International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 03 | Mar 2023 www.irjet.net p-ISSN: 2395-0072

PROGRESSIVE COLLAPSE ANALYSIS OF REINFORCED CONCRETE STRUCTURES WITH FLAT SLAB CONSIDERING EFFECTS OF GEOMETRICAL (HORIZONTAL and VERTICAL) IRREGULARITIES.

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Abstract -*This paper presents Progressive Collapse analysis(PCA) of Reinforced Concrete Structures with Flat slab considering effects of geometrical (horizontal & vertical) Irregularities. Progressive collapse failure starts with local damage and extend up to whole structure. Flat slab buildings are more prone to progressive collapse than moment frame buildings, its behavior to resist progressive collapse must be examined. Since absence of beams to redistribute load due to get more effect after removing columns. The current analytical research assesses the progressive collapse behavior of ten story RC flat slab building by Equivalent frame method. for study purpose five model considered they are RCC rectangular flat slab, flat slab having excessive opening, Re-entrant corner, mass irregularity and vertical geometrical irregularity by conducting Linear static progressive collapse analysis and dynamic PCA as per GSA guidelines (2016) and then result compared. This research explores the different plans for column removal situation in each model, unlike earlier studies where only one building model considered. Corner, edge and interior columns of each building model are analyzed by using static and dynamic PCA method. The results are analyzed for each case, in terms of demand capacity ratio (DCR) at critical sections, vertical joint displacement and chord rotation at column removal locations and thus sensitivity of building to progressive collapse is calculated accordance with relevant acceptance criteria consigned in DOD guidelines (2009).*

Key Words: **Progressive collapse, flat slab, vertical joint displacement, DCR, Chord rotation, GSA, DOD, local damage, static linear analysis, Time history, Dynamic analysis, ETABS**

1. INTRODUCTION

The collapse of load carrying structural element may lead to progressive collapse as a part or whole structure. According to GSA 2016 guidelines, progressive collapse is defined as extent of damage or collapse that is disproportionate to the magnitude of the initiating event. The progressive collapse initiates, when one or more load carrying members are removed. When one or more load carrying elements remove chain reaction of failures structure start. The guidelines of the GSA and DoD suggested the Alternate Path Method (APM) for progressive collapse analysis where a single column in the ground level is assumed to be unexpectedly missing and analyses are carried out to assess the ability of the weakened structure to pass through the missing column. The APM focuses on the vertical deflection of the building after the column has been suddenly removed. The collapsing structure seeks for alternative load path continuously for prevent progressive attention collapse and survive. Traditional design work not considered extreme loading conditions. Previously some experiences grab of structural engineer's attention Ronan point apartment building, Alfred.P. Murrah building, skyline plaza, world trade Centre. Based on the type of collapse occur, progressive collapse divided into pancake-type, zipper-type, domino-type, section-type, instability-type and mixed type collapse. The purpose of this study is to analyze the effect of geometrical irregular RC flat slabs for progressive collapse. progressive collapse analysis where a single column in the ground level is assumed to be unexpectedly missing and analyses are carried out to assess the ability of the weakened structure to pass through the missing column. PCA is classified as Pressure load- Internal gas explosion, Blast load, Extreme wind pressure and another type is Impact Load- Aircraft impact, Vehicular collision, Earthquake in this study analyses behavior of building under column loss at ground floor.

1.2 OBJECTIVE OF WORK

To study a 10story RCC rectangular flat slab having excessive opening, Re-entrant corner, mass irregularity and vertical geometrical irregularity type structure models prepared to simulate a column loss event and check results in terms of DCR and chord rotation and vertical joint displacement by using GSA and DOD guidelines. And understand behaviour of building under critical column loss scenarios by using static and dynamic PCA method.

2. Description of analytical model

The first model regular rectangular 6×5 bays of 5m span for one bay, second model 5×5 bays of 5m span plus shape Re-entrant corners plan, third model 4×2 bays of 5m floor slab

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have excessive opening at edge of slab, forth model of 7×5 bays of 5m span in plan having vertical geometrical irregularity on both side, and fifth model of 6×5 bays of 5m span in plan have mass irregularity at 4th and 8th storey. As shown fig 1,2,3,4 and 5 respectively. All models considered 3m floor to floor height of each story as total 10 storeys constructed in zone 3, medium soil, damping ratio 5% by using ETABS software. Flat slab is modelled using Equitant frame method. Thickness of the flat slab is considered as 200mm. for each building, the interior and exterior flat slab beam are of size 1200×200 mm and 600×200 mm, Respectively. The buildings have the same plan throughout the entire height. The column size is taken as 600×600 mm and A live load of 4.0 kN/m^2 and a superimposed dead load 2.0 kN/m^2 considered including partition, mechanical and plumbing load, Is applied to the floors. The grade of concrete as M30 and steel is Fe500. The building is designed for gravity load according to IS456:2000 for taking PCA result. As per IS 1893-2016 irregularities considered model 2 Re-entrant corner have offset A and length of that direction L, A/L>0.15 for model 3 opening located along edge > 10% of floor slab area. For model 4 and 5 vertical geometrical irregularities on both side offset A>0.25L on each side and mass irregularity mass at particular story > 2 times of that adjacent storey respectively.

