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Progressive Collapse Analysis of Steel Structure Subjected to Fire Loads

Anand Baldota R
PG Scholar, School of Civil Engineering,
REVA University, Rukmini Knowledge Park, Kattigenahalli
Yelahanka, Bangalore-560064, India

Bhavana B
Assistant Professor, School of Civil Engineering,
REVA University, Rukmini Knowledge Park, Kattigenahalli
Yelahanka, Bangalore-560064, India

Abstract
Progressive Collapse in a building occurs when any major structural load carrying member (like columns) leads to collapse of adjoining members, which in-turn leads to the additional collapse. In this paper, the G+ 8 moment resisting steel frame building is analyzed for progressive collapse considering two methods namely linear static and non linear static method by using ETABS 2015 software. In this attempt, the columns at different levels are subjected to varying temperatures ranging from 250℃-1000℃ with the material properties and yield strength as per IS 800-2007. Different load combinations are considered as per IS 875 part I & II. According to General Service Administration (GSA) 2016 guidelines fire load is applied additionally at different storeys to the selected columns. The structure is analyzed and the DCR values obtained are checked as per GSA 2016 permissible limits.

Keywords: Progressive collapse; fire loads; GSA guidelines 2016; Steel frame Structure; ETABS 2015.

Introduction
In general, a structure collapses progressively when one of its vital elements fails causing the failure and damage of the adjacent members. This can also lead to the partial collapse of the structures.
Steel is one of the most popular material used in construction for multi-storeyed structures or single storey buildings such as factories, warehouse etc. Compared to other structural materials steel has a high thermal conductivity and therefore during elevated temperatures, it loses its strength and stiffness at a faster rate. Hence in this study an attempt has been made to understand the progressive collapse of steel structures subjected to elevated temperatures.
Recently two important guidelines have been posed and developed i.e., GSA (General Service Administration) 2016 and UFC (Unified Facility Criteria) which addresses and explains the design requirements of progressive collapse for new and existing construction based on different categories. These guidelines recommend the DCR (Demand Capacity Ratio) values.

Literature Review
C.R.Chidambaram, Jainam shah, A Saikumar and K. Kartikeyan (2016) mentioned that the Progressive collapse leads to failure of the structure and this happens due to elimination of important structural members which are effected due to loadings from fire, impact loading blast loading etc.
KamelSayedKandil, EhabAbd El Fattah Ellobody and HanadyEldehemy (2013) perfomed an Experimental Investigation of Progressive Collapse of Steel Frames by conducting two new tests to augment available data highlighting the structural performance of multi-storey steel frames under progressive collapse.

Methodology
The modeling of the G+8 steel frame multi storey building as shown in fig.1 is done using ETABS 2015 software. Load combinations along with fire loadings ranging from 250℃-1000℃ at an interval of 150℃ are applied to the columns for alternate storeys. After the application of loads the structural analysis and design is carried out using linear static and non linear static methods. From the analysis the results are obtained in terms of DCR values, before and after the application of fire loads which are checked with permissible limits mentioned in GSA 2016 guidelines.

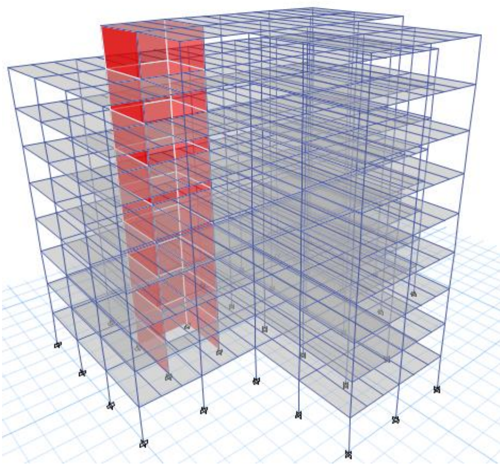

Figure 1: 3D model of steel structure

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Table 1: Input considered for analysis

