Behavior of a Reinforced Concrete Structure under Various Column Removal Cases of Collapse

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ABSTRACT

Structure designed according to the code provisions is supposed to be safe and not life threatening even during various accidental loading conditions. The safety can be assured by making the structure redundant and ductile, so that when a critical load carrying member fails the alternate load path is initiated hence the failure is not sudden. The potential of a Reinforced Concrete (RC) frame structure designed as per IS 456 2000 for collapse is assessed in this study by following column removal scenarios recommended by the US General Service Administration (GSA). In order to assess the behaviour a ten storey RC frame is considered. Finite Element software is used for modelling and analyzing the structure. The results showed that the structure designed according to Indian Standard is proved to be redundant under the various cases.

Keywords: Reinforced Concrete *frame, GSA column removal cases, IS 456*

1. INTRODUCTION

When critical damage occurs locally due to accidental loads, structures need to have the ability to maintain the integrity and avoid total collapse. Accidental loading would include abnormal loads (e.g., gas explosions, vehicular collisions, and sabotage), severe fire, extreme values of environmental loads that stress the building system well beyond the design envelope, and misuse[1, 2]. Continuous, well-integrated and redundant framed structures usually can absorb a substantial amount of local damage. If the structural system consists of large-panel or bearing walls, precast concrete slabs it is difficult to provide continuity and ductility, inherently more vulnerable to local damage.

To enhance structural performance under abnormal loading conditions, International Building Code (ICC 2009) introduced structural integrity requirements for design of multistory buildings of specific occupancy categories, including buildings with occupancy of greater than 300 schools, hospitals, police stations and aviation control towers [3, 4, 5]. In addition, both the U.S. Department of Defense (DoD 2009) and the General Services Administration (GSA 2003) stipulate mandatory requirements for design of multistory buildings to resist progressive collapse. The

American Society of Civil Engineers Standard 7 (ASCE 2010) provides general guidelines for design of buildings to minimize the risk of progressive collapse. For concrete building structures, the American Concrete Institute Building Code 318 (ACI 2008) requires minimum continuity reinforcement to enhance overall structural integrity. Specifically GSA, General Services Administration, has provided certain guidelines to check the redundancy, alternate load path initiation by analyzing a structure for different column removal scenarios. The different column removal scenarios as suggested by GSA are:

1. Exterior corner column removal scenario
2. Exterior middle column removal scenario
3. Critical column removal scenario

During the design of a structure to resist catastrophic, unusual loads structural continuity, redundancy, robustness and ductility should be considered so that when a load resisting member fails alternate load path is initiated. From the GSA specifications if a structure is stable under different column removal cases it will be safe under accidental loads.

In this paper, ten storied reinforced cement concrete (RCC) framed structure designed as ordinary moment resisting frame (OMRF) according to IS 456 is considered. The structure was analysed for GSA column removal scenarios and extent or criticality of damage is observed. OMRF is considered because the reinforcement detailing may not be ductile.

2. DESIGN OF 10 STORIED BUILDING

- Ten Storey RCC building dimensions adopted are 23 m X 20 m
- Beam dimensions- 300 mm X 350 mm
- Column dimension- 450 mmX450 mm
- Live load- 2kN/m^2 at typical floor/ 1.5kN/m^2 on terrace
- Floor finish- 1kN/m^2
- Water proofing- 2kN/m^2 on terrace only
- Storey height – 3.5m
- Floors- G.F+9 upper floors
- Walls- 110 mm thick brick masonry walls.
- Material properties : Concrete M25 grade, Steel Fe415

The building was analysed for different load combinations using STAAD Pro and designed. The model of the RCC structure is as shown in Fig. 1.