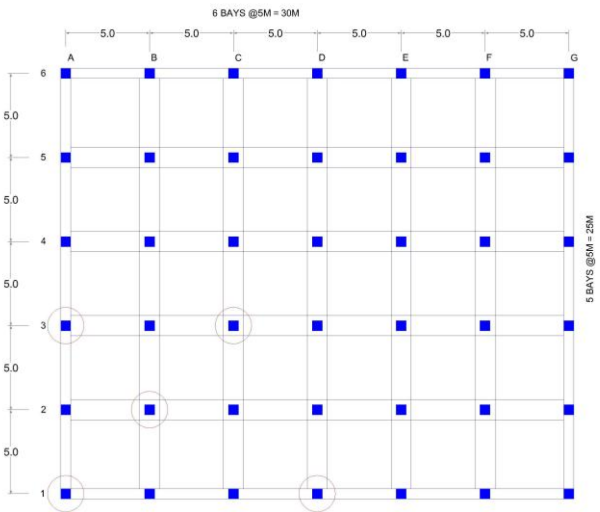

Fig -1: plan view of studied rectangular building as case 1

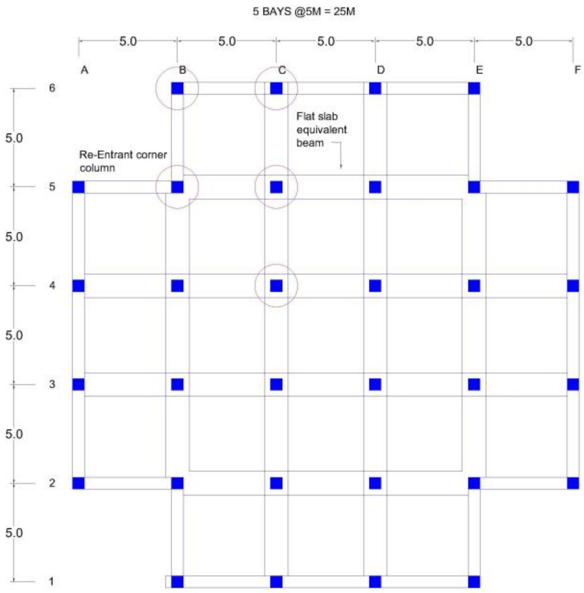

Fig -2: plan view of studied horizontal irregularity Re-entrant building as case no 2.

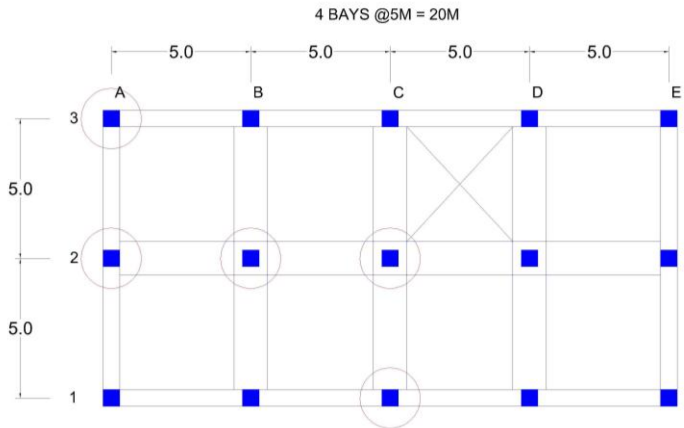

Fig -3: plan view of studied horizontal irregularity flat slab having excessive opening as case no 3.

Notations.

GSA	General Services Administration
DoD	Department of Defense
Δ	Joint vertical Displacement at column removal location
θ	Chord Rotation at column removal location.
CC	Corner Column
REC	Re-entrant column
ECS	Short edge column
ECL	Long edge column
IC	Interior column

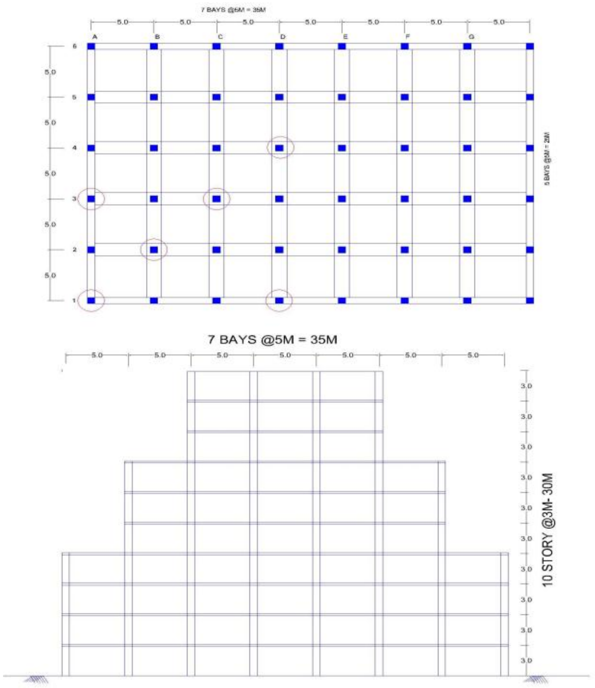

Fig -4: plan and elevation view of studied vertical Geometrical irregularity on both side as case no 4.

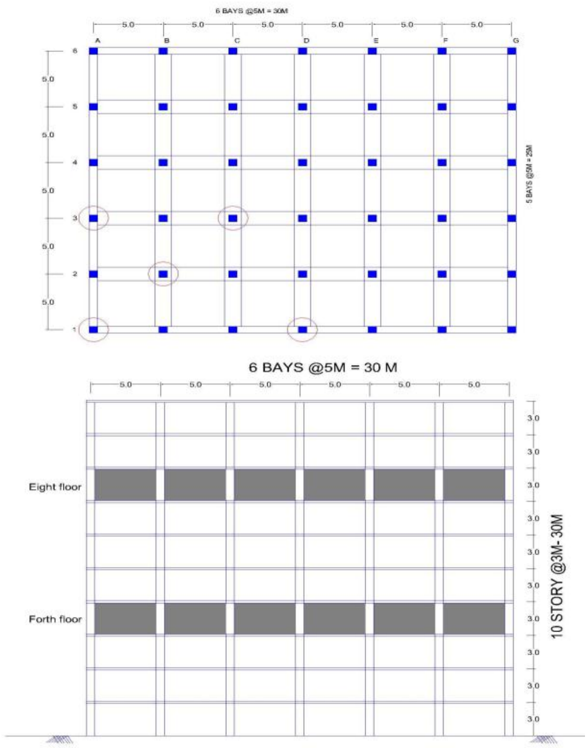

Fig -5: plan and elevation view of studied Vertical irregularity flat slab having Mass irregularity as case no 5.

