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PROGRESSIVE COLLAPSE ANALYSIS OF REINFORCED CONCRETE FRAMED STRUCTURE

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ABSTRACT

The progressive collapse of reinforced concrete structures is initiated when one or more vertical load carrying members are removed due to man-made or natural hazards. The building's weight transfers to neighbouring columns in the structure, leads to the failure of adjoining members and finally to the failure of partial or whole structure system. In which the collapsing system continually seeks alternative load paths in order to survive.

The present study addresses progressive collapse in RC structures resulting from instantaneous removal of columns. To study the collapse, typical columns are removed one at a time, and continued with analysis and design. A ten storey reinforced concrete framed structure was considered in the study as per General Services Administration (GSA) guidelines. Four different types of frames, one regular RC frame building (R.F) and three regular RC framed buildings with column removed (R.F.W.C.R) at different positions has been modeled and linear static analysis is carried out using software, ETABS. The structural behavior of the building for progressive collapse is analysed. The parametric studies comprise of DCR values of columns and beams, Support reactions of columns for seismic zones II, III, IV and V. The goal of this project was to provide data that would give insight in ways to help prevent progressive collapse from occurring in reinforced concrete structures.

Keywords: Progressive collapse, Seismic Zones II, III, IV and V, DCR values, reinforced concrete framed structure Column, Beam,Support reactions.

I. INTRODUCTION

The term 'progressive collapse' can be simply defined as the ultimate failure or proportionately large failure of a portion of a structure due to the spread of a local failure from element to element throughout the structure. Progressive collapse can be triggered by manmade, natural, intentional, or unintentional causes. Fires, explosions, earthquakes, or anything else causing large amounts of stress and the failure of a structure's support elements can lead to a progressive collapse failure. Progressive collapse is a complicated dynamic process where the collapsing system redistributes the loads in order to prevent the loss of critical structural members. For this reason beams, columns, and frame connections must be designed in a way to handle the potential redistribution of large loads. Some of the more famous examples of progressive collapse phenomena include the collapse of the World Trade Center towers due to terrorist attack, The bombing of the Murrah Federal Building in Oklahoma City, and the collapse of the Ronan Point building due to a gas explosion. Though research being

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done, such as that in this study, progressive collapse failures can be better prepared for and possibly prevented in the future.

II. OBJECTIVES OF THE STUDY:

- The main objective of this project is to find critical columns and beams in building which causes maximum damage or collapse after the removal.
- Four different types of frames, Regular RC frame building (R.F) and three Regular RC frames with column removed (R.F.W.C.R) at different positions are considered.
- DCR values of columns and beams and Support reactions of columns are the main factors considered for study.

III. SCOPE OF STUDY

- This study is restricted to ten storey building with plan dimensions 20x 16m.
- Only linear static analysis is performed using ETABS.
- The column and beam sizes are maintained uniform for the frame.
- The beam and column are modeled with member element and the base of the structure is considered as fixed.

IV. PROGRESSIVE COLLAPSE ANALYSIS PROCEDURES:

Different classifications of design strategies exist as well the first contributions to the subject identified three basic design methods for progressive collapse prevention.

a) Event control
b) Indirect design
c) Direct design

a) EVENT CONTROL:

protection against incidents that might cause progressive collapse.

b) INDIRECT DESIGN:

The ‘indirect design’ approach is included by many international standards such as the GSA [1], the DoD. However, it fails to give specific guidance for the collapse-resistant design of structures. For instance, the GSArecommends the following list of general features, as a ‘supplementary guidance’ that must be considered in the initial phases of structural design, prior to the structural analysis, in order to ‘provide for a much more robust structure and increase the probability of achieving a low potential for progressive collapse’ for reinforced concrete structures.

c) DIRECT DESIGN:

Considering resistance against progressive collapse and the ability to absorb damage as a part of the design process. The ‘specific local’ resistance method and the ‘alternate path method’ have been identified as the two basic approaches to direct design. Slightly different categorizations have been proposed since.