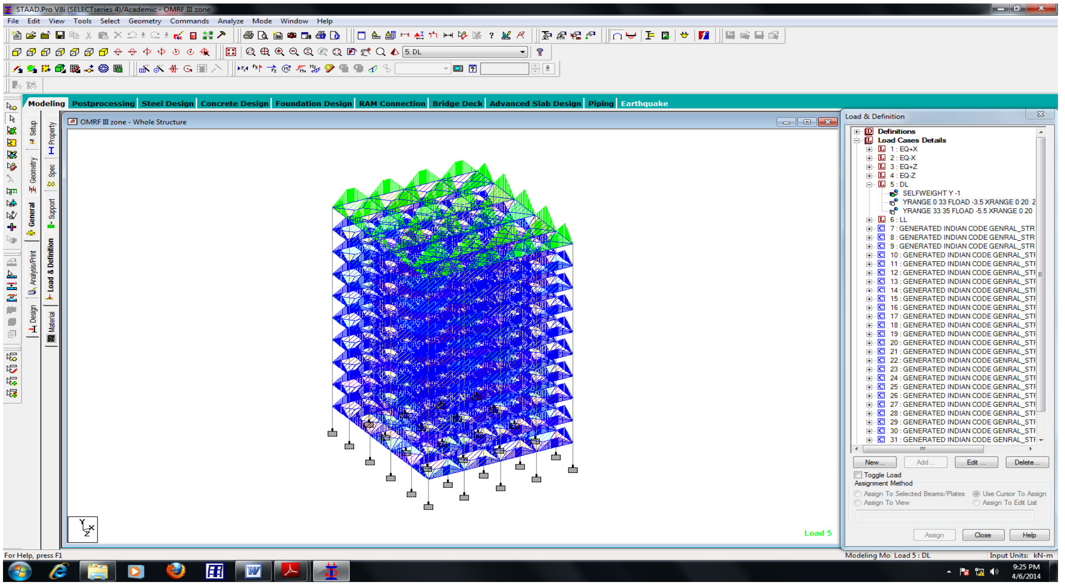

Fig. 1 STAAD PRO model with the loading conditions

The structure so designed is modeled in Finite Element Analysis software Seismostruct. The software is chosen because the details of reinforcement can be given as an input and the performance, failure criteria can be seen during the analysis. The building model is shown in Fig. 2. Bending Moment Diagram (BMD) of the frame analysed under gravity load condition is shown in Fig. 3.