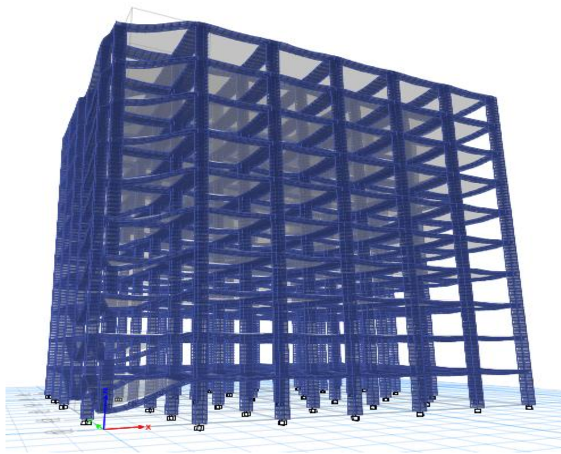

Fig -6: Sample of deflected shape of building when corner column removed

3. ANALYSIS METHODOLOGY

The cases of removal of column at ground floor level as shown in plan view indicating circle around column in fig no1,2,3,4 and 5 as well specimen deflected shape of building in as shown in fig 6. The effect of geometrical irregularities on each model column removal DCR values taken at nearby critical column the DCR should not exceed 2 for rectangular building and other four irregular building 1.5 otherwise, they considered as susceptible to progressive collapse as being severely damaged as per GSA guideline. The calculation of connection rotation at column removal location determined in a frame via the chord rotation. And values of this chord rotation compared with permissible plastic rotation angle according to GSA and DOD recommendations.

DCR= Qud/Qce

Where, Qud = Acting force computed in the component (shear, moment, axial force),

Qce = Expected ultimate, unfactored capacity of the component.

Chord rotation, **$\theta = \Delta / L$**

Where, θ = chord rotation (plastic rotation angle) in radians, Δ = vertical displacement, and L = length of member.

3.1 Static analysis procedure is as follows

1. As per GSA guidelines Remove corner column, edge column and interior column alternately from the ground storey as shown in Fig 1,2,3,4 and 5 highlighted red circle
2. Two load combinations which follow the GSA guideline for the presentation of the gravity loads are used. A load combination of (1.2 DL + 0.5 LL) is used for gravity loads

for floor spaces on the side from removed column and 2(1.2 DL + 0.5 LL) for additional gravity loads for floor spaces over the removed column. To account for dynamic effects, a factor of 2.0 is provided in the Static analysis as a dynamic magnification factor as per GSA guideline.

3. Perform static analysis as per GSA using the software ETABS

4. Demand Capacity Ratio (DCR) of sectional forces of critical columns in the ground storey nearby removal column and vertical displacements at the top of removed columns are evaluated for the specific column removal case.

5. In case of the removal of columns in the ground storey, the responses of critical neighboring columns are evaluated and results compare with guideline values.

3.2 Dynamic analysis procedure is as follows

in this process involves the removal of columns in real-time, which innately accommodates amplification factors, inertia and damping forces. This analysis has the key benefit of being able to account for the dynamic amplification effects. In this paper, the dynamic progressive collapse analysis procedure, shown in Fig 7. is briefed as follows:

1. The gravity loading of 1.2 DL + 0.5 LL is uniformly applied in the entire span of the frame according to GSA guidelines.

2. Prior to the removal of the column, its reaction force is determined.

3. The column is removed and replaced by a force (P) equal and opposite to its reaction force. This reflects the original case where the column is still in place and carries the gravity loads.

4. To simulate the conditions of dynamic column removal, the member force (P) is suddenly removed using a time-history step function as shown in Fig 7.

5. The member force is applied till 2.5 sec. so that the structure reaches a stable condition, and finally, the force is suddenly removed. The total time of dynamic analysis is considered as 5.0 s, which is adequate to evaluate the maximum response and attain a steady-state under 5% of damping ratio. The gravity loads remain unchanged until the end of the analysis time.

6. The time over which a column is lost, in a real bomb explosion, is very short. The column removal time should be less than 1/10 of the natural period associated with vertical vibration as recommended by DoD. In this study, the column removal time is hence taken as 0.05 s, which indicates a instantaneous removal. The dynamic effects of the column removal time close to 0.05 s would result in adverse dynamic effects.

7. Perform dynamic analysis as per GSA using the software ETABS.

8. Evaluate the results in terms of DCR of sectional forces of critical columns and vertical displacements at the top of the removed column, where demands, as well as displacements, are taken as the peak values (absolute maximum) of responses from the calculated time history responses.

corner column (CC), edge column (EC) and interior column (IC) are dynamically removed alternate manner, i.e. only one column is removed at one time now carrying out dynamic progressive collapse analysis, the above discussed 1–8 steps are followed. The results of dynamic analysis are then compared with that of static analysis

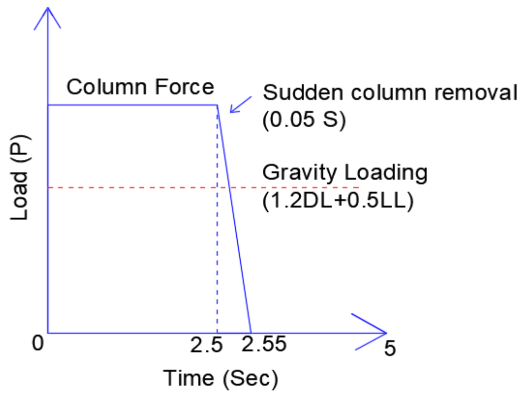

Fig -7: Load time history

4. RESULTS AND DISCUSSION

The responses of columns 3B,3D,2C and 4C are evaluated when Interior column (3C) is removed in ground floor in case no 1. in the scenario of removal of LONG edge external column ECL (D1) the responses of columns 1C,1E,2D are evaluated in case no 1. Like same way for all cases (1 to 5) corner column (CC), short edge column (ECS), long edge column(ECL), Interior column(IC), Re-entrant column (REC) removed on ground floor. The responses of adjacent to the removed column are evaluated as shown in table no 1,2,3,4 and 5 for case no 1,2,3,4 and 5 respectively as there DCR values exceed the limit 1.5 for irregular structure and 2 for regular structure then development of progressive collapse is considered as per GSA guidelines. The Vertical Displacement calculated at joint where column is removed and Chord rotation value kept it below the 0.05 (rad) for flat slab structure at the location of removal of column, defined as per GSA and DOD guideline. vertical displacement(Δ) and chord rotation (θ) at location of removal of column results for all cases shown in table no 6.

the predicted results also indicate that the building would not be prone to progressive collapse neither statically nor dynamically.