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Direct Design: 'Alternate Load Path'

More specifically, the 'alternate load path' (ALP) method is adopted. Most of the current literature on progressive collapse is based on this technique. The ALP method consists in considering stress redistributions through Progressive collapse analysis procedures out the structure following the loss of a vertical support element. The structure is bound to find alternative paths for the forces initially carried by the failing elements. It is thus a threat-independent approach to progressive collapse. Different strategies are suggested for linear static, non-linear static and non-linear dynamic analyses. The vertical load combinations to be applied to the structure under study are:

GSA = DL + 0.25 LL

DoD = (0.9 or 1.2) DL + (0.5 LL or 0.2 SL) where

DL = Dead loads (i.e. permanent loads);

LL = Live loads (variable loads);

SL = Snow loads.

These loads are multiplied by a 'dynamic factor' of 2 in the static analyses in order to implicitly and crudely take into account the dynamic effects.

V. METHODOLOGY:

The present objective of this work is to study the behaviour of conventional RC framed building subjected to column loss. The parametric studies comprise of DCR values of beams and columns, Support reactions of columns for all seismic zones in India. For these cases, models has been created for conventional RC framed building with column removed at different positions in three models, analyzed with ETABS for seismic zones II, III, IV and V.

<u>All the properties of Building are mentioned below</u>:

Size of Beam in all Direction: 300*450 mm,Size of column: 400*450 mm, Thickness of Slab: 120 mm, Live Load:2.5 KN/m^2,Floor Finish: 2 KN/m^2,Importance Factor: 1,ResponseReduction Factor: 5,Type of soil: medium.

5.1 MATERIAL PROPERTIES

- The material used for analysis is Reinforced concrete with M-30 grade concrete and Fe-415 grade reinforcing steel.
- The Stress-Strain relationship used is as per IS 456:2000. The basic material properties used are as follows:

Modulus of Elasticity of steel, Es = 20,0000MPa,Ultimate strain in bending, $\sum_{cu}$ =0.0035, Characteristic strength of concrete fck = 20MPa,Yield stress for steel, fy = 415 MPa.

5.2 FUNCTION AND LOADING

The frames are analysed for gravity loads and seismic loads. . Live load on the frames is considered as 2kN/m^2. The frames are analysed for a load combination of (2DL + 0.5LL).

In this study, the structure was assumed to function as a Residential building, subjected to designed loads in accordance with IS: 875-1987 for dead and imposed loads. Seismic loadings and load combinations were considered in accordance with IS: 1893 (Part1):2002.

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Each frame is analysed for the following four cases:

i. Regular Frame or R.F
ii. Regular Frame With Removed Column(C1) in ground storey or R.F.W.C.R(C1)
iii. Regular Frame With Removed Column(C11) in ground storey or R.F.W.C.R(C11)
iv. Regular Frame With Removed Column(C13) in ground storey or R.F.W.C.R(C13)

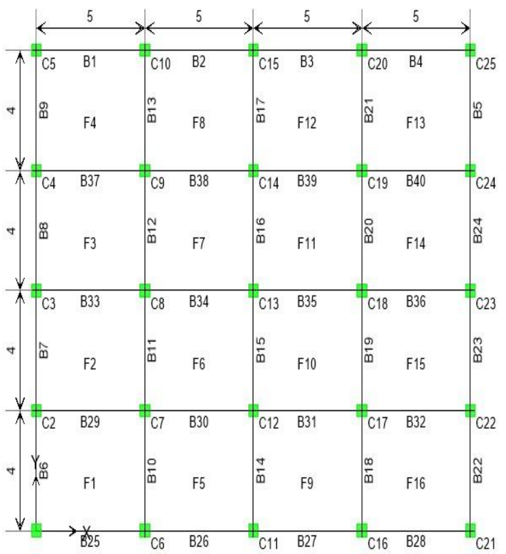

Fig. 1.1 Plan of considered regular frame (R.F) (units in 'm')

