Review paper on Effect of Column Removal Scenarios on the Robustness of Steel Plate Shear Wall Structures

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Abstract

The robustness of steel plate shear wall (SPSW) structures under abnormal loading conditions has become a critical area of research in modern structural engineering. This study investigates the effect of column removal scenarios on the progressive collapse resistance and overall robustness of SPSW systems. The sudden loss of a primary vertical load-carrying element can trigger severe redistribution of internal forces, potentially leading to disproportionate collapse. To evaluate this behavior, analytical models of multi-story SPSW buildings are developed and analyzed using nonlinear static and dynamic methods in ETABS. Several column removal cases are considered at different locations—corner, edge, and interior columns—to assess the structural response, including plastic hinge formation, load redistribution, lateral deformation, and energy dissipation capacity. The study compares the load-resisting mechanisms and redundancy of SPSW systems under varying removal scenarios and examines the influence of parameters such as story height, panel thickness, and boundary frame stiffness. The results demonstrate that SPSW structures exhibit high redundancy and ductility, with the infill steel plates playing a vital role in redistributing loads after column loss. However, the degree of robustness significantly depends on the column location and the continuity of boundary frames. The findings contribute to a better understanding of the progressive collapse mitigation potential of SPSW systems and provide insights for improving design provisions under extreme event scenarios.

INTRODUCTION

Progressive collapse refers to a situation where the localized failure of a structural element, such as a column, leads to a chain reaction of subsequent failures, resulting in partial or complete collapse of the entire structure. Such events are often caused by abnormal or accidental loads including explosion, fire, vehicle impact, or design and construction errors.

1.2 Importance of Robustness
Robustness refers to the ability of a structure to withstand unexpected damage or local failure without experiencing disproportionate collapse.

Assessing robustness under column removal scenarios ensures that the structure maintains alternate load paths and continues to carry loads safely after the loss of a member.
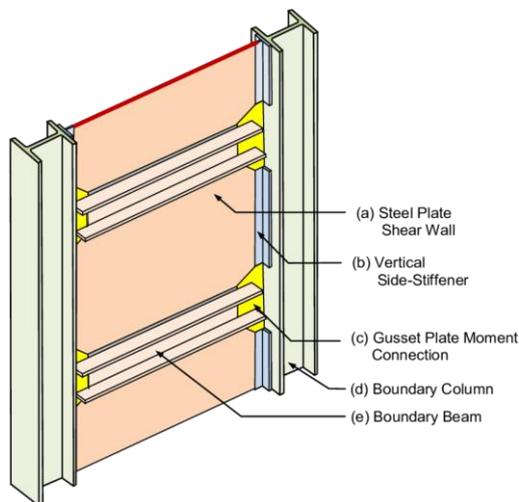
Fig. 1 Steel Plate Shear Wall (SPSW) Systems

(a) Steel Plate Shear Wall
(b) Vertical Side-Stiffener
(c) Gusset Plate Moment Connection
(d) Boundary Column
(e) Boundary Beam

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.
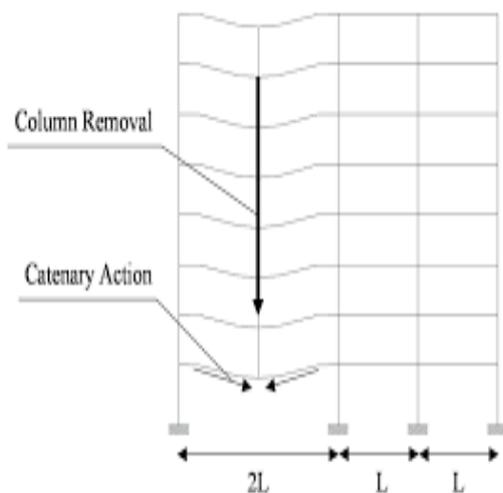

Fig. 2 Column Removal Scenarios

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

1. To develop analytical models of steel plate shear wall structures using finite element software such as ETABS or ABAQUS.
2. To simulate different column removal scenarios (corner, edge, and interior) and study the resulting redistribution of forces and deformations.
3. To evaluate the structural response parameters such as displacement, rotation, and axial force in the boundary frame and infill plates.
4. To determine the residual load-carrying capacity and identify the most critical failure mechanisms under progressive collapse conditions.
5. To recommend design improvements for enhanced robustness and redundancy in SPSW systems.

