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EVALUATION OF A HIGH-RISE RC FRAME WITH OUT-OF-PLANE CANTILEVER IRREGULARITY

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Abstract: The present study examines the seismic performance of a G+11 reinforced concrete (RC) frame building located in Seismic Zone V, emphasizing the influence of out-of-plane geometric irregularity introduced through 3-meter cantilever overhangs. The building, with plan dimensions of 32 m × 16 m and a storey height of 3.0 m, utilizes 450 mm × 550 mm beams and 500 mm × 650 mm columns as part of its lateral load–resisting system. Non-Linear Dynamic Analysis (NLDA) was conducted in ETABS to evaluate the configuration, which includes single-sided cantilever projections (C1) modeled at varying vertical extents—top storey, full height, and ground storey. Key seismic response parameters, including storey displacement, and fundamental time period, were assessed to quantify the impact of this particular irregularity pattern. Results indicate that even a single-sided projection produces noticeable increases in lateral displacement when compared with a regular model, with the full-height C1 configuration showing the highest sensitivity to seismic excitation. The study highlights that out-of-plane irregularities, even when limited to a single side, can significantly influence dynamic behaviour and must be carefully considered in seismic design.
Keywords: *Seismic, Displacement, Time period*

1. Introduction

The persistent challenge of ensuring the **seismic safety** of **Reinforced Concrete (RC) frame buildings** constitutes a foundational concern within modern earthquake engineering (Moehle, 2015). While advancements in material science and analytical methods have enhanced design practices, the performance of structures during major seismic events remains intrinsically linked to their geometric configuration and the presence of any significant **irregularities** (Chopra, 2017). A structure's ability to resist inertia forces generated by ground motion relies heavily on a predictable and symmetrical distribution of mass, stiffness, and strength throughout its volume, allowing for efficient energy dissipation (Pauley & Priestley, 1992). Deviations from this ideal symmetry, particularly **geometric irregularities**, are known to disrupt the intended load path and significantly exacerbate seismic risk (Taranath, 2010).

Among the various types of structural non-uniformities, **out-of-plane geometric irregularities** present a unique and often under-studied complexity. These irregularities, which include features such as large **cantilever projections** or abrupt changes in the plan dimensions (setbacks that extend laterally rather than vertically), fundamentally alter the structure's dynamic properties (Stafford Smith & Coull, 1991). The introduction of an out-of-plane asymmetry, such as a **cantilever overhang** extending substantially from one face of the building, shifts the **center of mass** away from the **center of rigidity** (or stiffness) in that plane (Clough & Penzien, 1993). This eccentric relationship is the primary mechanism through which these features introduce significant **torsional coupling** under lateral seismic excitation. Instead of undergoing pure translational movement, the structure experiences a combined movement of translation and rotation, which disproportionately increases the forces and displacements in the perimeter elements furthest from the center of rigidity (Humar, 2002).

A common architectural and functional element, the **cantilever overhang**, frequently used to maximize floor space or provide shading, is a prime example of such an out-of-plane irregularity. While locally sound, when these projections are large (e.g., 3 meters or more) and span a significant portion of the building's façade, they introduce a large, eccentric mass that can destabilize the overall system (Taranath, 2010). The inherent asymmetry causes the building's global response to become more complex, increasing the demand on the columns and beams located at the irregular perimeter. This can lead to localized failure or, critically, a premature onset of non-linear behavior in specific elements, triggering a **soft-storey mechanism** or excessive drift (Fajfar, 1999).

Previous research efforts in seismic structural analysis have predominantly concentrated on **vertical irregularities** (mass, stiffness, or strength irregularities along the height) and in-plane torsional irregularities (due to non-symmetric shear wall placement) (Chopra, 2017). These studies have successfully demonstrated how abrupt changes in floor plate properties can localize damage (FEMA 356, 2000). However, the specific, isolated influence of a **large, single-sided cantilever**—an irregularity defined by an extension *outside* the main vertical structural envelope—warrants a dedicated, focused investigation, as it creates a different kind of eccentric loading (Moehle, 2015).

Specifically, the impact on key seismic response parameters is of paramount interest. The **storey displacement** (or inter-storey drift ratio) is the most direct indicator of potential structural and non-structural damage, and it is anticipated that the torsional effects induced by the cantilever will lead to significantly amplified displacements at the building's corners (Priestley et al., 2007). Furthermore, the addition of mass and the corresponding change in the stiffness distribution due to the cantilever can lengthen the structure's **fundamental time period** (Chopra, 2017). A longer period may, depending on the site-specific ground motion characteristics (Seismic Zone V), either place the structure in a lower-demand region of the response spectrum or, conversely, bring it into resonance with the dominant period of the ground motion, leading to catastrophic failure (Newmark & Hall, 1982).

