Parametric Study on Progressive Collapse for RC Structure

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Abstract— The failure of single structural element which leads to complete collapse of structure can be defined as progressive failure or in short it can be defined as collapse of building by the transformation of local failure to global failure. In the present study a 12 storey, L shaped a symmetrical RCC building is taken under consideration with storey height as 3 meter, beam size uniform throughout the building and column dimension varying along height. The bay size is 4 meter in X-direction and 3.5 meter in Y-direction. The structure is analyzed under gravity loads only by using linear static method as per G.S.A guidelines. Totally 4 different analysis results are obtained by removing 4 different columns at specified locations as per G.S.A. According to G.S.A standards, if the D-C Ratio of any structural element exceeds 2 then it is considered as unsafe and Interaction ratio should not exceed 1. The results for; Bending-moment', 'Axial-Load' and 'Interaction ratio' are obtained and compared with one and other. After analyzing and comparing the results it is concluded that, the Interior Column removal at the base case was critical case among the 4 cases.

Keywords: RC Structure, GSA, DCR, RCC Building

I. Introduction

Structures are designed to withstand some ultimate forces or stresses. But when load acting on an element increases beyond ultimate value failure of a member occurs. When a load carrying structural member in a building fails it causes the failure of some other adjacent members, and the failure of other member causes failure of some more adjacent or higher storey members, this goes on continuing causing failure of whole structure. This phenomenon is called Progressive-Collapse or progressive failure. In short it may be defined as the process in which local failure becomes global failure.

First Progressive-Collapse has pointed out in the year 1968 occurred in the Ronan point 22 storey building at London. The sudden gas explosion at 18th floor caused the failure of corner columns from top to bottom. The other examples of Progressive-Collapse are, Collapse of World trade center in 2001, collapse of Alfred P Murrah Federal building in 1995 at Oklahoma City, collapse of Hotel New World in 1986 at Singapore.

The analysis may be carried out by removing one vertical load carrying element or more than one. Progressive failure occurs due to extreme loading of normal loads and abnormal loads. The main cause of progressive failure is abnormal loads which may be listed as, loads due to gas explosion, vehicle impact loads, loads due to over pressure of wind, Blast loads, Earthquake loads etc.

When building is subjected to any abnormal loads, the structural elements are damaged first. The damage of Vertical structural member is more hazardous than damage of horizontal member. When any vertical member like column got damaged due to sudden impact of load it causes the load distribution to other adjacent or neighboring elements. If the adjacent members have sufficient capacity to withstand additional load then there will be no failure but when they cannot, then the failure of member occurs. When that member fails again its adjacent member should have capacity to withstand or else failure goes on increasing resulting in a chain action of failure causing structural collapse.

Any building has to withstand two types of loads. The load causing structural failure is type 1 and the additional load generated due to failure of one or more structural elements is type 2. The type 1 loads are externally applied or acting loads but type 2 loads are generated internally due to moment of structural elements.

A. Aim of the project

To study the behavior of RC structure for progressive-Collapse using Linear-Static method as per G.S.A guidelines by observing

1) The variations in bending moment and axial force.
2) The DCR values of beams and
3) Variation of Interaction ratio

II. GUIDLINES AND CALCULATIONS AS PER GSA (General Service administration)

The main aim of this guideline is to ensure that "when failure occurs at the beginning, which is referred as local failure and this local failure should be limited at some damage less point so that global failure i.e. whole structure failure can be stopped".

A. Demand Capacity Ratio

G.S.A classifies a structural member as safe or unsafe depending on D-C Ratio values only. If the value of D-C Ratio is in the permissible limit then it is safe otherwise it is to be mentioned as unsafe.

It is defined as the ratio of "force acting on the structural member to ultimate capacity of the member".

$$\text{D-C Ratio} = P_{ACTING} / P_{ULTIMATE}$$

P_{ACTING} = Force acting on the element. It may be any type of force like 'Bending-moment', shear force, Axial-load or any combined force.

$P_{ULTIMATE}$ = Ultimate force or capacity of the member in terms of 'Bending-moment', shear force, Axial-load or any combined force.

According to G.S.A, the permissible value of G.S.A is limited to

D-C Ratio<= 2.0 for typical structures
D-C Ratio<=1.5 for atypical structures

B. Linear Static Analysis

This method is very simple and applicable only for regular structures and the response to PC potential is calculated from Demand Capacity Ratio(DCR) which should be within 2.

