International Journal of Future Generation Communication and Networking
Vol. 13, No. 4, (2020), pp. 419–429

Collapse Analysis Of Steel Structure Under Elevated Temperatures

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Abstract

Initial local damage spreading from one component to the other componentcausing the failure of the entire structure or disproportionately is defined as progressive collapse. Disproportionate collapse results from small damage or minor action triggering the collapse of a relatively whole part of the structure. The present study investigates a three dimensional, four storey rectangular shaped moment resisting steel frame structure subjected to fire loads. The investigated parameter comprise of the application of elevated temperatures in each consecutive storeys. The main objective of this study is to understand the responses due to staticlinear loading in the structure caused by different column removal scenarios. Linear static progressive collapse analysis is carried out using the finite element software-SAP 2000 and the results obtained in terms of Demand Capacity Ratio (DCR) for the selected columns which are checked for permissible limits as mentioned in General Services Administration (GSA) guidelines. The comparisons are drawn before and after the effect of fire. Based on the DCR values obtained the collapse of the structure is predicted. The force redistribution and influence on the axial forces due to column loss are also studied. The effect of fire has significant change in DCR values which indicates the redistribution of moments at different levels.

Keywords:*Demand Capacity Ratio (DCR), Elevated Temperature, Linear Static, Progressive Collapse, SAP 2000.*

Introduction

Steel structures are widely used all over the world. It has its own advantage of customizing its own kind. In-spite of its many advantages, steel in its own is vulnerable to fire. Raised temperatures in the structural steel causes decrease in strength and stiffness which ultimately leads to failure/collapse of structure due to excessive deformations.Progressive collapse is relatively anunusualincidence as a consequence of unexpected loading such as fire, seismic activities or blasts on buildings, that cause local failure and then extends to other structural parts. The General Service Administration (GSA)defines progressive collapse as “a situation where local failure of a primary structural component leads to collapse of adjoining members which, in turn, leads to additional collapse[1].In the present study the performance of a regular building subjected to temperatures is evaluated under progressive collapse.

In the last decade, many researches were conducted to study the nature of progressive collapse on different structures.

Sezen.H(2016)conducted collapse performance of nine existing multi-storey buildings, built of masonry, RC and steel structuresthrough experimentations and software modelling. Individual column or multiple columnsof the first floor were actuallydetached from each structure during thesetests. His work concluded that in frame buildings, when a column is suddenly lost, a large portion,70-80% of the total load conveyed by that column within a perimeter frame will be carried by nearby columns of the same perimeter frame. 20-30%of the remaining load of thedetached column will be taken by the inside columns [2].

Chidambaram.C.R et.al,(2016)evaluated the progressive collapse performance of a G+7 steel structure. Columns at variousfloors were subjected to 550^0 C temperature. Columns at intermediate, re-entrant, edge and cornerlocations were detacheddistinctlyin alternate storeys. Conclusions made from the research mentioned that intermediate column was found to be much critical,in comparison to column removal atre-entrant and corner locations by 27.8 % and 16.36% respectively. The structure was safe against progressive collapse as the obtained DCR of everycomponent were within the limit 2[3].

Gernay.Tet.al,(2018) described the mechanisms that were noticed when a major component of a frame i.e., column, is affected by fire. It is mentioned that the tension developing in the column exposed to fire and simultaneously overloading the nearby columns in compression, would possibly lead to collapse of members not directly affected by fire but trigger a progressive collapse.They suggested that localized fires affecta portion of a building while the rest remaining cold, lead to particulardetrimental effects causing local damage[4].

Sushanth V Shettyet.al, (2018)Performed the progressive collapse analysis of steel structure subjected to fire damage. The response of the structure due to column loss due to fire load was studied. The effect of fire at ground floor had significant change in DCR values at upper levels, which indicated the redistribution of moments of columns at different levels. Through this analysis, critical columns could be identified and strengthened prior to accidental incidents, which helps in avoiding the collapse of the structure [5].

HarinadhaBabuRaparla.K et.al,(2015) conductedthe work on a group of four bare frames for understanding their collapse behaviour. They conducted linear analysis and from the results it was inferred that applied element method can be used for the study of progressive collapse, beginning from zero loadsuntil total collapse [6].

