Analysis of Progressive Collapse of RCC Building With Blast Loading And Seismic Loading

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Abstract- *This project work presents the progressive collapse analysis of RCC building for blast and seismic loading. In structure due to the spread of local damage form element to element ultimately whole or proportionately larger structure gets collapsed in progressive collapse. Progressive collapse analysis is performed on low rise for G+4, medium rise for G+17 and high rise for G+22 building and its validation in accordance with General Services Administration 2013 Guidelines, to check Demand Capacity Ratio of a respective structure. The response of RCC framed structure under blast and seismic loading is checked in this work. Regular framed structures of G+4, G+17, G+22 are designed and analyzed using Staad proV8i SS5.Time history analysis method is used for progressive collapse analysis. Columns are removed to initiate the progressive collapse. The El Centro data is used for seismic time history analysis and for blast analysis time history load is calculated as per IS 4991.Natural frequency, storey drift ,base shear ,vertical displacement before and after column removal are calculated and Demand Capacity ratio is checked .The obtained DCR values shows that columns are safe for low rise(DCR is 1.5),Medium rise (DCR IS 1.6)and high rise building(DCR is1.9) DCR within the acceptance criteria.*

Keywords- Progressive Collapse, Demand capacity ratio, column removal, blast and seismic loading, Staad pro

I. INTRODUCTION

Progressive collapse could be a scenario wherever native failure of a primary structural element ends up in the collapse of neighboring members that, in turn, ends up in further collapse. Explosive loading became a major drawback that has got to be addressed very often. Progressive collapse happens once a structure has its loading pattern or boundary conditions modified such structural parts are loaded on far side their capability and fail. The abnormal loads initiate the progressive collapse. Modern building style and construction practices enabled one to create lighter and additional optimize structural systems with significantly lower over design characteristics. Damage to the assets, loss of life and social panic are factors that need to be reduced if the threat of terrorist action cannot be stopped. Planning the structures to be totally blast and seismic resistant is not a sensible and economically possible. But current engineering and field knowledge will enhance the new and existing building to mitigate the results of an explosions and seismic activities. The guideline U.S. General Services Administration (GSA) provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure. In this procedure, structure during this procedure, one in all the necessary vertical structural parts within the load path i.e. column, load bearing wall etc. is removed to simulate the local damage scenario and the remaining structure is checked for available alternate load path to resist the load. In this research work progressive collapse analysis on low G+4, medium G+17and high riseG+22building is performed and its validation in accordance with GSA 2013.Response of RCC frame structure under blast and seismic loading is analysed and DCR of low rise, medium rise and high rise building for blast and seismic loading according with GSA 2013 is find out. Time history analysis is done in Staad pro to analyse the different parameters in progressive collapse.

AIM

To Study progressive collapse analysis Of RCC low, medium and high rise building during progressive collapse with blast and seismic loading using stadd pro.

II. OBJECTIVES

- To perform progressive collapse analysis on low, medium and high rise building and its validation in accordance with GSA guidelines.
- To check Response of RCC frame structure under blast and seismic loading.
- To check c/d ratio of low rise building, high rise building for different earthquake zones in according with GSA 2013.
- To check ductility of members and to check its remedial measures like Ductile detailing, base isolation etc.

- To check effect of redundancy on steel structures in progressive collapse analysis.
- To analyse the time of collapse of building.
- To determine the rescue plan zone area for safety of people.

Modelling Guidance as per GSA

a)General:

The analytic model(s) used in assessing the potential for progressive collapse should be modeled as accurately as possible to the anticipated or existing conditions. This includes all material properties, design details, etc. In addition, the analyst shall realistically approximate the type of boundary conditions (e.g., fixed, simple, etc.), and should be aware of any limitations or anomalies of the software package(s) being used to perform the limitatio

b) Vertical Element Removal :

The vertical element (i.e., the column, bearing wall, etc.) that is removed should be removed instantaneously. While the speed at which an element is removed has no impact on a static analysis, the speed at which an element is removed in a dynamic analysis may have a significant impact on the response of the structure. Because of this, it is recommended for the case where a dynamic analysis is performed, the vertical supporting element should be removed over a time period that is no more than 1/10 of the period associated with the structural response mode for the vertical element removal.