1) It is suitable for the materials which are linearly elastic that means materials with same dimension and elastic behavior.
2) Widely used because it is more simple method to understand and easy to execute.
3) The drawback is, it will not consider any amplification factors, inertia and damping force so this method is suitable only for analyzing plain or simple structures whose behavior is predictable.
4) Load combination used in this method for Progressive-Collapse is
5) Load acting = 2(DL + 0.25 LL)
6) The results are differentiated depends on demand capacity ratio which should be less than 2 for typical and 1.5 for atypical structures.

C. Loading conditions

Following load combinations are used for progressive collapse analysis.
For Linear & Non linear static analysis : 2(DL+0.25LL)
For Linear & Non linear dynamic static analysis : (DL+0.25LL)
where, DL= Dead Load and LL= Live load
Dynamic amplification factor of 2 is provided for static analysis case.

D. Interaction Ratio

The columns in the present case are the columns subjected to Axial-load and Bi-axial moment as the analysis is three dimensional frame analysis. In the corner columns of the building the Bi-axial bending is more predominant. Even though the exact design is difficult, the design of these columns is done with the help of Interaction ratio. After the analysis has been done the design of concrete frame structure is carried out. Then the flexure details like rebar percentage, Axial-load and moments are taken for respective columns and checked for interaction formula.
The interaction formula is given by
$[M_{UX} / M_{UX1}]^{\alpha n} + [M_{UY} / M_{UY1}]^{\alpha n} \leq 1.00$
M_{UX}, M_{UY} - Moments about x and y axis due to design load
M_{UX1}, M_{UY1} – Maximum uniaxial moment for Axial-load Pu about x and y axis respectively
P-M-M ratio must be less than 1.0 As per guidelines

III. PROBLEM DESCRIPTION

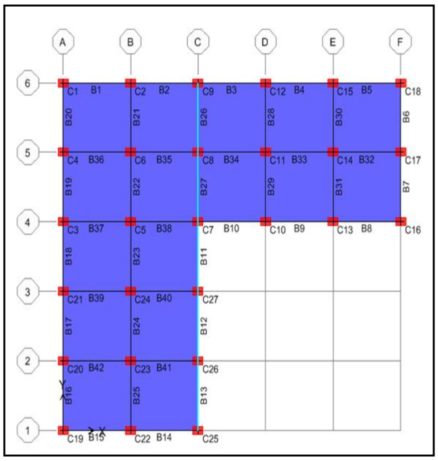

Fig. 1: Plan View

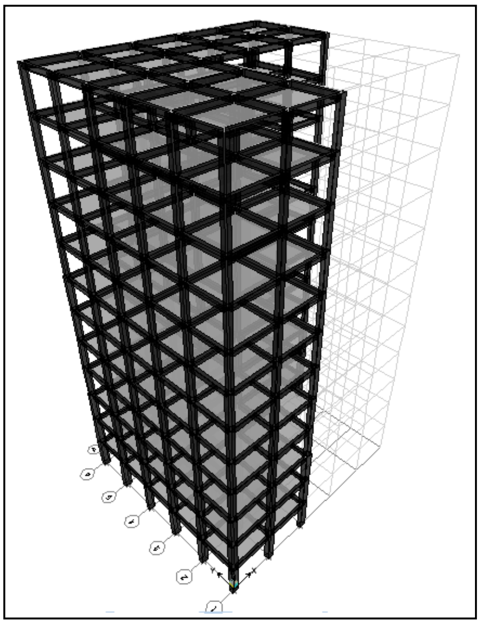

Fig. 2: 3-D View

The structure is in 'L' shape and consists of 12 storeys with bay size as 4 meters in X direction and 3.5 meters in Y direction. Height of each storey is taken as 3 meters and height from plinth to floor is also taken as 3 meters.

Beams dimensions are maintained constant in all storey's but the column dimensions are reduced with the increase in floor and hence the building can be considered to have geometric irregularity. The loading is taken as per G.S.A guidelines that is (DL +LL) for before removal case and 2(DL + 0.25 LL) for after removal case. The design has been done as per IS: 456 code using ETAB version 9.7 software.

