A COMPARATIVE STUDY ON PROGRESSIVE COLLAPSE OF STEEL AND COMPOSITE STRUCTURE SUBJECTED TO TEMPERATURE LOAD

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Abstract - *An unfair event can make damage to the structural building leading to the failure of vertical load bearing components and end by a progressive collapse of the whole structure or part of it. The outcome of progressive collapse may be unfortunate in the matter of injuries and depletion of lives. In this investigation, response of a G+9 moment resisting steel and composite frame structure at various temperatures was evaluated using the ETABS. Here sections at various levels were given a temperature load of 550°C, 750°C and 1000°C. As per GSA rules, corner, edge and intermediate columns were applied a temperature load independently at various levels for both steel and composite structures. Load combinations are applied according to the IS 875 Part I and Part II. Demand Capacity Ratio (DCR) values of load applied columns and beams connected to that column are achieved and compared. In both steel and composite structures, the lower floors were considered more vulnerable than the upper floors. If the DCR value exceeds limits, structure need to be revamped to prevent a progressive collapse with considerable increase in steel sections. The models represented the general actions accurately of the 10 storey building that were subjected to temperature load which provide important information about the new design criteria for progressive collapse.*

Key Words: Progressive Collapse, DCR, Temperature Load.

1. INTRODUCTION

Progressive collapse is a fairly uncommon phenomenon, because it involves both an irregular loading to cause local harm and a system that lacks sufficient stability, ductility and resilience to sustain the spread of failure. Progressive collapse majorly occur due to damage of primary structural member leading to failure from members to members and remaining members are not efficient of taking the weight of the building resulting in failure of whole structure or large part of it. The reasonable fire behaviour of building structures relies upon a few boundaries, the most significant of which are (i) the structural setup and design (ii) fire force, term, and spread (iii) structural loading and limit conditions (iv) fire assurance dissemination and (v) structural details.

Steel as a development material has been generally utilized in different kinds of structures due to its effortlessness in construction and structural efficiency. At the same time it has the major drawback of easily exposed to rapid temperature variations. Therefore from past several years' research has been conducted to study the behaviour of steel structures under fire condition.

Steel-concrete hybrid systems incorporate the benefits of steel and concrete systems, making them particularly ideal for high-rise and super-tall buildings.

1.1 OBJECTIVES

The main aim of this study is to check the ability of steel structure and composite structure to resist progressive collapse of a building due to fire as per GSA guidelines, which are achieved by studying the effects of the following.

1. Under static condition, to study the demand capacity ratio of G+9 steel framed structure and composite structure as per guidelines from GSA.
2. Linear static analysis of the structure subjected to fire using software ETABS 2016.
3. Effect of fire at different levels of a building subjected to seismic loading.
4. Effect of fire on Edge, Intermediate and Corner columns of a building.

2. METHODOLOGY

The demand capacity ratio (DCR) of steel structure and composite structure at alternative beams and columns are calculated as per the guidelines provided by the GSA. The cases considered regarding the location of application of the temperature load to the alternative floors as following:

1. Analysis when temperature load applied to alternative floor columns located at corner.
2. Analysis when temperature load applied to alternative floor columns located at centre.
3. Analysis when temperature load applied to alternative floor columns located at edge.

All three cases are analysed to both steel and composite structures in accordance to the Indian Standard Code for Seismic analysis. DCR is calculated for each beam connected to load applied column. The data utilized for analysis of structure is shown below Table 1, 2 and Table 3.

Table -1: Material properties

Material	Significance
Concrete	M-20
Steel	Fe345
Rebar	HYSD500

Table -2: Sectional data

Parameter	Steel Structure	Composite Structure
Column	350x350x25mm	350x350x16mm
Beam	ISMB450	ISMB450
Slab Thickness	150mm	150mm
Storey Height	3m	3m

Table -3: Seismic Load Parameters

Parameter	Value
Importance Factor, I	1
Response Reduction Factor, R	5, SMRF
Soil Type	II, Medium
Zone Factor, Z	0.16 (Zone III)
Time Period in X direction	0.627sec
Time Period in Y direction	0.627sec

ETABS is structural analysis software that is commonly used for user friendly functionality and is easy to understand. Using the definition of FEM, this bodes with a complex level of geometry and also manages the deformations with the conditions given for support.

