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## Efficient Configuration of Steel Lateral Load Resisting System (LLRS) Considering Progressive Collapse

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Peer Review Information	Abstract
<p><i>Submission: 11 Oct 2025</i></p> <p><i>Revision: 10 Nov 2025</i></p> <p><i>Acceptance: 22 Nov 2025</i></p> <p><b>Keywords</b></p> <p><i>Lateral load resisting system, Progressive Collapse, Nonlinear static pushover analysis (NSPA), Nonlinear time history analysis</i></p>	<p>The stability and safety of high-rise and complex structures largely depend on the effectiveness of their lateral load resisting systems (LLRS). Conventional designs primarily focus on resisting wind and seismic forces; however, recent catastrophic events have highlighted the vulnerability of structures to progressive collapse, where local failures can trigger disproportionate structural damage. This research addresses the efficient configuration of steel LLRS with explicit consideration of progressive collapse mechanisms. A comprehensive literature review identifies limitations in existing approaches, including inadequate redundancy, lack of alternative load paths, and insufficient integration of seismic and dynamic effects. The study proposes an optimized configuration of steel LLRS that redistributes loads under localized damage scenarios to enhance robustness and minimize failure propagation. The methodology involves nonlinear static pushover analysis (NSPA) and nonlinear time history analysis (NLTHA) to evaluate and validate structural performance under varied loading and damage conditions. The expected outcome is a more resilient LLRS framework capable of preventing disproportionate collapse, thereby safeguarding lives, reducing economic losses, and improving structural sustainability.</p>

### Introduction

#### General

The efficient configuration of a Steel Lateral Load Resisting System (LLRS) considering progressive collapse is a critical aspect of structural engineering and building design. Progressive collapse refers to the catastrophic failure of a structure, where the failure of one or a few structural components leads to the cascading collapse of the entire building/ frames. This can have devastating consequences in terms of loss of life, property damage, and economic impact.

In the realm of structural engineering and design, the concept of LLRS is fundamental. These systems are primarily designed to withstand horizontal forces, such as those generated by

wind, earthquakes, or other lateral loads. However, in recent years, the focus has expanded to consider not only their ability to resist static lateral loads but also their capacity to withstand the progressive collapse of a structure.

Progressive collapse refers to the spread of localized structural failure in a building or structure that can result from a single initiating event, such as a blast, impact, or even a natural disaster. Understanding and mitigating the risk of progressive collapse is crucial for safeguarding lives, protecting property, and ensuring the continued functionality of essential infrastructure.

Efficient configuration in the context of steel LLRS refers to the strategic design and placement of steel elements and systems within a structure

to optimize their load-resisting capabilities while simultaneously minimizing material usage and construction costs. This includes selecting appropriate steel members, connections, and bracing systems to efficiently distribute lateral loads throughout the structure.

### Type of load resisting system

#### A. Moment Resisting Frame (MRF)

Action: Resists lateral loads through bending in beams and columns.

Behavior: Joints are rigid, maintaining angles between members.

Used in: High-rise buildings, seismic zones.

Advantage: High ductility, flexible layout.

Disadvantage: Larger member sizes, more complex joints.

#### B. Braced Frame

Action: Uses diagonal braces to resist lateral loads through axial forces.

Types:

Concentric Braced Frame (CBF)

Eccentric Braced Frame (EBF)

Used in: Industrial buildings, towers.

Advantage: Efficient for lateral load resistance, simpler joints.

Disadvantage: Bracing may interfere with openings or space usage.

#### C. Shear Wall System

Action: Reinforced concrete walls resist lateral forces by shear and bending.

Used in: Residential buildings, high-rises.

Advantage: High stiffness and strength.

Disadvantage: Limits architectural flexibility

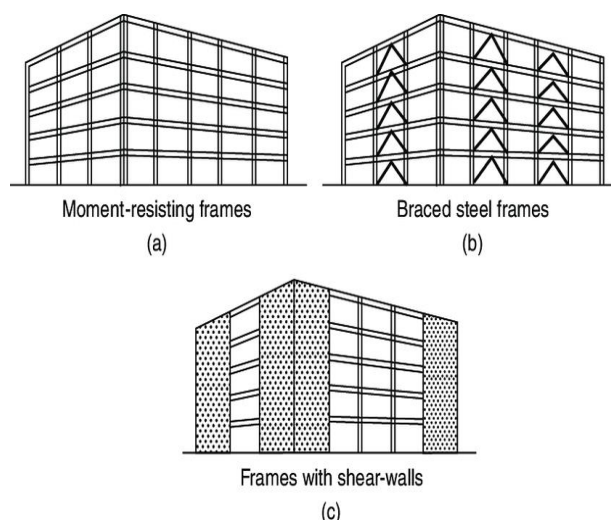


Fig. 1. Type of Load Resisting Frame

### Progressive Collapse

Progressive collapse is a structural failure mechanism where the failure of a small part of a building or structure leads to a chain reaction of

failures, causing a larger portion or the entire structure to collapse. This type of collapse is particularly dangerous because it can happen rapidly and unexpectedly, often without much warning.

