iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: V Month of publication: May 2021

DOI: https://doi.org/10.22214/ijraset.2021.34421

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue V May 2021- Available at www.ijraset.com

Comparative Study of High-Rise Residential Building for Progressive Collapse as per Indian & American Code

Anurag Jamankar[1], Prof. Atul B. Pujari[2]
[1, 2]ME Structure, KJCOMER, Pune, Savitribai Phule Pune University.

Abstract: The progressive collapse is the condition where the collapse of one or few structural members occurs which tends to collapse of other members and then progresses to partial or whole collapse of structure. Progressive collapse RCC structure G+20 building is analyzes using the General Service Administration (GSA-2016) guidelines. To use linear statics analysis method as per GSA (2016) guidelines for the axial force, bending moment, shear force, joint displacement of member and also to check on the basis of ETABS G+20 building software. Design of the buildings is performed using ETABS 2018 for three different threat-independent column removal conditions. To check performance of structure at all load combination in linear static and nonlinear static analysis Performed along with two different codal provisions. And then also checked performance for Demand Capacity Ratio as per GSA (2016) guidelines. From the result it is conclude that the parameters given in ASCE codes are taken by considering many structural failures which include progressive collapse as well. Also, ASCE codes are clearer and well explained about progressive collapse. Hence if observed the results, structure analyzed with ASCE code seems more stable and susceptible to progressive collapse.
Keywords: Progressive Collapse, RCC frame structure, IS code, ASCE-07, Linear Static Analysis, Nonlinear static analysis, GSA 2016, ETABS 2018.

I. INTRODUCTION

Progressive collapse was appeared not so a long time ago. For the first time engineers faced with this phenomenon in 1968 when the Ronan Point apartment building was destroyed. A gas explosion in a corner on the 18thfloor blew out the exterior wall panel and failure of the corner bay of the building spread upward to the roof structure and down till the ground level, but the entire building did not suffer. progressive collapse has been used to describe the propagate of an initial local failure in a manner like a chain reaction that causes to partial or total collapse of the structure. The basic characteristic of the progressive collapse that the end state of the destructions is disproportionately greater than the failure that made the collapse. Catastrophic failures of structures, due to progressive failure, have occurred, therefore highlighting the need to design against such events. Extensive research has been conducted into steel structures; however, the response of existing RCC frame structure located in to accidental or malicious events is not fully understood while its design. Residential building are prone to have any accidental event like bursting of gas cylinder, removal of key structural element for internal renovation, therefore many structures may be at risk of progressive collapse. These structural forms have alternative load paths which can protect such structures after the loss of a key element, but the capacity of these can be difficult to assess due to the nonlinear material and geometric factors. Additionally, the sudden removal of a structural element is a dynamic event, and so such factors must be included to obtain accurate indication into the response. Study of structural response leads to decide the preventive measures for the progressive collapse.

Fig 1 collapse of a part of the Ronan Point apartment

Fig 2 Plasco Building Progressive Collapse

Fig 3 Sikkim Earthquake Caused Collapse of Government Building

To decrease probability of progressive collapse of reinforcing structural member's particular attention should be paid to the reliability of the anchorage reinforcement, especially at the intersection of structural elements. The incorporation of redundant load paths in the vertical load carrying system helps to ensure that alternate load paths are available in the event of local failure of structural elements. The ability of a structure to re-distribute or transfer loads along these load paths is based in large part on the interconnectivity between adjacent members. This is often called "tying a building together" by using an integrated system of ties in three directions along the principal lines of structural framing. In a catastrophic event, members and their connections may have to maintain their strength through large deformations and load redistributions associated with the loss of key structural elements.

II. LITERATURE REVIEW

In the light of the state-of-art and the practice in analysis of progressive collapse of RCC structure, it is essential to review the past contributions made in analysis. Presented herein are the research accomplishments in the realm of (1) behaviour of building under loss of structural element, in general; (2) Progressive collapse mechanism; (3) Analytical studies of forces in elements; (4) prevention techniques for progressive collapse.

Pearson, C., and Delatte, N. (2005), The resulting gas explosion in 22-story Ronan point apartment tower, in London initiated a partial collapse of the structure that killed four people and injured 17 (one of whom subsequently died). On investigation, the apartment tower was found to be deeply flawed in both design and construction. The apartment tower lacked alternate load paths to redistribute forces in the event of a partial collapse. When the structure was dismantled, investigators found appallingly poor workmanship at the critical connections between the panels.