The technique employed is linear elastic, in static state. The system is modelled three-dimensionally. Two type of structure will be modelled, i.e. steel structure and composite structure. Beam elements are used for beam modelling and column modelling. Membrane elements are used in slab modelling. The building modelled in this software consists of 10 storeys for both steel and composite structure. For composite structure, Column is to be filled by M20 grade concrete. The sizes of the structural members are shown in Table 2. 2D plan views of steel and composite structures are shown in figure 1 and 2 respectively.

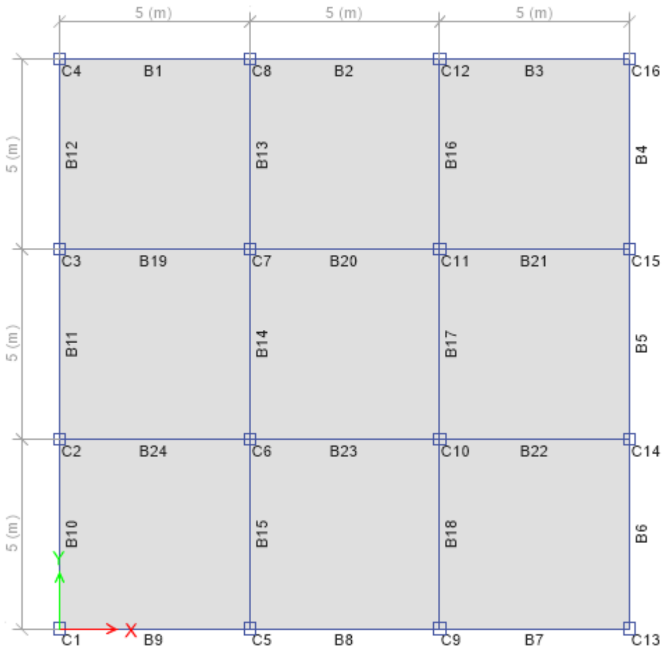

Fig -1: Plan of the Steel Framed Structure

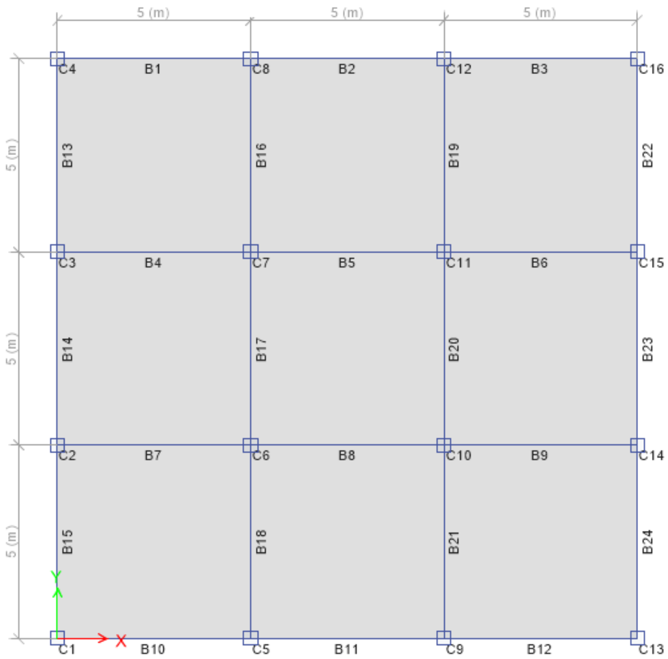

Fig -2: Plan of the Composite Framed Structure

Loads and Load combinations are applied according to the IS 875 Part I and Part II. The load combinations considered are shown in table 4. Live load on the floor taken as 3 kN/m^2 and on the roof taken as 1.5 kN/m^2. Floor finish as 1.5 kN/m^2. Wall load of 11.73kN/m was applied on the beams. Earthquake loading is calculated on the basis of IS 1893 regulations (part 1):2002. The temperature load is applied at corner column, edge column and re-entrant column of each ground floor, second floor, fourth floor, sixth floor and eighth floor. For every case of temperature load, static analysis is done.