Columns(Built up I sections taken by preliminary design)		Ground to 8th Floor
	Depth	900mm
	Flange width	500mm
	Flange thickness	35mm
	Web thickness	35mm
Primary Beams	ISWB500	
Secondary Beams	ISMB350	
Material Properties `	Concrete	M25
	Steel	Fe250
	Rebar	Fe415
Thickness of slab	125mm	
Zone	2	
Response Reduction Factor	5	
Important Factor	1	
Time Period(X)	0.49seconds	
Time Period(Y)	0.54seconds	

Loads and its combinations are considered as per IS 875 Part I and II. For the application of fire loads re-entrant, intermediate, edge and corner columns have been selected as shown in fig. 2. In the initial stages these columns start expanding with temperature and as the temperature goes on increasing the column loses its rigid nature because its modulus of elasticity is reduced.

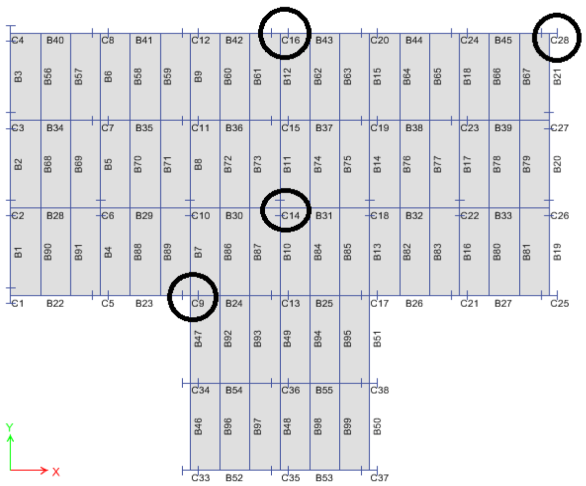

Figure 2: Typical Plan view of steel structure showing the selected columns.

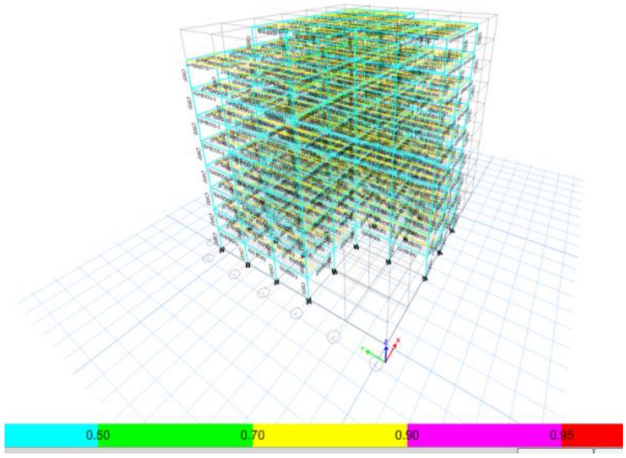

Figure 3: Showing DCR values for Initial stage of fire loading (250℃-550℃)

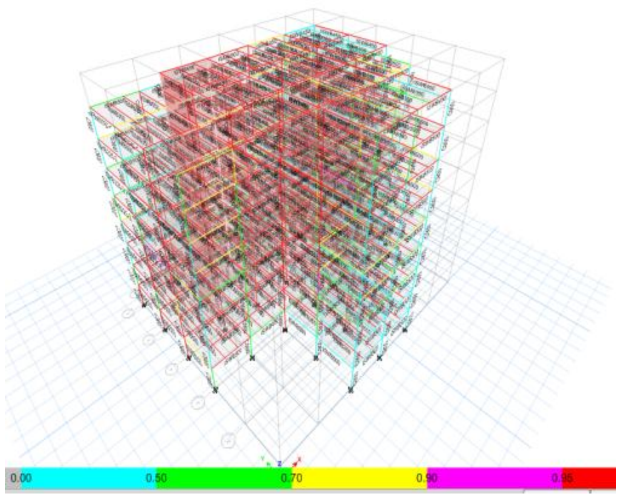

Figure 4: Showing DCR values for final stage of fire loading (700℃-1000℃)

Results and Discussions

Linear static analysis

Linear static analysis is carried out for the selected columns and the results obtained in terms of DCR values are tabulated, only for re-entrant column (C9) in table 2 and the graph is plotted, similarly for all other columns the DCR values are as shown in the graphs.