R. Shankar Nair, The twin towers of World Trade Center1 and 2 collapsed on Sept. 11, 2001. Boeing767 jetliner crashed and the structure above collapsed, having lost its support; the weight and impact of the collapsing upper part of the tower caused a progression of failures extending downward all the way to the ground.

Michael Bayfield. et al (2013), this paper provides a basic understanding of the buildings progressive collapse and case studies of various progressive collapse. It also gives a detail investigation of the collapse cause due to explosion of the gas cylinder which leaded the first progressive collapse of Ronan tower in 1968.

Denis Mitchell, et al (1983) the response of slab structures after initial failure is investigated inorder to determine a means of preventing progressive collapse. Analytical models for predicting the post-failure response of slabs are presented and the predictions are compared with experimental results.

A.R. Rahai, M. Banazadeh, M.R. Seify Asghshahr & H. Kazem [1] presented study addresses progressive collapse in RC structures resulting from both instantaneous and gradual removal of columns. Vertical displacement in the upper node of the removed column, redistribution of forces after removing the column, plastic deformations in adjoining elements, and the stress imposed on the sections of the beams adjacent to the removed column in both instantaneous and gradual cases are studied.

Mrs. Mir Sana Fatema, and Prof. A.A. Hamane the purpose study as the shear capacity of beams is high none of the beam in any column removal case is going to fails in shear, i.e. shear in beam is not critical in progressive collapse.

III.OBJECTIVE

1) To study response of RCC structure which are designed for all load combination against progressive collapse.
2) For this structure is considered on different Code Parameters.
3) To study consider G+20 storey RCC structure analysis, this structure for all types of load combination.
4) To calculate the progressive collapse potential of a G+20 storey building as per GSA (2016) Guidelines. Linear static and linear dynamic (response spectrum analysis) analysis has been done.
5) Using GSA 2016 guidelines again analyzing the structure.
6) To check performance of structure, use the D.C.R, axial force shear force and bending moment are considered. .
7) Also, check the structural performance of high rise structure designed based on different codes.

IV.MODELING

To calculate the progressive collapse potential of a 20-storey building as per GSA (2016) Guidelines. In this problem, 3-dimensional finite element models of 20-storey building in zone V were analyzed for three different cases along with IS code and American code parameters. Both linear static and linear dynamic methods of analysis have been used following IS: 1893 (Part l)-2002, and ASCE-07-08. The seismic analysis of all the frame models for various load combinations according to codes has been done by using software ETABS 2018.

Modelling of Building The building for the study is 20 storey symmetrical R.C. building. The structure consists of four bays of 8 m in the longitudinal X-direction and four bays of 8 m in the transverse Y-direction. Typical floor-to-floor height is 3.2m.

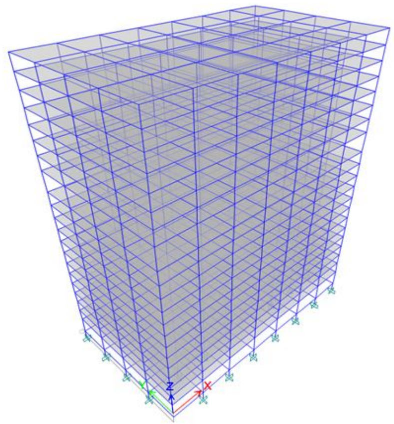

Fig 4 3D Model ETABS 2018

V. RESULTS AND DISCUSSION

1) In Case -I column is removed from the mid span of building and hence the redistribution of forces occurred. From ASCE and IS code values of redistributed forces not much differ from each other because of equivalent parameters considered. Values of DCR differs in both the structural models. Additional bending moment is induced in column and due to which redistribution occurred. Due to continuous behavior shear and moment transferred to adjacent column and load on column is increased due to which at that particular junction plastic hinges are formed.
2) In Case-II column from the corner of structure is removed due to which drastic changes in building behavior has been observed. Due to removal of corner column total building got tilted in one direction and torsion induced in the structure. The whole building failed as the corner column removed because there was not any alternate path to distribute those excessive forces occurred in the elements or structure, hence adjacent columns to corner columns failed continuously and few of them failed at the same time. Hence, Case II can be the most critical case among the other two.
3) In Case-III columns at the initial storeys removed and modeled after few storeys by resting on the beams. In this case column is acted as a gravity column which is resting on the beam and due to which excessive load at the center of beam is induced. At initial stages of analysis plastic hinges formed in beam and later on in column supporting those beams. As the structure is all about load path and load distribution for stable behavior, it can be seen that the DCR values were higher than that of the first case but were less than second case.