Table -4: Load Combinations

SL. No	Load Combinations
1	1.5 (DL + LL)
2	1.5 (DL + LL) + T
3	1.2 (DL + LL ± EQ)
4	1.2 (DL + LL ± EQ) + T
5	1.5 (DL ± EQ)
6	1.5 (DL ± EQ) + T
7	0.9 DL ± EQ
8	0.9 DL ± EQ + T

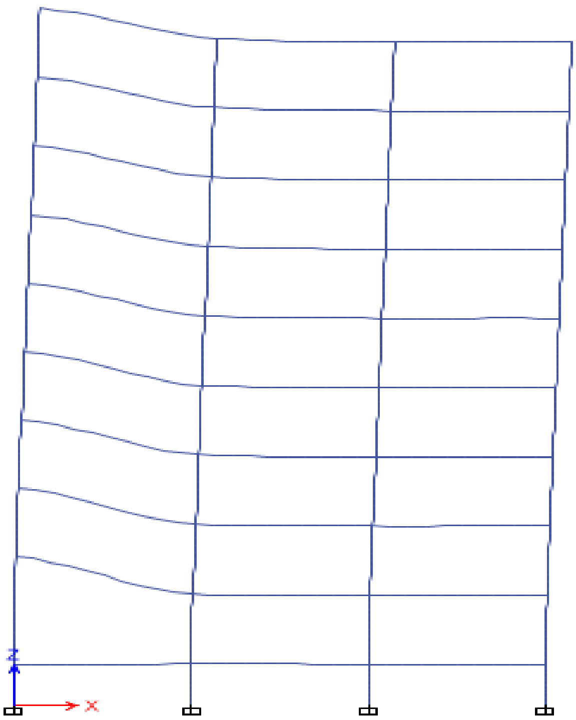

Fig -3: Deformed form of Ground Floor Corner Column at 1000°C

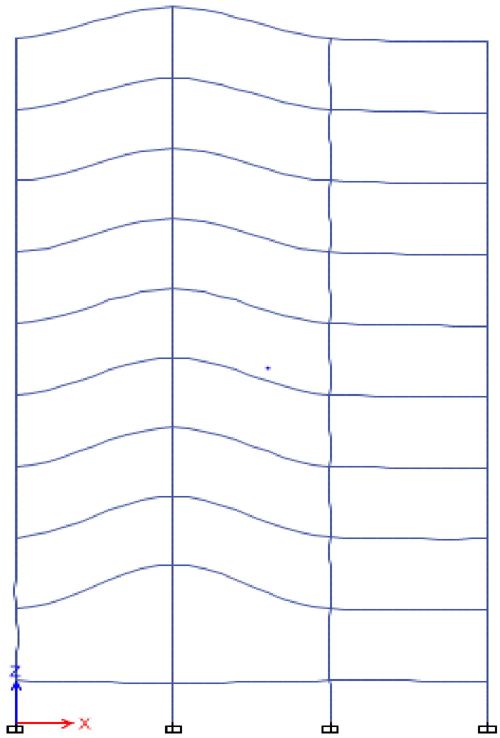

Fig -4: Deformed form of Ground Floor Intermediate Column at 1000°C

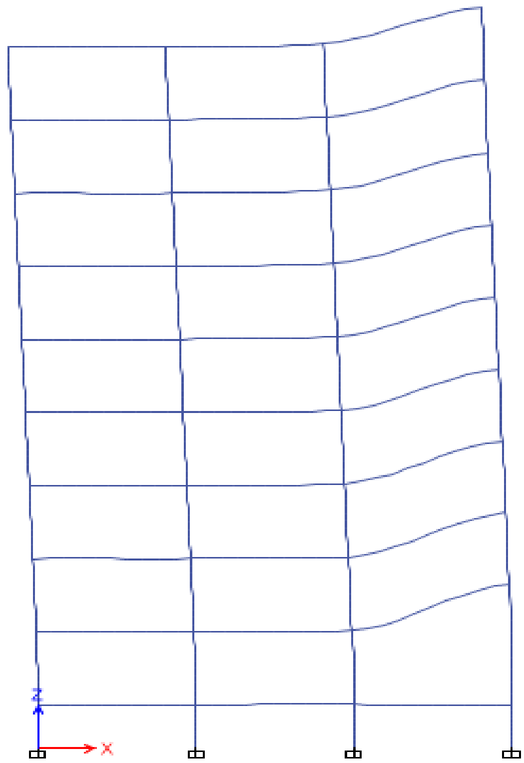

Fig -5: Deformed form of Ground Floor Edge Column at 1000°C

3. RESULTS AND DISCUSSION

3.1 A COMPARISION ON STEEL AND COMPOSITE STRUCTURE

Temperature load was applied to a corner column C4 of both steel and composite structure. Demand Capacity ratio was noted when temperature load applied to alternative floors such as ground, second, fourth, sixth and eighth floor.

Table -5: DCR Values of Steel Structure Corner Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C4	0.458	0.727	0.81	0.932
	BEAM B1	0.824	1.343	1.549	1.854
	BEAM B12	0.824	1.343	1.549	1.854
SECOND FLOOR	COLUMN C4	0.382	0.562	0.647	0.753
	BEAM B1	0.801	1.33	1.522	1.763
	BEAM B12	0.801	1.33	1.522	1.763
FOURTH FLOOR	COLUMN C4	0.296	0.45	0.521	0.61
	BEAM B1	0.721	1.242	1.431	1.688
	BEAM B12	0.721	1.242	1.431	1.688
SIXTH FLOOR	COLUMN C4	0.194	0.337	0.394	0.469
	BEAM B1	0.541	1.078	1.199	1.518
	BEAM B12	0.541	1.078	1.199	1.518
EIGHTH FLOOR	COLUMN C4	0.091	0.28	0.354	0.447
	BEAM B1	0.212	0.67	0.835	1.041
