Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 6, June -2017

ASSESSMENT OF PROGRESSIVE COLLAPSE POTENTIAL IN REGULAR AND IRREGULAR RC STRUCTURES USING LINEAR STATIC ANALYSIS

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Abstract— *Now-a-days buildings became more vulnerable to the threat of terrorism, accidents, fire explosions, etc. Progressive collapse is that when a local structural load carrying member fails, the additional loads are transferred to neighboring structural members and it may leads to global failure due to overloading. This causes greater and disproportionate damage comparing to the initial impact. Assessing the probability of progressive collapse deserves attention concerning the safety of human life and resultant economic impact in the society. Through this project, the progressive collapse potential of a multistoried typical as well as an atypical buildings -C shape are evaluated using numerical methods of analysis. Linear static loading responses in the building subjected to various column removal scenarios were studied. United States General Services Administration (GSA 2003) guidelines have been used for the evaluation.*

Keywords *— Progressive Collapse, Linear analysis, Regular and Irregular structures, Static loading, ETABS 2015*

I. INTRODUCTION

The progressive collapse occurs when the structure gets changes in the loading patterns or boundary conditions and as such their intended capacities are exceeded beyond the limits. Thus the residual structure is forced to seek alternate load paths to redistribute the loads from the collapsed member. For example when a local load carrying element especially vertical load carrying member column due to either natural or manmade hazards, the gravity loads are transferred to the adjacent columns in the structure. If they are not capable to resist and redistribute the additional gravity loads, they also fail. This continues until the additional load is stabilized and this results in the collapse of a substantial part of the structure. Thus the initial impact may get magnified to a greater extend. Recently buildings and structures across the world have become more vulnerable to the threat of terrorism, accidents, explosions, earthquakes etc. Hence such a study is found relevant. As most buildings are reinforced concrete buildings, an assessment of progressive collapse in such a RC building was opted.

Progressive collapse generally occurs under the abnormal loads. Abnormal loads usually acts over a relatively short period of time in comparison with ordinary design loads. A normal building is not designed to resist these abnormal loads. Therefore when it is subjected to such type of loads, progressive collapse takes place. The potential abnormal loads that can trigger the progressive collapse are categorized as per follows:

1.1. Pressure Loads

- Internal gas explosions
- Blast
- Wind over pressure
- Extreme values of environmental loads

1.2. Impact Loads

- Aircraft impact
- Vehicular collision
- Earthquake
- Design and construction errors
- Overload due to occupant misuse
- Storage of hazardous materials

II. GUIDELINES

The United States General Service Administration (GSA 2003) has provided guidelines to assess the progressive collapse potential. The purposes of the guidelines are stated as follows [1]:

- Assist in the reduction of the potential for progressive collapse in new Federal Office Buildings
- Assist in the assessment of the potential for progressive collapse in existing Federal Office Buildings
- Assist in the development of potential upgrades to facilities if required

It provides the different positions of column removal, loading conditions as well as the acceptance criteria for different analysis methods.

2.1. Linear Static Analysis loading

For static analysis purpose, GSA recommends a general loading factor. The load case is given in equation (1)

$$\text{Load} = 2(DL + 0.25LL) \quad (1)$$

Where,
DL = Dead Load and LL = Live load

2.2 Acceptance Criteria

Acceptance criteria for the primary and secondary structural components shall be determined as Demand Capacity Ratio (DCR) as in equation (2)

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

Where,
Q_{UD} = Acting force (demand) determined in component or connection/joint (moment, axial force, shear, and possible combined forces) obtained from the linear elastic analysis.
Q_{CE} = Expected ultimate, un-factored capacity of the component and/or connection/joint (moment, axial force, shear and possible combined forces)
Permissible DCR values given by GSA are:

- DCR < 2.0 for typical structural configurations
- DCR < 1.5 for atypical structural configurations

DCR values that exceed the allowable values are considered to be severely damaged or collapsed. In the calculation of capacities of the components or connections, GSA guidelines allow to increase the design material strengths by strength-increase factors to determine the expected material strengths. Strength-increase factors given in the guidelines for both concrete and reinforcing steel are 1.25.