c) Linear Static Methods

The loading is taken as per G.S.A guidelines that is [DL+ 0.25LL] for before removal case and 2[DL + 0.25 LL] forafter removal case. The design has been done as per IS: 456 code.Where,DL = Self weight and LL = Live load

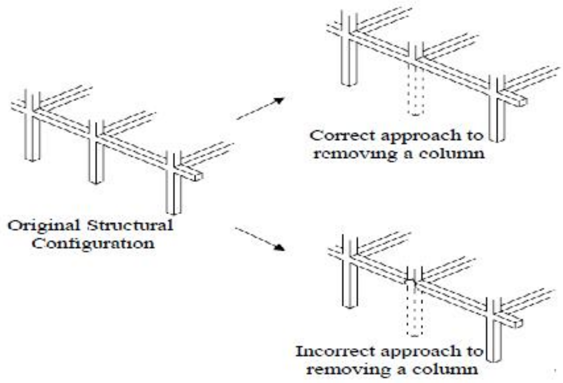
d) Demand Capacity Ratio Value

According to G.S.A structural member are said to be safe or unsafe based on DCR value. The members are safe if the DCR value is within the specified limit or else it is unsafe.DCR is ratio of the structural member force after the sudden removal of a column to the member strength (capacity).

According to G.S.A, the permissible value of DCR value is limited to 1.5 for low rise buildings, 1.6 for medium rise building and 1.9 for high rise buildings.

e) Sketch of correct and incorrect approach of removing a column

Also the vertical element removal shall consist of the removal of the vertical element only. This removal should not impede into the connection/joint or horizontal elements that areattached to the vertical element at the floor levels.



Removal of column for blast loading

III. MODELLING

Dynamic analysis using the time history analysis calculates the underground structure responses at discrete time steps using discretized record of synthetic time history as base motion. Time history analysis is the study of the dynamic response of the structure at every addition of time, when its base is exposed to a particular ground motion. The blast wave parameter is calculated by IS 4991 and for seismic base shear IS1893-2002 code is used. DCR is the ratio of Member force to the Member strength. Acceptance criteria as per GSA guidelines(1.5 for typical building, 2 for a typical building.)

The space frame building is modelled in STAAD-Pro. The beams and columns are modelled as beam elements and the slab is modelled as a plate element Computer modelling of the buildings is performed using the finite element software STAAD-Pro (Non-linear). The beams and columns are modelled as frame elements and the slab is modelled as a shell element. The bottom of the frame is fixed. The diaphragm action is considered at every floor level. The beams and columns are properly connected using the end offsets provision .Here the models are loaded with blast and seismic load 3D model of the frame building is done using Staad-pro. Time-history analysis is used to determine the dynamic response of a structure to arbitrary loading. The blast loading is carried out as per IS4991[5] and seismic loading is carried out as per IS:1893[6].The basic wind speed is 55m/s,buildings are situated in Zone V,Soil type isIII. For most real structures which contain stiff elements, a very small time step is required to obtain a stable solution. Reducing the integration time step will increase the accuracy, and generally a time step size which is less than 0.01 times the dominating period is selected. The non-linear direct integration time history analyses are run for a duration of 2swith 2000 time steps for all the buildings, and encompassed one cycle of structural response. In blast loading C4type explosive is used.C4 i.e. composition C-4is a type of plastic explosive family of chemical explosive. This C4 group is taken, since terrorist groups have used C4 type in terrorist attacks as it is very stable and insensitive to most physical shocks.

Model specifications of G+4, G+17, G+22 storey building are shown in table 1 as below:

TABLE 1
Specifications of G+4, G+17, and G+22 storey building

Specifications	G+4	G+17	G+22
Beam size	230×500mm	230×500 mm	230×500 mm
Column size	230×600 mm	Up to 4th floor 230×450 mm. 4th floor to 7thfloor 230×420 mm 7th floor to 10thfloor 230×400 mm 11th floor to 17th floor 230×380 mm	Up to 4th floor 230×450 mm 4th floor to 7th floor 230×420 mm 7th floor to 10th floor 230×400 mm 11th floor to 22th floor 230×380 mm
Slab thickness	150 mm	150 mm	150 mm
Storey height	3 m	3m	3m
Grade of Concrete	M25	M25	M25
Explosive Type	C4	C4	C4

3D view ofmodels of G+4 storey low rise, G+17 storey medium rise and G+22 storey high rise building are shown in figure 1(a), 1(b) and 1(c) respectively.