Vertical displacement time history of top of removed columns when the columns CC, EC and IC are instantaneously removed at t = 2.5 s are shown in Figs. 8–12, respectively. It can be observed from the time history response that time t = 0.0 s to t = 2.5 s demonstrate a period for achieving static equilibrium. Then, the columns CC, EC and IC are alternately removed at time t = 2.5 s in 0.05 s to account for instantaneous removal. After that, time t = 2.55 s to t = 4.5 s shows the displacement cycle due to dynamic behavior. And from time t = 4.55 s to t = 5.0 s shows a period for stabilizing the vibration. The maximum vertical displacements at the top of removed columns for static analysis are also shown as constant dotted lines for different simulation buildings. The analysis results showed that both the DCR of sectional forces and the vertical displacements at top of removed columns are greater for static analysis than for dynamic analysis. This could be attributed to the fact that the static analysis is performed by amplifying the gravity loads by a factor of 2.0 following the recommendations of GSA while the un-factored gravity loads are used in dynamic analysis. It seems that the static analysis leads to conservative results.

Table -1: DCR of critical adjacent columns (axial force) when particular column as per GSA guideline removed for case no 1, rectangular building.

CASE NO 1: rectangular building				
Removal of IC (3C)				
Column name	3B	3D	2C	4C
DCR for static	1.031	1.022	1.17	1.17
DCR for Dynamic	0.85	0.84	0.95	0.96
Removal of IC (2B)				
Column name	2A	2C	B1	B3
DCR for Static	0.81	1.0	0.82	1.20
DCR for Dynamic	0.61	0.94	0.61	0.94
Removal of ECL (D1)				
Column name	1C	1E	2D	
DCR for Static	0.628	0.629	1.21	
DCR for Dynamic	0.52	0.52	0.92	
Removal of CC (1A)				
Column name	2A	1B		
DCR for Static	0.63	0.636		
DCR for Dynamic	0.53	0.53		
Removal of ECS (3A)				
Column name	2A	4A	3B	
DCR for Static	0.63	0.631	1.12	
DCR for Dynamic	0.54	0.52	0.93	

Table -2: DCR of critical adjacent columns (axial force) when particular column as per GSA guideline removed for case no 2, Re-entrant building.

CASE NO 2: horizontal irregularity, Re-entrant building				
Removal of CC (6B)				
Column name	5B	5C	6C	
DCR for static	0.85	0.825	0.615	
DCR for dynamic	0.74	0.75	0.51	
Removal of REC (5B)				
Column name	6B	5A	5C	4B
DCR for static	0.49	0.49	1.09	1.1
DCR for dynamic	0.37	0.37	0.91	0.91
Removal of ECS (6C)				
Column name	6B	6D	5C	
DCR for static	0.46	0.63	1.138	
DCR for dynamic	0.36	0.52	0.95	
Removal of IC (5C)				
Column name	6C	4C	5B	5D
DCR for static	0.79	1.13	0.97	1.12
DCR for dynamic	0.59	0.94	0.77	0.93
Removal of IC (4C)				
Column name	5C	3C	4B	4D
DCR for static	1.12	1.13	1.12	1.13
DCR for dynamic	0.93	0.94	0.93	0.94

Table -3: DCR of critical adjacent columns (axial force) when particular column as per GSA guideline removed for case 3, floor slab have excessive opening.

CASE NO 3: horizontal irregularity flat slab having excessive opening				
Removal of IC (2C)				
Column name	2B	1C	3V	2D
DCR for static	1.06	0.74	0.53	0.86
DCR for dynamic	0.99	0.62	0.46	0.83
Removal of IC (2B)				
Column name	2A	2C	1B	3B
DCR for static	0.79	0.97	0.79	0.78
DCR for dynamic	0.59	0.78	0.59	0.59
Removal of CC (3A)				
Column name	3B	2A		
DCR for static	0.66	0.65		
DCR for dynamic	0.55	0.54		
Removal of ECS (2A)				
Column name	3A	2B	1A	
DCR for static	0.36	0.95	0.37	
DCR for dynamic	0.35	0.93	0.35	
Removal of ECL (1C)				
Column name	1B	1D	2C	
DCR for static	0.65	0.653	1.0	
DCR for dynamic	0.54	0.54	0.81	

Table -4: DCR of critical adjacent columns (axial force) when particular column as per GSA guideline removed for studied vertical Geometrical irregularity on both side irregularities.

CASE NO 4: studied vertical Geometrical irregularity on both side				
Removal of IC (3C)				
Column name	3D	3B	2C	4C
DCR for Static	1.13	0.70	0.98	0.987
DCR for Dynamic	0.94	0.56	0.8	0.81
Removal of IC (4D)				
Column name	3D	5D	4C	4E
DCR for Static	1.13	1.12	1.03	1.13
DCR for Dynamic	0.94	0.93	0.84	0.94
Removal of IC (2B)				
Column name	1B	3B	2A	2C
DCR for Static	0.36	0.55	0.25	0.80
DCR for Dynamic	0.34	0.53	0.23	0.77
Removal of ECS (3A)				
Column name	2A	4A	3B	
DCR for Static	0.249	0.244	0.58	
DCR for Dynamic	0.2	0.2	0.5	
Removal of ECL (1D)				
Column name	1C	1E	2D	
DCR for Static	0.57	0.63	1.14	
DCR for Dynamic	0.47	0.52	0.95	
Removal of CC (1A)				
Column name	2A	1B		
DCR for Static	0.249	0.32		
DCR for Dynamic	0.2	0.28		

Table -5: DCR of critical adjacent columns (axial force) when particular column as per GSA guideline removed for Mass irregularity building.

