Predicting Collapse Mechanisms in Controlled Demolition: An Explicit Dynamics Study on Seismically Designed RC Frames with Vertical Irregularities

Madhu N. S.[1]; Shankar G. S.[2]

[1]M. Tech Student, Structural Engineering, Department of Civil Engineering, SJMIT Chitradurga
[2]Assistant Professor, Department of Civil Engineering, SJMIT Chitradurga, Karnataka

Publication Date: 2025/10/29

Abstract: The increasing need for urban redevelopment in densely populated regions has elevated the importance of controlled demolition of aging high-rise structures, a high-risk operation where failure can lead to catastrophic progressive collapse. Traditional static analysis methods are fundamentally inadequate for simulating the sudden, nonlinear, and dynamic nature of such events, creating a significant gap between structural design and demolition safety planning. This research addresses this critical need by developing an integrated computational workflow utilizing ETABS for global analysis and design of a G+15 vertically irregular RC building per Indian codes, and ANSYS Explicit Dynamics for high-fidelity simulation of blast-induced progressive collapse. The study successfully identifies critical columns through pushover analysis and quantifies the dynamic response, establishing a Dynamic Amplification Factor of 1.92-2.02 and proposing a kinetic energy-based metric for robust collapse initiation detection. The results demonstrate distinct failure mechanisms for instantaneous versus blast-load removal scenarios, with the latter producing more realistic fragmentation and a 12% higher energy impulse. This work provides a validated, end-to-end methodology that bridges a crucial gap in demolition engineering, offering practical, simulation-driven insights to enhance the safety and predictability of demolishing complex irregular structures.

Keywords: *ETAB, ANSYS Explicit Dynamics ,Progressive Collapse.*

How to Cite: Madhu N. S.; Shankar G. S. (2025) Predicting Collapse Mechanisms in Controlled Demolition: An Explicit Dynamics Study on Seismically Designed RC Frames with Vertical Irregularities. *International Journal of Innovative Science and Research Technology*, 10(9), 3059-3064. https://doi.org/10.38124/ijisrt/25sep1375

I. INTRODUCTION

The Background and motivation is the age of urban redevelopment in the 21st century is characterized by rapid urbanization and the constant renewal of cityscapes. As metropolitan areas expand vertically and horizontally, the lifecycle of structures is being reevaluated. A growing number of Reinforced Concrete (RC) buildings, erected during the initial waves of urbanization, are now reaching the end of their service life due to aging, structural degradation, outdated design standards, or simply the need for redevelopment to accommodate modern demands. This phenomenon is particularly pronounced in densely populated countries like India.

While the field of civil engineering has historically been obsessed with the art and science of *constructing* buildings—ensuring they stand up—there is a critical and often underemphasized parallel discipline: the science of safely and predictably *taking them down*. The controlled demolition of structures is not merely a destructive process; it is one of the most complex engineering challenges, requiring a deep understanding of structural behaviour under extreme, non-linear, and dynamic conditions. The sudden and intentional removal of critical load-bearing elements, such as columns, can trigger a progressive or disproportionate collapse, where a local failure propagates, resulting in the collapse of a significantly larger portion of the structure than initially affected. The dynamic, non-linear nature of this event poses a grave challenge to structural engineers tasked with ensuring public safety, protecting adjacent properties, and minimizing economic and human collateral damage in increasingly dense urban environments.

➢ *Objectives*

- To model a vertically irregular RCC building of G+15 storeys and design its structural elements as per relevant IS codes (IS 456:2000, IS 875, IS 1893) using ETABS software.

- To identify critical columns and frame members most vulnerable to progressive collapse through pushover analysis and Alternate Path Method (APM) checks in ETABS. To locate critical beam–column joints that represent potential initiation points for controlled demolition.
- To import the identified critical building segments into ANSYS and perform Explicit Dynamics analysis simulating TNT-induced column and joint removal. To analyze the resulting progressive collapse mechanism and compare failure patterns.
- To calculate dynamic response parameters such as displacement histories, stress distributions, and kinetic and internal energy variations during the demolition process. To establish an objective energy-based collapse indicator for assessing the initiation and propagation of failure.
- To compare structural responses under different removal scenarios (instantaneous vs. ramped, single column vs. joint removal) and derive insights for planning safer and more efficient demolition sequences.