Table 2: DCR values for Re-entrant column (C9)

RE-ENTRANT COLUMNS SUBJECTED TO FIRE LOADS AT VARIOUS TEMP.				
LOCATIONS	MEMBERS	TEMPERATURE	DEMAND CAPACITY RATIO BEFORE FIRE	DEMAND CAPACITY RATIO AFTER FIRE
1st FLOOR	C9	250°C	0.23	0.449
3rd FLOOR	C9		0.176	0.387
5th FLOOR	C9		0.123	0.304
7th FLOOR	C9		0.069	0.208
1st FLOOR	C9	400°C	0.23	0.627
3rd FLOOR	C9		0.176	0.552
5th FLOOR	C9		0.123	0.443
7th FLOOR	C9		0.069	0.31
1st FLOOR	C9	550°C	0.23	0.84
3rd FLOOR	C9		0.176	0.756
5th FLOOR	C9		0.123	0.623
7th FLOOR	C9		0.069	0.448
1st FLOOR	C9	700°C	0.23	0.985
3rd FLOOR	C9		0.176	0.881
5th FLOOR	C9		0.123	0.721
7th FLOOR	C9		0.069	0.513
1st FLOOR	C9	850°C	0.23	1.164
3rd FLOOR	C9		0.176	1.047
5th FLOOR	C9		0.123	0.802
7th FLOOR	C9		0.069	0.611
1st FLOOR	C9	1000°C	0.23	1.344
3rd FLOOR	C9		0.176	1.213
5th FLOOR	C9		0.123	1.002
7th FLOOR	C9		0.069	0.713

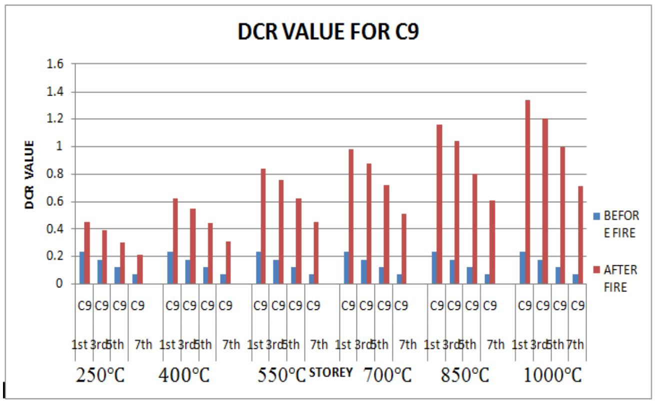

Figure 5: Graphs showing the DCR values for Re-entrant columns (C9) at various temperatures

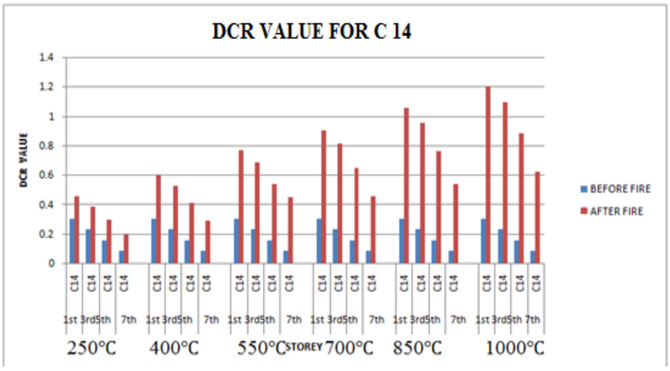

Figure 6: Graphs showing the DCR values for Intermediate columns (C14) at various temperatures

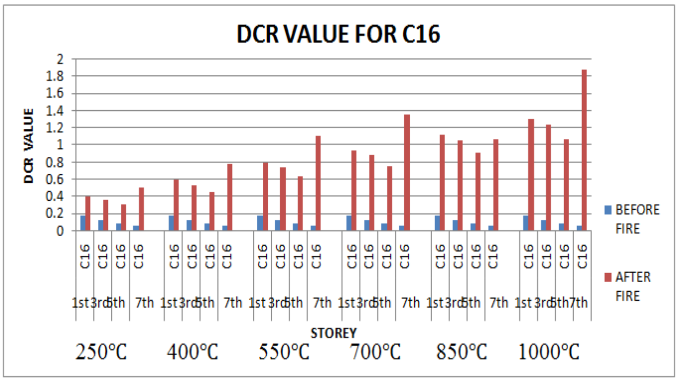

Figure 7: Graph showing the DCR values for edge column (C16) at various temperatures