Paresh V. Patel et.al, (2012)evaluated the progressive collapsepotential of 4 and 10-storey irregular shaped RC structures in SAP2000 by carrying out both static and dynamic linear analyzes due tocolumn removals at five distinct locations. Calculated the DCR values of components and found that in all cases the obtained values exceeded the permissible limits. Suggested that out of the three methods introduced to mitigate progressive collapse, bracing provided at the floor level appearedto be the most efficient and economic approach[7].

Objective of the project

The main objective of this study is to assess the progressive collapse potential of a steel structure subjected to fire loads designed as per Indian standards, due to different column removalscenarios.

Research Significance

In the recent years, steel structures are widely used in India and very less research is made on progressive collapse of steel buildings exposed to fire throughout the floors at storey level.

In the present study, an attempt is made to study the performance of three dimensional, four storey rectangular shaped moment resisting steel frame exposed to fire under progressive collapse on removal of critical columns during the analysis.

Analytical study

SAP2000, a FEM software is used for the analytical investigation of progressive collapse of a steel structure. The primary data considered for the study and the method to evaluate the progressive collapse performance of the structure are presented.

Preliminary Datum

A typical four storey moment resisting steel frame is selected for the analysis. Size of building, plan is 32m x 16m. Typical height of floor = 3m and bay width in both directions = 4m. Frame sections of the beam and column are ISHB-350 and grade of steel is E350. The gravity loads acting are Dead load (DL) - self-weightof structural members, calculated from SAP2000 directly, wall load applied on beams = 17.69 kN/m, Live load (LL) 2.67kN/m is applied on the beams.

According to data mentioned above, the three dimensional structure is modelled and analyzed using SAP 2000(Figure 1). The stresses developed and the DCR values, obtained from this model are found to be within limits, and hence the structure is considered to be safe.

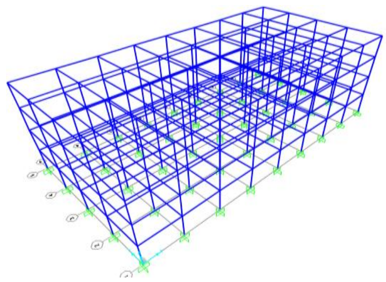

Figure 1: Three dimensional view of regular building

Further, the same model is then subjected to temperature loads applied at all consecutive storeys one after the other, beginning with a temperature of 70°C and increasing at an interval of 15°C. It is observed that as the temperature increases the stresses in columns are also increasingand at 100°C, the stress values for some members of the structure, exceeded the yield stress of the material. Hencein this study related to collapse of the structure, the analysis is carried out at a steady temperature of 100°C. Out of the entire model (Figure 2) represents only those members with labels, that are mentioned in the graphs,also indicating the location of corner, longer side central column, shorter side central column and intermediate column removal scenarios sequentiallyof all storeys that are considered for the analysis.

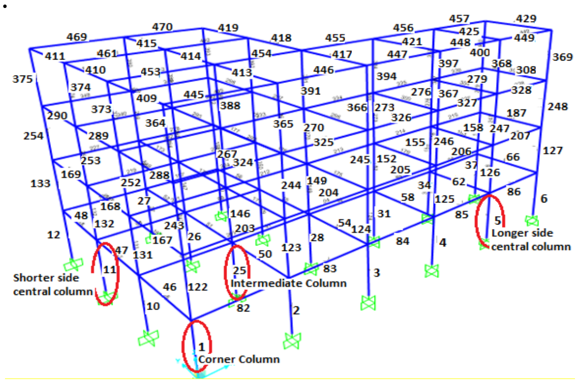

Figure 2: Column removal scenarios of regular building

Method to study progressive collapse - Linear Static Analysis (LSA)

LSA,a basic method of analyses is performed to understand the behaviour of structures. In this method, the structural analysis incorporates materialsunder linear elastic behaviour and deformation concept excluding the buckling phenomena. It consists of a single step, in which the deformations and internal forces are solved based on the geometry, materials and the applied loadings.

Load case for Linear Static Analysis

A loading factor for the purpose of static analyses is recommended by GSA. Load case is as mentioned in (1)

Load Case = 2 (DL + 0.25LL) ….... (1)

where, DL = Dead Load and LL = Live load.

Load factor is considered as 2. For consideration of material and geometric non linearity existing in components and also for accounting the dynamic behavior of progressive collapse, the load case has to be multiplied with this loading factor.