A. Material and Sectional Properties

Concrete used is of M30 grade (fck- 30 N/mm2) Reinforcement steel is of Fe 415 grade (fy – 415 N/mm2) Beam dimension – 230mm X 400mm,Slab thickness – 150 mm, Wall thickness – 230 mm ,Column dimension – 400mm X 600mm – 1^{st} to 3^{rd} storey, 300mm X 500mm – 4^{th} to 7^{th} storey 300mm X 400mm – 8^{th} to 12^{th} storey
Load considered

1) Dead load – Self weight of the members
2) Live load – 3 KN/m^2
3) Floor finish – 1.5 KN/m^2
4) Wall load – 13.8 KN/m^2
5) Parapet load – 6.9 KN/m^2

B. Load combinations

Load case considered in design & analysis of building before column removal: (DL+LL).

After column removal: For Linear & Nonlinear static analysis: 2(DL+0.25LL)

Where, DL= Dead Load(including wall load, floor finish and parapet load) LL= Live load.

C. Different column removal cases

1) Case 1 Exterior middle column C 22 removal at the base
2) Case 2 Corner column C7 removal at the base
3) Case 3 Interior column C6 removal at the base
4) Case 4 Interior column removal case at 3^{rd} floor

D. Observations

1) Variations in bending moments and axial forces
2) Demand capacity ratios (DCR) of beams
3) Variations in interaction ratios of column (P-M M ratio).

IV. ANALYSIS AND RESULTS

Positions of column removal for different cases are shown in Fig no.3 and relevant bending moments and axial forces for before and after removal of column C 7 case 2 is shown in Fig no 4 5 6 and 7. Building is analyzed under gravity loads and results are tabulated.

The DCR values are calculated for each beam affected and the variation is observed. It is been found that when base column is removed the first 3 floors are exceeding the DCR limit. The axial force variation is tabulated with and without considering dynamic affect. Interaction ratio is calculated as per formulae given above by taking flexural details given by E-tabs.