CASE NO 5: studied Vertical mass irregularity				
Removal of IC (3C)				
Column name	3B	3D	2C	4C
DCR for Static	1.11	1.1	1.26	1.27
DCR for Dynamic	0.94	0.93	1.05	1.06
Removal of IC (2B)				
Column name	2A	2C	1B	3B
DCR for Static	0.87	1.01	0.88	1.23
DCR for Dynamic	0.66	0.99	0.67	1.03
Removal of ECL (1D)				
Column name	1C	1E	2D	
DCR for Static	0.67	0.675	1.21	
DCR for Dynamic	0.57	0.57	1.01	
Removal of CC (1A)				
Column name	2A	1B		
DCR for Static	0.68	0.684		
DCR for Dynamic	0.58	0.58		
Removal of ECS (3A)				
Column name	2A	4A	3B	
DCR for Static	0.67	0.679	1.213	
DCR for Dynamic	0.57	0.57	1.02	

Table -6: vertical joint displacement(Δ) and chord rotation(θ) at the location of removal of column.

CASE NO 1				
Column location	Δ For Static (in mm)	Δ For Dynamic (in mm)	θ For static (in rad)	θ For dynamic (in rad)
IC(3C)	147.0	113.94	0.0294	0.0227
IC (2B)	129.1	100.1	0.0258	0.0200
ECL (D1)	123.7	98.5	0.0247	0.0197
CC (1A)	135.8	111.0	0.0270	0.0222
CCS (3A)	124.4	99.0	0.0248	0.0198
CASE NO 2				
Column location	Δ For Static (in mm)	Δ For Dynamic (in mm)	θ For static (in rad)	θ For dynamic (in rad)
CC(6B)	115.1	94.96	0.0230	0.0189
REC (5B)	103.2	81.77	0.0206	0.01635
ECS (6C)	124.3	98.89	0.0248	0.01977
IC (5C)	116.1	90.13	0.0232	0.0180
IC (4C)	117.2	92.1	0.0234	0.0184
CASE NO 3				
Column location	Δ For Static (in mm)	Δ For Dynamic (in mm)	θ For static (in rad)	θ For dynamic (in rad)
IC(2C)	93.31	76.9	0.0186	0.01538
IC (2B)	114.6	89	0.0229	0.0178
CC (3A)	142.8	116.64	0.0285	0.02332
ECS (2A)	52.1	50.81	0.0104	0.0100
ECL (1C)	128.6	102.26	0.0257	0.0204
CASE NO 4				
Column location	Δ For Static (in mm)	Δ For Dynamic (in mm)	θ For static (in rad)	θ For dynamic (in rad)
IC(3C)	116.4	91.47	0.0232	0.01829
IC (4D)	116.9	91.72	0.0233	0.01834
IC (2B)	92.8	88.39	0.0185	0.0176
ECS (3A)	114.5	90.43	0.0229	0.0180
ECL (1D)	124.4	99.00	0.0248	0.0198
CC(1A)	125.5	101.5	0.0251	0.0203
CASE NO 5				
Column location	Δ For Static (in mm)	Δ For Dynamic (in mm)	θ For static (in rad)	θ For dynamic (in rad)
IC(3C)	154.7	121.68	0.0309	0.0243
IC (2B)	135.5	106.7	0.0271	0.0213
ECL (D1)	129.6	104.43	0.0259	0.0208
CC (1A)	141.65	116.83	0.0283	0.0233
CCS (3A)	130.39	105.0	0.0260	0.0210

DCR sample calculation for case 1, corner column(1A) removal condition.

DCR= Qud/Qce

Where,

Qud = Acting force computed in the component (shear, moment, axial force),

Qce = Expected ultimate, un-factored capacity of the component.

DCR < 2 For typical structural configuration and DCR < 1.5 For atypical structural configuration. The current case no 1 rectangular building having removal of corner column at ground floor (1A) study model is made typical as shown in fig no 6 adjacent column of that (1A) column i.e., (2A) have axial load 3929 KN

Qud= 3929 KN from software

Qce= PU= 0.4FCK(AC) + 0.67FY(ASC)

= 0.4 x 30 x (600 x600) + 0.67 x 500 x (360000-ASC)

=ASC, 20mm dim 12no bar and 25mm dim 4no of bars used for 600mm square column,

=ASC, (3.1415/4 x 20^2 x12) +(3.1415/4 x25^2 x4) = 5733.40mm square

= (4.251 x10^6) + (1.92 x10^6)

QCE=6171 kilo newton

DCR= 3929/6171

DCR= 0.636 < 2 OK.

Chord rotation sample calculation for case 1, corner column(1A) removal condition.

Chord rotation θ = Δ / L

Where, θ = chord rotation (plastic rotation angle) in radians, Δ = vertical displacement, and L = length of member.

Vertical joint displacement value 135.89mm as shown in fig. no 6 as per GSA guideline for load combination 2(1.2DL+0.5LL)

θ = 135.89/5000

θ = 0.027 rad. < 0.05rad

ok as per DOD guideline for flat slab.