Procedure of Linear Static Analysis

- Model the three dimensional building with all gravity loads and temperature loads, perform the analysis and design
- Based on the analysis and design, identify the critical members.
- Create and apply load case according to GSA guidelines.
- Column removals are created by detaching critical columns of all floors from the indicatedpositionseach at a time as specified in GSA guidelines.
- Linear static analyses is performed for each removal of the column. The "Demand to Capacity Ratio"is calculated and the resultsare evaluated according to the criteria of acceptance mentioned in guidelines.

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Acceptance Criteria

Acceptance criteria for the elements shall be evaluated by Demand Capacity Ratio (DCR) as in (2)

$DCR = Q_{UD} \backslash Q_{CE}$ ……. (2)

where, Q_{UD} = Acting force (demand) in component/connection and Q_{CE} = Expected ultimate, un-factored capability of the component/connection.

Permissible DCR values given by GSA are:

DCR < 2.0 for typical structural configurations

DCR < 1.5 for atypical structural configurations

DCR exceeding the permissiblelimits are considered to be severely damaged. DCR calculated from LSA helps to determine the potential for progressive collapse of building.

Linear Static Analysis Results

Linear static analysis is carried out for critical column removals at all storey levels and the results obtained in terms of DCR before and after column removals are plotted (Figures 3 to 18).

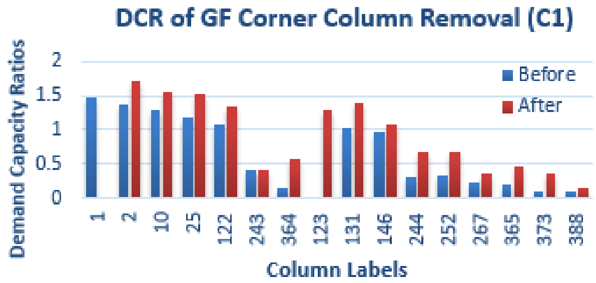

Figure 3: DCR of GF Corner Column Removal (C1)

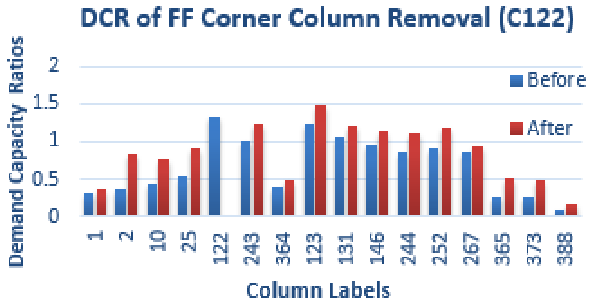

Figure 4: DCR of FF Corner Column Removal (C122)

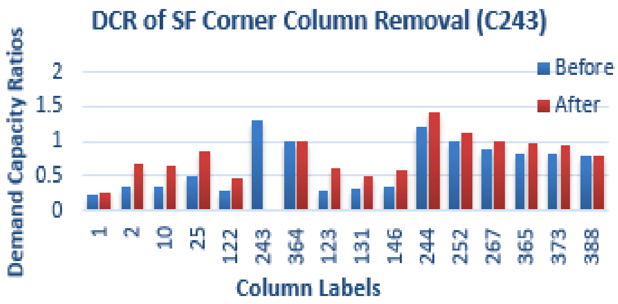

Figure 5: DCR of SF Corner Column Removal (C243)

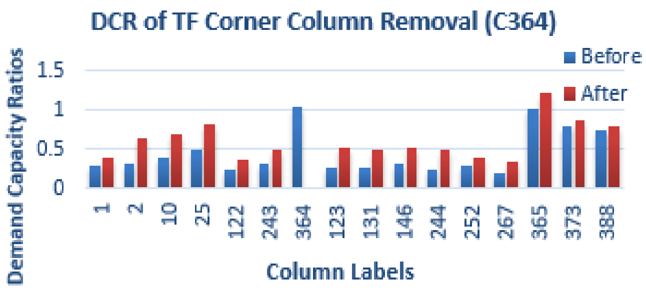

Figure 6: DCR of TF Corner Column Removal (C364)

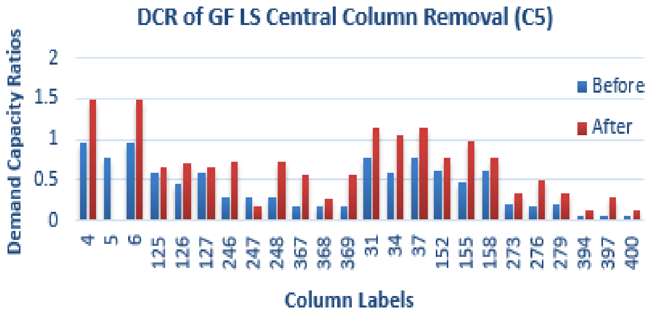

Figure 7: DCR of GF LS Central Column Removal (C5)

