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# Linear Static Analysis For Progressive Collapse Of Steel Structure Under Fire Loads

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**ABSTRACT :**Progressive collapse is defined as extension of initial collapse, from a part of structure to another one that may result in destruction of steel structure. Possible risks and abnormal loads that causes progressive collapse are as follows aircraft collision, design or construction error, firing, gas explosion etc. Such phenomenons are not consider in designing typical structure, since possibility of occurring these kinds of risks is very low. In this study G+8 steel frame structure was analyses the columns are subjected to different load combination along with fire loadings ranging from 250℃ -1000℃ at an interval of 150℃ for alternate storey's, selecting the columns are corner, edge, intermediate and re- entrant columns.. Load combinations were adopted as per IS 875 Part I and II. Then the structure is checked for the DEMAND CAPACITY RATIO (DCR) value in terms of linear static analysis for the columns which are obtained and compared with as per GSA guidelines 2016 by using software E-TAB 2015.

**Keywords –** progressive collapse, fire load, DCR values E-TAB 2015 GSA guidelines,

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## I. INTRODUCTION

The introduction of the paper should explain the nature of the problem. Generally the structure takes place the progressive collapse when there is a chance of failing the members and damaging to the adjacent members. The study of structural elements it leads to the final or partial collapse of the structure when extreme loads transfer to the vertical member starts to fails, due to this other adjacent members will also fails. When a column is effected by the accidental impact of vehicle, fire blast, or any kind of natural disaster, the weight of building will transfer to the adjacent columns in the building.

The behavior of the steel frame building in progressive collapse under fire loads. The most under researched area in the structural engineering of the progressive collapse due to the scarcity relative negligence which leads to the progressive collapse. According to the code book the standard designs and codes are provide limited and also it is based on the analysis of guidelines or against to the progressive collapse deign. The guidelines also recommended to obtained and compared the DCR values.

Since from past two decades, a lot of researchers has been done to study the progressive collapse behavior of steel frame building under fire loads.

This event motivated the engineer and academic researchers to research comprehensively and develop the acceptable design criteria for preventing or reducing progressive collapse of structures.

Progressive collapse is one of the most under-researched areas in structural engineering due to the relative scarcity of the circumstances leading to progressive collapse. The current design standards and building codes provide limited prescriptive or performance-based guidance on analysis or design to guard against progressive collapse. The two important guidelines have been posed and develop recently GSA 2016 & UFC which address and explain the design requirements of progressive collapse for new and existing constructions based on different categories. These guidelines also recommended DCR values to evaluate the intensity of damage of individual members of the structure due to progressive collapse.

## II. LITERATURE REVIEW

One of the main reasons for the failure of structure is progressive collapse, it occurs due to the damage of a column or shear wall by fire blast. In this case study etab2015 is used to predict the sensitivity of the structure to progressive collapse due to fire load at different level temp of 550℃,this is mainly done in G+8 moment resisting low rise steel frame residential building.

Marjanishviili and Agnew[9] have been applied to the linear static and non linear static analyses for studying the progressive collapse based on the U.S GSA guidelines. According to the authors the acceptance criteria for GSA is not accurate for the linear and non linear static method analyses, hence create more deformations.

Kim and kim[11] there had done the investigation on the moment resistance steel frame structure has the capacity for progressive collapse by using alternate path method which is based on the GSA and UFC guidelines, and there also been compared with different linear and nonlinear static procedure.

As per their conclusion, the corner column which has high potential for progressive collapse was suddenly removed. If in case there is an multi storey building which has increasing the potential for progressive collapse, but the capacity of resistance decreases.

M.A. Hadianard, M. Wassegh M. and Soltani Mohammadi. There have attempt to study and investigate on the linear and non linear static analysis for progressive collapse. Steel frame building is designed for seismic. There have try to attempted the 14th international conference that computing about civil engineers.

