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A COMPREHENSIVE REVIEW OF PROGRESSIVE COLLAPSE MITIGATION IN MULTISTOREY STRUCTURES USING BELT WALL SYSTEMS AND COLUMN REMOVAL ANALYSIS

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Abstract: Progressive collapse is a critical structural safety concern in multi-story buildings, in which localized damage or failure of a structural member can trigger a disproportionate sequence of failures and potentially lead to partial or complete structural collapse. Such failures may result from accidental or extreme events, including explosions, vehicle impacts, fire, construction-related incidents, or unexpected loss of load-bearing members. Therefore, assessing the ability of multi-story structures to withstand localized damage and developing effective mitigation measures are essential for improving structural robustness and resilience. The present study investigates the progressive collapse behaviour of a G+14 reinforced concrete building under different column removal scenarios using ETABS. The structural response of the building is evaluated by considering localized column loss at critical locations and examining the resulting changes in structural behaviour. Key response parameters, including displacement, internal forces, load redistribution, and overall structural stability, are considered to assess the vulnerability of the structure to progressive collapse. In addition, the study examines the implementation of belt walls as a structural strengthening and mitigation system and evaluates their influence on the response of the building following column removal. A comparative assessment of the structural behaviour of the building with and without belt wall implementation is carried out to determine the effectiveness of the proposed system in reducing the adverse effects associated with localized column failure. The study provides insights into load redistribution mechanisms and the role of belt wall systems in enhancing structural integrity and resistance to progressive collapse. The findings are intended to contribute to the development of safer and more resilient multi-story reinforced concrete buildings and to support the application of practical progressive-collapse mitigation strategies in structural design..

Keywords — Multi Story Building, High Rise Building, Structures, Belt Wall, Progressive Collapse.

I. INTRODUCTION

The safety and resilience of multi-story buildings against accidental and extreme loading events have become important considerations in modern structural engineering. As buildings become taller, more complex, and increasingly dependent on interconnected structural systems, the consequences of localized structural damage can become more significant. One of the critical failure mechanisms associated with such damage is progressive collapse, in which the failure of one or more structural members initiates a chain reaction that results in disproportionate damage to adjacent members and may ultimately lead to partial or extensive collapse of the structure. Progressive collapse can occur following accidental events such as vehicle impact, explosions, fire, construction-related incidents, or unexpected failure of critical load-bearing elements. Unlike conventional structural failure, progressive collapse involves the redistribution of loads following the loss of a structural member. When a column is suddenly removed or becomes incapable of carrying its design load, the gravity loads supported by that member must be transferred to surrounding beams, columns, slabs, and other structural components. The ability of the structure to redistribute these loads depends on factors such as structural configuration, member stiffness, ductility, redundancy, continuity, connection strength, and the availability of alternative load paths. If the remaining structural system cannot accommodate the redistributed loads, additional members may fail, resulting in progressive propagation of damage.

The assessment of progressive collapse is therefore an important aspect of structural robustness and resilience. Conventional design approaches generally focus on the resistance of individual structural members to specified design loads. However, progressive collapse assessment requires consideration of the behaviour of the structural system following the loss of a critical member. This system-level approach helps identify vulnerable structural locations and provides an

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opportunity to develop suitable mitigation measures that can limit damage propagation and improve the overall integrity of the building. In the present study, the progressive collapse behaviour of a G+14 reinforced concrete (RC) multi-story building is investigated using ETABS. The numerical model is developed to represent the structural behaviour of the building under normal loading conditions as well as under selected column-removal scenarios. The removal of a column represents a localized damage condition in which the corresponding load-carrying capacity is suddenly lost. Different column locations can produce different load redistribution patterns and structural responses; therefore, the location and configuration of the removed column are important parameters in progressive collapse assessment. Following column removal, the structural system may experience increased demands in adjacent beams and columns, changes in internal force distribution, and increased displacement in the affected region. The redistribution of gravity loads can generate additional bending moments, shear forces, axial forces, and deformation in neighbouring structural members. The resulting response provides an indication of the ability of the building to develop alternative load paths and maintain overall stability after localized damage. Accordingly, parameters such as joint displacement, beam and column forces, deformation patterns, load redistribution, and structural stability can be evaluated to assess the progressive collapse response.