LITERATURE REVIEW
Gaurav Swamietal (2025)
This research investigates the robustness of tall composite modular buildings using alternate load path method (ALP) subjected to sudden element removal under the effect of gravity loads. A finite element model of a 50-storey modular building was developed with concrete filled steel tubular (CFST) columns and composite shear walls (CSW) in Abaqus. Core CSW were designed instead of conventional reinforced concrete shear walls to benefit with their modularity, effective time frame and better load sharing. Conventional steel columns were replaced with CFST columns to provide improved buckling and post buckling resistance. Non-linear dynamic and static analyses were conducted to investigate the real-time response, load transfer behavior and the ultimate failure scenarios. The 50-storey composite modular building showed sufficient resistance against progressive collapse under column and module loss scenarios. It was observed that the intermodule connections play a critical role in a module loss scenario, whereas the adjacent beams play a crucial role in the event of column removal. Dynamic amplification factors (DAF) were interpreted using the non-linear static analysis and compared with the available guidelines by general service administration (GSA). DAF of 1.20 was calculated for the 50-storey modular building subjected to critical corner module removal which was significantly lower than the value of 2.0 as suggested by GSA guidelines. A detailed parametric study was conducted to evaluate the DAF for various locations in the floor layout and the elevation of building. DAF of 1.223 and 1.216 were observed for a 30-storey and 40-storey modular building, respectively.

Shoaib Mansourietal (2025)

Concrete-filled double-steel-plate (CFDSP) composite shear walls, known for their efficient structural performance and enhanced seismic resilience, are the focus of this study, which investigates their seismic response under displacement-controlled cyclic loading. Despite the growing use of fiber-reinforced polymer (FRP) in structural retrofitting, its application in enhancing the seismic performance of CFDSP composite shear walls has not been thoroughly explored. The experimental analysis involved testing two CFDSP walls filled with self-compacting concrete (SCC) and strengthened with FRP wraps. Both specimens were identical in shape and configuration, with the variation introduced in the type of FRP material used for strengthening. One specimen was strengthened with carbon fiber-reinforced polymer (CFRP) wraps, while the other was retrofitted with glass fiber-reinforced polymer (GFRP) wraps. Testing continued until ultimate drift ratios of 3.90 % for the GFRPstrengthened specimen and 3.84 % for the CFRP-strengthened specimen were achieved. The performance of the composite shear wall specimens was evaluated by comparing key parameters such as lateral strength, ductility, stiffness, and energy dissipation capacity. Following the experimental tests, numerical analysis was conducted to validate the experimental results. With an acceptable agreement between the experimental and numerical results, a non-retrofitted CFDSP wall was analyzed to further investigate the effect of FRP strengthening on the structural performance of the specimens. Additionally, a numerical parametric study was conducted to assess the effects of different types of FRP wraps, the number of FRP layers, fiber orientation angle, FRP wrap configuration, and the concrete's compressive strength on the lateral strength of CFDSP walls. The results indicate that, in addition to improvements in other structural parameters, the lateral strength of shear walls retrofitted with CFRP and GFRP increased by 49.66 % and 21.80 %, respectively, compared to the non-retrofitted numerical model. On the other hand, the parametric study identified bidirectional CFRP wraps with a 90° fiber orientation as the most effective retrofitting scheme for enhancing the lateral strength of composite shear walls.

Jing-Zhou Zhangetal (2025)

