): Axial forces on each column in G+12.

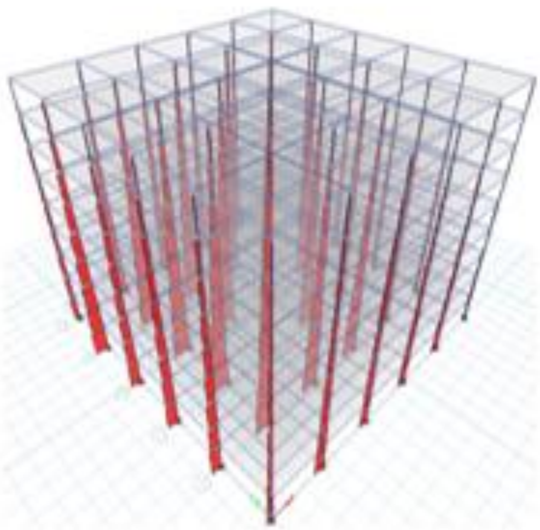

Fig 4(b): Axial forces on each column in G+8.

Figures 4(a) and 4(b) clearly illustrate that axial load increases progressively from the top storey to the bottom. This is due to the cumulative effect of loads from each successive floor being transferred to the columns below, resulting in a gradual rise in axial force down the height of the structure.

VII HINGE RESULT

Hinge Results and Structural Capacity

Hinge results can be observed at various points of a structural member. These results help determine the capacity of each part to resist bending moments. This analysis provides insight into how much bending moment a particular structural element can withstand. As is known, bending moments occur due to applied loads, and as the load increases, the overall moment acting on the structure also increases. When the structural element reaches its maximum capacity to resist further loading, it forms a plastic hinge. Beyond this point, any additional load may lead to failure.

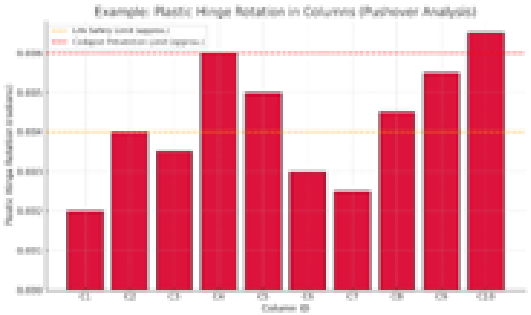

Fig 5: This graph presents the plastic hinge rotation of columns during a pushover analysis. Here's what it depicts:

- X-Axis (Column IDs): It lists the columns (C1 to C10).
- Y-Axis (Plastic Hinge Rotation): It quantifies the rotation in radians.
- Key Safety Limits:
    - Life Safety Limit: Represented by a horizontal line at 0.004 radians.
    - Collapse Prevention Limit: Marked at 0.008 radians.

The bars show how each column responds. For example:

- C10 Exceeds the Collapse Prevention Limit: It indicates a high risk of failure.
- Others Vary: Some remain below the safety threshold, while others lie in between.

This graph effectively highlights which columns might need reinforcement or reevaluation to ensure structural integrity and safety.

VIII CONCLUSION

This research paper focuses on the pushover analysis of buildings with varying story configurations and geometries to examine their behavior and resistance when subjected to earthquake forces. The study was primarily conducted on **G+4**, **G+8**, and **G+12** storied buildings, both with regular and irregular structures, to understand the effects of pushover analysis on buildings with the same number of stories but different geometrical designs. **Fig 7 and 9** illustrate the significant differences in results when the geometry of the same structure is altered, even though the load remains constant.

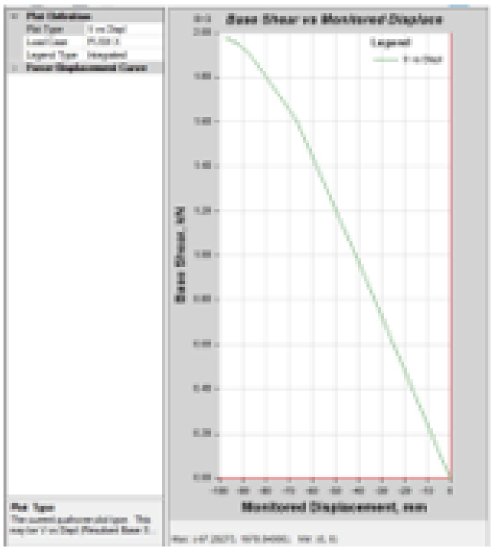

Fig 6: Displacement due to PUSH-X in G+4 (Irregular).

Monitored Displacement (mm)	Base Shear (kN)
-97.26	1.9788
-90	1.9
-80	1.75
-70	1.6
-60	1.4
-50	1.2
-40	1
-30	0.75
-20	0.5
-10	0.25
0	0

Table 2: Result values showing Displacement v/s Base shear in G+4 irregular building.

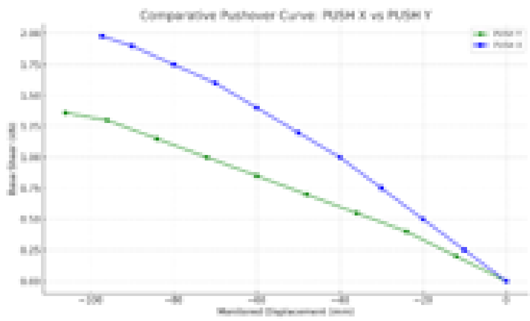

Fig 7: Comparative Pushover Curve: PUSH X vs PUSH Y.