In addition to assessing the unstrengthened structure, this study investigates the potential application of a belt wall system as a structural mitigation measure. Belt wall systems can provide additional stiffness and connectivity within a multi-story building and may facilitate the redistribution of structural forces over a larger portion of the building. Their effectiveness in mitigating progressive collapse depends on their location, stiffness, structural connection, and interaction with the existing structural system. Therefore, the incorporation of belt walls is examined to determine their influence on the structural response following localized column loss. The concept of providing additional structural continuity and stiffness is particularly relevant to high-rise and multi-story buildings, where lateral and gravity-load-resisting systems interact as an integrated structural system. A properly designed strengthening system can provide alternative load-transfer mechanisms and reduce excessive deformation in regions affected by localized damage. In this

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context, the evaluation of belt walls provides an opportunity to investigate whether an additional structural system can improve the robustness of an RC building subjected to column-removal conditions.

II. PROGRESSIVE COLLAPSE

Progressive collapse is a structural failure phenomenon in which localized damage or failure of one or more structural members initiates a sequence of failures in adjacent members, resulting in damage that is disproportionate to the original initiating event. The failure may remain localized, develop into partial collapse, or, in severe cases, propagate through a substantial portion of the structure. Progressive collapse is therefore fundamentally a system-level structural behaviour, rather than simply the failure of an individual beam, column, slab, or connection.

The concept of progressive collapse received considerable attention following the Ronan Point apartment building incident in London in 1968, where a localized gas explosion caused the failure of part of the building and highlighted the potential for localized damage to propagate through a structural system. The incident encouraged researchers and structural engineers to investigate the mechanisms by which local failures can produce disproportionate structural consequences and to develop approaches for improving structural robustness.

The basic mechanism of progressive collapse involves the loss of a load-carrying structural element and the subsequent redistribution of its load to surrounding members. For example, when a column is suddenly damaged or removed, the gravity loads previously carried by that column must be transferred to adjacent columns, beams, slabs, walls, and connections. If these members possess sufficient strength, stiffness, ductility, continuity, and redundancy, the structure may develop alternative load paths and remain stable. However, if the redistributed demands exceed the capacity of the surrounding members, additional failures may occur, allowing the damage to propagate.

Several types of accidental or extreme events can initiate conditions associated with progressive collapse. These may include gas explosions, vehicle impacts, fire, blast loading, construction errors, accidental overloads, foundation failures, or unexpected loss of structural members. The initiating event itself may be relatively localized; however, the resulting structural response can be significantly larger because of load redistribution and

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interaction among interconnected structural components.

A major characteristic of progressive collapse is the difference between the initial local damage and the final extent of structural damage. The initiating event may affect only a limited portion of a building, whereas the subsequent failure sequence can extend beyond the directly affected area. Consequently, structural design for robustness seeks to ensure that localized damage does not result in disproportionate collapse.

A. Mechanism of Progressive Collapse

The progression of collapse can generally be understood through the following sequence:

Initiating Event → Localized Member Failure → Load Redistribution → Increased Demand on Adjacent Members → Secondary Failure → Damage Propagation → Partial or Extensive Collapse

Following the failure of a critical column or other load-bearing element, the surrounding structural members experience changes in their internal force distribution. Adjacent beams may develop increased bending moments and shear forces, while neighbouring columns may experience increased axial loads. Connections and floor systems may also become important in transferring forces away from the damaged region.

The ability of a structure to resist progressive collapse is influenced by several factors, including:

- Structural redundancy: Availability of multiple load paths through which forces can be redistributed.
- Continuity: Ability of beams, slabs, columns, and connections to maintain structural connectivity after local damage.
- Ductility: Ability of structural members and connections to undergo deformation while continuing to carry load.
- Strength: Capacity of individual members to resist the increased forces generated by load redistribution.
- Stiffness: Ability of the structural system to control excessive deformation following member loss.
- Connection performance: Capacity of beam-column and slab-column connections to transfer forces after localized damage.