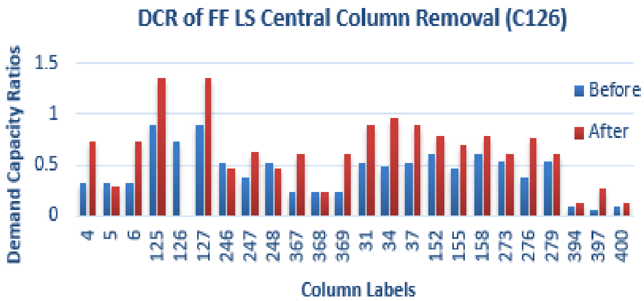

Figure 8: DCR of FF LS Central Column Removal (C126)

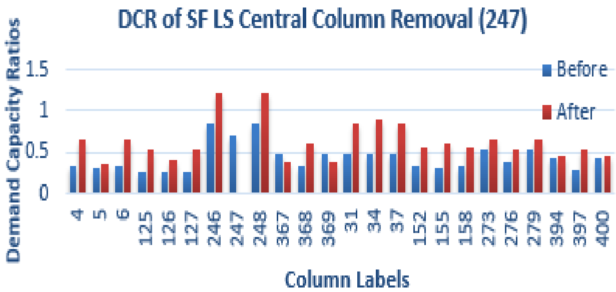

Figure 9: DCR of SF LS Central Column Removal (C247)

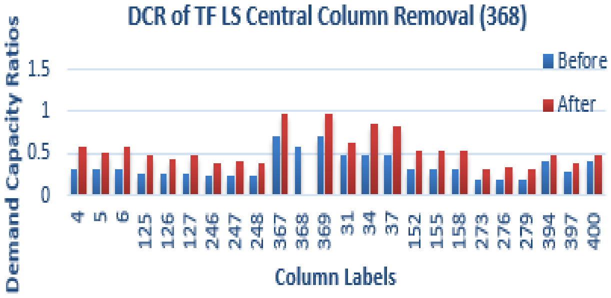

Figure 10: DCR of TF LS Central Column Removal (C368)

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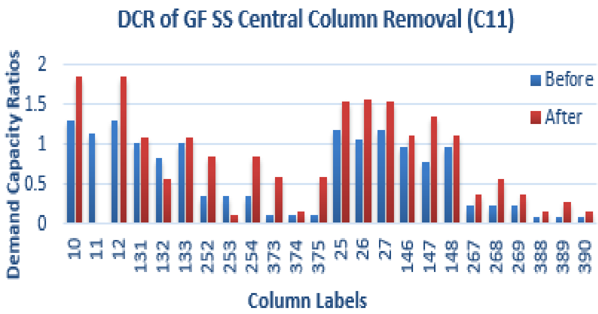

Figure 11: DCR of GF SS Central Column Removal (C11)

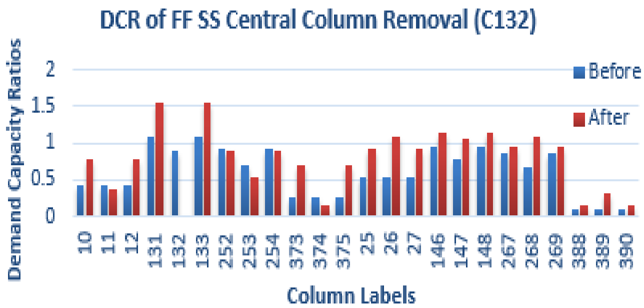

Figure 12: DCR of FF SS Central Column Removal (C132)

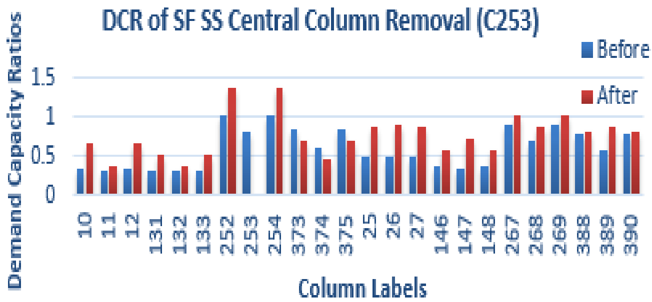

Figure 13: DCR of SF SS Central Column Removal (C253)