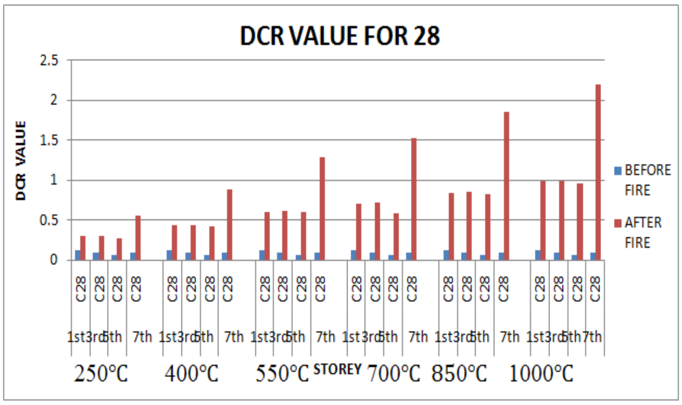

Figure 8: Graph showing the DCR values for Corner columns (C28) at various temperatures.

From the above figures, it is observed that the DCR values at initial stages are less than 1. As the temperature crosses 550°C to 1000°C the DCR values goes on increasing and crosses the limit i.e., 1 this is because steel loses its strength due to reduction in young modulus (E), hence the progressive collapse will occur.

Non-Linear static analysis

Non-Linear static analysis is carried out for the selected columns and the results obtained in terms of DCR values are tabulated, only for re-entrant column (C9) in table 3 and the graph is plotted, similarly for all other columns the DCR values are as shown in the graphs.

Table 3: DCR values for Re-entrant column (C9)

RE-ENTRANT COLUMNS SUBJECTED TO FIRE LOADS AT VARIOUS TEMP.				
LOCATIONS	MEMBERS	TEMPERA-TURE	DEMAND CAPACITY RATIO	
			BEFORE FIRE	AFTER FIRE
1st FLOOR	C9	250°C	0.22	0.468
3rd FLOOR	C9		0.166	0.407
5th FLOOR	C9		0.113	0.325
7th FLOOR	C9		0.058	0.229
1st FLOOR	C9	400°C	0.22	0.637
3rd FLOOR	C9		0.166	0.57
5th FLOOR	C9		0.113	0.471
7th FLOOR	C9		0.058	0.348
1st FLOOR	C9	550°C	0.22	0.833
3rd FLOOR	C9		0.166	0.752
5th FLOOR	C9		0.113	0.629
7th FLOOR	C9		0.058	0.471
1st FLOOR	C9	700°C	0.22	1.029
3rd FLOOR	C9		0.166	0.935
5th FLOOR	C9		0.113	0.787
7th FLOOR	C9		0.058	0.595
1st FLOOR	C9	850°C	0.22	1.225
3rd FLOOR	C9		0.166	1.118
5th FLOOR	C9		0.113	0.945
7th FLOOR	C9		0.058	0.719
1st FLOOR	C9	1000°C	0.22	1.633
3rd FLOOR	C9		0.166	1.302
5th FLOOR	C9		0.113	1.105
7th FLOOR	C9		0.058	0.844

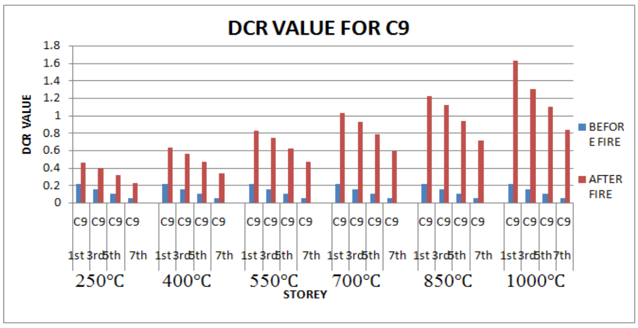

Figure 9: Graph showing the DCR values for re-entrant column (C9) at various temperatures.