To sustain in such case there is one remedial measure which can be follow by providing higher beam size to the beam supporting gravity column. Due to such application beam can sustain excessive load occurring on it and also sagging moment can be reduced. In all the cases reinforcement in the elements can be increased drastically and it will not be economical. Hence providing better beam column connection by giving enough development length or anchorage length such failure can be avoided.

A. DCR Values

1) *Case I:* Removing Column Support at midspan of beam

TABLE I
DCR values and Displacement (IS code) Case I

Floor Level	DCR value	Displacement (mm)
Ground Storey	1.57	49.05
5th Storey	1.5	96.92
10th Storey	1.389	100.691
15th Storey	1.15	104.75
20th Storey	1.18	127.6

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TABLE III
DCR values and Displacement (ASCE code) Case I

Floor Level	DCR value	Displacement (mm)
Ground Storey	1.746	57.63
5th Storey	1.965	85.75
10th Storey	1.645	90.46
15th Storey	1.356	100.65
20th Storey	1.246	104.74

2) *Case II:* Removing column located at corner of building

TABLE IIIII
DCR values and Displacement (IS code) Case II

Floor Level	DCR value	Displacement (mm)
Ground Storey	1.983	89.37
5th Storey	3.982	100.67
10th Storey	2.796	115.29
15th Storey	2.574	126.37
20th Storey	2.425	134.98

TABLE IVV
DCR values and Displacement (ASCE code) Case II

Floor Level	DCR value	Displacement (mm)
Ground Storey	2.124	105.63
5th Storey	4.265	117.26
10th Storey	3.874	128.3
15th Storey	3.174	149.3
20th Storey	2.854	169.47

3) *Case III:* Column Resting on Beam

TABLE V
DCR values and Displacement (IS code) Case III

Floor Level	DCR value	Displacement (mm)
Ground Storey	1.43	74.64
5th Storey	1.865	84.87
10th Storey	1.985	91.64
15th Storey	2.148	98.09
20th Storey	2.354	108.65

TABLE VI
DCR values and Displacement (ASCE code) Case III

Floor Level	DCR value	Displacement (mm)
Ground Storey	1.64	88.26
5th Storey	1.71	92.755
10th Storey	1.89	104.63
15th Storey	2.044	114.74
20th Storey	2.157	128.5

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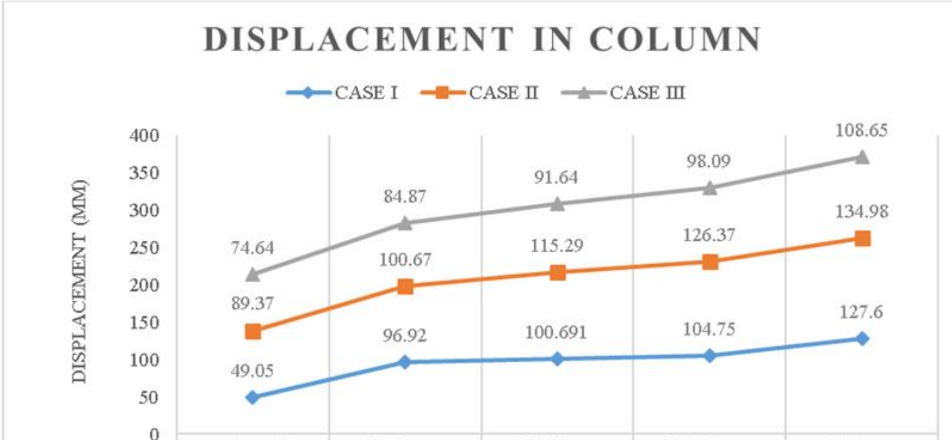
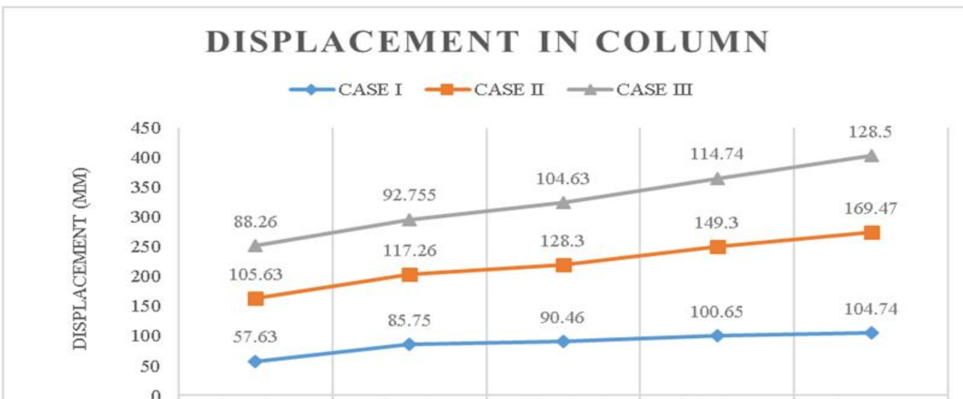
B. Column Displacement