### Key Concepts

a) Initiating Failure: The collapse typically begins with the failure of a single structural component or element, such as a column or beam. This initial failure can be triggered by various factors, including design flaws, material defects, or external forces (e.g., explosions, impacts).

b) Domino Effect: Once the initial component fails, the loads that it was carrying are redistributed to adjacent components. If these adjacent components are not designed to handle the extra load, they may also fail. This process can continue, leading to a cascading failure that affects a large portion of the structure.

c) Energy Transfer: The failure of structural elements can cause a transfer of energy to other parts of the structure, which can exacerbate the collapse. For instance, a collapsing floor may drop onto the floor below, causing additional damage and failures.

d) Design and Safety: Modern building codes and design practices aim to prevent progressive collapse by incorporating safety features such as redundancy, robustness, and load distribution systems. This might involve designing structures with enough spare capacity to withstand localized failures without triggering a larger collapse.

e) Real-World Examples: One of the most famous examples of progressive collapse is the collapse of the World Trade Center towers on September 11, 2001. The initial impact of the planes caused significant structural damage, and the subsequent fires weakened the remaining structure, leading to the progressive collapse of the towers.

### Problem Statement

The problem statement is Efficient Configuration of Steel Lateral Load Resisting System (LLRS) Considering Progressive Collapse

### Aim

Considering limitation of past research gap following aims and objectives are defined.

- To propose efficient & effective Configuration of Steel Lateral Load Resisting System (LLRS) Considering Progressive Collapse.
- LLRS will be design to redistribute loads in the event of localized damage to avoid disproportionate loading on remaining elements.

## Objectives

- To assess of conventional LLRS for progressive collapse.
- To prepare efficient configuration of LLRS considering progressive collapse.
- To validate the said efficient configuration through numerical analysis such as Non Linear Push Over Analysis [NSPA], Non Linear Time History Analysis [NLTHA].

## Literature Review

**Jinkoo Kim** <sup>etal</sup> In this study the progressive collapse-resisting capacity of steel moment resisting frames is investigated using alternate path methods recommended in the GSA and DoD guidelines. The linear static and nonlinear dynamic analysis procedures are carried out for comparison. It is observed that, compared with the linear analysis result, the nonlinear dynamic analysis provided larger structural response and the result varied more significantly depending upon the variables such as applied load.

**H.R. Tavakoli** <sup>etal</sup> Progressive collapse is a catastrophic structural phenomenon that can occur because of human-made and natural hazards. The research on progressive collapse generally focuses on gravity and blast loading. Observations of buildings damaged by earthquake have shown that earthquake load also may cause local partial or complete failure of critical elements and may lead to progressive failure. The study is conducted on multi story buildings by applying alternate load path method. The results show that parameters such as number of bays, height and location of eliminated elements have great influence on progressive collapse potential of buildings under seismic loading.

**John R Sh, Mohmed** <sup>etal</sup> The effect of an outrigger and belt system, mainly provided for resisting lateral wind and seismic loads, on the progressive collapse analysis of a 52 floor high rise building is presented in this paper. The main lateral load resisting element of the building is reinforced concrete core located at the centre of the building.

The blast effect is simulated by the sudden removal of some columns at selected locations in the ground and first floor. Three different scenarios are considered for blast event. The building was analyzed for the different scenarios for progressive collapse. It is shown that the use of outrigger and built system adds to different load paths to the building that contributes to its resistance to progressive collapse. While the model without outrigger system went through full failure and 100% damage, the case with outrigger system was able to resist the blast event with minimum local damage. It is

concluded that a well-proportioned outrigger and built system can prevent progressive collapse, protect properties and save lives.

**Hirebet Sharada Bai** <sup>etal</sup> It is necessary to consider gravity and seismic loads as well as all the load combinations during analysis of the structure. Provision of both ESB and ISB effectively reduce large joint displacements found in bare frame. The best performing LLRS among the two LLRS considered is ISB as all the parameters considered reduce in this case when compared with bare frame. When these LLRS considered in the study are employed in field for upgrading or retrofitting a structure, it is necessary to ensure proper connections between existing structure and LLRS provided.