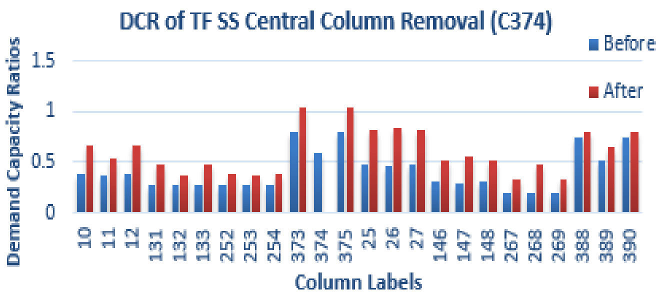

Figure 14: DCR of TF SS Central Column Removal (C374)

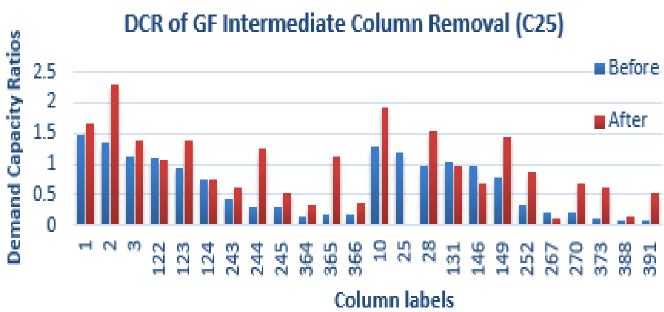

Figure 15: DCR of GF Intermediate Column Removal (C25)

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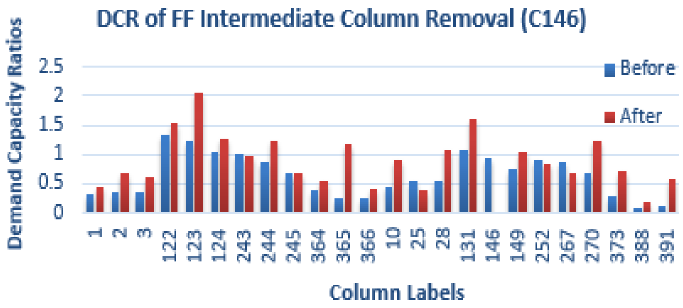

Figure 16: DCR of FF Intermediate Column Removal (C146)

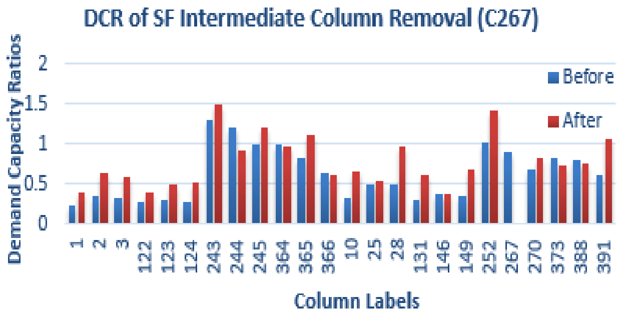

Figure 17: DCR of SF Intermediate Column Removal (C267)

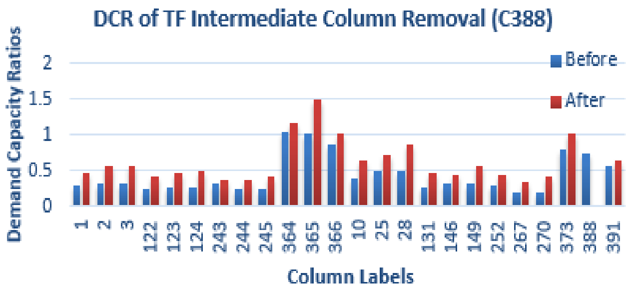

Figure 18:DCR of TF Intermediate Column Removal (C388)

Bending Moment and Axial Force

The ratio of bending moment and axial force of the damaged building to that of the bending moment and axial force of the intact building respectively were calculated to check the redistribution of moments in the adjacent columns and adjoining beams that are associatedwith the detached column. The collapse to intact (C/I) ratios obtained are plotted (Figures 19 to 34).