	Ground	5th Storey	10th Storey	15th Storey	20th Storey
CASE III	74.64	84.87	91.64	98.09	108.65
CASE II	89.37	100.67	115.29	126.37	134.98
CASE I	49.05	96.92	100.691	104.75	127.6

Fig 5. Displacement values in Column (IS Code)



	Ground	5th Storey	10th Storey	15th Storey	20th Storey
CASE III	88.26	92.755	104.63	114.74	128.5
CASE II	105.63	117.26	128.3	149.3	169.47
CASE I	57.63	85.75	90.46	100.65	104.74

Fig 6. Displacement values in Column (ASCE Code)

Displacement chart shows the values of column joint displacement in various cases in both codal provisions. The parameters of both the codes were almost same except the fundamental timed period in case of earthquake. In IS code-based displacement values as the height of structure increased displacement got increased. If observed carefully both the charts it is observed that the case-II caused maximum displacement in column joint. Hence it can be also said that removal of column at the corner of structure may cause maximum damage to the structure. Discontinuity of column also breaks the load path distribution in the structure. In such cases alternative path method shall be applied

From above charts, it is observed that the Case-II i.e. removal of corner column of building shows maximum displacement compared to other two. But DCR values in such cases also can be increased and reasons are many for such case. One of the most important reasons for progressive collapse is the strong beam and weak column. Column is the member which supposed to support beams and beams supposed to support slab. But if beam provided is stronger than the column then there is definite failure of structure. Also, Load distribution path completely changes when discontinuity in any structural member is breaks

Demand Capacity Ratio (DCR) is the ratio of Member force to the Member strength.

According to the GSA guideline a typical frame building having DCR values greater than 1.5 indicate that the portion is severely damaged and have more damage potential.

VI. CONCLUSIONS

On the basis of present study and reviewed literature the following conclusions can be drawn:

A. After removal of particular column there is decreased in Axial and Banding moments of respective column.
B. Bending Moments for adjacent beams goes on increased and lead to failure (after Removal of column). From the analysis most critical column
C. The DCR values obtained for edge and central column exceeds the limit as per GSA guidelines, so the structure may fail for this load. It can be prevented by using larger steel sections or by increasing bracings.
D. From Comparing the Bending Moment and shear force for intact structure and all the three cases it has been concluded that in case 2 the bending moment and shear has been increased more (i.e., when the corner column is removed BM and SF increase more compared to other cases).
E. From GSA linear static analysis, higher behaviour factors resulted in lower resistance to progressive collapse for all the models in all column removal cases.
F. Joint displacement is more affected at the removal of internal and corner column.
G. Increase in beam size leads to strong beam weak column which causes progressive collapse.
H. Plastic hinges are generated from lower story to higher story with an increase of incremental vertical loadings.
I. Ground level column loss activate the damage above the column removal and don’t propagate to its neighboring spans.
J. Structures should be redesigned by plastic design method to prevent progressive collapse and to turned out to satisfy the given failure criterion in most of the model structures.
K. In building with ASCE parameters, behavior of building is more flexible and ductile compare to building with IS parameters. Also, from observation modal mass participation maximum in first three modes in building analyzed with ASCE code.
L. From the result it is conclude that the parameters given in ASCE codes are taken by considering many structural failures which include progressive collapse as well. Also, ASCE codes are clearer and well explained about progressive collapse. Hence if observed the results, structure analyzed with ASCE code seems more stable and susceptible to progressive collapse.