	BEAM B12	0.212	0.67	0.835	1.041

Table -6: DCR Values of Composite Structure Corner Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C4	0.458	0.658	0.768	0.905
	BEAM B1	0.722	1.318	1.535	1.806
	BEAM B13	0.722	1.318	1.535	1.806
SECOND FLOOR	COLUMN C4	0.37	0.585	0.68	0.799
	BEAM B1	0.761	1.329	1.536	1.794
	BEAM B13	0.761	1.329	1.536	1.794
FOURTH FLOOR	COLUMN C4	0.238	0.48	0.561	0.663
	BEAM B1	0.687	1.246	1.45	1.704
	BEAM B13	0.687	1.246	1.45	1.704
SIXTH FLOOR	COLUMN C4	0.172	0.342	0.406	0.487
	BEAM B1	0.517	1.091	1.3	1.561
	BEAM B13	0.517	1.091	1.3	1.561
EIGHTH FLOOR	COLUMN C4	0.125	0.403	0.512	0.648
	BEAM B1	0.231	0.723	0.907	1.137
	BEAM B13	0.231	0.723	0.907	1.137

Table 5 and 6 shows the DCR values of fire affected elements at different floor corner column of steel structure and composite structure respectively. Maximum DCR values were obtained at ground floor column at 1000°C for both steel and composite structure. Since the DCR values are in limit, progressive collapse will not occur.

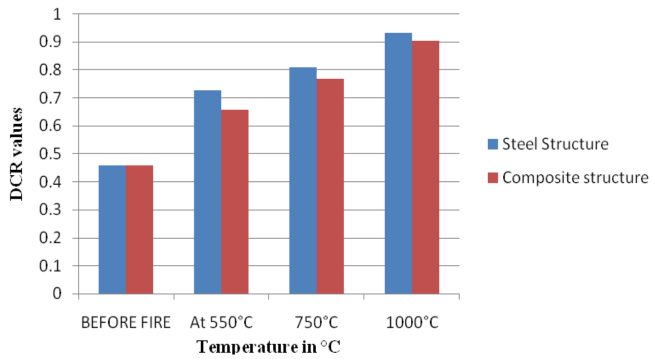

Fig -6: DCR Values of Ground Floor Corner Column

Maximum DCR values were obtained at ground floor column at 1000°C for both steel and composite structure. Before the fire load, DCR values are obtained equal for both steel and composite structure at ground floor column. For every increase in the temperature load steel structure shows maximum DCR value than the composite structure.