1. **PUSH X (Blue Curve):**
   - Shows a higher base shear capacity across the displacement range.
   - Peaks at around 2.0 kN at the largest negative displacement.
   - Indicates stronger performance or stiffness in the X-direction.
2. **PUSH Y (Green Curve):**
   - Lower base shear values throughout the range compared to PUSH X.
   - Peaks at about 1.4 kN, suggesting a relatively more flexible or weaker response in the Y-direction.

Interpretation:

- This graph is typically used in structural engineering to compare how a structure responds to lateral loads in two orthogonal directions (X and Y).
- The PUSH X direction can resist more lateral load before significant displacement, meaning it may be stiffer or better reinforced than the PUSH Y direction.
- The curves suggest directional dependency in the structural response, which can inform retrofitting, reinforcement, or design focus areas.

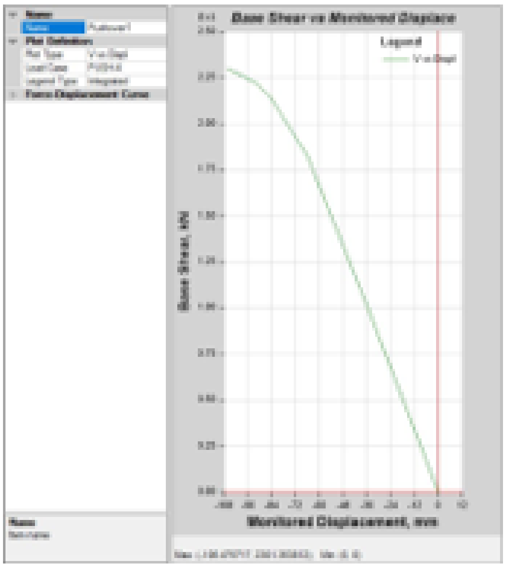

Fig 8: Displacement due to PUSH-X in G+4 (Regular).

From the results of different structures with the same number of stories, it is clearly observed that the base shear is highest in buildings with a regular configuration, while the maximum displacement is more likely to occur in irregular structures. Additionally, the **Base Shear vs Monitored Displacement** graph shows a linear relationship for irregular structures, whereas it follows a more curved, illustrative pattern for regular structures at certain points.

Monitored Displacement (mm)	Base Shear (kN)
-376.79	3.035
-340	2.8
-300	2.5
-260	2.2
-220	1.9
-180	1.6
-140	1.3
-100	1
-60	0.6
-20	0.2
0	0

Table 3: Result values of Base Shear v/s Monitored Displacement

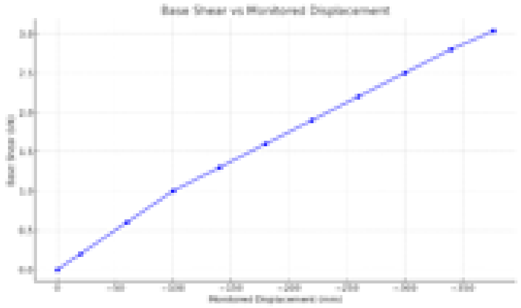

Fig 9: Base Shear v/s Monitored Displacement

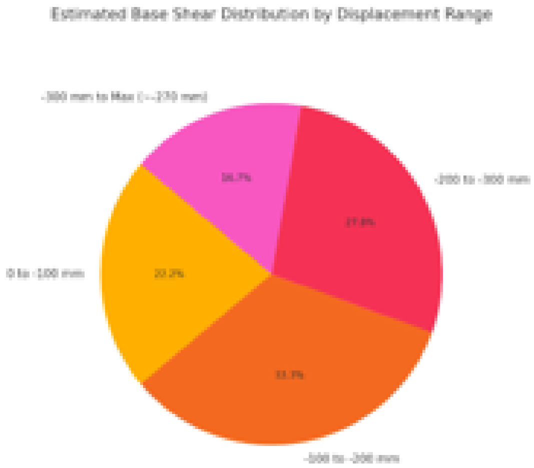

Fig 10: Estimated distribution of base shear across different displacement ranges.

Figures 9 and 10 illustrate how the results of a G+12 irregular building differ from those of a G+12 regular building. These figures clearly indicate the optimal configuration for structuring the geometry to ensure safety and resistance to greater loads with minimal effects. The pushover curve in these two graphs shows results for thirteen-story buildings with different plans but identical loading. While the loading influences each result, the geometry of the structure plays a critical role in shaping the outcomes. As seen in the graphs, base shear displacement increases as the structure's geometry changes. In the first case, displacement reaches a maximum point, while in the second case, the structure collapses as indicated by the drop in the curve, showing a double curve formation.

From these observations, we gain insight into the behavior of different systems at various junctures. Such findings help in understanding how to address structural failures and better resist external forces. This process, known as pushover analysis, is typically performed on existing structures, but in this research, we apply it to new structures using software to determine the key design values needed to enhance a building's strength and resistance.

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