The varying vertical extent of this out-of-plane irregularity is also a critical variable. A cantilever localized at the **top storey** might primarily affect the overall overturning moment and the roof-level drift, whereas a projection extending for the **full height** introduces persistent eccentricity across all floors, maximizing the torsional demands (Humar, 2002). A ground-storey cantilever might locally affect the transfer of shear into the foundation. Consequently, the use of advanced techniques like **Non-Linear Dynamic Analysis (NLDA)**, as facilitated by software such as ETABS, becomes indispensable for accurately modeling the non-linear material response and the complex dynamic interaction over the full time history of seismic excitation (Computers & Structures, 2016). **** Such detailed analytical work is crucial to generating data that can inform design engineers and code committees, ensuring that the necessary performance checks for structures incorporating such common yet seismically challenging architectural features are robustly mandated (ASCE/SEI 7-16, 2017). The quantification of the increase in **lateral displacement** and the shift in the **fundamental time period** relative to a regular model will thus provide a tangible measure of the structural detriment caused by this particular pattern of out-of-plane geometric asymmetry.

2. Research Objective

To quantify the influence of a large, single-sided, out-of-plane geometric irregularity (3-meter cantilever overhangs) on the seismic performance, specifically lateral displacement and fundamental time period, of a G+11 RC frame building in Seismic Zone V using Non-Linear Dynamic Analysis.

3. Methodology

The research methodology involves analytical modelling, structural analysis, and comparative evaluation of RCC frames having out-of-plane geometric irregularity. The study follows these key steps:

Structural Modelling: A G+11 storey RCC frame is modelled as the reference structure using standard design parameters per IS 456:2000. The building has uniform bay spacing in both directions, with fixed supports at the base. The structure is modelled in ETABS software.

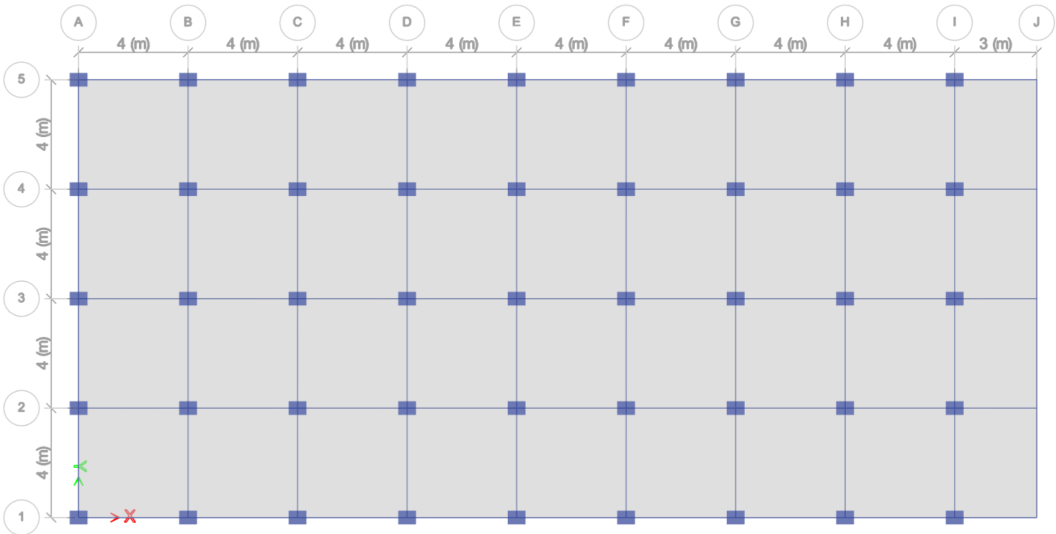

Fig. 1 RCC Frame with Single-Sided Cantilever projection

The study examines a G+11 RC frame building (32 X 16 m plan, 3.0 m storey height) utilizing 450 mm X 550 mm beams and 500 mm X 650 mm columns, with three configurations of a 3-meter cantilever projection (C1): at the top storey, full height, and ground storey.

Material Properties: The materials used in this study are selected based on standard construction practices and relevant design codes. The RCC frame is designed using **M30 grade concrete**, which provides adequate compressive strength and durability for mid-rise structures. **Fe500 grade steel** is used for reinforcement, offering high yield strength and ductility suitable for seismic applications.

Load Consideration: Loading is applied as per IS 875 (Part 1 and 2) for dead and live loads, while seismic loading is considered in accordance with IS 1893:2016, assuming the structure is located in Seismic Zone V. The response reduction factor (R) is taken as 5.0, appropriate for a ductile moment-resisting frame with special detailing. An important factor (I) of 1.2 is adopted, representing a standard-occupancy building.