This paper examines the collapse performance of column-supported modular steel buildings (CSMSB) under various column loss scenarios. It recognized the differences in collapse mechanisms between the double-layer steel beams and point-restrained slabs of CSMSB and those of traditional steel frame structures. Detailed analyses focused on the anti-collapse contributions of beams and slabs, investigating the effects of column loss location, slab thickness, rebar ratio and beam height on collapse performance. Comparisons were conducted on the effectiveness and economy of improving the collapse resistance of CSMSB by changing different structural parameters, including changes in slab thickness, rebar ratio and beam dimensions. A proposed integrity enhancement strategy—incorporating vertical connections between the double-layer beams—was evaluated for its effectiveness in improving collapse resistance of the structure. Results indicate that the robustness of CSMSB is the greatest in scenarios involving general interior column loss (GICL), and smallest in corner column loss (CCL). The anti-collapse contributions of the slab are basically the same at initial stage for the four scenarios, while at the final collapse state, the slab contribution is the smallest in GICL (35 %) and the greatest in CCL (70 %). Axial restraints significantly influence the collapse resistance of CSMSB, particularly at large deformation. Compared with rebar ratio and slab thickness, increasing the beam height is the most effective and economic approach to enhance the collapse resistance of CSMSB. Furthermore, adding vertical connections between the double-layer beam can significantly enhance the collapse resistance of the CSMSB in different scenarios. However, resistance increase rate of the structure decreases with the increase of the connection number.

Jingsheng Zhouetal (2025)

Progressive collapse occurs due to the propagation of localized initial failures caused by extreme or abnormal events. Current design methods attempt to prevent such collapses by enhancing connectivity between building components and improving the strength of individual members. These measures ensure that the loads previously carried by failed components are effectively redistributed to the remaining structural system. However, existing design methods have primarily been developed based on studies of framed buildings, with limited attention on mid-rise cold-formed steel (CFS) load-bearing wall buildings. This highlights the need for a specific design approach for the building to resist progressive collapse, as pursued in this paper. To analyse the structural performance after stud wall removal, numerical simulations of entire buildings were employed. An 8-storey archetype

building was first designed, considering vertical gravity and wind (leeward) loads, which incorporated the recently proposed joist-to-joist bottom plate (JJ) connection from the literature to enhance the structural robustness. Numerical analysis of the archetype building was then performed under five stud wall removal cases. To reduce the computational cost, a simplified finite element (FE) model was proposed. Based on observations from the simulation results, a hand calculation design approach was developed. This approach includes methods to account for dynamic effects and tributary areas, as well as a design strategy to reduce the required design strengths of structural members. Comparisons are made between the proposed hand calculation approach and the predictions obtained from numerical analysis.

Jingsheng Zhouetal (2025)

This study investigates the robustness of steel moment-resisting frames (MRFs) under column loss scenarios, both in undamaged and post-seismic conditions. In this context, robustness is defined as the ability of a damaged structure to prevent progressive collapse following an earthquake. A parametric investigation was conducted on 48 three-dimensional MRF configurations, varying key design and geometric parameters such as the number of storeys, span length, and design load combinations. Nonlinear dynamic analyses were performed using realistic ground motions and column loss scenarios defined by UFC guidelines. The effects of pre-existing seismic damage, façade claddings, and joint typologies were explicitly accounted for using validated component-based modelling approaches. The results indicate that long-span, low-rise frames are more vulnerable to collapse initiation due to higher plastic demands, while higher-rise frames benefit from load redistribution through their increased redundancy. In detail, long-span, low-rise frames experience roughly ten times higher displacement demands than their short-span counterparts, and post-seismic damage has limited influence, yielding rotational demands within 5–10% of the undamaged case. The Reserve Displacement Ductility (RDR) ranges from approximately 6.3 for low-rise, long-span frames to 21.5 for high-rise frames, highlighting the significant role of geometry in post-seismic robustness. The post-seismic damage was found to have a limited influence on the dynamic displacement and rotational demands, suggesting that the robustness of steel MRFs after a moderate earthquake is largely comparable to that of the initially undamaged structure. These findings support the

development of more accurate design and retrofit provisions for seismic and multi-hazard scenarios.

Research Gap

Despite extensive research on progressive collapse, most studies focus on single-material systems such as steel or concrete, with limited attention to hybrid systems like CFST–SPSW combinations. The nonlinear behavior of innovative modular and bolted–welded connections under sudden column loss or post-seismic conditions remains insufficiently explored. Dynamic effects are often simplified through constant DAF values, lacking realistic nonlinear time-history simulations. Moreover, there is a lack of experimental validation to support numerical findings, especially for tall modular and composite structures. Finally, the impact of structural irregularities on load redistribution and robustness in high-rise systems is still not thoroughly investigated.