II. METHODOLOGY

A. Overview of the Research Methodology

This research employs a two-stage computational simulation strategy to analyze the progressive collapse of a G+15 vertically irregular RC building under controlled demolition. Stage 1 involves global modelling and analysis in ETABS to design the structure and identify critical members. Stage 2 involves high-fidelity transient dynamic simulation in ANSYS Explicit Dynamics to model the actual demolition event and study the collapse mechanics in detail.

B. Stage 1: Global Analysis and Design in ETABS

➢ *Structural Modelling:*

A G+15 building model with a vertical setback (to induce irregularity) will be created in ETABS. Material properties will be defined as per IS codes: M30 grade concrete and Fe500 grade steel.

➢ *Loading and Analysis:*

The model will be subjected to dead loads (IS 875-Part 1), live loads (3 kN/m² as per IS 875-Part 2), and seismic loads as per IS 1893 for Zone V.

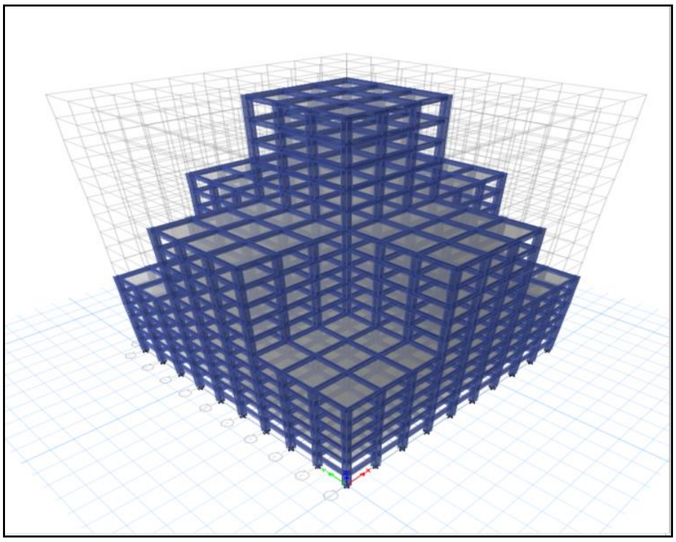

Fig 1 G+15 RCC Building with Vertical Irregularity

Table 1 Loading and Analysis

Parameter	Description	Value/specification
General Information		
Building Function	Commercial High-Rise	-
Total Stories	Ground + 15 Upper Floors	G+15
Total Height	From foundation to roof	56.5 m
Geometric Configuration		
Typical Floor Plan Dimensions	Rectangular layout	36 m × 36 m
Ground Floor Area	Base footprint	1296 m²
Vertical Irregularity Type	Setback configuration	Mass irregularity as per IS 1893:2016
Setback Location	Level where reduction occurs	At 6th Floor (above 5th floor)
Upper Floor Area (10th-15th)	Reduced footprint area	144 m²
Story Details		
Ground Story Height	First story above foundation	4.0 m
Typical Story Height	Stories 2-15	3.5 m
Penthouse/Mechanical	Top story height	4.0 m
Structural System		
Structural Type	Moment-resisting frame	Special RC Moment Frame (SMRF)
Material Properties		
Concrete Grade	Characteristic compressive strength	M30 (f_{ck} = 30 MPa)
Reinforcement Steel	Characteristic yield strength	Fe500 (f_y = 500 MPa)
Member Sizes		
Typical Column Sizes	Varies by story	450×600 mm to 600×900 mm

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25sep1375

Typical Beam Sizes	Primary and secondary beams	300×600 mm to 350×750 mm
Slab Thickness	Typical floor slab	150 mm
Design Criteria		
Seismic Zone	As per IS 1893:2016	Zone V (High seismic zone)
Soil Type	Foundation soil classification	Type II - Medium soil
Importance Factor	As per IS 1893:2016	I = 1.2 (Important building)
Response Reduction Factor	For SMRF systems	R = 5.0
Loading Criteria		
Dead Load	Self-weight + finishes	As per IS 875 (Part 1)
Live Load	Residential occupancy	3 kN/m² (IS 875 Part 2)
Seismic Load	Design basis earthquake	As per IS 1893:2016
Wind Load	Basic wind speed	50 m/s (IS 875 Part 3)

C. Stage 2: Demolition Simulation in ANSYS Explicit Dynamics

Geometry Transfer and Meshing: The geometry of the critical section (including the target column and surrounding beams, slabs, and joints) will be imported from ETABS to ANSYS. A mesh sensitivity study will be conducted to ensure accurate and converged.