## III. METHODOLOGY

In this study linear static method is used to carry out the progressive collapse analysis of G+8 storey of steel frame structure. The primary beams, secondary beams and the columns for application of different locations are selected as per GSA 2016 guidelines columns has been selected and applied the fire loads for those columns which there are in critical locations and applied the fire loads for alternate floor and note downing the DCR values after analyzing the structure by using software ETAB 2015

**Table 1:** Data used for analysis of structures

| | | |
|---|---|---|
| Columns(Built up I sections taken by preliminary design) | | Ground to 9th 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 |

G+8 storey building is molded as shown in (fig 1) for studying this it has been extended to 3D analysis of building by using software ETAB 2015 which can perform due to linear static analysis and design of the low rise steel structure and with concrete slab and plan is in irregular shape and data used for analysis for building as given in table 1

IS 875 Part I and II have been made use of for taking loads and choosing load combinations. Magnitude of 2.5 KN/$m^2$ was chosen as Live load and 12 KN/m wall load is applied on primary beams. The combinations of load considered as mentioned in table 2

**Table 2: Load combinations**

| SI No | Load Combinations |
|---|---|
| 1 | 1.5(DL+LL) |
| 2 | 1.2(DL+LL±EQ) |
| 3 | 1.5(DL±EQ) |
| 4 | 0.9DL±1.5EQ |

On the columns of the structure, fire load was applied, in initial stages the column is expanding with temperature and with increasing the temperature; it also loses its rigid nature and elasticity modulus in columns. Hence temperature effect the columns at the stage of 550º C

## IV. Results

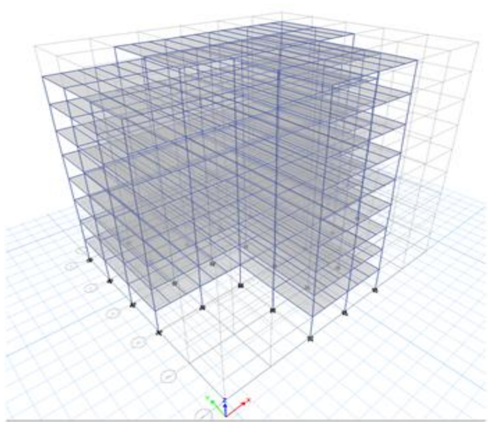


**Fig1.** 3DModel of steel building

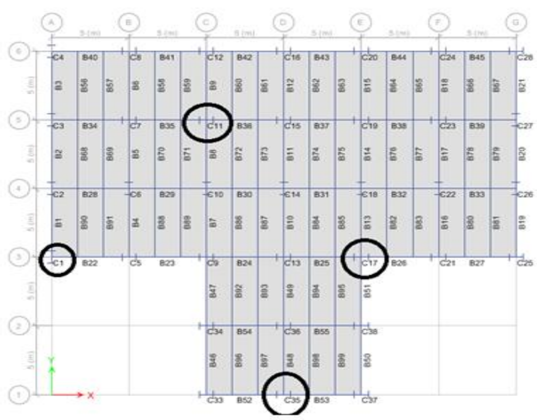


**Fig 2.** Plan view of the steel structure

Before analysis of the structure the temperature is applied starting 250℃ for the selected columns as shown in the above (fig 2) as per the GSA 2016 guidelines. Fire loads are applied to the edge column (C35), corner column (C1), intermediate column (C11), re-entrant column(C17) of every alternate floor (odd numbered floor) and calculated the DCR values of each column are noted. As per GSA 2016 guidelines the demand capacity ratio values should not exceed more than 1 or 2 if in case it exceed more than 1 or 2 then the progressive collapse takes place.

The analysis carried out at various elevated temperature the DCR values are noted and tabulated in the table 3. It is observed that the DCR values are effected by the temperature at 550℃ and it exceed the DCR limit more than 1 progressive collapse takes places.

| LOCATIONS | MEMBERS | TEMP. | DCR | |
|---|---|---|---|---|
| | | | BEFORE FIRE | AFTER FIRE |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.298 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 0.277 |
| 5$^{th}$ FLOOR | C1 | 250℃ | 0.072 | 0.223 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 0.425 |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.304 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 0.309 |
| 5$^{th}$ FLOOR | C1 | 400℃ | 0.072 | 0.296 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 0.594 |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.57 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 0.605 |
| 5$^{th}$ FLOOR | C1 | 550℃ | 0.072 | 0.593 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 1.278 |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.716 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 0.755 |
| 5$^{th}$ FLOOR | C1 | 700℃ | 0.072 | 0.749 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 1.634 |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.855 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 0.904 |
| 5$^{th}$ FLOOR | C1 | 850℃ | 0.072 | 0.838 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 1.989 |
| 1$^{st}$ FLOOR | C1 | | 0.131 | 0.994 |
| 3$^{rd}$ FLOOR | C1 | | 0.101 | 1.053 |
| 5$^{th}$ FLOOR | C1 | 1000℃ | 0.072 | 1.049 |
| 7$^{th}$ FLOOR | C1 | | 0.07 | 2.353 |