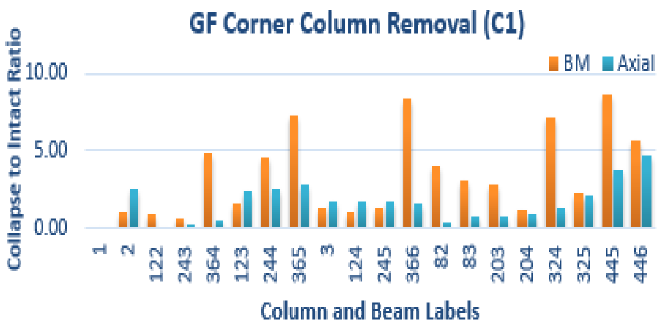

Figure 19: C/I ratio due to GF Corner Column Removal (C1)

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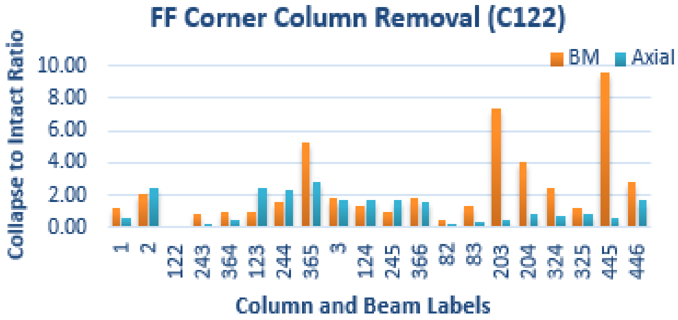

Figure 20: C/I ratio due to FF Corner Column Removal (C122)

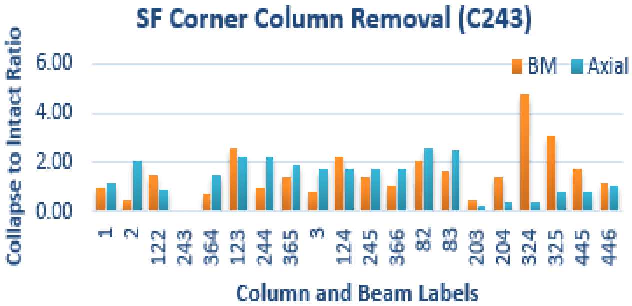

Figure 21:C/I ratio due to SF Corner Column Removal (C243)

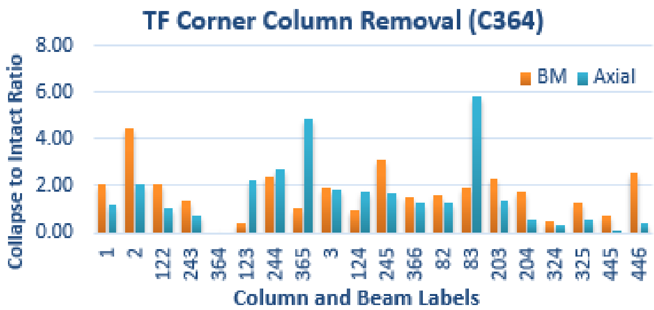

Figure 22:C/I ratio due to TF Corner Column Removal (C364)

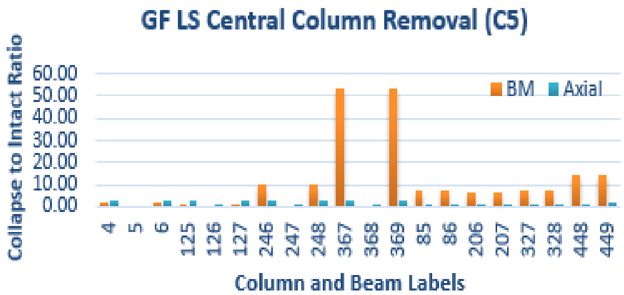

Figure 23:C/I ratio due to GF LS Central Column Removal (C5)

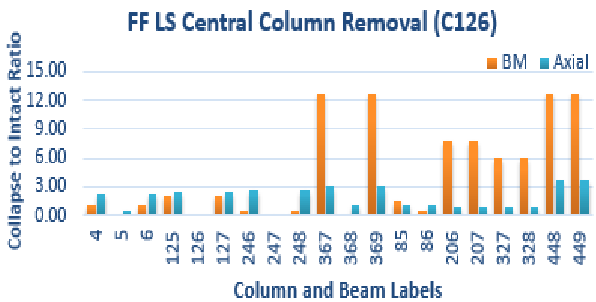

Figure 24:C/I ratio due to FF LS Central Column Removal (C126)