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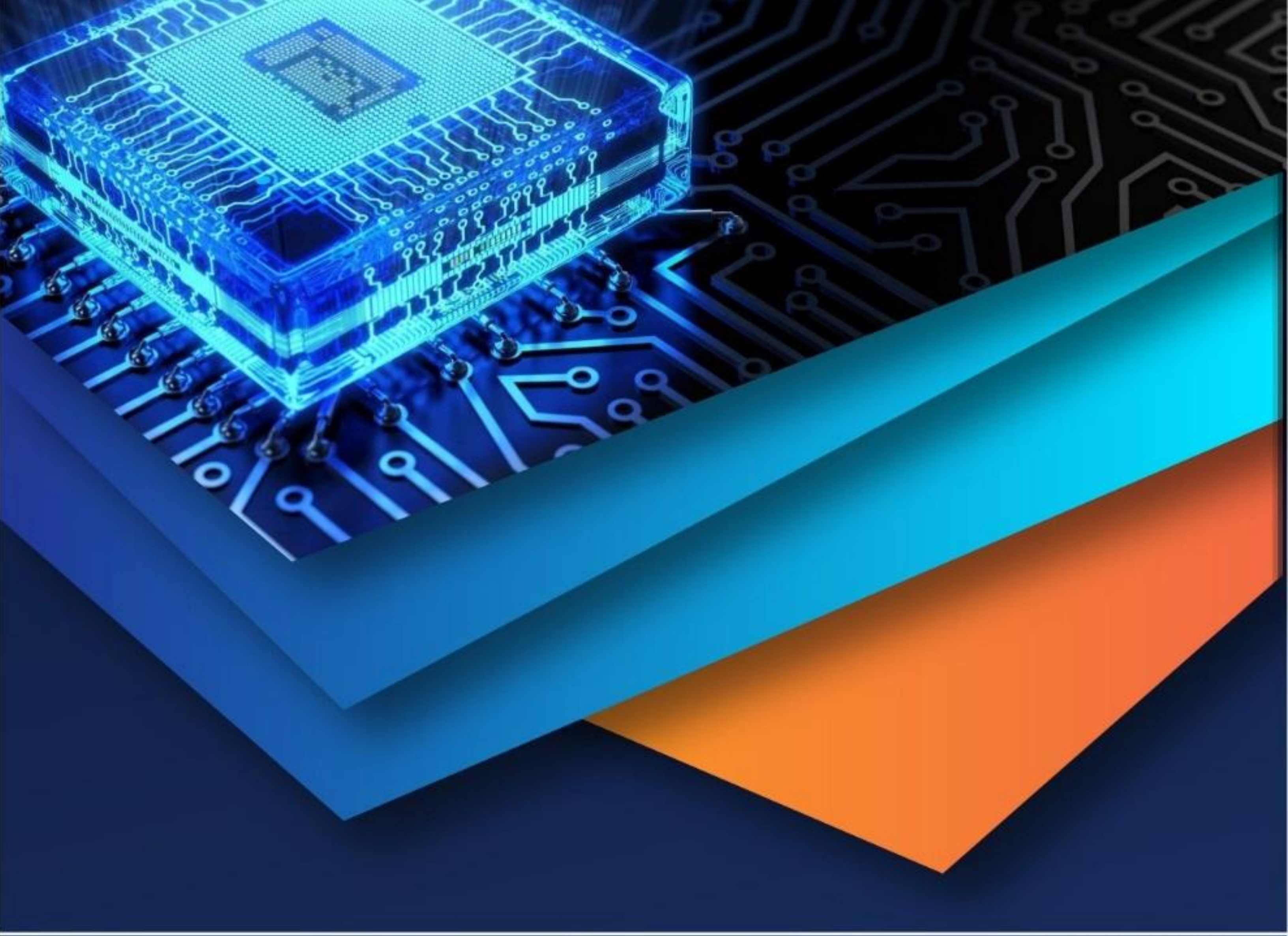

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