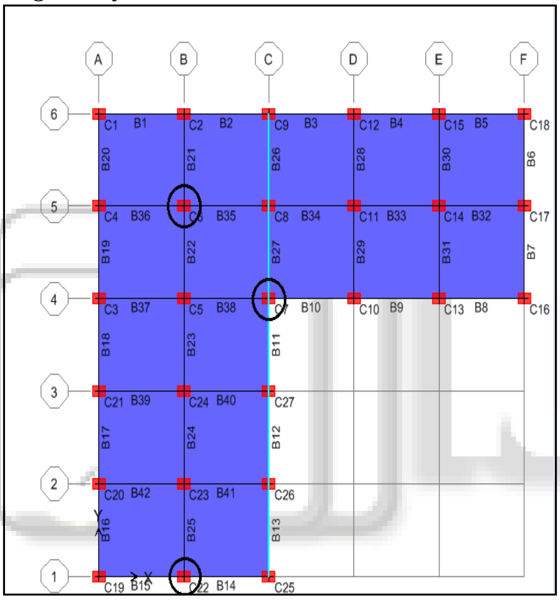

Fig. 3: Column removal positions for different cases

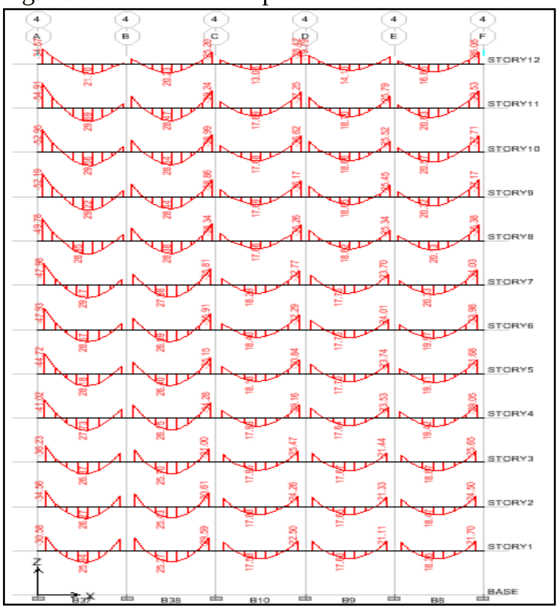

Fig. 4: Bending moment of beams before column C7 (case2) removal at base

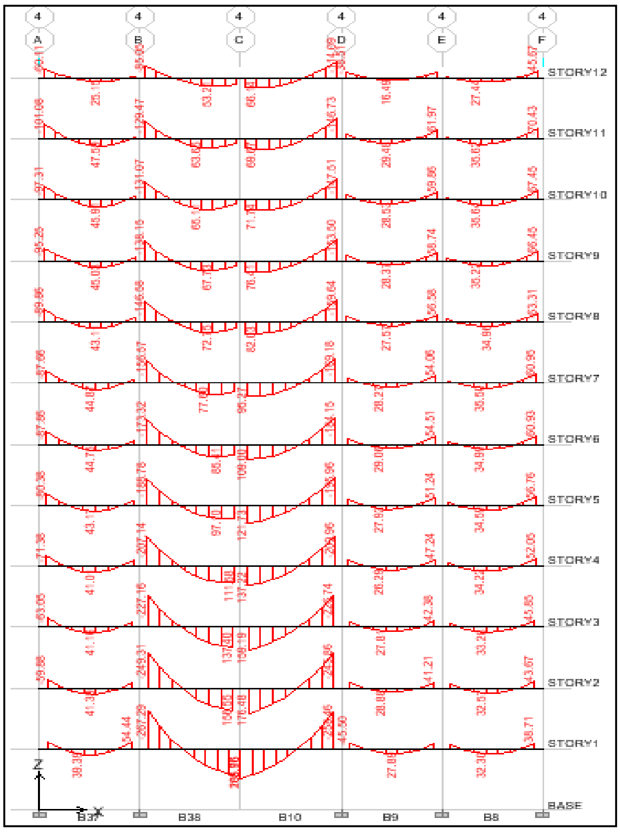

Fig. 5: Bending moment of beams after column removal

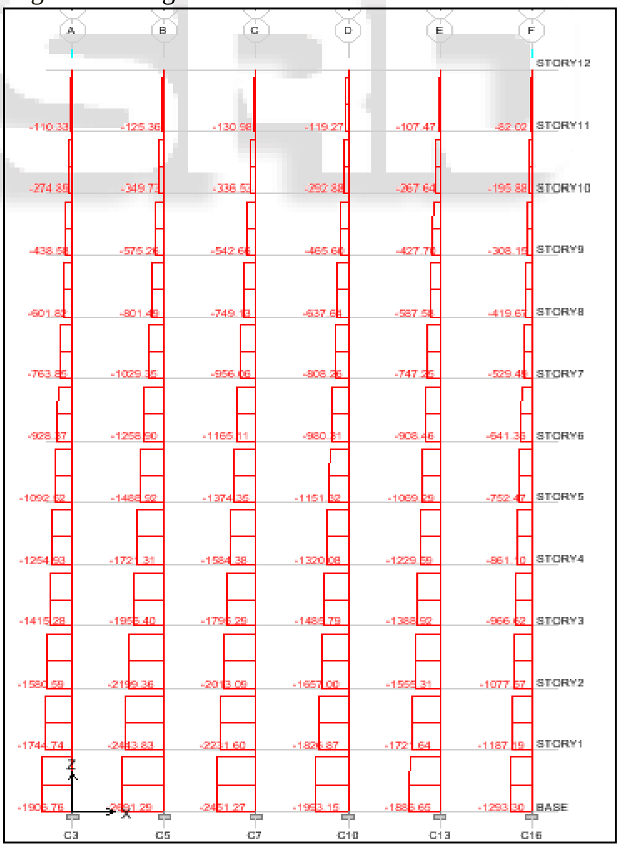

Fig. 6: axial forces of columns before column removal at base(case2)