- Building configuration: Arrangement and interaction of the vertical and horizontal load-resisting systems.

B. Column Removal as a Progressive Collapse Analysis Approach

Column removal is one of the commonly adopted approaches for numerical investigation of progressive collapse behaviour. In this approach, a selected column is removed from the structural model to represent a localized loss of load-carrying capacity. The resulting response of the building is then examined to determine whether the remaining structure can redistribute the affected loads without experiencing disproportionate failure.

The location of the removed column is an important consideration because different locations can produce different structural responses. Possible locations include corner columns, exterior columns, and interior columns. The resulting changes in displacement, bending moment, shear force, axial force, and load redistribution can be used to assess the structural response under localized damage conditions.

For the present study, column-removal scenarios are investigated in a G+14 reinforced concrete building using ETABS. The response of the structure is assessed under selected localized column-loss conditions, and the resulting structural behaviour is compared with the corresponding strengthened configuration.

C. Importance of Progressive Collapse Assessment

Progressive collapse assessment is important because conventional structural design primarily considers prescribed load combinations and member-level capacity, whereas progressive collapse involves the response of the entire structural system following an abnormal event. A building may have adequate capacity under conventional loading conditions but may exhibit significant vulnerability following the unexpected loss of a critical structural member.

Progressive collapse analysis can therefore help identify vulnerable regions, understand alternative load paths, evaluate structural redundancy, and investigate suitable strengthening or mitigation measures. It also provides useful information for developing structures capable of sustaining localized damage while limiting the extent of subsequent failure.

III. BELT WALL

A belt wall is a structural wall or reinforced concrete belt-type structural

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element incorporated into a building to provide additional stiffness, continuity, and force-transfer capability. The term should be distinguished from conventional retaining walls, which primarily resist lateral earth and groundwater pressures in below-grade construction. In the context of the present research, the belt wall is considered as an additional structural system within the multi-story building and is investigated for its potential contribution to structural stiffness, load redistribution, and progressive-collapse resistance.

In multi-story and high-rise structures, additional structural elements may be introduced to improve the overall behaviour of the building under gravity and lateral loading. A belt wall can provide structural continuity between portions of the building and can interact with the existing beams, columns, slabs, and other load-resisting elements. Depending on its configuration and connection to the primary structural system, the belt wall can influence the distribution of forces and deformation throughout the building.

A. Structural Function of a Belt Wall

The principal structural function of a belt wall in the present study is to provide an additional load-transfer and stiffening mechanism within the building. When localized damage occurs, such as the removal of a column, the surrounding structural members are required to carry additional loads. An appropriately connected belt wall may assist in redistributing these forces over a larger portion of the structural system.

The potential functions of a belt wall include:

- Increasing the overall stiffness of the structural system.
- Providing additional continuity between structural components.
- Facilitating redistribution of forces following localized member failure.
- Reducing excessive deformation in the affected region.
- Providing an additional structural load-transfer mechanism.
- Improving the overall robustness of the building.
- Contributing to resistance against lateral and gravity-induced structural demands.

The actual contribution of a belt wall depends on its geometry, thickness, material properties, location, reinforcement, connectivity, and interaction with the surrounding structural members. Therefore, its effectiveness should be established through structural analysis rather than assumed solely from its presence.

B. Belt Wall and Progressive Collapse Mitigation

The application of a belt wall as a progressive-collapse mitigation measure is based on the concept of improving structural continuity and providing additional pathways for force redistribution. When a column is removed, the structural system experiences an abrupt change in its load-carrying configuration. The affected gravity loads must consequently be transferred to adjacent members.

In a building without additional strengthening, the redistribution of loads may result in significant deformation and increased internal forces in beams and columns surrounding the removed member. The incorporation of a belt wall may alter the stiffness and force-transfer characteristics of the system and may therefore influence the magnitude and distribution of these structural responses.