**Table 4: DCR values of the Re-entrant columns**

From the analysis table 4 it is observed that DCR values are exceeding the limit at temperature of 550℃ and the temperature goes on increasing there is an increase in DCR values as well and it crosses the limit of 2 at every elevated temperature of about 1000℃

**Table 5: DCR values of the Intermediate columns**

| LOCATIONS | MEMBERS | TEMP | DCR | |
|---|---|---|---|---|
| | | | BEFORE FIRE | AFTER FIRE |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 0.395 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 0.416 |
| 5$^{th}$ FLOOR | C17 | 250℃ | 0.109 | 0.292 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 0.187 |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 0.495 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 0.426 |
| 5$^{th}$ FLOOR | C17 | 400℃ | 0.109 | 0.332 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 0.197 |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 0.913 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 0.816 |
| 5$^{th}$ FLOOR | C17 | 550℃ | 0.109 | 0.653 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 1.404 |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 1.082 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 1.023 |
| 5$^{th}$ FLOOR | C17 | 700℃ | 0.109 | 0.899 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 0.717 |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 1.293 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 1.225 |
| 5$^{th}$ FLOOR | C17 | 850℃ | 0.109 | 1.077 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 0.857 |
| 1$^{st}$ FLOOR | C17 | | 0.215 | 2.119 |
| 3$^{rd}$ FLOOR | C17 | | 0.18 | 1.429 |
| 5$^{th}$ FLOOR | C17 | 1000℃ | 0.109 | 1.261 |
| 7$^{th}$ FLOOR | C17 | | 0.058 | 1.004 |

From the analysis table 5 it is observed that DCR values are exceeding the limit at temperature of 700℃ and the temperature goes on increasing there is an increase in DCR values as well and it crosses the limit of 2 at every elevated temperature of about 1000℃

**Table 6: DCR values of the Edge columns**

| LOCATIONS | MEMBERS | TEMP | DCR | |
|---|---|---|---|---|
| | | | BEFORE FIRE | AFTER FIRE |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 0.429 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 0.365 |
| 5$^{th}$ FLOOR | C11 | 250℃ | 0.113 | 0.256 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.204 |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 0.449 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 0.385 |
| 5$^{th}$ FLOOR | C11 | 400℃ | 0.113 | 0.296 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.214 |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 0.796 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 0.706 |
| 5$^{th}$ FLOOR | C11 | 550℃ | 0.113 | 0.56 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.427 |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 1.003 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 0.901 |
| 5$^{th}$ FLOOR | C11 | 700℃ | 0.113 | 0.728 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.602 |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 1.186 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 1.071 |
| 5$^{th}$ FLOOR | C11 | 850℃ | 0.113 | 0.871 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.726 |
| 1$^{st}$ FLOOR | C11 | | 0.238 | 1.369 |
| 3$^{rd}$ FLOOR | C11 | | 0.178 | 1.241 |
| 5$^{th}$ FLOOR | C11 | 1000℃ | 0.113 | 1.014 |
| 7$^{th}$ FLOOR | C11 | | 0.062 | 0.85 |

From the analysis table 6 it is observed that DCR values are exceeding the limit at temperature of 850℃ and the temperature goes on increasing there is an increase in DCR values as well and it crosses the limit of 2 at every elevated temperature of about 1000℃

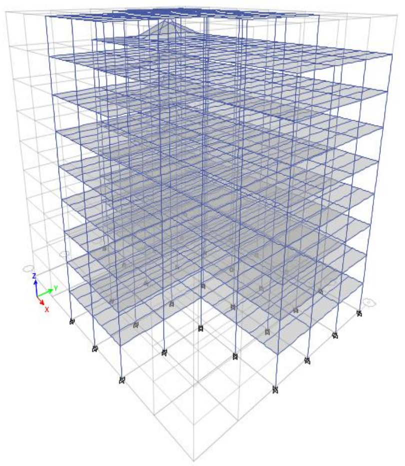


**Fig 3.** Initial shape of the fire loading

After giving a fire loads on column in the initial stage the temperature is 250℃ , steel column expands as shown in fig 3. As fire temperature increases, the columns loses its modulus of elasticity and rigidity. Then in the final stage it has melting point of steel ,the column get collapsed.