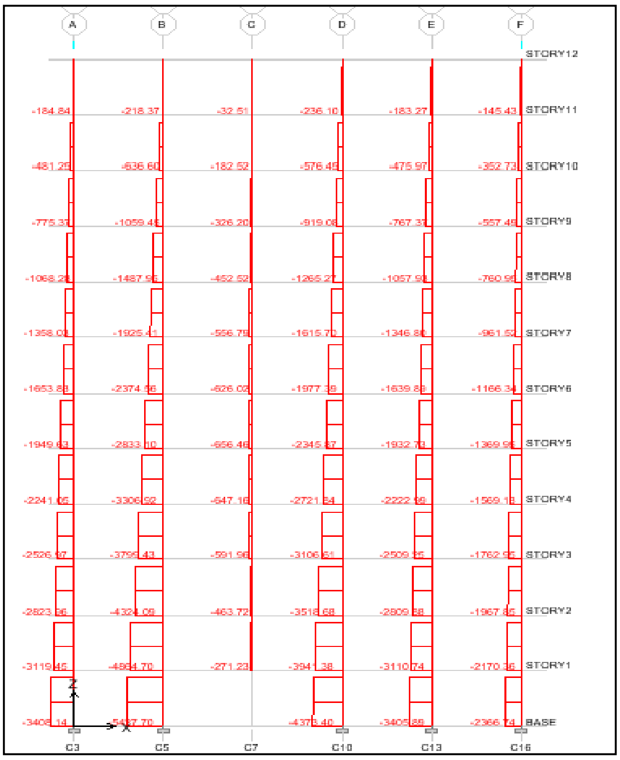

Fig. 7: axial forces of columns after column C7 removal

Similarly all the columns are removed one at a time and results for bending moment, axial force and interaction ratio is tabulated.

1) Case 1: When Exterior middle column (C22) is removed at the base the beams B14 B15 B25 are affected and most affected columns are C19 C23 C25.
2) Case 2: When corner column (C7) is removed at base, beams B10 B11 B27 B38 are affected and most affected columns are C5 C8 C10 C27.
3) Case 3: When interior column (C6) is removed at base the most affected columns are C5, C2 and C8 and beams B21 B22 B35 B36 are affected.
4) Case 4: When Interior column (C6) is removed at 3rd floor the most affected columns are C5, C2 and C8 and beams B21 B22 B35 B36 are affected.

It is been observed that in all the cases usually adjacent beams and columns are most affected compared to other structural elements. In the present study the columns are most affected compared to beams.

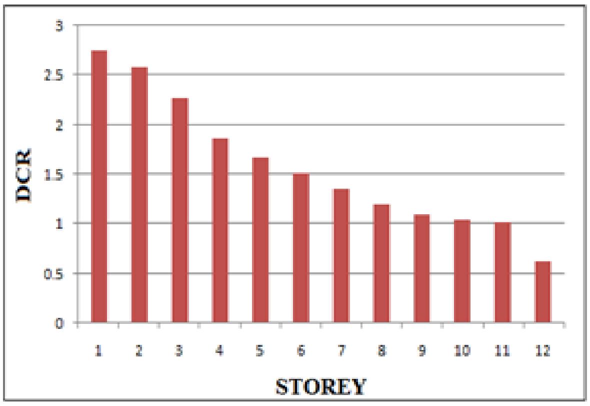

Fig. 8: D-C Ratio v/s Storey for B 27 beam when corner column C7 is removed

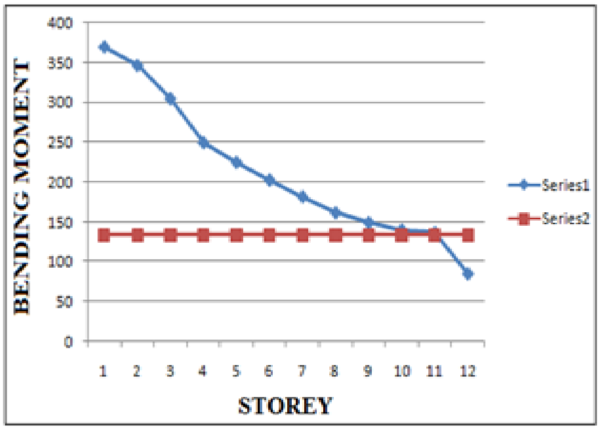

Fig. 9: 'Bending-moment' v/s Storey for B27 Series 1- Acting bending moment on the beam Series 2- Ultimate bending moment of beam