The effectiveness of the belt wall can be evaluated by comparing the structural response of the building with and without the belt wall under identical column-removal scenarios. Parameters such as maximum displacement, beam forces, column forces, deformation patterns, load redistribution, and overall structural stability can be considered in the comparison.

C. Belt Wall Configuration and Construction Considerations

The performance of a belt wall depends significantly on its connection with the primary structural system. Appropriate detailing is required to ensure that forces can be effectively transferred between the belt wall and the surrounding structural members. Important considerations include wall dimensions, reinforcement arrangement, concrete strength, connection details, location within the building height, and compatibility of deformation with the existing structural system.

For numerical modelling, the belt wall should be represented with appropriate material and geometric properties so that its stiffness and interaction with the surrounding structure are adequately captured. The structural model should also account for the connections between the belt wall and the adjacent beams, columns, and floor systems.

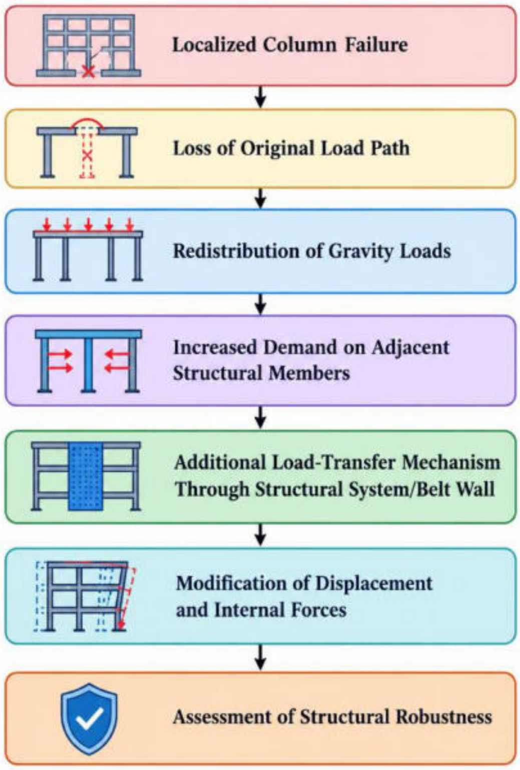
D. Role of Belt Wall in the Present Study

In this research, the belt wall is investigated as a structural mitigation system for reducing the adverse effects of localized column failure in a G+14 reinforced concrete building. The building is modelled and analysed using ETABS under selected column-removal scenarios. The structural response obtained from the model without a belt wall is compared with that of the corresponding model incorporating the belt wall.

The comparison is intended to determine how the additional structural system affects important response parameters such as displacement, internal forces, load redistribution, and structural stability. The analysis can provide an understanding of whether the belt wall contributes to improving the building's ability to accommodate localized damage and limit the propagation of structural failure.

E. Relationship Between Progressive Collapse and Belt Wall

The relationship between progressive collapse and belt wall implementation can be represented conceptually as:



Thus, progressive collapse analysis provides a means of evaluating the response of the building following localized damage, while the belt wall represents a potential structural modification intended to improve load redistribution and overall robustness. The effectiveness of the system must ultimately be evaluated through comparative structural analysis under defined loading and column-removal conditions.

IV. CONCLUSIONS

The present study investigated the progressive collapse behaviour of a G+14 reinforced concrete building under different column-removal scenarios using ETABS. The analysis showed that localized column failure can cause significant load redistribution, increased forces, and deformation in adjacent structural members. The response of the building depends on the location of the removed column and the strength, stiffness, continuity, ductility, and redundancy of the structural system. The study also evaluated the implementation of a belt wall as a progressive-collapse mitigation system. The belt wall provides additional stiffness, continuity, and load-transfer capacity, which can influence the structural response following column removal. Comparative assessment of the building with and without the belt wall helps evaluate its contribution to reducing deformation and improving structural robustness. Overall, the study highlights the importance of alternative load paths and adequate structural redundancy in preventing disproportionate failure. The belt wall can be considered a potential mitigation measure, provided its configuration, connectivity, and structural performance are appropriately designed and verified through detailed analysis.

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