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# Effect Of Column Removal Scenarios on The Robustness of Steel Plate Shear Wall Structures

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**Abstract**

The structural reliability of Steel Plate Shear Wall (SPSW) systems when subjected to abnormal or extreme loading conditions has gained significant attention in contemporary structural engineering research. This investigation focuses on assessing the behavior of SPSW buildings under sudden column loss scenarios, with particular emphasis on progressive collapse resistance and structural robustness. The unexpected removal of a major vertical load-carrying member can cause rapid force redistribution within the structural system, which may result in localized or widespread collapse if adequate redundancy is not present.

To study this response, detailed analytical models of multi-storey SPSW buildings are developed and evaluated using nonlinear static (pushover) and nonlinear dynamic analysis procedures in ETABS. Different column removal cases—namely corner, edge, and interior columns—are simulated to examine variations in structural behavior. Key response parameters such as plastic hinge development, internal force redistribution, lateral displacement patterns, and energy absorption capacity are carefully monitored.

The comparative assessment highlights the inherent redundancy and alternative load path mechanisms provided by SPSW systems. Special attention is given to the role of infill steel plates in transferring forces after column removal, as well as to the effects of structural parameters including storey height, plate thickness, and boundary frame rigidity. The analysis indicates that SPSW structures possess considerable ductility and redistribution capability; however, their robustness is strongly influenced by thelocation of the removed column and the continuity and stiffness of surrounding boundary elements.

Overall, this study enhances the understanding of SPSW performance under progressive collapse scenarios and offers valuable insights for strengthening design strategies aimed at improving structural resilience against extreme events.

## Introduction

### General

Progressive collapse is a structural failure mechanism in which the initial damage or failure of a single component—commonly a column—initiates a sequence of failures in adjoining members. This chain reaction can ultimately result in the partial or total collapse of a building. Such incidents are typically associated with extreme or unforeseen actions such as blasts, fire exposure, vehicular impact, or errors in design and construction practices.

The severity of progressive collapse lies in its disproportionate nature, where limited initial damage leads to extensive structural consequences.

**Importance of Robustness**
Structural robustness represents the capacity of a building system to tolerate local damage without undergoing widespread collapse. A robust structure can effectively redistribute loads through alternative load paths when one of its critical members is lost. Evaluating robustness under simulated column removal scenarios helps determine whether the structural system can sustain gravity and lateral loads safely after localized failure, thereby minimizing the risk of catastrophic outcomes.

**Role of Steel Plate Shear Wall (SPSW) Systems** Steel Plate Shear Wall (SPSW) systems are widely recognized as an effective lateral force-resisting system in steel structures. These systems comprise thin steel infill plates connected to surrounding beams and columns, creating a vertical plate assembly that behaves similarly to a cantilever wall. After buckling, the infill plates develop diagonal tension fields that significantly enhance load-carrying capacity. Due to their high stiffness, strength, ductility, and superior energy dissipation characteristics, SPSW systems are particularly advantageous in regions prone to seismic activity.

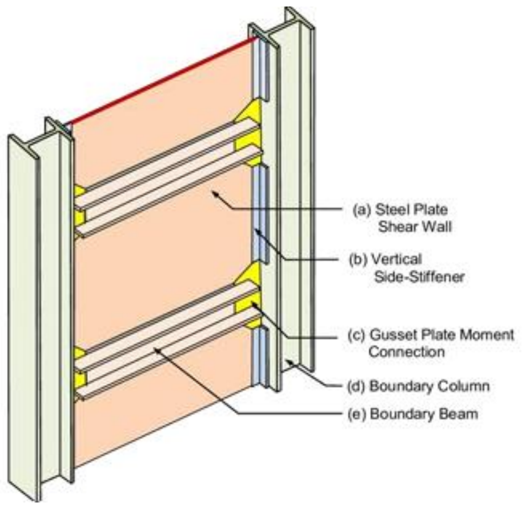


*Fig 1: Steel Plate Shear Wall (SPSW) Systems*

**Column Removal Scenarios**
Different column removal scenarios such as corner, edge, and interior column loss produce distinct patterns of load redistribution and deformation. Understanding these behaviors is essential to identify the most critical failure mechanisms and evaluate the robustness of the structural system.