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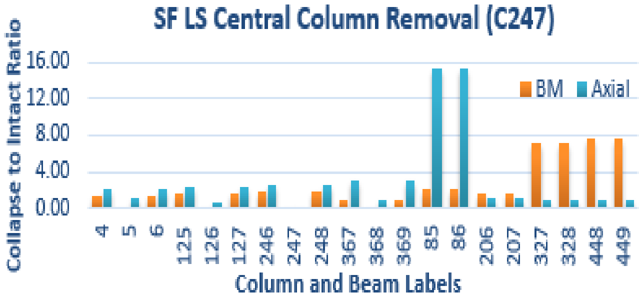

Figure 25:C/I ratio due to SF LS Central Column Removal (C247)

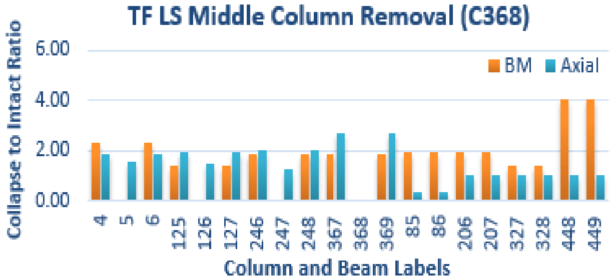

Figure 26:C/I ratio due to TF LS Central Column Removal (C368)

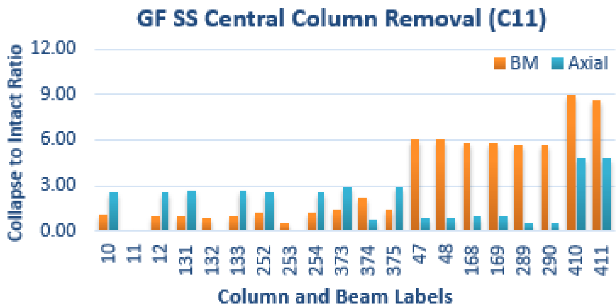

Figure 27:C/I ratio due to GF SS Central Column Removal (C11)

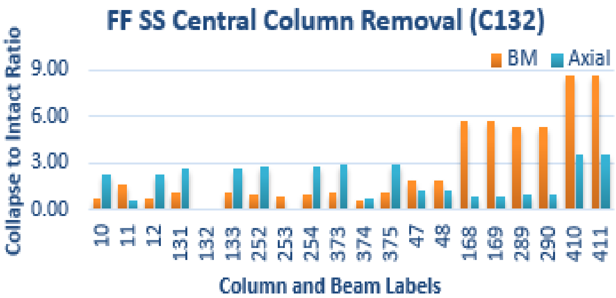

Figure 28:C/I ratio due to FF SS Central Column Removal (C132)

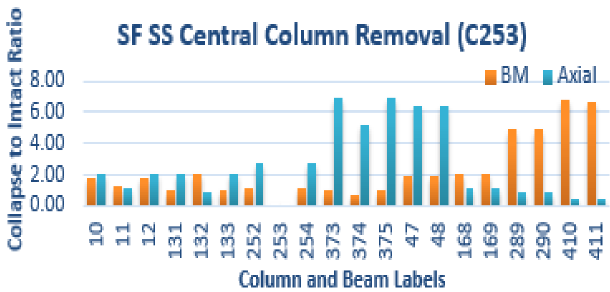

Figure 29:C/I ratio due to SF SS Central Column Removal (C253)

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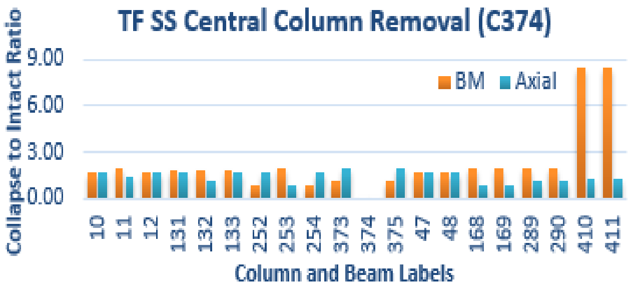

Figure 30:C/I ratio due to TF SS Central Column Removal (C374)