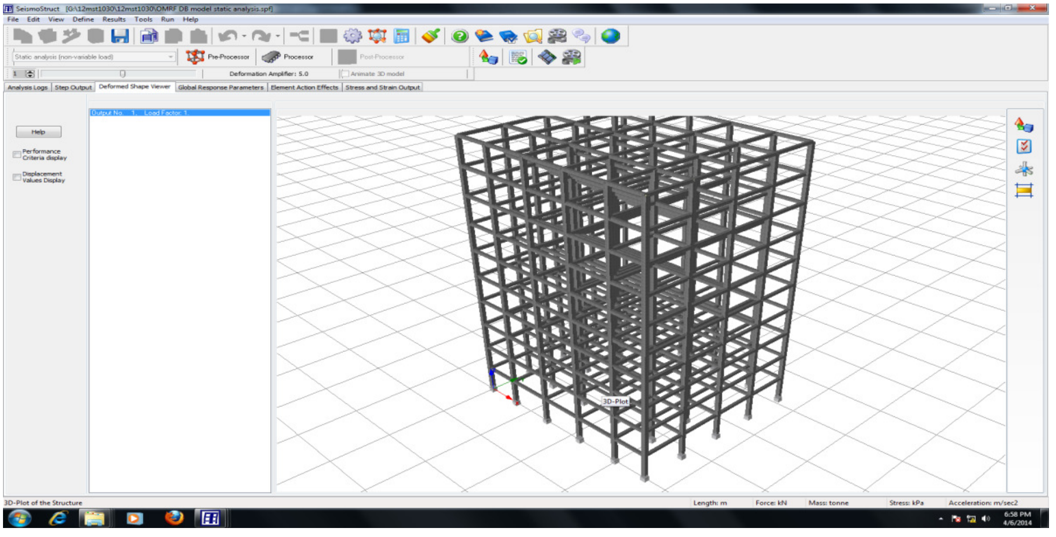

Fig. 2 Model of a frame in Seismostruct

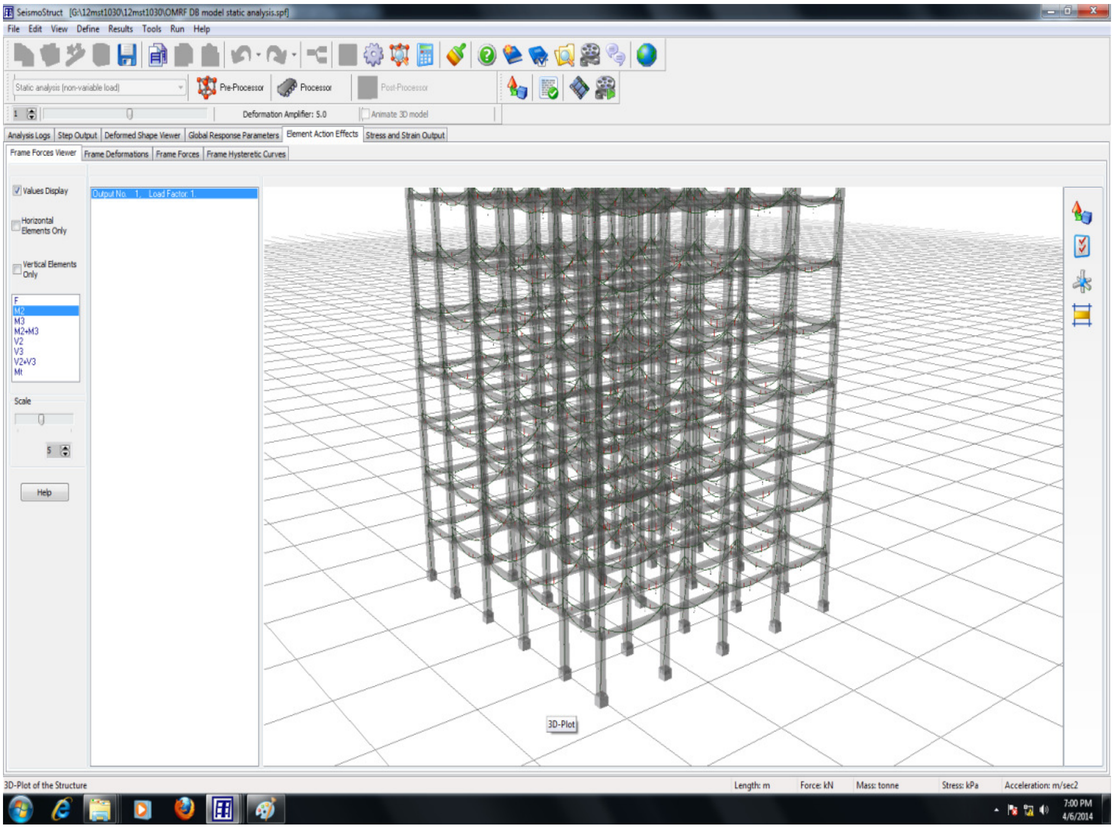

Fig. 3 BMD of building

3. COLUMN REMOVAL ANALYSIS

Once the model is ready it was analysed for three cases as specified by GSA

Case 1: External Corner Column Removal (ECCR)

Case 2: External Middle Column Removal on longer edge (EMCRLE)

Case3: External Middle Column Removal on shorter edge (EMCRSE)

The performance criteria were given as cracking of concrete, yielding of steel when their permissible values are reached.

Case 1: External Corner Column Removal (ECCR)

For the model shown in Fig. 2 corner column was removed and static analysis was carried out. Fig. 4 shows the BMD. Bending moment has been increased as expected with the removal of column.