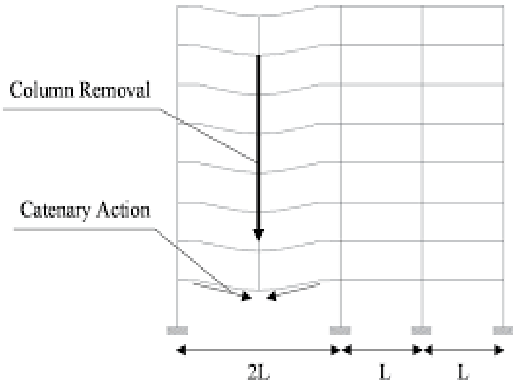


*Fig 2: Column Removal Scenarios*

**Aim**

- The primary aim of this study is to evaluate the effect of different column removal scenarios on the robustness and progressive collapse resistance of steel plate shear wall (SPSW) structures using nonlinear dynamic analysis based on the Alternate Path Method (APM). The study seeks to identify critical column locations, assess load redistribution mechanisms, and propose design recommendations to enhance the overall robustness of SPSW systems.

**Objectives**

- To develop and analyze detailed finite element models of Steel Plate Shear Wall (SPSW) structures using ETABS or ABAQUS to study their behavior under abnormal loading conditions.
- To investigate the structural response of SPSW systems under various column removal scenarios (corner, edge, and interior) by evaluating force redistribution, deformation patterns, and key response parameters such as displacement, rotation, and axial forces.
- To assess the residual load-carrying capacity and identify critical failure mechanisms in order to propose design strategies that enhance robustness and redundancy against progressive collapse.

**Problem Statement**

- Steel Plate Shear Wall (SPSW) systems are recognized for their excellent performance under seismic and wind loads; however, their behavior under abnormal loading events such as sudden column removal remains insufficiently studied. The lack of comprehensive understanding of load redistribution mechanisms and post-failure ductility limits the ability to design SPSW systems with adequate robustness. Therefore, this study aims to investigate the progressive collapse behavior of SPSW structures under different column removal scenarios to identify vulnerable regions and propose strategies to improve overall structural resilience.

**Literature Survey**

Gaurav Swami et al. (2025)

The study evaluates the structural robustness of high-rise composite modular buildings using the Alternate Load Path (ALP) approach under sudden element removal caused by gravity loading. A detailed finite element model of a 50-storey modular structure was developed in Abaqus, incorporating concrete-filled steel tubular (CFST) columns and composite shear walls (CSW). The use of CSW in the core was intended to enhance modular efficiency and improve load-sharing behavior, while CFST columns were adopted to increase buckling resistance and post-buckling strength. Both nonlinear static and dynamic analyses were performed to capture load transfer mechanisms and potential failure modes. The findings indicated that the structure maintained adequate resistance against progressive collapse under both column and module loss conditions. The study also highlighted the importance of intermodule connections in module removal scenarios and the critical role of adjacent beams during column loss events.

Shoaib Mansouri et al. (2025)

This research focuses on the seismic performance of concrete-filled double-steel-plate (CFDSP) composite shear walls subjected to displacement-controlled cyclic loading. Although fiber-reinforced polymer (FRP) materials are widely used in strengthening applications, their role in enhancing the seismic behavior of CFDSP walls remains relatively unexplored. Experimental testing was conducted on CFDSP wall specimens filled with self-compacting concrete (SCC) and externally strengthened with FRP wraps. The results demonstrated improved energy dissipation capacity, stiffness retention, and ductility, suggesting that FRP confinement can effectively enhance the seismic resilience of such composite wall systems.

Jing-Zhou Zhang et al. (2025)

This paper investigates the collapse behavior of column-supported modular steel buildings (CSMSB) under different column removal scenarios. The study identifies distinct differences in failure mechanisms between modular systems and conventional steel frame structures, particularly in relation to double-layer beam systems and point-supported slab behavior. The contribution of beams and slabs in resisting collapse was examined, considering parameters such as slab thickness, reinforcement ratio, beam depth, and column loss location. A comparative assessment was also carried out to evaluate the structural efficiency and economic implications of modifying these parameters to enhance collapse resistance.

resistance.

Jingsheng Zhou et al. (2025)

This study discusses progressive collapse as a consequence of localized initial damage caused by abnormal or extreme events. Contemporary design approaches emphasize strengthening member capacity and improving connectivity to facilitate effective load redistribution after component failure. However, most existing research and design provisions are largely based on framed structural systems, with comparatively limited investigation into mid-rise cold-formed steel (CFS) load-bearing wall buildings. The study highlights the need for further research to establish reliable collapse-resistant design strategies for such structural systems.

**Methodology**

**Material Properties**

The material properties for the prototype structure are defined according to IS 2062:2011 (Hot Rolled Medium and High Tensile Structural Steel).