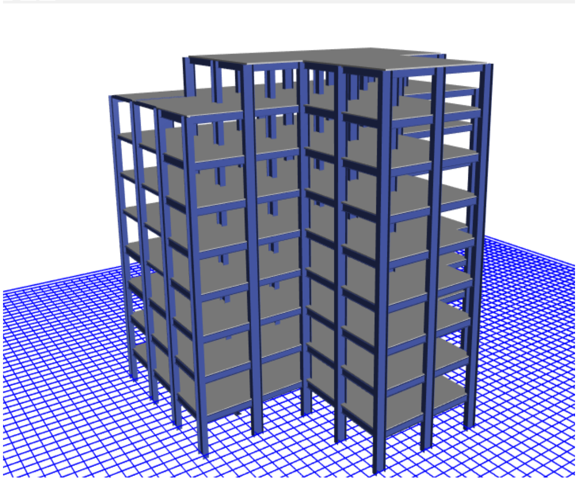
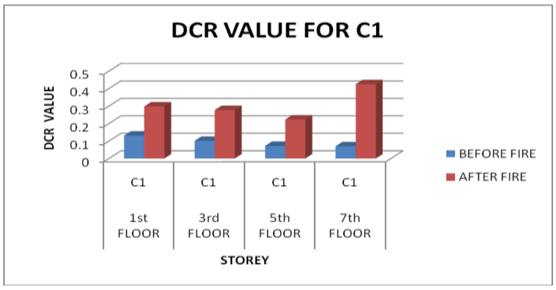


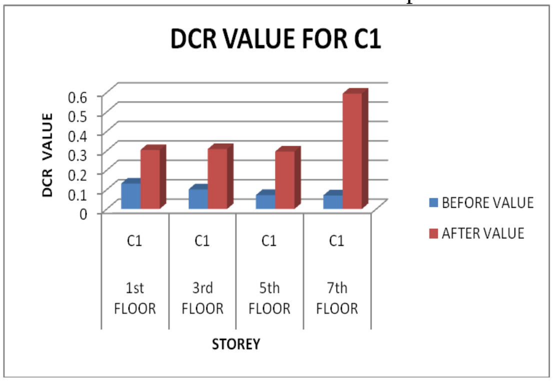
**Fig 4.** G+8 storey building (bay sixe 5X5)

Fig showing the graphs of DCR values for corner columns at various temperature and values are tabulated in table 3

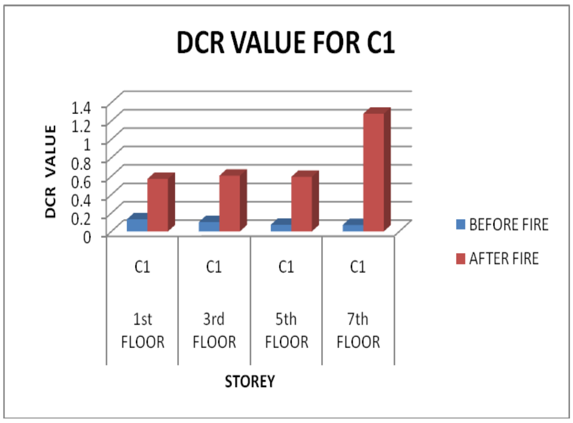
DCR values for Corner column at temp. 250℃