METHODOLOGY

The methodology for this study involves developing a numerical model of a steel plate shear wall structure and performing column removal simulations under gravity loading conditions. The selection of a prototype structure is a fundamental step in progressive collapse analysis because it defines the geometry, material properties, and boundary conditions used for simulation. The prototype must represent a typical steel building configuration that conforms to modern design standards and construction practices. For this study, a mid-rise steel frame building incorporating Steel Plate Shear Wall (SPSW) systems is selected as the prototype structure.

Design Standards and References

The design and analysis of the prototype structure are based on recognized international and national codes and guidelines to ensure accuracy and standardization. The following codes are adopted for the development of the prototype model:

- IS 800:2007 (General Construction in Steel – Code of Practice)
- IS 1893 (Part 1): 2016 (Criteria for Earthquake Resistant Design of Structures)
- IS 875 (Part 1, 2, 3): 2015 (Design Loads for Buildings and Structures)
- AISC 341-16 (Seismic Provisions for Structural Steel Buildings)
- GSA (2016) and DoD (2018) Guidelines for Progressive Collapse Evaluation

Structural Configuration

The prototype structure selected for this study is a 10-storey steel frame building with SPSW panels placed along the perimeter bays. The configuration is chosen to represent a realistic urban steel building with high stiffness and ductility demands.

- Number of Storeys: 10
- Bay Width: 6 m in both X and Y direction
- Storey Height: 3.5 m for each level
- Structural System: Moment-Resisting Frame (MRF) with Steel Plate Shear Walls in selected bays
- Infill Plate Thickness: 6–12 mm (varies with height)
- Boundary Elements: H-shaped beams and columns (ISMB / ISHB sections)

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): 2.0×10^5 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.
- 3.6 Modeling and Boundary Conditions
- The prototype structure is modeled in ETABS / SAP2000 for three-dimensional analysis. Key modeling features include
- SPSW panels modeled as thin shell elements with nonlinear properties to capture post-buckling tension field action.
- Boundary beams and columns modeled using frame elements with nonlinear plastic hinges.
- Base of the structure considered fixed to represent rigid foundation conditions..

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.

REFERENCES

Gaurav Swami, Huu-Tai Thai, Xuemei Liu, Journal of Building Engineering, "Robustness analysis for innovative tall composite modular buildings with composite shear walls", 2025.

Shoaib Mansouri, Alireza Rahai, Amirali Hosseinnia, Farhad Aslan, Structures, "Performance evaluation of FRP-strengthened self-compacting concrete filled double-steel-plate composite shear walls: Experimental and numerical studies", 2025.

Jing-Zhou Zhang a , Yi-Ting Deng a , Guo-Qiang Li b , Zhi-Wei Y, Engineering Structures, Robustness of column-supported modular steel buildings in column loss: Role of double-layer beams and point-restrained slabs, 2025.

Jingsheng Zhou, Huu-Tai Thai, Tuan Ngo, Journal of Building Engineering, "Numerical analysis and design approach for mid-rise cold-formed steel load-bearing wall buildings to resist progressive collapse", 2025.

Silvia Costanzo, David Cassiano and Mario D'Aniello, MDPI, "Robustness of Steel Moment-Resisting Frames Under Column Loss Scenarios with and without Prior Seismic Damage", 2025.
Debora Obkircher, Miguel Costas, Magnus Langseth, Arild Holm Clausen, International Journal of Impact Engineering, "Quasi-static and dynamic shear-out resistance in a steel fin-plate connection: An experimental and numerical investigation", 2024.

Damian Kukla, Aleksander Kozlowski, International Journal of Steel Structures, "Numerical Study of the Robustness of Steel Frames with Bolted End-Plate Joints Subjected to Sudden and Gradual Internal Column Loss, 2023.

Yuqing Yang , Zaigen Mu and Boli Zhu, "Study on Shear Strength of Partially Connected Steel Plate Shear Wall" 2022.

Wei Jian Yi1,2, Fan Yi1* and Yun Zhou, International Journal of Concrete Structures and Materials, "Experimental Studies on Progressive Collapse Behavior of RC Frame Structures: Advances and Future Needs" 2021.

David Cassiano, Open Modal Carlos Rebelo and Luís Simoes da Silva, " Robustness Assessment of Steel Moment Resisting Frames" 2017.