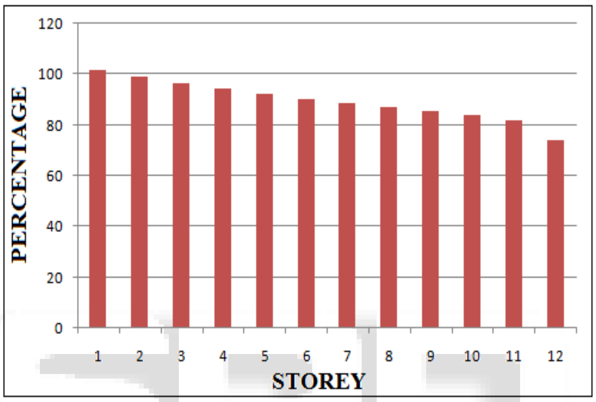

Fig. 10: Axial force % variation V/S storey of column C5 without considering dynamic factor

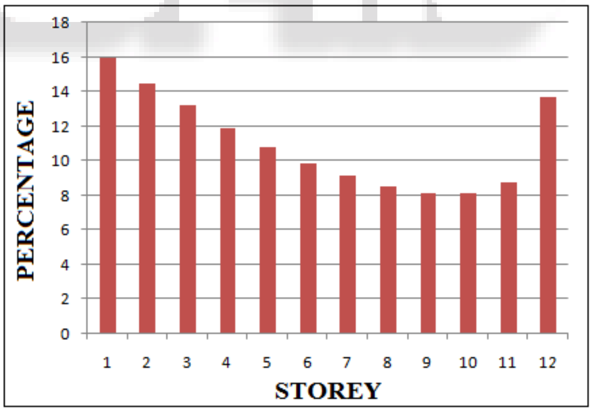

Fig. 11: Axial force % variation V/S storey of column C5 with considering dynamic factor

Sl.no	Dimension (mm)	I.R. for Column C 19	I.R for Column C 23	I.R for Column C 25
1	400 X 600	0.86	0.57	0.7
2	400 X 600	0.8	0.88	0.84
3	400 X 600	0.85	0.77	0.88
4	300 X 500	1	1	0.95
5	300 X 500	0.89	0.98	0.92
6	300 X 500	0.88	0.70	0.9
7	300 X 500	0.89	0.76	0.9
8	300 X 400	1	0.7	0.97
9	300 X 400	0.975	0.75	0.95

10	300 X 400	0.96	0.79	0.99
11	300 X 400	1	0.76	0.98
12	300 X 400	1.01	0.7	1

Table 1: Interaction Ratio after removal of column C22

V. Discussion on Results

From the results it is observed that

1) Before removal of column, usually 'Bending-moment' value is greater in top storey. But after removal of column the result is exactly opposite that is reversal of moment takes place which means as the height increases the 'Bending-moment' decreases, its value is greater at the bottom.
2) It is observed that before removal of column, the 'Bending-moment' in the adjacent beams were less than ultimate moment which means they were on much safer side, but after removal the 'Bending-moment' in adjacent beams is observed to be more than ultimate moment in almost all stories.
3) When we remove the column, the beam length increases and in building with equal frame it become twice the original, also there is increase in load on this new beam as the column which has to take the load is removed. It is the known fact that 'Bending-moment' is directly proportional to length and load, the bending moment increases at the bottom forming the plastic hinges to resist the failure once the column is removed.
4) In interior column removal case as the beam is supported on both side it act as continuous beam and the maximum drooping (sag) moment is observed at the center of beam. In exterior column removal case maximum hogging moment is observed at the support as it acts like cantilever.
5) The storeys above the removed columns are greatly affected but below story are much safer.
6) The columns which are reaching the limiting value of I.R ratio can be made safer by increasing the cross section or reinforcement.
7) The adjacent members of removed element are highly affected than other members & the junction where column dimension changes from one floor to other is highly effected region after removal of column at the base.

VI. Conclusion

1) For the structure under consideration in this paper, the D-C Ratio for beam exceeds the limit for above 3-4 floors only, for remaining storey the values are within limit.
2) The failure of vertical structural element is more hazardous than failure of horizontal structural elements.
3) The axial force at the base is higher in column removed case compared to normal case and from the comparison between the results of axial force with and without considering dynamic factor; we can conclude that it's better to design the building without considering dynamic factor as that case is more critical.
4) Interaction ratio after removal is observed to be reaching the limiting value in few columns. It can be made safe either by increasing the reinforcement or by increasing dimension of column.
5) The most critical case for progressive failure is found to be interior column removal case at the base.

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[12] Is: 875 Part – II, " Design loads for building and Structure