Analysis Type: A nonlinear time history analysis is performed to evaluate the seismic performance of each model using ground motion data from the 1999 Chi-Chi earthquake (Taiwan). This method captures the inelastic behaviour of the structure under actual dynamic loading conditions, providing a more realistic assessment of displacement, shear force, and overall structural response. The selected earthquake record, known for its high intensity and strong ground acceleration, is used to simulate real-world seismic effects on braced RCC frames with different steel sections and configurations.

4. Results & Discussion

The displacement profile of the structure across different storeys reveals a consistent trend of increasing lateral displacement with height for all three cases—C1-T, C1-A, and C1-G. At the base, displacement is naturally zero, while the maximum values are observed at the top storey (Storey 12), where C1-A records the highest displacement of 56.931 mm, followed by C1-G at 50.407 mm, and C1-T at 48.18 mm. This indicates that the structural system under condition C1-A is comparatively more flexible, resulting in larger lateral movements, whereas C1-T demonstrates the least displacement, suggesting greater stiffness and resistance to lateral forces.

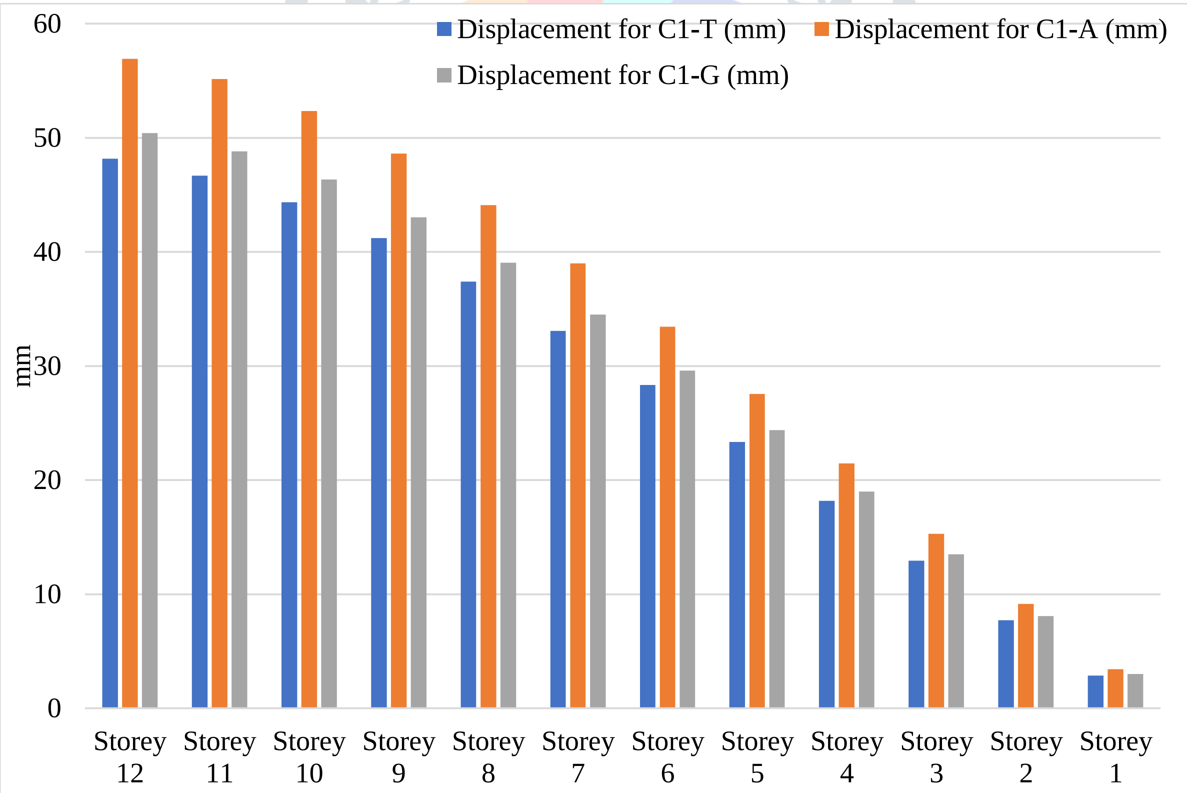

Fig. 2 Displacement for Overhang on one Side

Across all modes, the C1-A model consistently records the highest time periods, indicating greater flexibility and lower stiffness. For instance, in Mode 1, C1-A exhibits a time period of **1.427 sec**, which is approximately **4.6% higher** than C1-T (**1.364 sec**) and **5.5% higher** than C1-G (**1.352 sec**). Similar trends are observed in Modes 2 and 3, where C1-A shows increases of **4.3–4.7%** over C1-T and **5.4–4.9%** over C1-G. In higher modes (Modes 4–12), the percentage differences remain consistent, with C1-A showing **4–6%** higher time periods compared to C1-T and C1-G. For example, in Mode 5, C1-A records **0.415 sec**, which is **4.3% higher** than C1-T (**0.398 sec**) and **5.9% higher** than C1-G (**0.392 sec**). These elevated time periods in C1-A reflect its increased deformability and reduced lateral stiffness due to the overhang configuration.