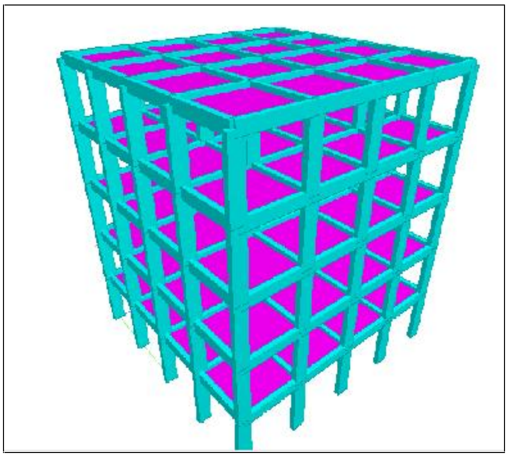


Fig1(a)G+4 storey

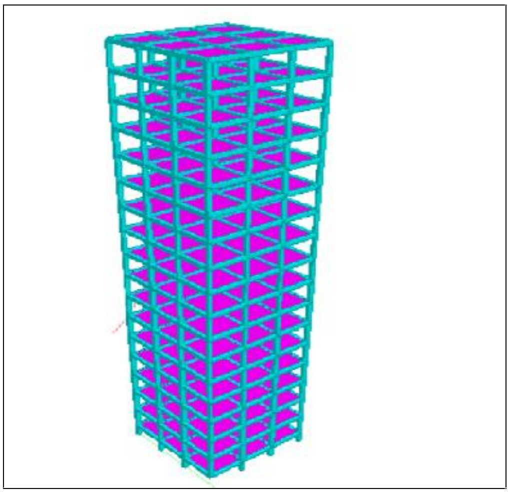


Fig1(b)G+17 storey

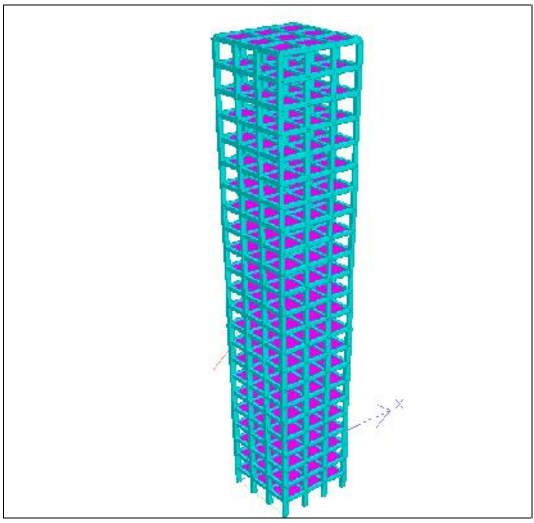
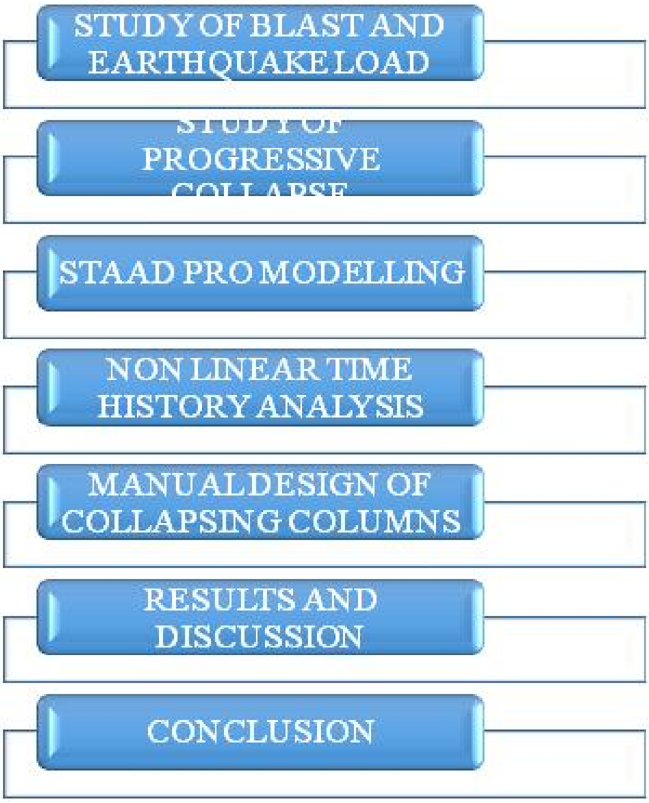