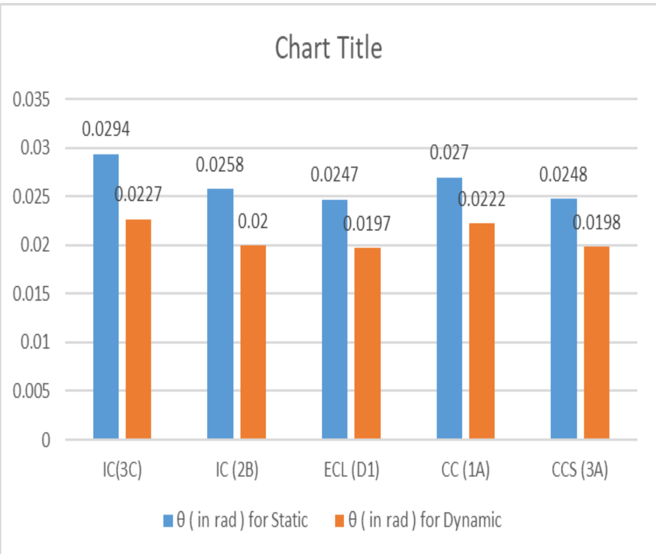

Chart -1: Chord rotation for case 1

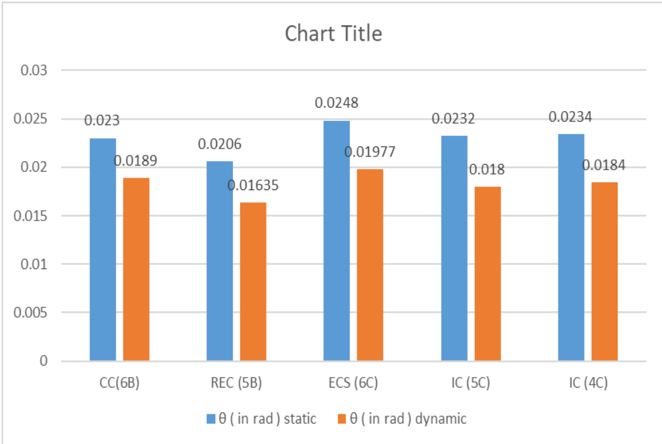

Chart -2: Chord rotation for case 2

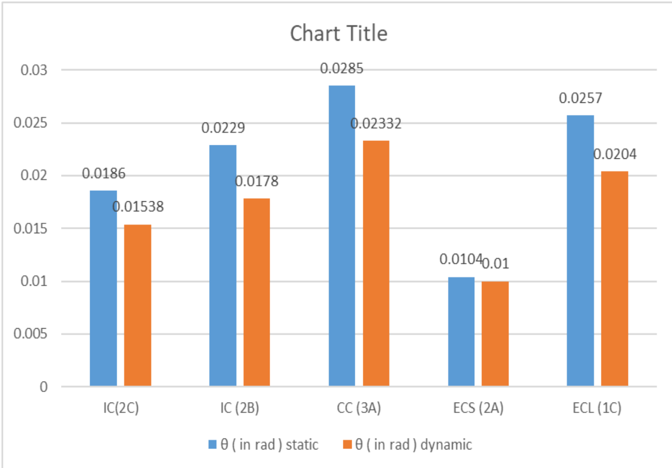

Chart -3: Chord rotation for case 3

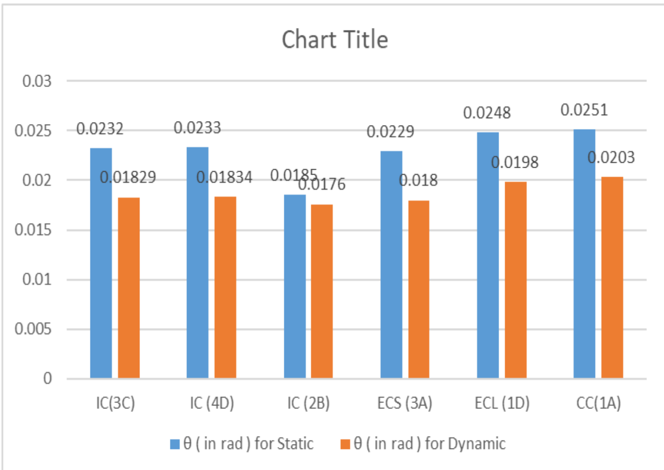

Chart -4: Chord rotation for case 4

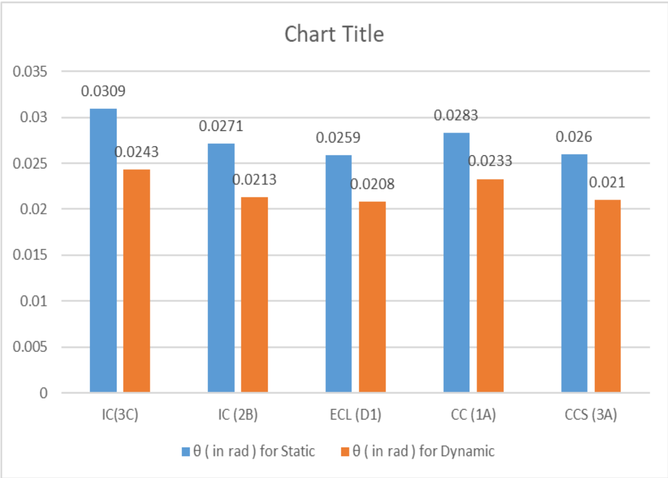

Chart -5: Chord rotation for case 5

When the corner column (CC) is instantaneously removed, a reduction of 15.4% on average is observed in the DCR of the sectional forces of the critical column, when compared to those in static removal scenario. Similarly, when the EC and IC columns are instantaneously removed, a reduction ranging from 16.18 to 20.4% on average is observed in the DCR of sectional axial forces of corresponding critical columns when compared to those in static removal case. In addition, when CC, EC and IC are instantaneously removed, the absolute maximum vertical displacements ΔCC, ΔEC and ΔIC show a reduction of 19.11%, 18.52% and 20.29% on average, respectively, when compared to those in the case of static removal of columns.

Table -7: Average Percentage change in DCR & vertical joint displacement in static and dynamic removal cases.

Average Percentage change of DCR in static and dynamic removal case for axial forces					
	Case no 1	Case no 2	Case no 3	Case no 4	Case no 5
IC	18.68	36.84	16.67	13.58	16.265
CC	16.26	13	16.79	16	14.95
EC	18	19.53	10.58	17.18	15.64
Average Percentage change of Vertical joint displacement in static and dynamic removal case for axial forces					
	Case no 1	Case no 2	Case no 3	Case no 4	Case no 5
IC	22.47	21.88	19.95	15.89	21.27
CC	18.26	17.49	18.31	24	17.52
EC	20.39	20.6	11.47	20.7	19.44

following assumptions have been used in the analytical models:(1) The floor loads (other than self-weight) are applied simply on the flat slab beams conforming to the area method (2) Support conditions are considered as fixed at the base. and (3) Gain of yield strength arising from the high rate of straining owing to instant column loss is ignored.