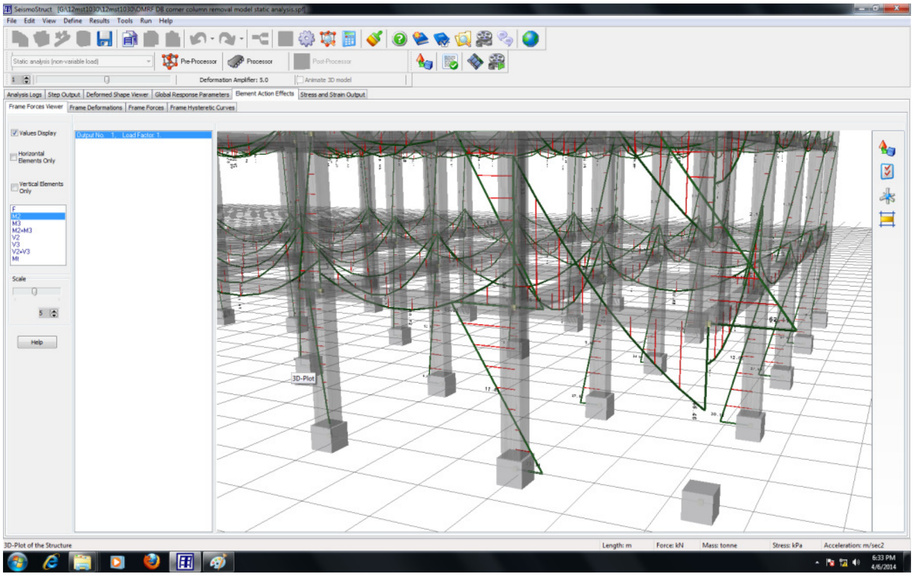

Fig. 4. BMD for case 1

Fig. 5 shows the deformed shape of the building. Cracks were observed in columns above the removed column and there is no yielding of steel which says indirectly that the alternate load path has been initiated and there is no much damage.

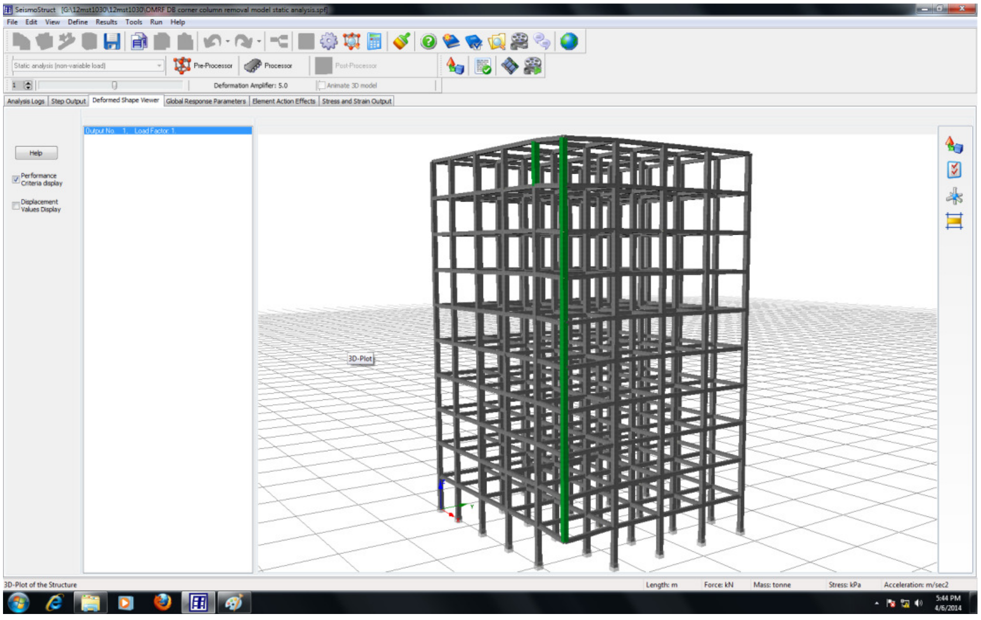

Fig. 5. Deformed shape for case 1

Case 2: External Middle Column Removal on longer edge (EMCRLS)

Fig. 6 shows the BMD of the building when subjected to EMCRLS. The bending moment has been increased with the removal of column but comparatively less compared to case 1.