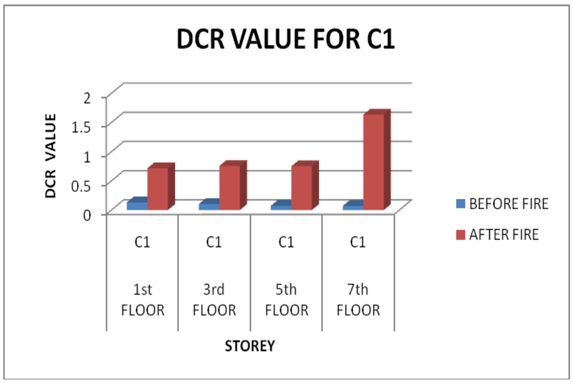

DCR values for Corner column at temp. 400℃



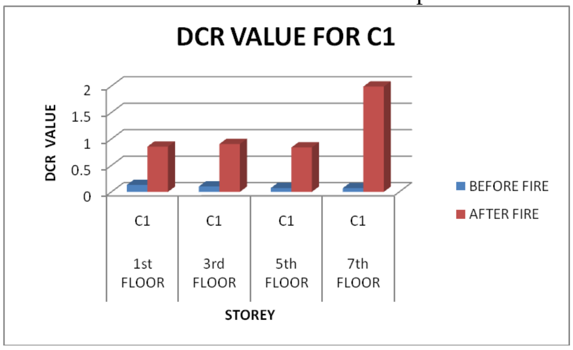

DCR values for Corner column at temp. 550℃




DCR values for Corner column at temp. 750℃




DCR values for Corner column at temp. 850℃




DCR values for Corner column at temp. 1000℃

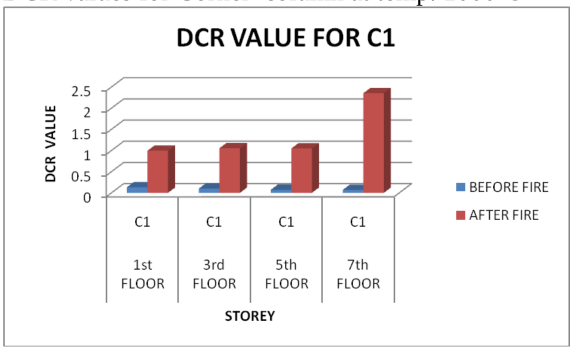
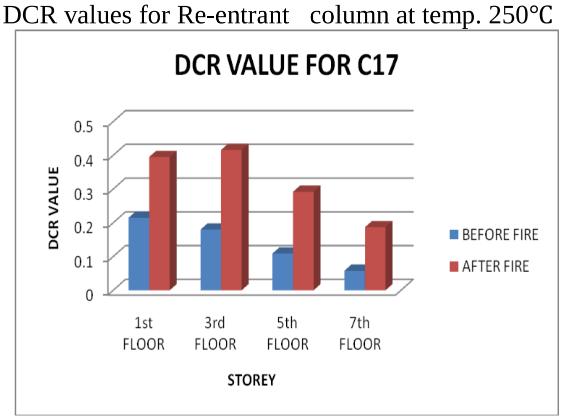
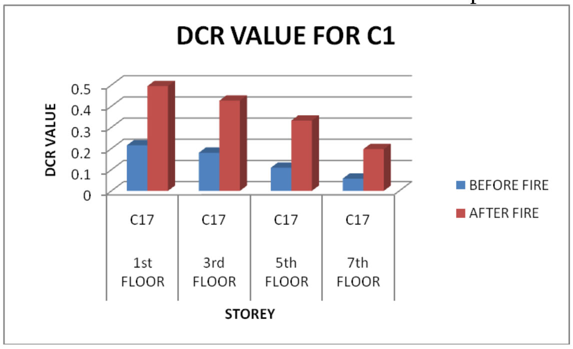



Fig showing the graphs of DCR values for Re-entrant columns at various temperature and values are tabulated in table 4

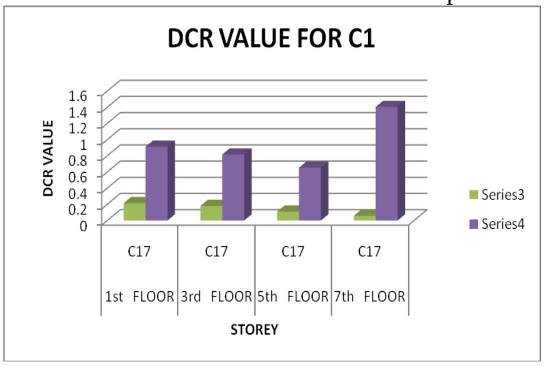
DCR values for Re-entrant column at temp. 250℃