**Abhijeet Baikerikar** <sup>etal</sup> A natural hazard like Earthquake causes damage to or collapse of buildings if not designed for lateral loads resulting due to Earthquake Hence for seismic resistance for high rise structures it is important to provide exclusive Lateral Load Resisting System (LLRS) which will supplement the behavior of moment resisting frames in resisting the lateral load. As the building height increases lateral displacement and drift increases. Base shear decreases as the time period increases.

**Hao Wang, Anqi** <sup>etal</sup> Progressive collapse of building structures is generally triggered by a local failure due to accidental actions, followed by subsequent chain effect of the structures which may result in wide range failure or even collapse of the entire buildings. This paper assesses the current researches on this issue from experimental study, numerical simulation and theoretical analysis. The majority of the experimental studies used the static loading pattern without considering the dynamic effect in actual collapse process. The numerical methods for progressive collapse have been introduced in this paper. The nonlinear dynamic effect in the simple structure is investigated based on the dynamic energy theories.

**Dr. Nurdeen Altwair** <sup>etal</sup> It is found that there is a strong influence of design for environmental performance on the structural performance the building, and that systems selected primarily with an eye towards energy use reduction may require substantial additional structural stiffening to meet safety and serviceability limits under lateral load cases.

**Wei-Jian Yi, Fan Yi** <sup>etal</sup> In the recent two decades, the progressive collapse of reinforced concrete (RC) frame structures attracted unprecedented research interests in the structural engineering community. Experiments are regarded as an essential method in this field since actual cases can barely provide sufficient and effective data to support rigorous research. In this paper,

prevailing experimental assumptions and configurations among over 100 series of experiments are quantitatively revealed by a bibliometric collection based on systematic search in an academic database.

**Bhagyashree Tayade** <sup>etal</sup> Progressive collapse occurs when one of the structural members fails, causing other structural members to fail. This leads to the collapse of all or part of the structure. Failure of a vertical structural member is the most common cause of progressive structural collapse Explosive charges, accidents or deliberate destruction can cause the column to fail and collapse. The analysis is performed by removing the columns at different locations one by one according to General Service Administration (GSA) guidelines, and then evaluating the radius and column DCR values. The results concluded that the column removed from the center is more vulnerable to progressive collapse.

## Methodologies

### Research Proposal

This research proposes to develop advanced numerical and experimental frameworks that incorporate connection flexibility, multi-column failure, seismic loading, and soil-structure interaction to more accurately simulate and mitigate progressive collapse in steel moment frames. This research aims to enhance the assessment of progressive collapse-resisting capacity in steel moment frames by integrating nonlinear dynamic analysis, seismic load considerations, and experimental validation to improve model accuracy and reliability. This research proposes a comprehensive comparative study of various lateral load resisting systems in multi-storey buildings by incorporating diverse structural configurations, bracing types, soil-structure interaction, and nonlinear material behaviour across different seismic zones. This research aims to optimize alternative load path (ALP) design strategies by evaluating their performance under seismic conditions and validating results through experimental studies to enhance reliability and reduce rehabilitation costs using FEMA-P58. This study proposes a comprehensive analysis of progressive collapse in structures with various lateral load resisting systems by incorporating different materials, dynamic seismic effects, soil-structure interaction, and optimized bracing configurations..

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### Methodology

The following methodology will be followed to achieve the aim and objective of research work.

- To do the continuous literature review to identify the work done and work available by other researcher.
- To evaluate the progressive collapse potential of conventional/existing steel LLRS through numerical analysis.
- Proposed the efficient steel LLRS considering numerical evaluation.
- Validation of proposed LLRS model through numerical evaluation under the suit of various lateral loads.

### Limitations

The efficient configuration of steel lateral load-resisting systems (LLRS) must address the limitations associated with progressive collapse. Current designs often lack sufficient redundancy and fail to provide alternative load paths when localized damage occurs. To mitigate disproportionate structural failure, LLRS should be designed to redistribute loads effectively during unexpected element loss. This requires a focus on structural continuity, robustness, and energy dissipation to enhance overall collapse resistance.

### Concluding Remark

- A literature survey has been carried out to understand the existing research and identify knowledge gaps.
- The aim and objectives of the study have been clearly defined.
- The problem statement has been formulated based on the findings from the literature review.
- The research methodology has been outlined to guide the investigation effectively.
- A detailed research plan has been prepared to structure the overall study process.

### Disclaimer

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