2.3. Step by step procedure of linear static analysis

Step 1: Prepare three dimensional model of structure and perform concrete design and determine the reinforcement to be provided in members.
Step 2: Based on the reinforcement provided, calculate the capacity of the member in flexure, “strength increase factor” is considered during progressive collapse.
Step 3: Load the model as per GSA load case. Column loss scenarios are created by removing ground floor column from the specified location one at a time as mentioned in GSA guidelines.
Step 4: Static linear analysis is performed and the demand for the specific column removal case are determined.
Step 5: Calculate the “demand to capacity ratio (DCR)” and evaluate the results as per the acceptance criteria provided in GSA guidelines.

III. METHODOLOGY

A G+9 storey typical and a C - shaped atypical reinforced concrete residential building of an importance factor 1 and response reduction factor 3 (IS code 1893-2002) was selected for performing progressive collapse analysis as per GSA guidelines. The structures were modelled using a commercially available computer program, ETABS 2015. Building size in plan is 25m x 20m. Bay size is taken as 5m in one direction (longitudinal direction) and 4m in other direction (transverse direction). Height of base to plinth is taken as 1.5m and plinth to ground floor as 3.4 m, which is not considered as a soft storey, walls are built on the plinth. Height of typical floor is 3.1m. The columns are assumed to be hinged to the foundations. The walls having 200 mm thickness are assumed on all the beams. Beam size is 200mm × 600mm, Column size is 500mm × 500mm and Slab thickness is 150mm and is considered as a membrane element. The concrete floors are modeled as rigid. Reinforced concrete design is carried out and area of steel is provided accordingly. Steel design for this building is governed by the earthquake load combination envelope. The materials used are Reinforced concrete with M-25 grade concrete for beams, M-40 grade concrete for columns and Fe-415 grade reinforcing steel. The Stress-Strain relationship used is as per I.S.456:2000.

3.1. Loading on the building

Both regular and irregular buildings are classified in zone V having soil type II according to the Indian Earthquake Code IS 1893 (2002). The corresponding loads applied, load cases and combinations given on the G+9 Storey building are:

3.1.1. Dead load

Self weight of the structural elements
Floor finish = 1.5 kN/m^2 and
Wall load on all beams is 11 kN/m

3.1.2. Live load

On roof 1.5 kN/m^2, and
On floors 3.0 kN/m^2

3.1.3. Load Cases and Load Combinations

(i) Following primary load cases are considered for design of building.

- Dead Load (DL)
- Live Load (LL)
- Floor Finish (FF)
- Wall Load (Wall)
- Earthquake Load along X direction (EQX)
- Earthquake Load along Y direction (EQY)

(ii) Along with the above cases, load combinations are considered for design of structural elements as per IS 1893:2002. All the structure elements are designed for envelopes of all the combinations.