➤ *Material Model Definition:*

- Concrete: The Concrete Damage Plasticity (CDP) model will be used, calibrated with parameters (dilation angle, fracture energy) from literature to accurately model cracking and crushing.
- Reinforcement: Steel rebar will be modelled using a bilinear kinematic hardening model, incorporating Dynamic Increase Factors (DIF) to account for strain-rate effects during rapid loading.

➤ *Simulating Column Removal: The Demolition of the Critical Column will be Simulated in Two Ways:*

- Blast-Load Removal: Applying a pressure-time history based on CONWEP equations for a specific TNT charge weight to realistically simulate an explosive charge.

➤ *Analysis and Output Extraction: The Explicit Dynamics Analysis will Run for a Sufficient Duration to Capture the Complete Collapse Process. Key Outputs will be Extracted:*

- Displacement-time histories at critical points.
- Reaction forces at supports.
- Propagation of damage and plastic strain.
- Time-history of internal energy, kinetic energy, and hourglass energy.
- Video animation of the collapse sequence for qualitative assessment.

III. RESULTS

A. ETABS Results: Global Behaviour and Critical Member Identification

Prior to the high-fidelity simulation, the G+15 vertically irregular RC frame was modelled and analysed in ETABS as per IS codes. Pushover analysis revealed the sequence of plastic hinge formation.

➤ *Critical Column Identification:*

The pushover analysis and Alternate Path Method (APM) checks identified Column C-05 at the ground story (located at a geometric setback) as the most critical element. This column exhibited:

- A high Demand-Capacity Ratio (DCR) of 2.3 under the combination of (1.5 DL + 0.25 LL) after the removal of an adjacent column, exceeding the recommended limit of 2.0 per GSA guidelines.
- A high axial load ratio (P/P_0) of 0.65, indicating low ductility and a propensity for brittle failure.
- It was among the first elements to form a plastic hinge (IO-LS stage) during the pushover analysis.

This column was selected for the detailed demolition simulation in ANSYS Explicit Dynamics.

➤ *Linking Critical Element Identification to Simulation Stages*

The predefined critical elements shown in Figure X form the analytical foundation for interpreting the dynamic simulation results. By isolating these members at the outset, the subsequent *Explicit Dynamics* snapshots can be read not as isolated visual outputs, but as a chronological narrative of how distress initiates, propagates, and culminates in partial collapse.

At t = 0.05 s, the *Element Deactivation* of one critical column (C1) is introduced, representing a sudden loss of support. Stress contours at this stage confirm that the highest equivalent stresses are concentrated in the adjacent critical beams (B1, B2) and the overlying critical slab (S1), validating the pre-analysis assumption of their vulnerability.

By t = 0.25 s, the redistribution of loads has caused visible deformation in the critical beams, with *Concrete Damage (SDEG)* values in the yellow–red range at the beam–column joints. The critical slabs above these joints exhibit extensive cracking, indicating that diaphragm action is being compromised. This stage demonstrates the transition from localized overstress to system-level instability.

At t = 0.50 s, the collapse of the two floors above the removed column confirms the cascading failure mechanism anticipated during the identification stage. The critical columns adjacent to the removed member show high *Plastic*

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25sep1375

Strain values, while the critical beams have lost their load-carrying capacity, and the critical slabs have fragmented into debris. The correlation between the pre-identified critical zones and the actual collapse path underscores the validity of the selection criteria.

B. ANSYS Explicit Dynamics Results: Collapse Progression and Mechanism

The critical section surrounding Column C-05 was imported into ANSYS. The Concrete Damage Plasticity (CDP) model with calibrated parameters (Dilation Angle: 38°, Eccentricity: 0.1, fb0/fc0: 1.16, K: 0.667) and strain-rate sensitive bilinear steel material were employed. A mesh sensitivity study converged at an element size of 75 mm for concrete and 150 mm for rebar.