Table -7: DCR Values of Steel Structure Intermediate Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C7	0.7	1.045	1.168	2.456
	BEAM B13	0.917	1.499	1.741	2.043
	BEAM B14	0.839	1.489	1.736	2.044
	BEAM B19	0.197	1.499	1.741	2.043
	BEAM B20	0.857	1.489	1.736	2.044
SECOND FLOOR	COLUMN C7	0.576	0.828	0.92	1.035
	BEAM B13	0.891	1.398	1.616	1.888
	BEAM B14	0.812	1.437	1.659	1.937
	BEAM B19	0.891	1.398	1.616	1.888
	BEAM B20	0.812	1.437	1.659	1.937
FOURTH FLOOR	COLUMN C7	0.445	0.632	0.7	0.785
	BEAM B13	0.837	1.261	1.475	1.741
	BEAM B14	0.747	1.343	1.56	1.83
	BEAM B19	0.837	1.261	1.475	1.741
	BEAM B20	0.747	1.343	1.56	1.83
SIXTH FLOOR	COLUMN C7	0.282	0.405	0.449	0.505
	BEAM B13	0.663	1.091	1.315	1.595
	BEAM B14	0.582	1.209	1.437	1.721
	BEAM B19	0.663	1.091	1.315	1.595
	BEAM B20	0.582	1.209	1.437	1.721
EIGHTH FLOOR	COLUMN C7	0.099	0.147	0.165	0.187
	BEAM B13	0.315	0.798	1.023	1.306
	BEAM B14	0.281	0.931	1.169	1.467
	BEAM B19	0.315	0.798	1.023	1.306
	BEAM B20	0.281	0.931	1.169	1.467

Temperature load was applied to a intermediate C7 of both steel and composite structure column. Demand Capacity ratio was noted when temperature load applied to alternative floors such as ground, second, fourth, sixth and eighth floor.

Table -8: DCR Values of Composite Structure Intermediate Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C7	0.713	1.086	1.222	1.392
	BEAM B4	0.811	1.47	1.719	2.029
	BEAM B5	0.771	1.468	1.721	2.036
	BEAM B16	0.811	1.47	1.719	2.029
	BEAM B17	0.771	1.468	1.721	2.036
SECOND FLOOR	COLUMN C7	0.578	0.861	0.964	1.092
	BEAM B4	0.865	1.393	1.621	1.906
	BEAM B5	0.799	1.434	1.664	1.952
	BEAM B16	0.865	1.393	1.621	1.906
	BEAM B17	0.799	1.434	1.664	1.952
FOURTH FLOOR	COLUMN C7	0.44	0.649	0.725	0.82
	BEAM B4	0.799	1.267	1.49	1.769
	BEAM B5	0.722	1.342	1.568	1.849
	BEAM B16	0.799	1.267	1.49	1.769
	BEAM B17	0.722	1.342	1.568	1.849
SIXTH FLOOR	COLUMN C7	0.213	0.411	0.46	0.552
	BEAM B4	0.635	1.106	1.339	1.63
	BEAM B5	0.561	1.21	1.445	1.739
	BEAM B16	0.635	1.106	1.339	1.63
	BEAM B17	0.561	1.21	1.445	1.739
EIGHTH FLOOR	COLUMN C7	0.096	0.129	0.141	0.157
	BEAM B4	0.35	0.834	1.071	1.366
	BEAM B5	0.321	0.949	1.194	1.502
	BEAM B16	0.35	0.834	1.071	1.366
	BEAM B17	0.321	0.949	1.194	1.502

Table 7 and 8 shows the DCR values of fire affected elements at different floor intermediate column of steel structure and composite structure respectively. Here the DCR values are in limit under 750°C; progressive collapse will not occur, but at 1000°C DCR value obtained exceeding limit at ground floor steel structure column and beam connected to that column.