3.2. Locations of Column Removal

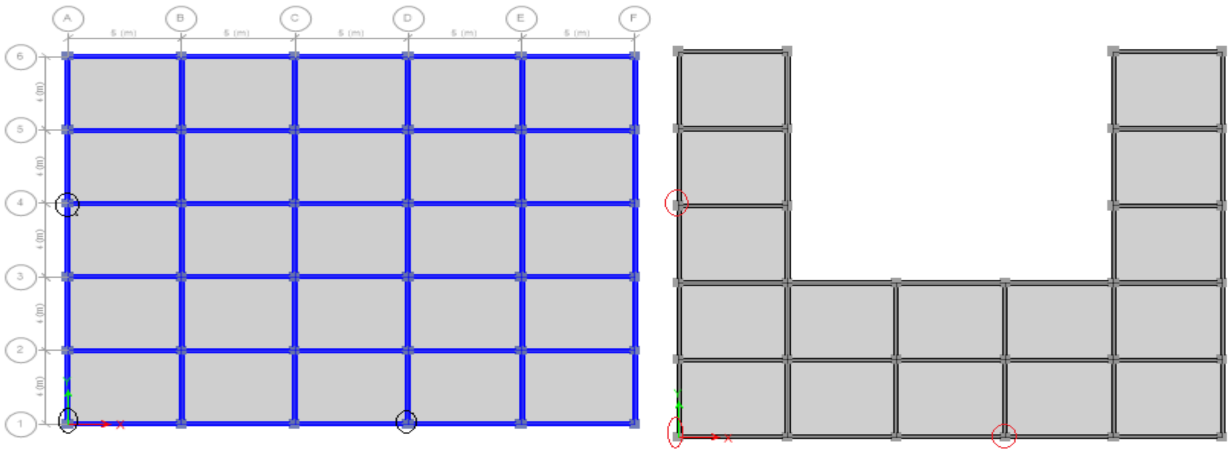


Fig.3.1. Column removal cases of typical and atypical structure-C shape

3.3. Three Dimensional Models Created

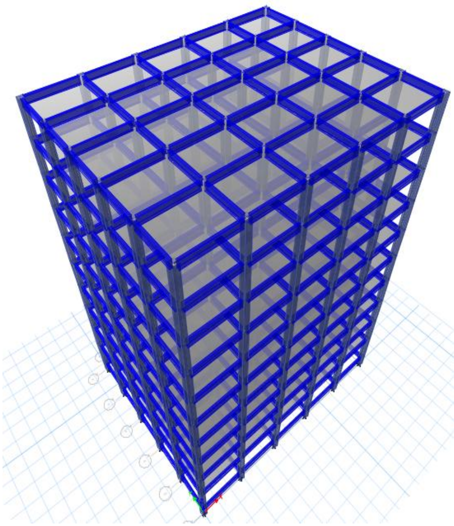


Fig.3.2. 3D model of typical building

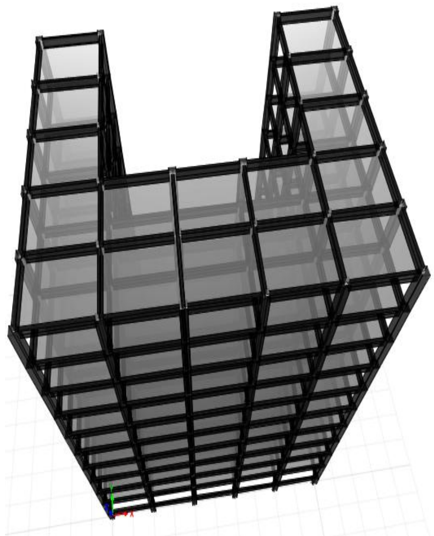


Fig.3.3. 3D model of atypical building

IV. RESULT AND DISCUSSION

To evaluate the potential for progressive collapse of a ten storey typical and atypical RC buildings using the linear static analysis, three column removal conditions is considered as per GSA guidelines - middle column removal of longer bay and shorter bay directions and corner column removal cases. DCR values of adjacent beams are calculated for flexure.

4.1. Results of typical building

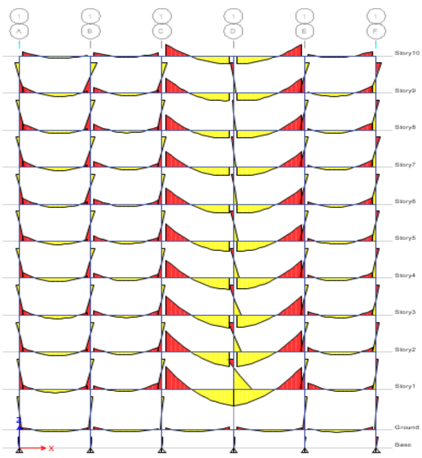
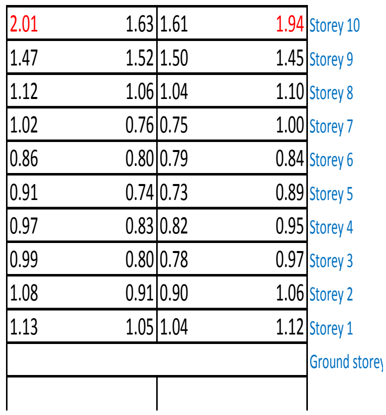


Fig.4.1. BMD for middle column removal in longer bay direction of typical building



2.01	1.63	1.61	1.94	Storey 10
1.47	1.52	1.50	1.45	Storey 9
1.12	1.06	1.04	1.10	Storey 8
1.02	0.76	0.75	1.00	Storey 7
0.86	0.80	0.79	0.84	Storey 6
0.91	0.74	0.73	0.89	Storey 5
0.97	0.83	0.82	0.95	Storey 4
0.99	0.80	0.78	0.97	Storey 3
1.08	0.91	0.90	1.06	Storey 2
1.13	1.05	1.04	1.12	Storey 1
				Ground storey

Fig.4.2. DCR value of the middle column removal in longer bay direction of typical building

DCR values were obtained maximum at top floors. This is because the beams at the top most level are having least amount of reinforcement. Therefore the capacity of beams at top level is substantially less compared to beams at ground floor level from where the column is being removed.
Similarly DCR values for middle column removal case of shorter bay direction and corner column removal were evaluated. The results are plotted in figure 4.3 and figure 4.4.