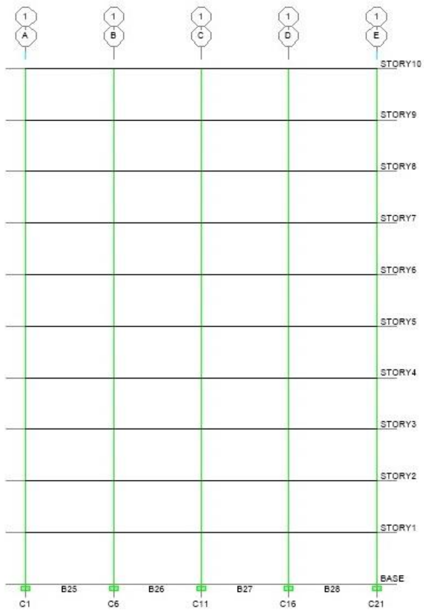

Fig.1.2 Elevation of considered Regular frame (R.F)

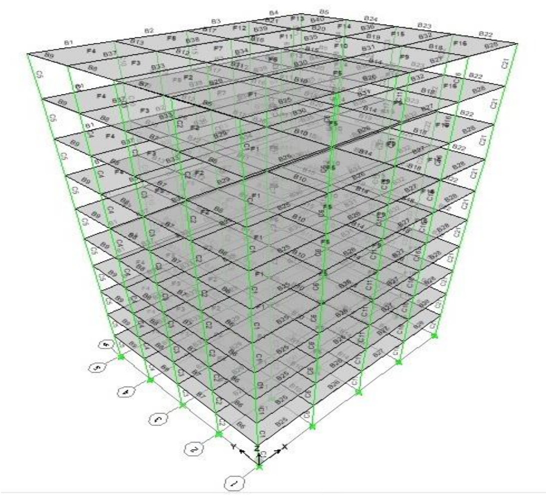

Fig.1.3 3-D of considered Regular Frame (R.F)

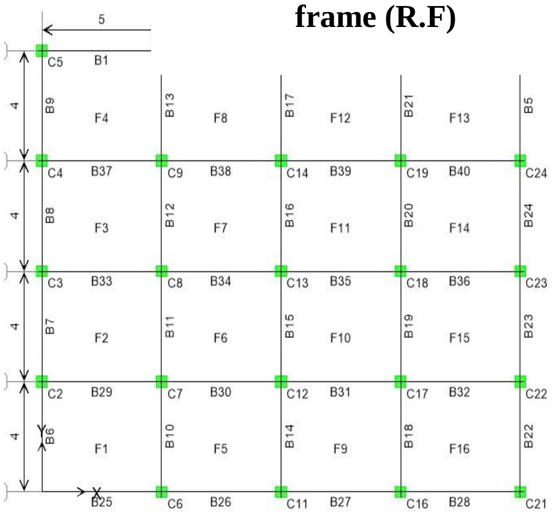

Fig. 1.4 Plan of considered R.C frame with column (C1) removed in ground storey

(units in 'm')

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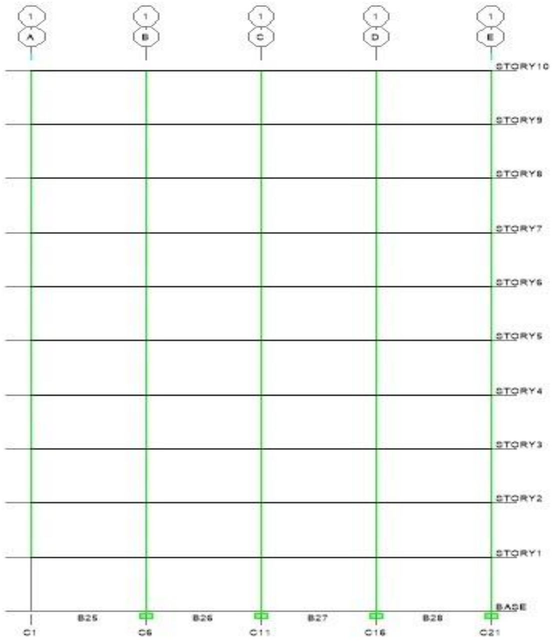