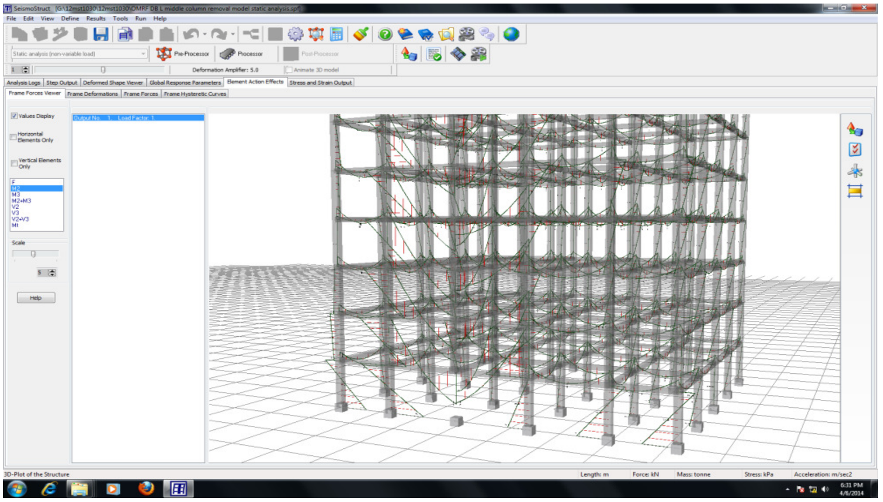

Fig.6. BMD of middle column (longer side) removed

Fig. 7 shows the deformed shape of the building. The steel in the beams adjacent to the column yielded and high deformation has been observed which lead to the failure of the beams.

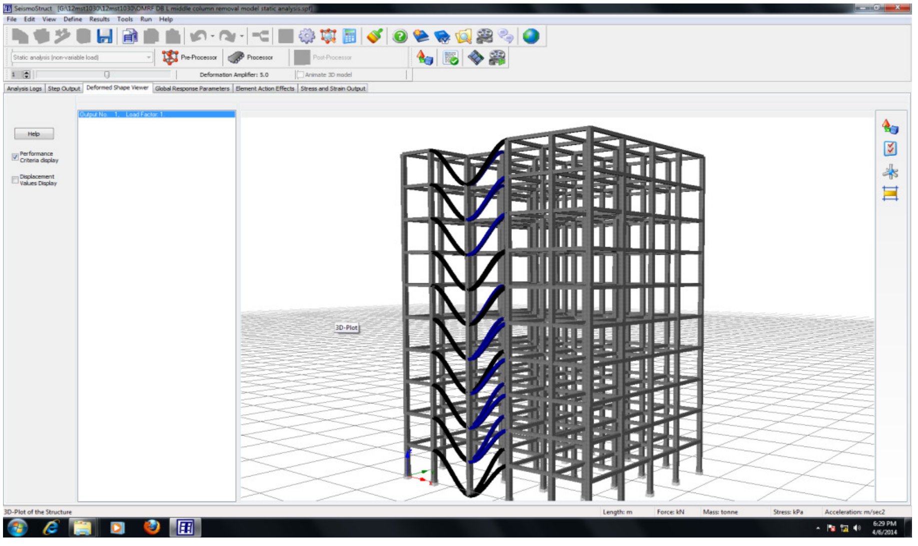

Fig. 7. Deformed Shape of middle column removed (longer side)

Case 3: External Middle Column Removal on shorter edge (EMCRSS)

Fig. 8 shows the BMD of the building when subjected to EMCRSS. It can be observed that the bending moment has been increased with the removal of column as compared to the Fig 3. But the increase compared to the other two removal cases is very less.