Fig1(c)G+22 storey

IV. METHODOLOGY

The methodology flow chart of progressive collapse analysis is as below:



To analyze high rise steel structure for blast loading, we have to make model of high rise steel structure using Stadd-pro software which can resist all types of loading such as dead load, live load, seismic load, using IS800-2000 and IS1893. The following parameters are to be checked after analysis of blast loading on structure, Demand Capacity Ratio (D.C.R.). Bending moments.(B.M). Shear Force.(S.F). deflection. story drift. Loading due to blast will not be linear as intensity of loading depends on various criteria so for analysis of structure Non-Linear dynamic analysis is to be done. The blast is applied in X direction. The total column-beam joints are on the front face of building. The forces due to blast loading should be applied to the buildings as triangular loading functions calculated separately for each joint of the front face of the building, taking into account the distance to each joint from the source of explosion. Once the reflected pressure at each beam-column joint is calculated it should be multiplied with Tributary area to get the peak load at that joint. Positive time duration can also be find out, now we can generate the Load-Time history of each joint as input STAAD-Pro. The response of building with and without soft storey in terms of displacement, velocity and acceleration will be obtained.

The step-by-step procedure for conducting the linear elastic, static analysis for progressive collapse as per GSA is as follows.

A) System Development

Step 1. Remove a vertical support from the location being considered and conduct a linear-static analysis of the structure as indicated in Section 4.1.2.2. Load the model with 2(DL + 0.25LL).

Step2. Determine which members and connections have DCR values that exceed the acceptance criteria. If the DCR for any member end connection is exceeded based upon shear force, the member is to be considered a failed member. In addition, if the flexural DCR values for both ends of a member or its connections, as well as the span itself, are exceeded (creating a three hinged failure mechanism. the member is to be considered a failed member. Failed members should be removed from the model, and all dead and live loads associated with it.

Step 3. For a member or connection whose Q_{UD}/Q_{CE} ratio exceeds the applicable flexural DCR values, place a hinge at the member end or connection to release the moment. This hinge should be located at the center of flexural yielding for the member or connection. Use rigid offsets and/or stub members from the connecting member as needed to model the hinge in the proper location. For yielding at the end of a member the center of flexural yielding should not be taken to be more than ½ the depth of the member from the face of the intersecting member, which is usually a column

Step 4. At each inserted hinge, apply equal-but-opposite moments to the stub/offset and member end to each side of the hinge. The magnitude of the moments should equal the expected flexural strength of the moment or connection, and the direction of the moments should be consistent with direction of the moments in the analysis performed in Step 1.
Step 5. Re-run the analysis and repeat Steps 1 through 4. Continue this process until no DCR values are exceeded. If moments have been re-distributed throughout the entire building and DCR values are still exceeded in areas outside of the allowable collapse region, the structure will be considered to have a high potential for progressive collapse.

B) Determination of Base Shear

The total design base shear along any principal direction shall be determined by this expression $\mathbf{V_b = A_h * W}$

Where, V_b = Base shear due to Earthquake
Ah = design horizontal seismic coefficient for a structure

W= seismic weight of building

$$A_h = \frac{ZIS_a}{2Rg}$$

Z = zone factor given in Table 2 of IS 1893:2002 (part 1) for the maximum considered earthquake (MCE) and service life of a structure in a zone. The factor 2 is to reduce the MCE to the factor for designate earthquake (DBE).

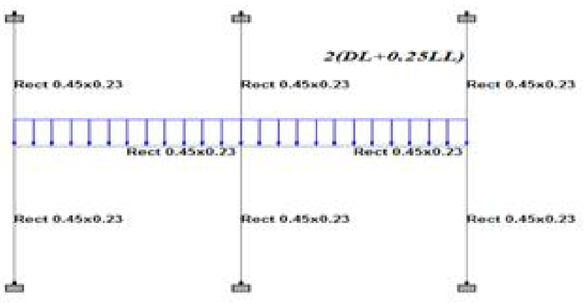
I is the importance factor, depending upon the functional use of the structure, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical or economic importance. The minimum values of importance factor are given in table 6 of IS 1893:2002.