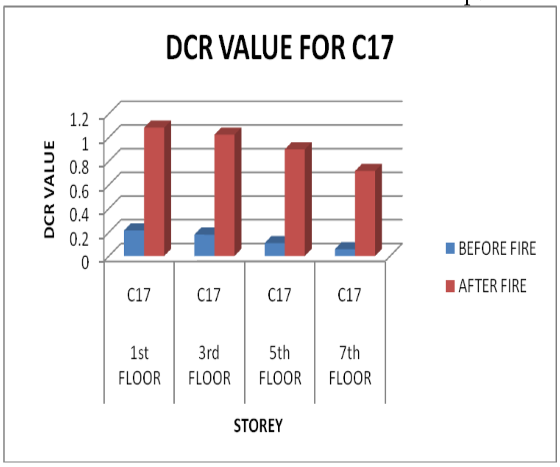

DCR values for Re-entrant column at temp. 400℃



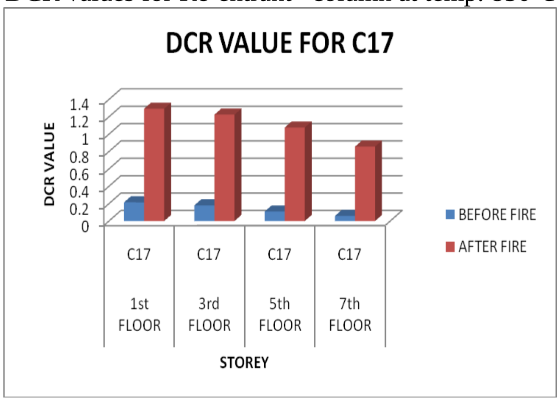

DCR values for Re-entrant column at temp. 550℃




DCR values for Re-entrant column at temp. 700℃




DCR values for Re-entrant column at temp. 850℃



DCR values for Re-entrant column at temp. 1000°C

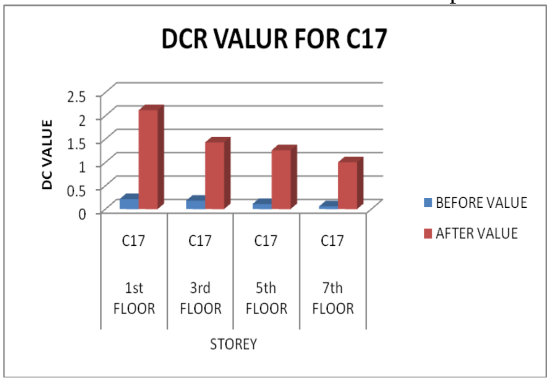
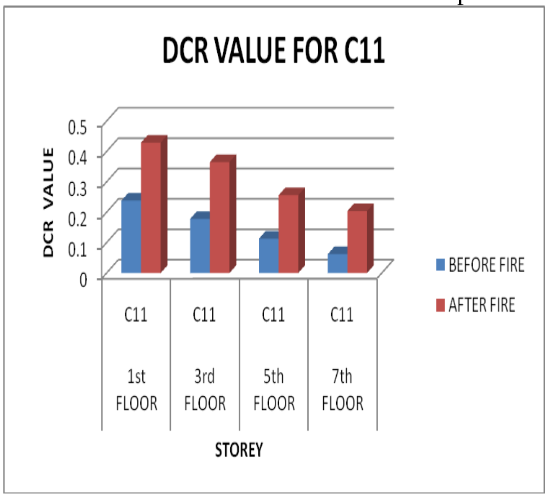
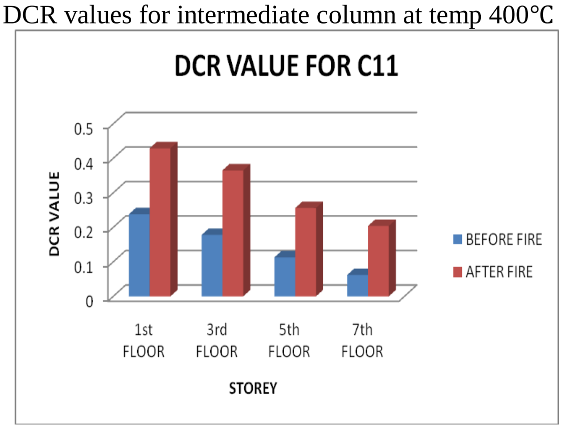



Fig showing the graphs of DCR values for Intermediate columns at various temperature and values are tabulated in table 5

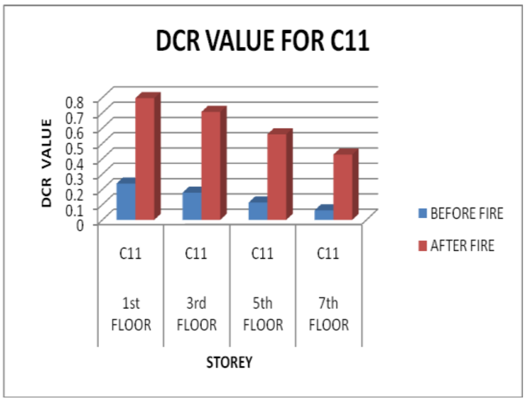
DCR values for Intermediate column at temp 250°C