Fig.1.5 Elevation of considered Regular frame (R.F)

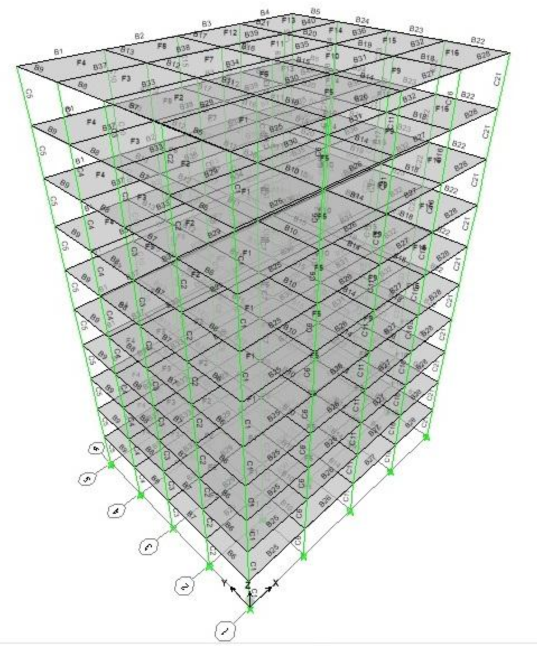

Fig.1.6 3-D of considered RegularFrame (R.F)

VI. RESULTS

6.1 COLUMN DCR VALUES: For Seismic Zone-II:

Column No.	R.F.W.C.R (C1)	R.F.W.C.R (C11)	R.F.W.C.R (C13)
C1	Removed	0.78	1.00
C2	6.21	1.25	1.00
C3	1.33	1.25	1.00
C4	1.42	1.25	1.00
C5	1.36	1.22	1.00
C6	0.85	0.92	1.00
C7	1.35	1.27	1.02
C8	1.29	1.21	1.16
C9	1.26	1.19	1.03
C10	1.26	1.19	1.00
C11	0.80	Removed	0.96
C12	1.21	5.11	4.00
C13	1.21	1.13	Removed
C14	1.21	1.20	4.07
C15	1.21	1.20	0.96

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C16	0.86	0.93	1.00
C17	1.13	1.24	1.02
C18	1.14	1.18	1.16
C19	1.14	1.18	1.05
C20	1.14	1.19	1.00
C21	0.91	0.80	1.00
C22	1.07	1.21	1.00
C23	1.06	1.21	1.00
C24	1.05	1.20	1.00
C25	1.07	1.19	1.00

6.2 BEAM DCR VALUES

For Seismic Zone- II:

BEAM NO.	R.F.W.C.R (C1)	R.F.W.C.R (C11)	R.F.W.C.R (C13)
B1	1.10	1.00	1.00
B2	1.09	1.00	1.00
B3	1.12	1.00	1.00
B4	1.09	1.00	1.00
B5	0.87	0.76	1.00
B6	7.83	0.80	1.00
B7	0.56	0.80	1.00
B8	0.68	0.80	1.00
B9	0.64	0.78	1.00
B10	0.73	0.81	1.00
B11	0.68	0.76	0.96
B12	0.68	0.76	1.03
B13	0.64	0.73	1.00
B14	0.74	8.63	1.32
B15	0.74	1.67	7.10
B16	0.74	0.76	7.08
B17	0.72	0.73	0.90
B18	0.80	0.79	1.00