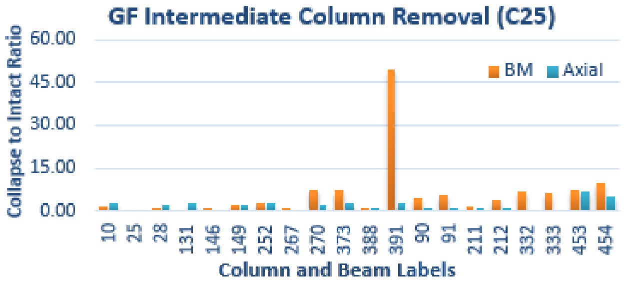

Figure 31:C/I ratio due to GF Intermediate Column Removal (C25)

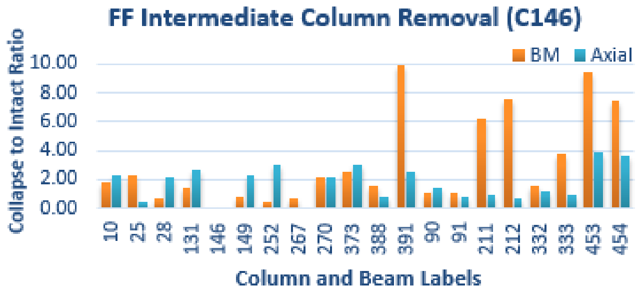

Figure 32:C/I ratio due to FF Intermediate Column Removal (C146)

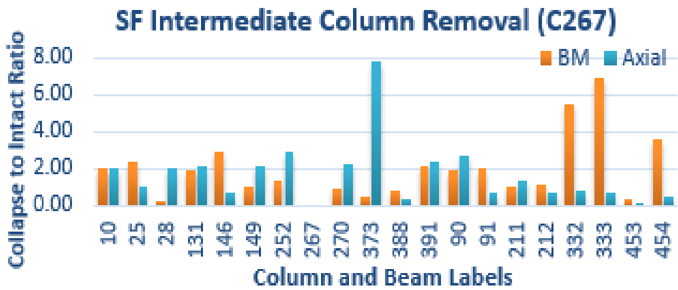

Figure 33:C/I ratio due to SF Intermediate Column Removal (C267)

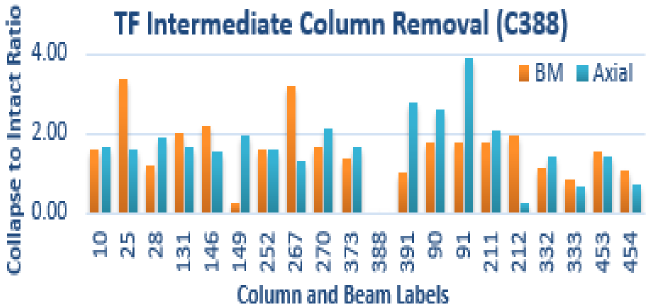

Figure 34:C/I ratio due to SF Intermediate Column Removal (C388)

Conclusion

In this paper, the behaviour of four storey rectangular moment resisting steel frame structure subjected to elevated temperature under various column removal scenarios at all floors is studied. Based on the studies the following conclusions are drawn.

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1. From the progressive collapse analysis, it can be concluded that, demand capacity ratios are most significant in predicting the stability of the structure.
2. Due to the application of 100^0C temperature throughout the floor, it was noted that some of the members exceeded the yield stress, but still did not undergo failure as the obtained DCR of all the critical members where within the permissible limit of 2 as specified by GSA guidelines.
3. Demand capacity ratio for different column removal scenarios are obtained and it was observed that the values were well with-in the acceptance criteria for longer side and shorter side central column removals at all floors and hence may not undergo progressive collapse for 100^0 C temperature.
4. The maximum DCR value experienced by a member at a temperature of 100^0C is 1.73 in case of corner column removal, hence if the temperature exceeds beyond this there would be possibility of spread of collapse.
5. In case of intermediate column removal of ground and first floor, DCR values exceeded the acceptance criteria for the members that are adjacent to the removed column and hence will trigger progressive collapse. However in the other members damage did not propagate.
6. From graphs it is observed that the bending moment of the columns exactly above the location of removed column remains unchanged, whereas the bending moment of the columns in the storey adjacent to either side of the removed column and above have increased. The bending moments of adjoining beams have also increased as the redistribution of momentsis more in beams.
7. Due to the removal of columns the axial forces are majorly transferred to the adjacent columns and hence the effect of the removal or failure is reduced. The member loss distributes the initial load balance of external loads, internal forces to adjacent components. Based on this alternate path for the load flow can be figured out.

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