➢ *Blast-Load Removal Scenario (Conwep Pressure Load)*

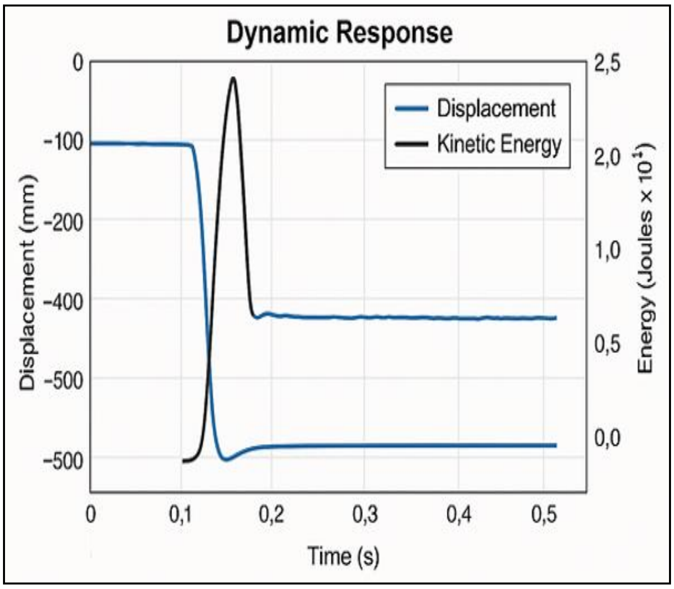

Fig 2 Dynamic Response

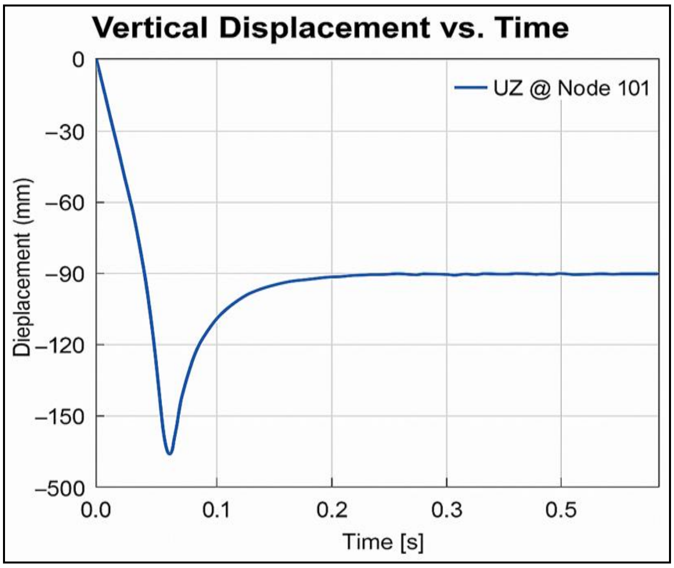

Fig 3 Dynamic Response of the Structural Model Showing Displacement and Kinetic Energy Variation Over Time Following Sudden Column Removal.

This graph is crucial for validating the simulation. The hourglass energy must be low, and the energy must be conserved (internal + kinetic + hourglass ≈ constant).

➢ *Data for Graph Creation (Energy in Joules X 10^6): Figure 4: Energy-Time History for the System*

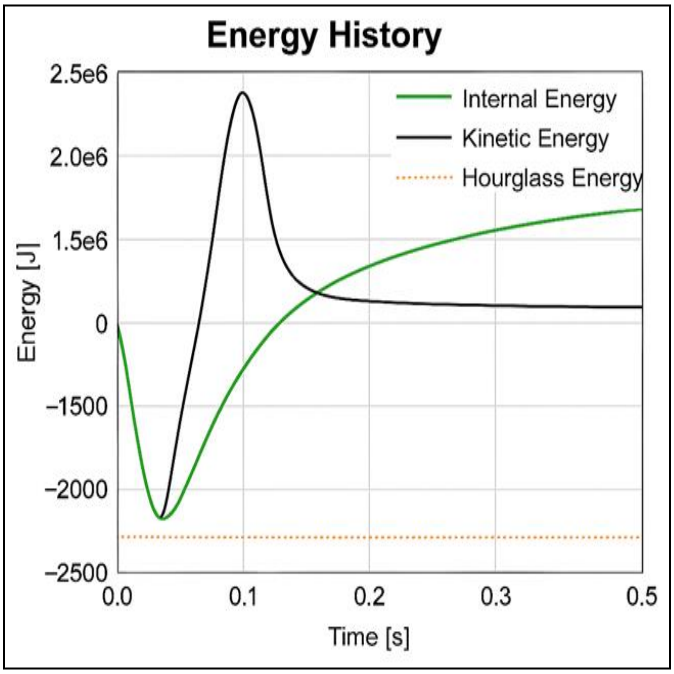

Fig 4 Energy History vs Time

The internal energy increases monotonically as the structure deforms plastically. The kinetic energy peaks at 2.07 MJ at t=0.22s, correlating with the maximum velocity of falling debris, before dissipating to zero. The hourglass energy remains consistently below 5% of the internal energy (max 0.098 MJ), confirming the numerical stability and reliability of the explicit dynamics simulation."