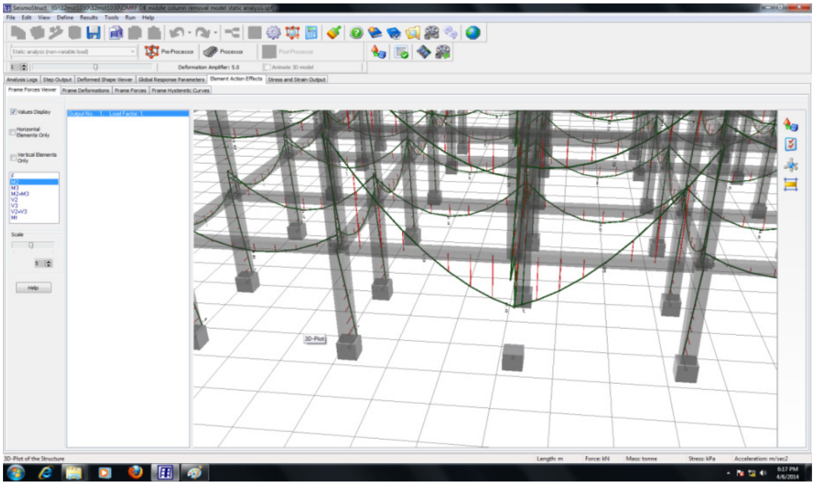

Fig. 8 BMD for case 3

Fig. 9 shows the deformed shape of the building. In this case the deformation is very less compared to other two cases. Neither the cracking of concrete nor the yielding of steel is observed.

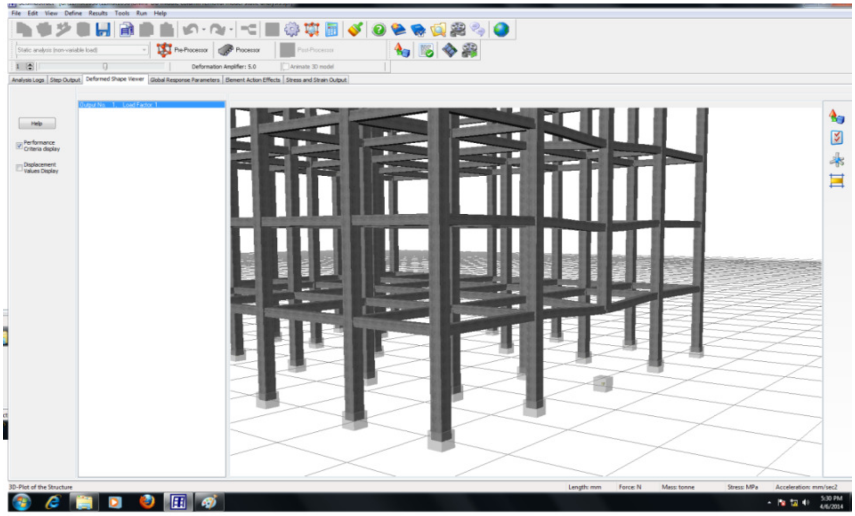

Fig. 9 OMRF

The displacements at the nodes where column removal was done are shown in Table.1 and bending moments in Table 2. EMCRLS was done at Node 116, ECCR was done at Node 281 and EMCRSS was done at node 283.

Table 1 Displacements at the nodes

Case no	Node116 (mm)	Node281 (mm)	Node283 (mm)
Standard	0.783	0.43	0.69
Case 1	0.788	43.52	0.70
Case 2	79.22	0.45	0.69
Case 3	0.78	0.44	44.26

Table 2 Bending moments at nodes

Case no	Node 116	Node281	Node283
Standard	23.17	22.67	23.14
Case 1	18.43	66.46	21.12
Case 2	91.98	29.08	23.84
Case 3	23.30	31.23	67.40

4. CONCLUSIONS

From the analysis it can be concluded that local damage due to accidental loads in an OMRF designed as per IS 456 will not lead to total collapse. External middle column on the longer edge is the critical column for the current structure and under this case may lead to failure which needs further investigation.

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