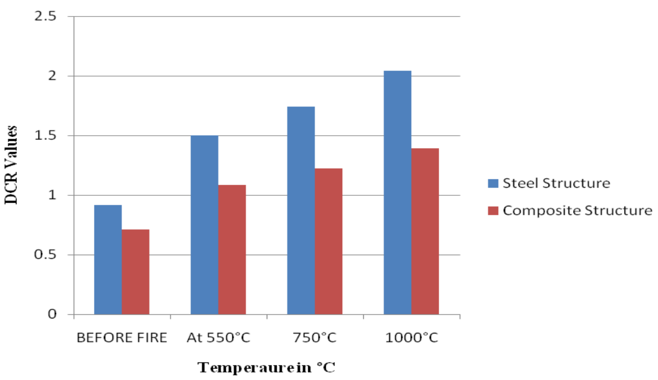

Fig -7: DCR Values of Ground Floor Intermediate Column

An increment in temperature from 550°C to 1000°C shows increment in the DCR values of column. For every increase In the temperature load, steel structure shows maximum DCR value than the composite structure. At 1000°C, DCR value of steel structure corner column exceeding 2, so the progressive collapse will occur.

Temperature load was applied to a Edge C14 of both steel and composite structure column. Demand Capacity ratio was noted when temperature load applied to alternative floors such as ground, second, fourth, sixth and eighth floor.

Table -9: DCR Values of Steel Structure Edge Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C14	0.538	0.851	0.948	1.072
	BEAM B5	0.766	1.426	1.683	2.003
	BEAM B6	0.824	1.416	1.659	1.961
	BEAM B22	0.917	1.416	1.615	1.864
SECOND FLOOR	COLUMN C14	0.448	0.653	0.744	0.858
	BEAM B5	0.736	1.383	1.618	1.911
	BEAM B6	0.801	1.339	1.562	1.84
	BEAM B22	0.891	1.407	1.589	1.816
FOURTH FLOOR	COLUMN C14	0.345	0.512	0.584	0.674
	BEAM B5	0.657	1.292	1.521	1.808
	BEAM B6	0.721	1.216	1.435	1.707
	BEAM B22	0.837	1.241	1.505	1.727
SIXTH FLOOR	COLUMN C14	0.226	0.368	0.424	0.493
	BEAM B5	0.492	1.154	1.394	1.693
	BEAM B6	0.541	1.047	1.275	1.559
	BEAM B22	0.663	1.172	1.358	1.589
EIGHTH FLOOR	COLUMN C14	0.115	0.265	0.322	0.392
	BEAM B5	0.191	0.859	1.105	1.429
	BEAM B6	0.212	0.731	0.977	1.285
	BEAM B22	0.315	0.76	0.922	1.123

Table -10: DCR Values of Comp. Structure Edge Column

COLUMN LOCATION	MEMBERS	BEFORE FIRE	AFTER FIRE		
			550°C	750°C	1000°C
GROUND FLOOR	COLUMN C14	0.561	0.842	0.944	1.082
	BEAM B9	0.811	1.388	1.598	1.861
	BEAM B23	0.683	1.406	1.668	1.994
	BEAM B24	0.722	1.388	1.637	1.947
SECOND FLOOR	COLUMN C14	0.482	0.701	0.789	0.913
	BEAM B9	0.865	1.405	1.601	1.847
	BEAM B23	0.71	1.38	1.623	1.925
	BEAM B24	0.761	1.334	1.565	1.854
FOURTH FLOOR	COLUMN C14	0.338	0.551	0.63	0.728
	BEAM B9	0.799	1.328	1.521	1.762
	BEAM B23	0.634	1.291	1.529	1.825
	BEAM B24	0.687	1.219	1.447	1.731
SIXTH FLOOR	COLUMN C14	0.233	0.375	0.46	0.534
	BEAM B9	0.635	1.181	1.381	1.631
	BEAM B23	0.473	1.156	1.402	1.71
	BEAM B24	0.517	1.059	1.295	1.59
EIGHTH FLOOR	COLUMN C14	0.132	0.3	0.361	0.437
	BEAM B9	0.35	0.814	0.994	1.219
	BEAM B23	0.211	0.878	1.13	1.456
	BEAM B24	0.231	0.765	1.009	1.324

Table 9 and 10 shows the DCR values of fire affected elements at different floor edge column of steel structure and composite structure respectively. Maximum DCR values were obtained at ground floor column at 1000°C for both steel and composite structure.