R is the response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. The need for introducing R in base shear formula.

Sa/g is the average response acceleration coefficient for rock and soil sites as given in IS 1893:2002 (part 1). The values are given for 5 % of damping of the structure.

C) Verification of GSA guidelines for vertical loads

Column size-0.23*0.45M,Span of beam-5M,Span of column-5M,No of bay's-2no
Beam size -0.23*0.45M,Load combination as per GSA
Sol-DL=
(25*0.23*0.45)*2=5.6,L.L=2*0.25*3=1.5,TOTAL=6.66KN
Now we know that, Demand=wl^2/8=(6.66*5^2)/8 =20.81KN



Loading diagram frame

Considering simply support. But by GSA rule,DCR= Q_{UD}/Q_{CE}
Q_{UD} = Acting force (demand) determined in component or connection/joint (moment, axial force, shear, and possible combined forces)

Q_{CE} = Expected ultimate, un-factored capacity of the component and/or connection/joint (moment, axial force, shear and possible combined forces)
= (20.81/15.02)=1.38

Therefore,DCR<1.5for atypical structural configurations Hence ok.

D) Comparative Studyofportalframebeforeandafter collapse

Comparative study of portal frame before and after collapse is as follows

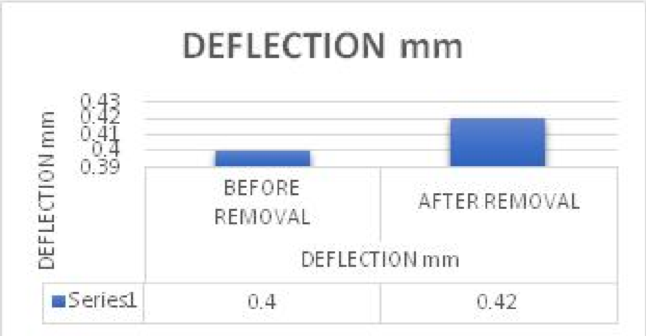


Fig 2(a) Deflection comparison

From the above graph the deflection of frame before removal of column is up to 0.44 mm and after removal is up to 0.42 mm, deflection after removal greater than before removal.

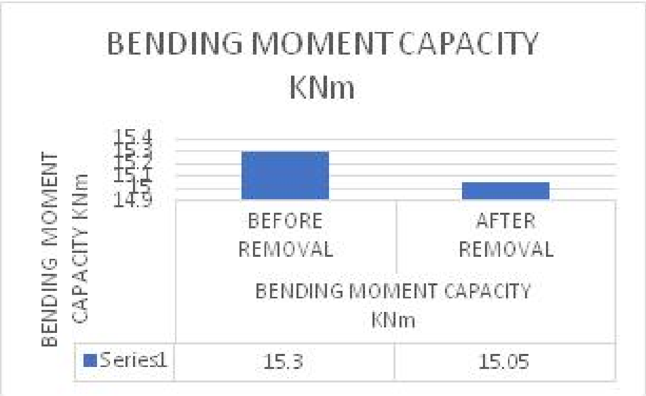


Fig 2(b) Bending Moment capacity comparison

From the above graph the Bendingof frame before removal of column is up to 15.3 and after removal is up to 15.05, Bending after removal smaller than before removal.

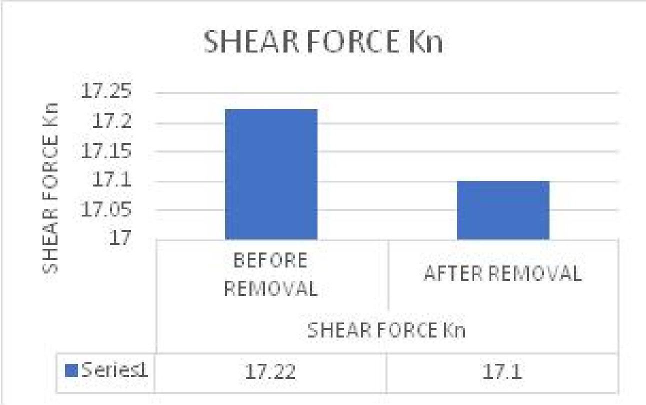


Fig 2(c) Shear Force comparison

From the above graph the Shear force of frame before removal of column is up to 17.22 and after removal is up to 17.1, Shear force after removal smaller than before removal.