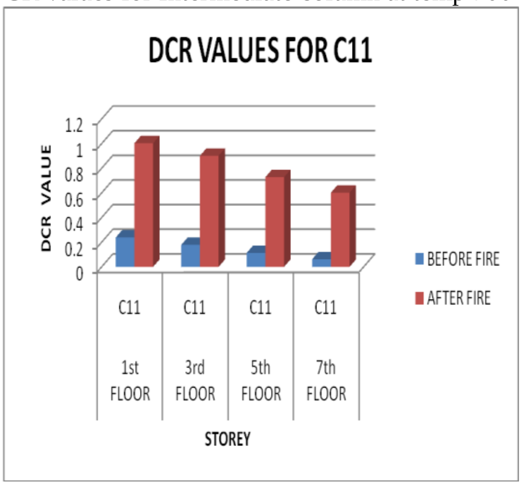

DCR values for intermediate column at temp 400°C



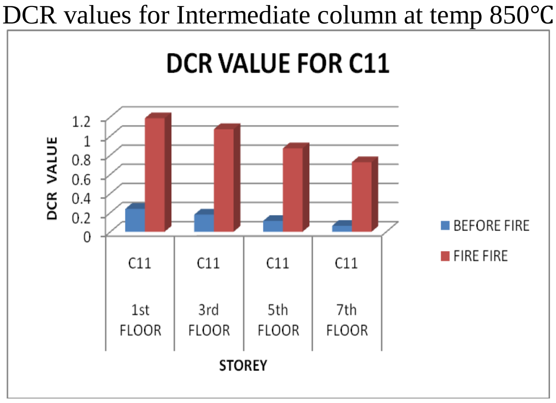

DCR values for Intermediate column at temp 550°C




DCR values for Intermediate column at temp 700°C




DCR values for Intermediate column at temp 850°C




DCR values for Intermediate column at temp 1000°C

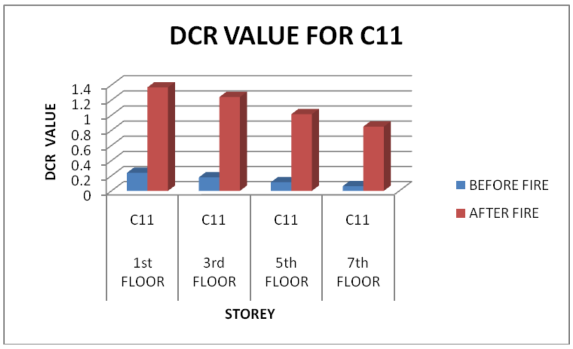
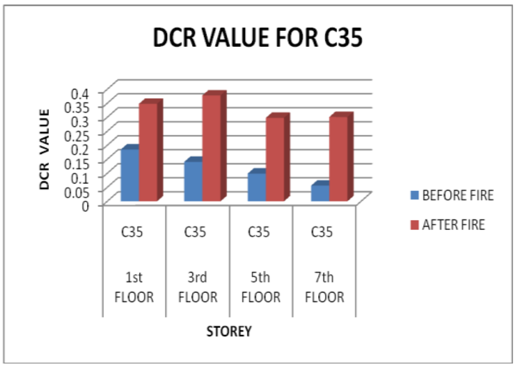
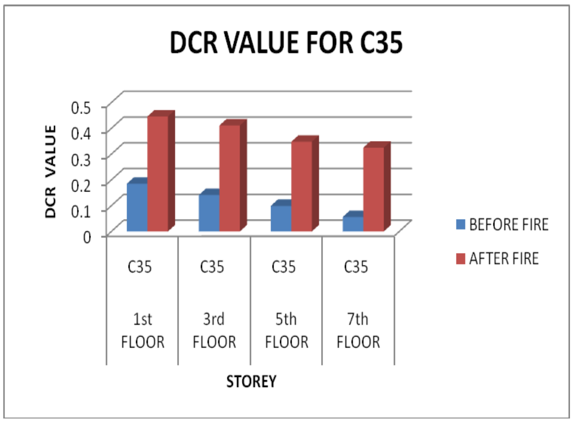