1.85	1.69	1.72	1.81	Storey 10
1.37	1.46	1.50	1.38	Storey 9
0.90	1.00	1.03	0.91	Storey 8
0.82	0.83	0.85	0.82	Storey 7
0.73	0.78	0.79	0.73	Storey 6
0.79	0.75	0.76	0.79	Storey 5
0.87	0.85	0.86	0.87	Storey 4
0.97	0.98	0.98	0.96	Storey 3
1.10	1.06	1.05	1.09	Storey 2
1.04	1.31	1.31	1.04	Storey 1
				Ground storey

Fig.4.3. DCR value for the middle column removal in shorter bay direction of typical building

1.74	1.95	1.29	1.17	Storey 10
1.21	1.69	1.13	0.92	Storey 9
0.88	1.29	0.97	0.73	Storey 8
0.77	0.90	0.67	0.69	Storey 7
0.77	0.74	0.56	0.68	Storey 6
0.80	0.73	0.51	0.70	Storey 5
0.85	0.83	0.57	0.74	Storey 4
0.93	0.85	0.56	0.79	Storey 3
1.06	1.02	0.68	0.87	Storey 2
1.06	1.00	0.64	0.88	Storey 1
				Ground storey

Fig.4.4. DCR value of the corner column removal of typical building

4.2. Results of atypical building

1.52	1.81	1.79	1.47	Storey 10
1.17	1.11	1.10	1.15	Storey 9
0.95	0.81	0.80	0.93	Storey 8
0.88	0.68	0.67	0.87	Storey 7
0.87	0.65	0.64	0.85	Storey 6
0.88	0.66	0.65	0.87	Storey 5
0.92	0.70	0.69	0.91	Storey 4
0.98	0.78	0.77	0.97	Storey 3
1.07	0.88	0.87	1.06	Storey 2
1.11	1.00	0.99	1.10	Storey 1
				Ground storey

Fig.4.5. DCR value of the middle column removal in longer bay direction of atypical building

1.45	1.96	2.04	1.56	Storey 10
1.09	1.13	1.20	1.14	Storey 9
0.84	0.81	0.85	0.88	Storey 8
0.74	0.69	0.73	0.78	Storey 7
0.74	0.67	0.70	0.78	Storey 6
0.77	0.69	0.72	0.81	Storey 5
0.84	0.76	0.79	0.87	Storey 4
0.92	0.87	0.90	0.96	Storey 3
1.05	1.01	1.04	1.08	Storey 2
1.13	1.25	1.27	1.15	Storey 1
				Ground storey

Fig.4.6. DCR value of the middle column removal in shorter bay direction of atypical building

1.61	1.78	1.00	1.16	Storey 10
1.15	1.33	0.67	0.93	Storey 9
0.86	0.86	0.49	0.75	Storey 8
0.77	0.73	0.43	0.71	Storey 7
0.77	0.69	0.42	0.70	Storey 6
0.80	0.71	0.44	0.72	Storey 5
0.87	0.77	0.48	0.76	Storey 4
0.95	0.85	0.54	0.82	Storey 3
1.09	1.01	0.65	0.90	Storey 2
1.10	0.95	0.59	0.91	Storey 1
				Ground storey

Fig.4.7. DCR value of the corner column removal of atypical building

DCR values are critical at top floors and gone beyond the limit of 1.5 (for atypical structures) at top floor in all the three cases of atypical building.

V. CONCLUSIONS

Based on the limited study of progressive collapse in a typical and atypical structures, following conclusions can be drawn:

- DCR values are found out for beams. It is observed that DCR in flexure in beam exceeds permissible limit of 1.5 in all column removal cases for atypical structure but the severity varies from each column removal cases.
- Thus linear static analysis reveals that irregular structures are more vulnerable to progressive collapse comparing to regular structures.
- DCR values directly depends the BM and thereby quantity of steel. Hence adequate reinforcement is required to limit the DCR within the acceptance criteria.
- Increasing beam size will be effective in avoiding or delaying progressive collapse.
- Also seismically designed buildings possess inherent ability to resist progressive collapse as the DCR values doesn't gone much worse.

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