E) Concluding remarks of comparison

In this report the GSA guidelines of progressive collapse report is analyzed for a low rise structure for RCC structure. For Analysis purpose FEM tool STAAD-Pro is used and following conclusions are drawn.

- Capacity demand ratio criteria is satisfied for model therefore no need to revise design.
- After removing internal column the deflection is increased by 13%.
- After removing internal column the bending moment capacity is decreased by 5% which is in permissible limit.
- After removing internal column shear stress capacity is decreased by 3% which is in permissible limits.

V. RESULTS

The result values of storey drift, naturalfrequency and base shear along with their maximum values comparison are shown in below tables:

TABLE 2 (storey drift)
Summary of results for Storey Drift of G+4,G+17,G+22 Building models:

Storey no.	Storey Drift G+4		Storey Drift G+17		Storey Drift G+22	
	Before removal of column	After removal of column	Before removal of column	After removal of column	Before removal of column	After removal of column
0	0	0	0	0	0	0
1	1.54	1.54	1.771	1.9712	1.925	2.079
2	6.16	6.17	7.084	7.8976	7.7	8.3295
3	13.87	13.89	15.9505	17.7792	17.3375	18.7515
4	24.66	24.7	28.359	31.616	30.825	33.345
5	34.35	34.4	39.5025	44.032	42.9375	46.44

TABLE 3 (Base shear)
Summary of results for base shearof G+4,G+17,G+22 building models

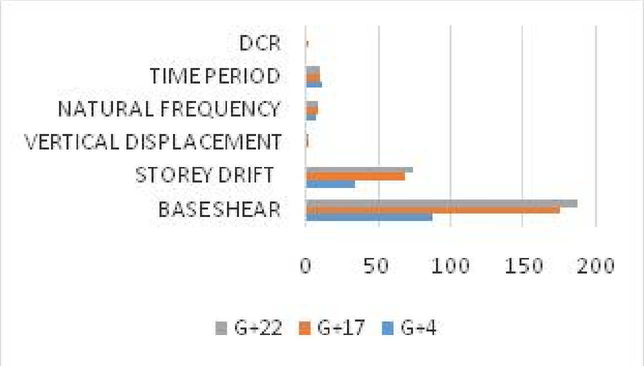
Storey no.	Base Shear G+4		Base Shear G+17		Base Shear G+22	
	Before removal of column	After removal of column	Before removal of column	After removal of column	Before removal of column	After removal of column
0	0	0	0	0	0	0
1	3.91	3.934	4.4965	4.9175	4.8093	5.7043
2	15.709	15.736	18.06535	19.67	19.32207	22.8172
3	35.346	35.405	40.6479	44.25625	43.47558	51.33725
4	62.838	62.942	72.2637	78.6775	77.29074	91.2659
5	87.513	87.658	100.64	109.5725	107.641	127.1041

TABLE 4 (Natural frequency)
Summary of results for Natural frequencyof G+4, G+17,G+22 building models

Mode	NATURAL FREQUENCY G+4		NATURAL FREQUENCY G+17		NATURAL FREQUENCY G+22	
	Before removal of column	After removal of column	Before removal of column	After removal of column	Before removal of column	After removal of column
1	2.166	2.28	2.0565	2.508	2.071	2.622
2	2.711	2.854	2.574	3.139	2.592	3.282
3	2.717	2.86	2.579	3.146	2.598	3.289
4	6.352	6.687	6.0316	7.355	6.075	7.690
5	6.623	6.972	6.288	7.6692	6.334	8.017
6	8.152	8.582	7.740	9.4402	7.796	9.869

TABLE5

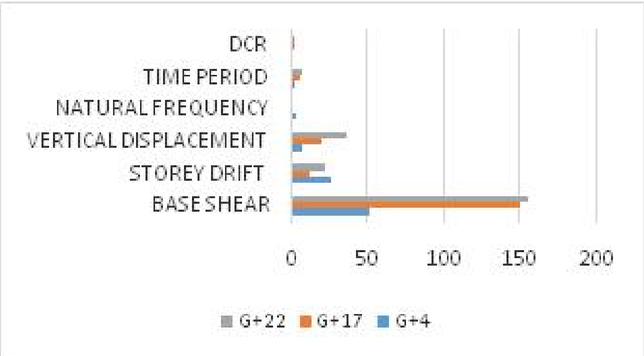
Summary of maximum values of different parameters of G+4,G+17,G+22 storey buildingmodels with blast loading.