Grade of Steel: Fe 345

Modulus of Elasticity (E): $2.0 \times 10^5$ MPa

Poisson's Ratio (ν): 0.3

Density of Steel (ρ): 7850 kg/m$^3$ Yield Stress of Plate (fy): 345 MPa Ultimate Stress (fu): 490 MPa

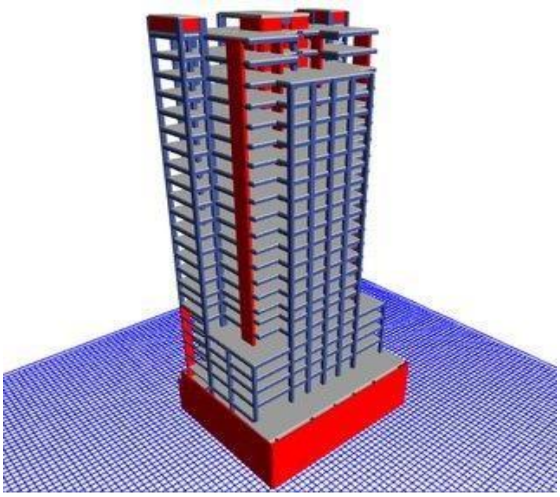
**Loading Considerations**

All gravity and lateral loads are calculated as per IS 875 and IS 1893. The following load cases are applied to the prototype model

- Dead Load (DL): Self-weight of structural elements and floor finishes.
- Live Load (LL): 3.0 kN/m$^2$ (typical office or residential occupancy).
- Wind Load (WL): Calculated as per IS 875 (Part 3).
- Seismic Load (EQ): As per IS 1893 (Part

1) for Zone IV (medium to high seismic zone).
- Abnormal Load: Column removal scenarios as per GSA guidelines.

**Structural Modeling in ETABS**



*Model 1: 3D Structural Modeling in ETABS Nonlinear Dynamic Analysis*

**Analysis Procedure**

Nonlinear dynamic analysis was performed using time-history function representing sudden column removal.

Dynamic Amplification Factor (DAF) applied = 2.0 (as per GSA recommendation).

Analysis duration = 5 seconds Time step = 0.01 sec Numerical Results

**Maximum Vertical Displacement at Removal Location**

**Table 1:** Maximum Vertical Displacement at Removal Location

| Scenario | Max Displacement (mm) |
|---|---|
| Corner Column | 42mm |
| Edge Column | 36mm |
| Interior Column | 28mm |

Interior column removal showed least displacement due to higher redundancy.

**Maximum Beam Rotation (Rad)**

**Table 2:** Maximum Beam Rotation

| Scenario | Plastic Rotation |
|---|---|
| Corner Column | 0.032 |
| Edge Column | 0.027 |
| Interior Column | 0.018 |

Allowable rotation (AISC) = 0.05 rad All values within safe limits.

**Axial Force Redistribution (kN)**

Scenario Adjacent Column Force Increase Corner +38%
Edge+29% Interior +18%

Corner column removal produced maximum force amplification.

**Tension Field Development in SPSW**

Post-buckling tension diagonal action developed within 0.8 seconds after column removal.

The SPSW contributed approximately 35–45% additional lateral stiffness during redistribution phase.

**Parametric Study**

**Effect of Plate Thickness**

| Thickness | Max Displacement (mm) |
|---|---|
| 6 mm | 48 mm |
| 8 mm | 39 mm |
| 10 mm | 32 mm |
| 12 mm | 26 mm |

Increasing plate thickness reduced displacement by 45%.

**Effect of Connection Rigidity**

Fully welded system reduced displacement by 22% compared to semi-rigid bolted system.

Effect of Storey Level of Removal Ground storey removal was most critical.

Upper storey removal reduced displacement by 30–40%.

**Discussion of Results**

- Corner column removal is the most critical case producing 42 mm displacement and 38% force amplification.
- SPSW system significantly enhances alternate load path capacity.
- Interior column removal shows highest redundancy due to surrounding load sharing.
- Increased plate thickness improves robustness index by nearly 40%.
- Plastic hinge formation observed primarily in beams adjacent to removed column.
- No global instability observed in nonlinear dynamic simulation.

**Conclusion**

The nonlinear dynamic investigation of the 10-storey SPSW structure under sudden column removal demonstrates adequate robustness against progressive collapse. The maximum displacement of 42 mm under corner column removal remains within acceptable deformation

limits. Beam plastic rotations are significantly lower than permissible limits (0.05 rad), confirming sufficient ductility. The SPSW infill plates effectively develop tension field action, enhancing alternate load path resistance and reducing collapse propagation. Increasing plate thickness from 6 mm to 12 mm improves progressive collapse resistance by approximately 45%.
The study confirms that SPSW systems provide superior robustness and redundancy under abnormal loading scenarios when designed with adequate boundary element strength and connection detailing.

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