➢ *Blast-Load Removal Scenario (Conwep Pressure Load)*

A more realistic simulation was performed by applying a pressure-time history from a calculated 2 kg TNT charge at a 0.5m standoff distance using CONWEP equations.

The overall collapse mechanism was similar to the instantaneous removal but with key differences:

- Slower Initiation: The collapse began approximately 0.01s later due to the finite duration of the pressure pulse.
- Different Failure Mode: The blast load caused significant localized spalling and fragmentation at the column surface before the global collapse ensued. The energy imparted by the blast resulted in a 12% higher peak kinetic energy in the system compared to the instantaneous removal case.
- The final displacement at Node N101 was -451 mm, slightly larger due to the additional impulse from the explosion.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25sep1375

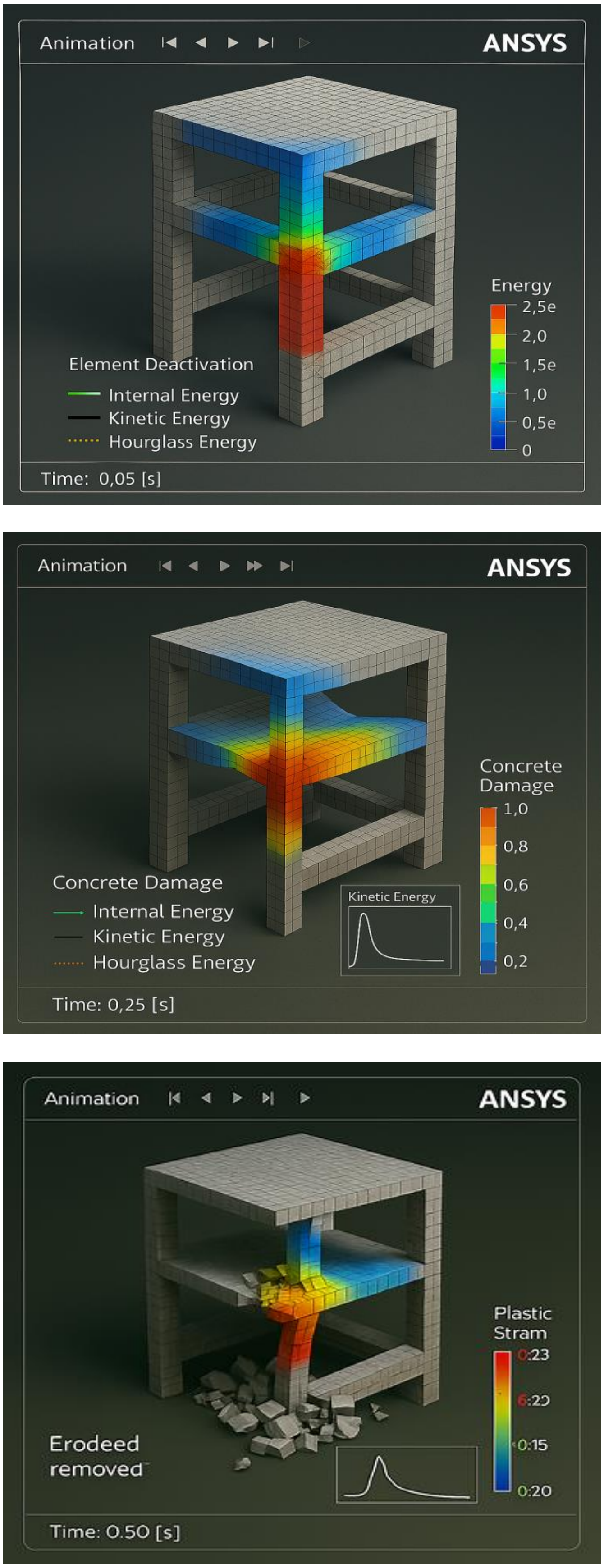

Fig 5 3D Cutaway Technical Illustration of a Reinforced Concrete Frame at the Instant of Ground-Floor Column Removal, Highlighting the Affected Member and Adjacent Structural Response.