Model	G+4	G+17	G+22
Base shear	87.513	174.753	186.91
Storey drift	34.35	68.58	74.55
Vertical displacement	1.747	2.5	3.1
Natural frequency	8.582	9.44	9.86
Time period	11.7	10.5	10.1
DCR	1.5	1.6	1.9

TABLE 6

Summary of maximum values of different parameters of G+4,G+17,G+22 storey building models with seismic loading



Model	G+4	G+17	G+22
Base shear	51.37	149.326	155.29
Storey drift	26	13	23
Vertical displacement	7.4	20	36.7
Natural frequency	4.017	1.749	1.34
Time period	2.5	5.72	7.6
DCR	1.5	1.9	1.4

Discussion of results

In this paper GSA 2013 guideline code is used for progressive collapse analysis. Step by step procedure of column removal is done and DCR is checked for low, medium and high rise building. DCR value, Storey drift, Base Shear, Time period, Natural frequency is compared for G+4, G+17, G+22 for seismic analysis and blast load analysis. For seismic analysis the column from extreme left i.e. plinth level first column is removed and it is observed that low rise (G+4) medium rise(G+17) and high rise(G+22) building are safe. However, for blast load analysis the columns for maximum load is removed and it is observed that low rise(G+4),medium rise and high rise(G+22) building are safe same as seismic load analysis as DCR ratio is within the acceptance criteria(DCR<2) which is given in GSA 2013 guideline.

VI. CONCLUSIONS

From non-linear dynamic analysis of building subjected to blast load before column removal and after column following conclusions are drawn.

1. column removals have significant effect on blast performance of buildings.
2. For G+4 100 kg TNT, due to column removal there is 40.82%, 36.10% & 27.83% increase in displacement, velocity and acceleration respectively.
3. For G+4 200 kg TNT, due to column removal there is 44.96%, 32.87% & 23.03% increase in displacement, velocity and acceleration respectively.
4. For G+4 300 kg TNT, due to column removal there is 44.44%, 31.6% & 21.558% increase in displacement, velocity and acceleration respectively.
5. For G+4 400 kg TNT, due to column removal there is 44.186%, 31.24% & 21.51% increase in displacement, velocity and acceleration respectively.
6. For G+17 100 kg TNT, due to column removal there is 17.82%, 16.25% & 14.23% increase in displacement, velocity and acceleration respectively.

7. For G+17 200 kg TNT, due to column removal there is 18.92%, 17.1% & 15.5% increase in displacement, velocity and acceleration respectively.
8. For G+17 300 kg TNT, due to column removal there is 19.4%, 18.2% & 21.58% increase in displacement, velocity and acceleration respectively.
9. For G+17 400 kg TNT, due to column removal there is 21.2%, 19.4% & 22.4% increase in displacement, velocity and acceleration respectively.
10. For G+22 100 kg TNT, due to column removal there is 15.20%, 15.30% &13.15% increase in displacement, velocity and acceleration respectively.
11. For G+22 200 kg TNT, due to column removal there is 17.84%, 15.63% & 14.25% increase in displacement, velocity and acceleration respectively.
12. For G+22 300 kg TNT, due to column removal there is 18.54%, 16.59% & 20.35% increase in displacement, velocity and acceleration respectively.
13. For G+22 400 kg TNT, due to column removal there is 20.26%, 17.56% & 21.35% increase in displacement, velocity and acceleration respectively.
14. DCR ratio in all cases is less than by 2 hence sections need not to be redesigned considering blast load and seismic load.
15. While comparing base shear, storey drift and vertical displacement the amplitude due to removal of column increased by 25-30% for shear, storey drift and vertical displacement because stiffness of structure decreased due to removal of column.
16. For low rise building the difference after column removal is more than that of high rise building as high rise building will have more stiffness.

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