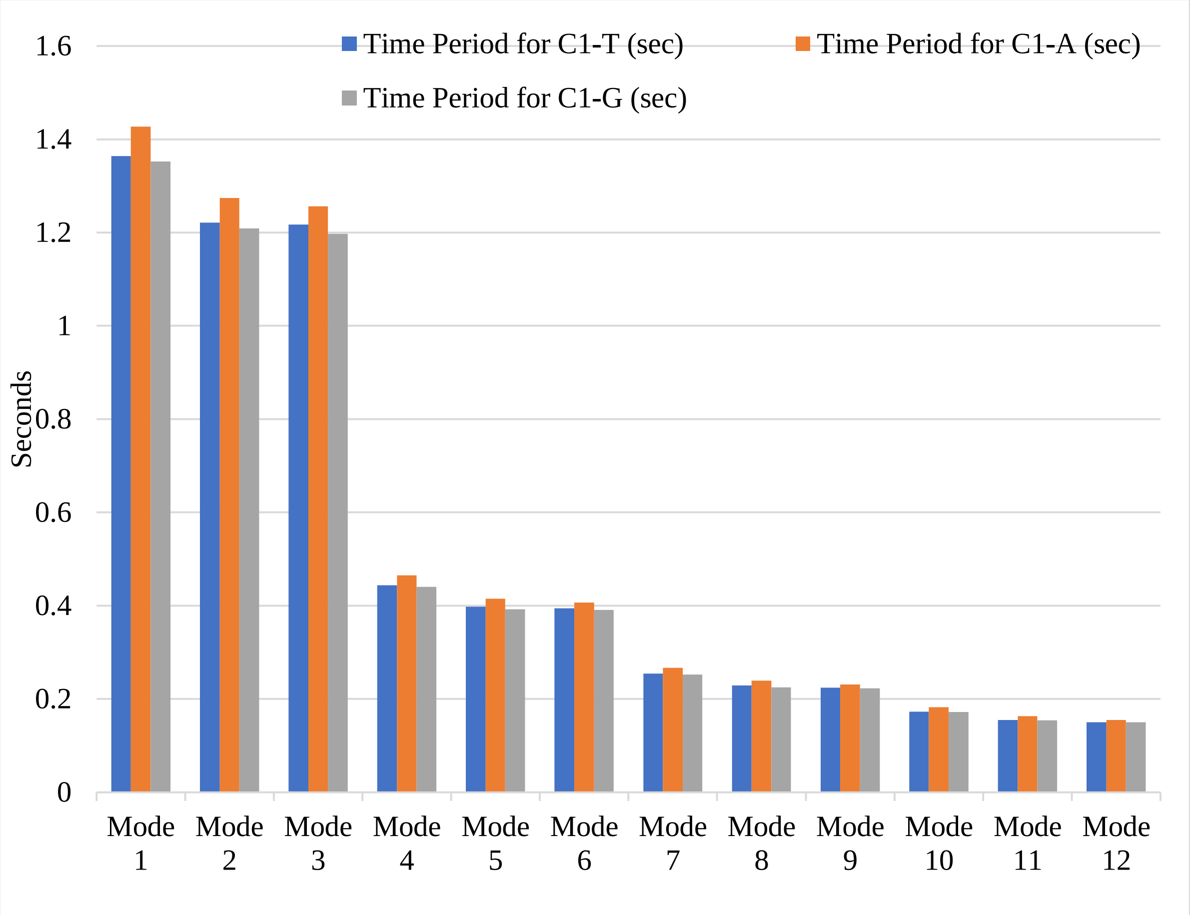

Fig. 3 Time Period for Overhang on one side

5. Conclusions

The introduction of the 3-meter single-sided cantilever (C1) significantly impacts the seismic performance of the G+11 RC frame building. The irregularity causes a noticeable lengthening of the fundamental time periods, suggesting a reduction in structural stiffness. While the C1-T (Top Storey) configuration shows the greatest period lengthening in the first mode, the C1-A (Full Height) configuration is the most seismically sensitive, consistently producing the maximum lateral displacement across all storeys. Specifically, the roof displacement (Storey 12) is highest for C1-A ($\approx$ 57 mm), confirming that persistent eccentricity along the building's height is the most detrimental scenario. These results emphasize that out-of-plane irregularities induce significant torsional effects that must be rigorously addressed in seismic design using advanced non-linear analysis.

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