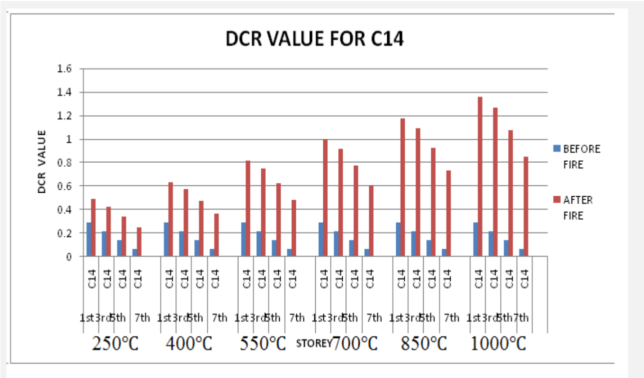

Figure 10: Graph showing the DCR values for intermediate column (C14) at various temperatures

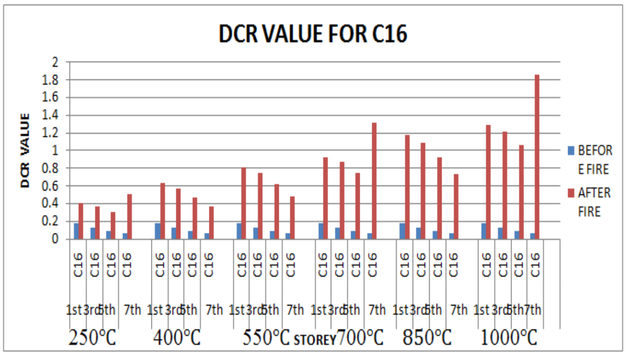

Figure 11: Graph showing the DCR values for edge column (C16) at various temperatures

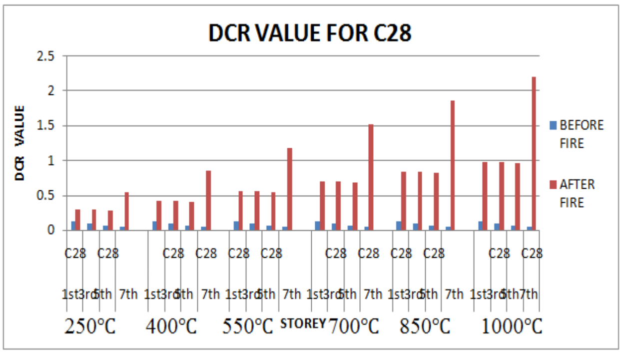

Figure12: Graph showing the DCR values for corner column (C28) at various temperatures

From the above figures, it is observed that the DCR values at initial stages are less than 1. As the temperature crosses 550°C to 1000°C the DCR values goes on increasing and crosses the limit i.e., 1 this is because steel loses its strength due to reduction in young modulus (E), hence the progressive collapse will occur.

Conclusions

- Due to various combinations of static load present on the structure, material starts degrading at elevated temperature. As temperature is increased, the respective demand capacity ratio values (DCR) of the column also gets increased.
- For columns subjected to temperature from 250℃-550℃, the obtained DCR values are well with-in limits for most of the columns i.e. less than 1 as per GSA 2016 guidelines. Hence the structure will not undergo any progressive collapse under this range of temperature.
- At around 600℃ temperature, DCR values of column on an average is twenty times more than the respective DCR values at ambient temperature condition and at around 800℃ the values are hundred times of that ambient temperature.
- When temperature reaches more than 700℃, DCR values of columns increases excessively as mechanical properties such as modulus of elasticity, yield or ultimate stress and coefficient thermal expansion changes to large extend at this temperature. Yield stress is decreased by about 60% at 700℃.
- As the temperature increases further from 700℃-1000℃ the DCR values obtained for corner column, intermediate column and re-entrant column exceeds the specified limits, hence the structure will undergo progressive collapse. This can be resolved by using built up sections or adding extra bracings and also by providing larger steel sections.

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