B19	0.80	0.75	0.96
B20	0.80	0.75	1.03
B21	0.78	0.72	1.00
B22	0.88	0.78	1.00
B23	0.88	0.78	1.00
B24	0.88	0.78	1.00
B25	2.56	0.98	1.00
B26	1.11	3.06	1.00
B27	1.03	2.49	1.00
B28	1.03	1.08	1.00
B29	1.02	1.01	1.00
B30	1.05	1.03	1.02
B31	1.05	0.98	0.98
B32	1.05	1.01	1.00
B33	1.07	1.00	0.98
B34	1.07	1.00	2.62
B35	1.07	1.00	2.01
B36	1.07	1.00	1.06
B37	1.09	1.00	1.00
B38	1.08	1.00	1.02
B39	1.08	1.00	0.98
B40	1.08	1.00	1.00

6.3 SUPPORT REACTIONS

Support reaction is the force exerted by support on the imposed force. Support reactions of the all frames are tabulated for seismic zone-II:

For Seismic Zone-II:

Column No.	Regular Frame	R.F.W.C.R (C1)	R.F.W.C.R (C11)	R.F.W.C.R (C13)
C1	1544.556	Removed	1424.762	1380.692
C2	1661.465	2691.811	1661.393	1660.565

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C3	1670.159	1706.886	1670.226	1669.412
C4	1657.591	1691.978	1658.339	1659.356
C5	1088.879	1056.005	1208.23	1252.837
C6	2037.139	2643.805	2399.755	1874.394
C7	1963.295	2014.45	2006.2	1991.705
C8	1963.694	1965.729	1965.37	2274.518
C9	1958.83	1958.133	1959.696	1990.108
C10	1577.908	1515.877	1697.275	1743.021
C11	2044.846	2092.765	Removed	1885.406
C12	1966.883	1968.277	2812.664	2562.745
C13	1966.678	1966.754	1972.839	Removed
C14	1953.314	1952.686	1954.094	2552.33
C15	1386.46	1338.056	1505.625	1554.504
C16	2036.922	2071.513	2399.908	1874.546
C17	1963.298	1963.702	2006.206	1991.71
C18	1963.556	1963.494	1965.232	2274.38
C19	1949.727	1949.189	1950.59	1981.002
C20	1378.751	1343.972	1497.748	1543.496
C21	1544.358	1552.642	1424.898	1380.827
C22	1661.584	1641.61	1661.314	1660.487
C23	1670.138	1642.302	1670.205	1669.39
C24	1656.993	1621.296	1657.939	1658.956
C25	1085.546	1021.588	1204.563	1249.171

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VII. CONCLUSIONS

[1.] When column C1 was removed, Support reactions of adjacent column C2 is increased by 55%, 56%, 58%, 62% in Zone II, Zone III, Zone IV and Zone V respectively and column C6 is increased by 29% in all zones.

[2.] When column C11 was removed, Support reactions of adjacent column C12 is increased by 43%, 43%, 45%, 46% in Zone II, Zone III, Zone IV and Zone V respectively and column C6 and C16 were increased nearly by 28% in all zones.

[3.] When column C13 was removed, Support reactions of adjacent column C8 and C18were increased nearly by 15% and column C12 and C14 were increased by 30% in all zones.

[4.] For removed column C1, DCR value of column C2 exceeds the permissible limit.

[5.] For C11 column removed, DCR of column C12 exceeds the permissible limit.

[6.] For C13 column removed, DCR of columns C12 and C14 exceeds the permissible limit.

[7.] For C1 column removed, DCR of B6, B25 beams exceeds more than permissible limit i.e,(DCR> 2).

[8.] For C11 column removed, DCR of B14, B26 beams exceeds more than 2.The beam B27 exceeds permissible DCR only in Zone V.

[9.] For C13 column removed, DCR of B15 and B16 beams exceed 2. B34 beam have DCR more than 2 in Zone V, Zone IV, Zone III.

[10.] To avoid the progressive failure of beams and columns, caused by failure of particular column, adequate reinforcement is required to limit the DCR within the acceptance criteria.

[11.] The adequate reinforcement provided in extra to beams which are unsafe can develop alternative load paths and prevent progressive collapse due to the loss of an individual member.

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