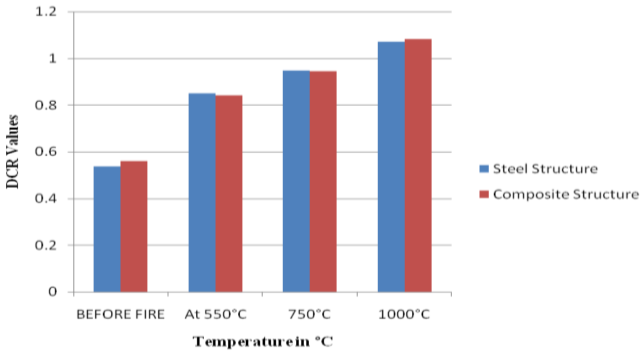

Fig -8: DCR Values of Ground Floor Edge Column

For every increase in the temperature load, steel structure shows maximum DCR value than the composite structure. At 1000°C, DCR value of beam B5 which is connected steel structure edge column C14 exceeding 2, so the progressive collapse will occur.

3.2 A COMPARISON BETWEEN CORNER, INTERMEDIATE AND EDGE COLUMN

Table -11: Critical percentage of DCR values of steel structure at ground floor level

COLUMN	CRITICAL PERCENTAGE OF DCR VALUES		
	550°C	750°C	1000°C
INTERMEDIATE	43.75	44.2	163.52
EDGE	17.06	17.04	15.03
CORNER	0	0	0

At 550°C, intermediate and edge column are 43.75% and 17.06% critical compared to corner column respectively. At 750°C, intermediate and edge column are 44.2% and 17.04% critical compared to corner column respectively. At 1000°C, intermediate and edge column are 163.52% and 15.03% critical compared to corner column respectively.

Table -12: Critical percentage of DCR values of composite structure at ground floor level

COLUMN	CRITICAL VALUES IN PERCENTAGE		
	550°C	750°C	1000°C
INTERMEDIATE	65.05	59.12	53.82
EDGE	27.97	22.92	19.56
CORNER	0	0	0

At 550°C, intermediate and edge column are 65.05% and 27.97% critical compared to corner column respectively. At 750°C, intermediate and edge column are 59.12% and 22.92% critical compared to corner column respectively. At 1000°C, intermediate and edge column are 53.82% and 19.56% critical compared to corner column respectively.

4. CONCLUSIONS

By this study following conclusions are made

1. At 1000°C intermediate column and beam connected to that column DCR values are exceeding limit. Therefore members in intermediate location are unsafe in both steel and composite structure and they are considered as critical members.
2. In a steel structure, when the temperature load of 550°C is applied on ground floor column, intermediate and edge column are 43.75% and 17.06% more critical compared to corner column respectively.
3. In a steel structure, when the temperature load of 750°C is applied on ground floor column, intermediate and edge column are 44.2% and 17.04% more critical compared to corner column respectively.
4.In a steel structure, when the temperature load of 1000°C is applied on ground floor column, intermediate and edge column are 163.52% and 15.03% more critical compared to corner column respectively.
5. In a composite structure, when the temperature load of 550°C is applied on ground floor column, intermediate and edge column are 65.05% and 27.97% more critical compared to corner column respectively.
6. In a composite structure, when the temperature load of 750°C is applied on ground floor column, intermediate and edge column are 59.12% and 22.92% more critical compared to corner column respectively.
7. In a composite structure, when the temperature load of 1000°C is applied on ground floor column, intermediate and edge column are 53.82% and 19.56% more critical compared to corner column respectively.

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