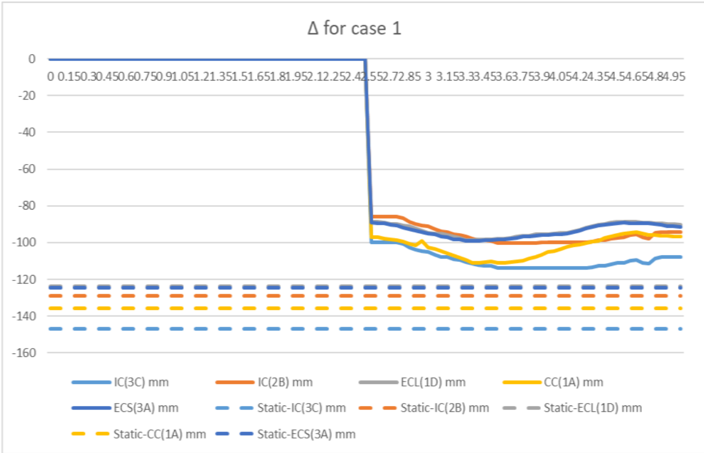

Fig -8: Time history response of vertical displacement when all columns instantaneously alternately removed at t=2.5 sec for case no 1

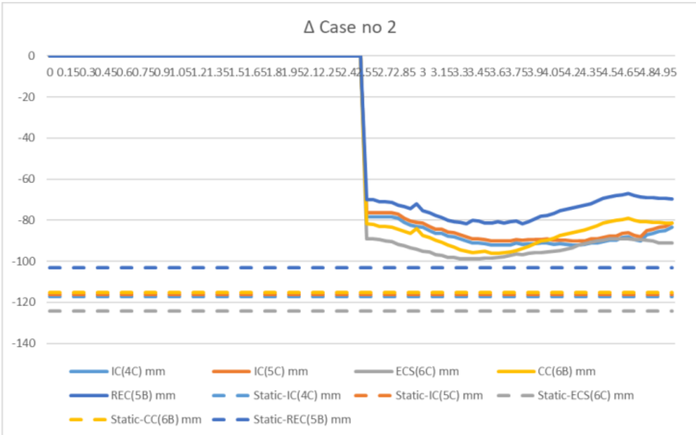

Fig -9: Time history response of vertical displacement when all columns instantaneously alternately removed at t=2.5 sec for case no 2

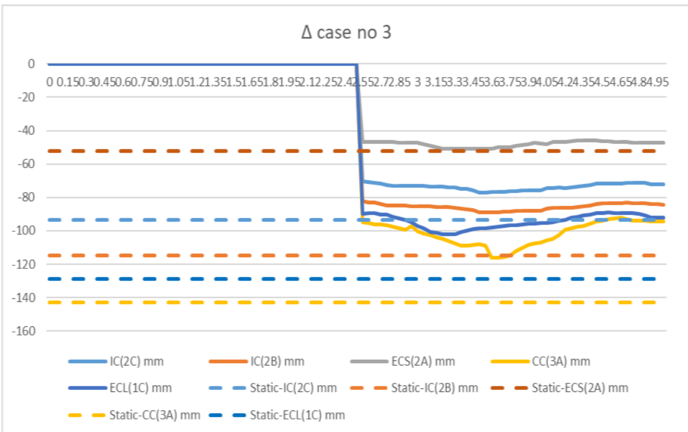

Fig -10: Time history response of vertical displacement when all columns instantaneously alternately removed at t=2.5 sec for case no 3

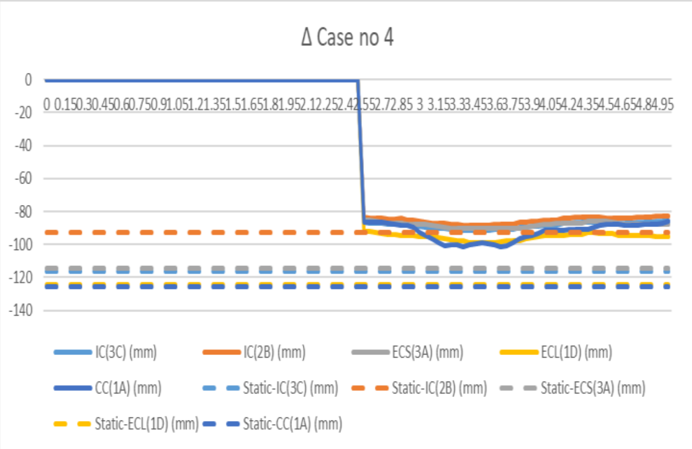

Fig -11: Time history response of vertical displacement when all columns instantaneously alternately removed at t=2.5 sec for case no 4

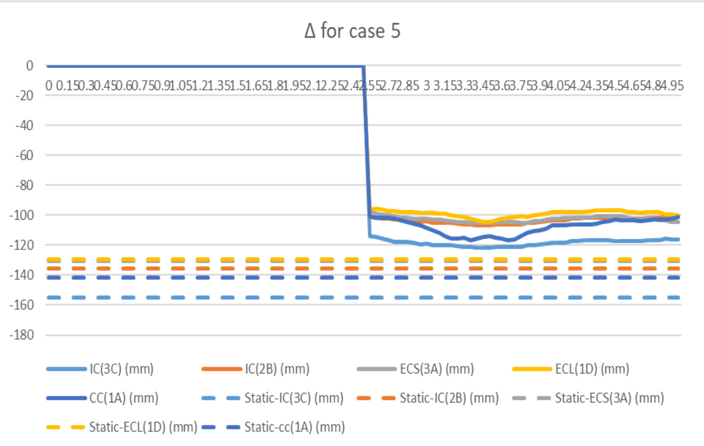

Fig -12: Time history response of vertical displacement when all columns instantaneously alternately removed at t=2.5 sec for case no 5.

5. CONCLUSIONS

- The joint displacement and Chord rotation at column removal locations are evaluated when different locations of column on each building removes the finding indicates the studied flat slab is more vulnerable in case of corner Column remove than edge columns.

- Joint Displacement and Chord Rotation values are inversely proportional to progressive collapse resistance as chord rotation decreases, Progressive Collapse Resistance increases.

- The numerical results showed that both the DCR of sectional forces and the vertical displacements at top of removed columns are greater for static analysis than for dynamic analysis. The application of dynamic magnification factor to the static analysis leads to conservative results.