Fig showing the graphs of DCR values for Edge columns at various temperature and values are tabulated in table 6

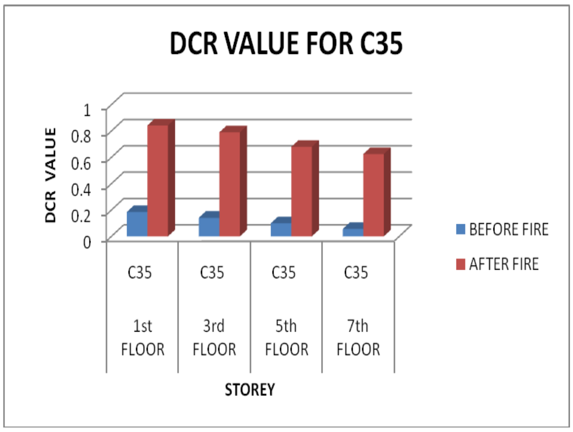
DCR values for Edge column at temp 250℃



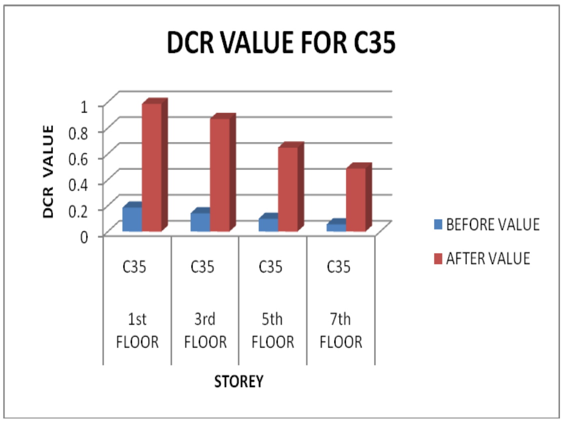

DCR values for Edge column at temp 400℃



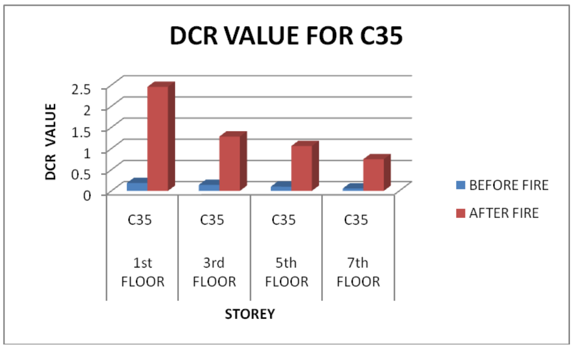

DCR values for Edge column at temp 550℃



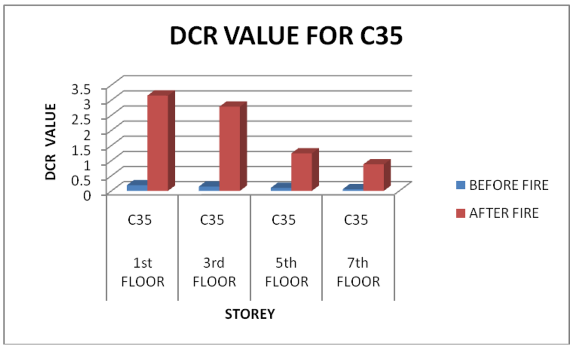

DCR values for Edge column at temp 700℃




DCR values for Edge column at temp 850℃




DCR values for Edge column at temp 1000℃




## V. CONCLUSIONS

From the above discussions the following are drawn

By referring the table 3,4,5,and 6, the obtained demand capacity ratio value (DCR) are with-in limits i.e. less than 2 as per GSA 2016 guidelines, specified for columns that the temperature ranges from 250℃-550℃ for the selected columns, hence the structure will not undergo progressive collapse under fire loads.

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 may undergo progressive collapse. This can be resolved by the sections or adding extra bracings and also by providing by larger steel sections.

The progressive collapse of steel structure under fire conditions vary with the loadings. when small loads levels applied on the structure, the occurs horizontal movement of the steel frame before the collapse of the frame where the collapse is generally confined to the storey above the heated floor. The mode for high loadings of progressive collapse, in the form of downward collapse of the whole structure, may occur as early as about 400℃

Since the DCR value of each column at initial stage of fire loads are with in the limit 2 as per GSA 2016 guidelines, the building is safe against the progressive collapse due to fire load.

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