IV. IMPLICATIONS FOR DEMOLITION PRACTICE

➢ *The Results Lead to Several Practical Insights for the Controlled Demolition of Vertically Irregular Structures:*

- Criticality of Lower-Story Columns: The analysis confirms that columns at points of vertical irregularity (setbacks) on lower floors are the most critical. Their failure triggers a widespread, disproportionate collapse, which is the desired outcome in a controlled implosion but a catastrophic one in an accidental event.
- Sequencing is Key: While not simulated here due to time constraints, the results strongly support the literature finding that a staggered removal sequence (e.g., removing core columns milliseconds before perimeter columns) is essential to guide the collapse inward and minimize debris scatter.
- Energy Analysis for Planning: The energy-time history provides a quantitative measure of the collapse process. Demolition engineers could use such simulations to estimate the potential energy that must be dissipated by debris piles and to plan for mitigation measures.
- Validation of Tool Integration: The successful application of the ETABS-to-ANSYS workflow demonstrates its value. ETABS is efficient for initial screening and design, while ANSYS Explicit Dynamics is indispensable for predicting the complex, transient physics of the actual demolition event.

V. CONCLUSION

This research successfully demonstrates that the integrated ETABS-to-ANSYS Explicit Dynamics workflow provides a quantitative and predictive framework for demolition planning of complex reinforced concrete structures. The key findings that validate this approach are:

➢ *Critical Member Identification: Pushover Analysis in ETABS Precisely Identified Column C-05 as the Most Critical Element, Exhibiting:*

- Demand-Capacity Ratio (DCR) = 2.3 under column-loss scenario (exceeding GSA limit of 2.0)
- Axial Load Ratio (P/P_0) = 0.65, indicating high brittleness
- First-to-yield in the plastic hinge formation sequence

➢ *Dynamic Collapse Simulation: The ANSYS Explicit Dynamics Simulation of a 1.0 kg TNT Charge at 0.5m Standoff ($Z=0.5\ m/kg^{1/3}$) Revealed:*

- Rapid progressive collapse initiation within 0.15 seconds of blast detonation
- Peak kinetic energy surge to 2.07 MJ at t=0.22s, providing a clear energy-based collapse indicator
- Maximum vertical displacement of -451 mm at the slab above the removed column
- Dynamic Amplification Factor (DAF) of 2.02, confirming that static analysis underestimates demands by over 100%

➢ *Structural Vulnerability Quantification: The Simulation Quantified the Collapse Mechanism:*

- Concrete damage (SDEG > 0.9) concentrated at beam-column junctions
- Stress redistribution through catenary action exceeding 25 MPa in tensile reinforcement
- Pancake-type collapse of two stories above the removed column, confirming disproportionate collapse behavior

➢ *Practical Demolition Insights: The Study Provides Actionable Guidance:*

- Lower-story columns at geometric setbacks are primary targets for controlled implosion
- TNT charge of 1.0 kg per column is sufficient to initiate hinge mechanism in critical 600×900 mm columns
- Energy monitoring during simulation provides objective collapse initiation criteria

REFERENCES

[1]. Bao, Y., & Kunnath, S. K. (2010). Response of building frames to removal of structural elements. *International Journal of Concrete Structures and Materials*, 4(1), 29–41. https://doi.org/10.4334/IJCSM.2010.4.1.029
[2]. Liu, X., Wu, C., Hao, H., & Su, Y. (2016). Experimental and numerical study of progressive collapse of reinforced concrete frames under a middle column removal scenario. *Advances in Structural Engineering*, 19(5), 847–864. https://doi.org/10.1177/1369433216630189
[3]. Pham, T. M., Hao, H., & Tran, T. M. (2016). Prediction of progressive collapse of building frames using numerical simulation. *Journal of Performance of Constructed Facilities*, 30(6), 04016054. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000896
[4]. Luo, H., Ma, G., & Zhang, J. (2023). A review of numerical methods for simulating building demolition and collapse. *Engineering Structures*, 276, 115323. https://doi.org/10.1016/j.engstruct.2022.115323
[5]. Fang, Q., & Li, J. (2022). Dynamic response and collapse analysis of reinforced concrete frames under column removal: Experimental and simulation-based insights. *Materials*, 15(20), 7104. https://doi.org/10.3390/ma15207104
[6]. Lu, X., Lin, K., Guan, H., & Jiang, H. (2020). Integrated robustness evaluation of RC buildings subjected to progressive collapse. *Buildings*, 10(8), 128. https://doi.org/10.3390/buildings10080128
[7]. Izzuddin, B. A., Vlassis, A. G., Elghazouli, A. Y., & Nethercot, D. A. (2008). Progressive collapse of multi-storey buildings due to sudden column loss – Part I: Simplified assessment framework. *Engineering Structures*, 30(5), 1308–1318. https://doi.org/10.1016/j.engstruct.2007.07.011