- When the corner column (CC) is instantaneously removed, a reduction of 15.4% on average is observed in the DCR of the sectional forces of the critical column, when compared to those in static removal scenario. Similarly, when the EC and IC columns are instantaneously removed, a reduction ranging from 16.18 to 20.4% on average is observed in the DCR of sectional axial forces of corresponding critical columns when compared to those in static removal case. In addition, when CC, EC and IC are instantaneously removed, the absolute maximum vertical displacements ΔCC, ΔEC and ΔIC show a reduction of 19.11%, 18.52% and 20.29% on average, respectively, when compared to those in the case of static removal of columns.

- The Irregular Structure also sustains progressive collapse effect after removal of columns Alternately, and the effect of flat slab on PCA is very influential because the existence of flat slab after removal of column does not experience overall collapse, but some structural elements collapse. Load distribution after removal of column through nearby critical column is done, Column DCR <1.5 for irregular and DCR<2 FOR regular structure, gives limit of safety member.

- The result values of vertical joint displacement and chord rotation and DCR is taken as per GSA load combination. building is designed for seismically forces hence seismically designed building columns have inherent ability to resist progressive collapse.

- The purely RC regular flat slab structural system is less vulnerable than irregular flat slab structure because the ductility of these structural system is generally limited by the deformation capacity of slab column connection. i.e., penetration force in the slab at the connections, which should retain its load bearing capacity when column removes adjacent column get additional load and this is related with maximum displacement and DCR are less than 2 as well chord rotation is less than 0.05 in all cases therefore adjacent all members are safe.

- Vertical joint displacement(Δ) value is directly proportional to chord rotation(θ), maximum value of Δ and θ on internal column(IC) in case no 1 they are geometrical regular building and in case no 5 they have same plan as case 1 only mass irregular on 4th and 8th floor for case 5. Other than this cases approximately max values get in case of corner column removal in all remaining cases(CC)

- DCR values for column adjacent to removal column maximum when central Internal column removes, then another Internal column, edge column of longer side, then edge column on shorter side, and finely corner column.

- As the structural response depends on degree of irregularity, type, location those factor need to be taken care while designing any structure. This would help in incorporating irregularities in structures without compromising their performance.

- Some Flat slab on the ground floor of a building when the critical column and inner sides of a building are removed is collapsed but does not affect the floor above, because the load on the upper floor moves to a flat slab system on the ground floor of the building. The irregular building structure did not collapse after the removal of the column. In general, if the structures are designed and detailed with an adequate level of continuity, redundancy, and ductility can develop alternative load paths which in return prevents the loss of an individual member and prevent progressive collapse

ACKNOWLEDGEMENT

The authors acknowledge my project guide Dr Atul. B. Pujari, Associate professor in Civil Engineering, KJ's Educational Institute KJ College of Engineering and Management Research Pune, Maharashtra, India for providing the necessary facilities and guidance for the completion of this research work.

REFERENCES

[1] GSA, Design guidelines for new federal Office building and major modernization projects, Progressive Collapse Analysis, The US general service administration, 2016.

[2] UFC, Unified Facilities Criteria (UFC), Design of building to resist progressive collapse. The USA Department Of Defense.

[3] Sivq naveen, Nimmy Mariam Abraham, anitha kumara.,(2018) "Analysis of irregular structure under earthquack loads" Ravindra nagar, Vinay Agrawal, Suyash Garge., (2020) "progressive collapse behavior of reinforced concrete flat slab building subject to column failure in different storys"

[4] Zabihullah, Priyanka singh, Mohammad zamir., (2020) "Effects of (vertical and horizontal) geometrical irregularities on seismic response of rc structures"

[5] suyash Garg, Vinay Agarwal, Ravindra nagar., (2021) " Sustainability assessment of methods to prevent progressive collapse of rc flat slab building"

[6] Suyash Garg, Vinay Agrawal and Ravindra Nagar "Improved progressive collapse resistance of irregular reinforced concrete flat slab buildings under different corner column failures"

[7] P. olmati, J. sagseta, D.cormie, A.E.K. jones., (2016) "Simplified realibility analysis of punching in reinforced concrete flat slab building under accidental actions"

[8] D. z. yankelevsky, Y.s.karinski, V.r.feldgun., (2020) "Dynamic punching shear failure of rc flat slab column connection under collapse slab impact"

[9] Silpa g, Yamini sreevalli., (2020) "A review of progressive collapse of reinforced concrete flat slab structure"

[10] Justin M Russell , John S Owen and Iman Hajirasouliha ., (2018) "Nonlinear behavior of reinforced concrete flat slab after a column loss event"

[11] S. M. Marjanishvili, P.E., M. ASCE., (2013) " Progresive analysis procedure for progressive collapse"

[12] Dario Coronelli a, Marco Lamperti Tornaghi b, Luca Martinelli a, Francisco-Javier Molina b, Aurelio Muttoni….etc and all., (2021) "testing of full scale flat slab building for gravity and lateral loads"

[13] Saeed Sarvari, M. Reza Esfahani.,(2020) "an experimental study on post punching behavior of flat s

[14] Rasha T.S. Mabrouk , Amr Bakr, Hany Abdalla., (2017) " Effect of flexural and shear reinforcement on the punching behavior of reinforced concrete flat slab.

[15] Szczepan wolinski., (2017) "Robustness and vulnerability of flat slab structures Niramjan Chaudhary, nitin verma., (2020) "Seismic behavior of flat slabs in multi story buildings.

[16] J.M. Russella, J.S. Owenb , I. Hajirasoulihac., (2019) "dynamic column loss analysis of reinforced concrete flat slab"

[17] Kai Qiana , Yun-Hao Wengb , Bing Lic.,(2018) "impact of two column missing on dynamic response of rc flat slab structures"

[18] Colin gurley.,(2008) differences between progressive collapse and earthquake resistance.

[19] Khaja ateequddin, waseemsohail.,(2019) has analysed Effects of irregularity shape on flat slap multistory building under lateral loading using etabs.

[20] Users guide ETABS 2016, Integrated building design software. Computers and structures inc,Berkely 2016

[21] Is 456:2000, plain and reinforced concrete- code of practice, buero of Indian Standers, new delhi 2000

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