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Study of Progressive Collapse Analysis of RCC Irregular Building

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Abstract: Progressive collapse is a series of failures that spread beyond the original local breakdown, either over the entire building or just a part of it. Buildings intended to withstand seismic events have good robustness against progressive collapse, according to study on the failure of structures due to progressive collapse. To evaluate its robustness, however, no in-depth studies have been done so far. So, the purpose of this research is to examine the potential resistance to progressive collapse of buildings with seismic design. In the present study High rise R.C.C. irregular building with different types of irregularities has been analyzed with and without removal of column to find out critical column. The study is done with the aid of the commercial software ETABS. Various seismic parameters like maxi-mum lateral displacement, story drift ratio, time period, overturning moment etc. has been compared.

***Index Terms* - Progressive collapse, Irregularity, Response spectrum analysis, ETABS, Soft story, Floating column Introduction**

I. INTRODUCTION

Progressive type collapse is a condition in which a primary structure's locally failing components, such as columns, cause the collapse of the entire structure. When a building structure has its own loading arrangement adjusted in such a way that structural parts fail as a result of loading above their capacity, this is known as a progressive-type collapse. The top structure's weight is transferred to nearby structural components when a column fails. That portion of the structure fails if these components are improperly built to disperse the additional impact load. Unless additional loading is dissipated, the structure's load-bearing components, like columns, fail. As a result, nearby sections of the building also collapsed, doing greater damage to it than the earlier catastrophe. The analytical method for progressive failure is based on the alternate load path technique, which is advised in the design and analysis standards. Since it forms the basis for the analysis of progressive type collapse, the demand capacity ratio is a critical factor in this scenario. In this thesis, it is determined if a progressive form of collapse will occur or not based on the relationship between the beam's bending moment and its unfactored moment carrying capacity.

Numerous academic articles have been written on the structure's gradual collapse. Finding cures for progressive-type collapse is the goal of research on it. The contractors renovate buildings without first examining the structure; this is a modern issue with significant political and social significance. Since most Indian structures are located in densely populated areas, it is crucial to understand progressive-type col-lapse. A lack of knowledge about the analysis and design of structures or errors in the architects' planning are to blame for many of the structures that have collapsed over the previous 40 years. The study of the subject is crucial if you want to avoid all of these. Buildings with soft floors have been built in the last several years in response to consumer demand. Although it makes parking easier, it also makes the building more vulnerable. The use of this kind of structure is not advised by structural engineers. Any car could crash into the column while being parked, and the column could then collapse. This is extremely risky because when a column element fails, the building collapses whole, whereas when a beam element fails, the structure collapses locally. When one column fails, the pattern of loading shifts, overloading the neighbouring structural components, ultimately leading to the collapse of the building structure.

The entire planet is also at risk from terrorist assaults. A partial or complete break-down of the structure may result from a terrorist strike on the crucial column. In this instance, the collapse of one column instigates a chain reaction that finally results in the collapse of the entire structure. Progressive type collapse is the phrase used to describe the collapse of a whole structure or a significant portion of it as a result of the loss or failure of a relatively small portion of it. An uneven structural collapse is referred to as a "uneven collapse" because of how it relates to the source of the col-lapse. The minor structural component fails, causing the building structure to fall more massively and violently. This causes a different reaction, which causes further structural components to fail. A progressive sort of collapse is typically brought on by a variety of events. To meet the needs of modern society, structural engineers design and develop infrastructure and structures using their knowledge. Structures must be built to handle typical loads brought on by things like self-weight, human habitation, wind, earthquakes, and other loading events, according to building codes.

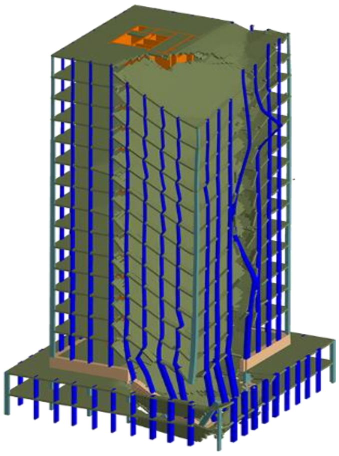

Fig. 1. Progressive Collapse of RCC building

II. RELATED WORK

Hamid Mirzahosseini et. al. (2023) studied the analyses and calculated robustness indices indicated that using HPFRCCs materials in beam-column joints significantly improved the robustness of concrete moment frames subject to progressive collapse. Furthermore, the damage distribution based on plastic rotation results confirmed that the robustness of concrete moment frames with HPFRCC joints subjected to progres-sive collapse was significantly improved. [1]

Hrushikesh Baisane, Prof. L.R. Wankhade (2022) focused on the determination and quantification of Contribution of RC shear walls to energy-based collapse. Their main aim is to enhance the analysis of progressive collapse performance of regular and irregular composite structures using by providing Shear wall. They found out that the lateral displacements or drifts were more in without shear wall structure when compared to the with shear wall structure. Also found that from the base reactions of structure obtained in the story shear is higher in simple structure than in shear wall structure. [2]

M. Vinay et. al. (2022) considered research work 10 storey regular Reinforced Concrete framed structure and was seismically designed with IS 1893:2016 in SAP2000 version 20 modeling. . They compared numerical results by analyzing col-umns and beams separately by calculating demand capacity ratios and the require-ment of percentage of steel for failed structural elements are predicted both in flexure and shear stresses. The failed structural elements were re-designed to resist progressive collapse in order to satisfy the acceptance criteria recommended by the guidelines. They showed that the incorporation of perimeter beams in buildings improved the progressive collapse resistance as it reduces joint displacement and chord rotation at column removal locations by providing sufficient stiffness and load paths for in-creased gravity loads. They concluded that results can be used to develop and cali-brate the nonlinear numerical model for analyzing high-rise building progressive col-lapse behavior and can help provide information that may improve new and existing reinforced concrete core-wall building robustness against progressive collapse. [3]

Sidi Shan, Wei Pan (2022) investigated the structural robustness of multi-story steel-framed modular structures against progressive collapse by using pushdown analysis. A six-story structure with five modules per floor was designed and estab-lished. The applied load, failure process and load redistribution mechanisms were studied under module removal scenarios. Parametric analyses were also conducted to investigate influences of cross-sectional dimensions of frame members, number of stories and bays, arrangements of bracings, and module removal scenarios on the robustness of the modular structures. Their results showed that the prototype modular structure designed with Hong Kong design code can withstand collapse under module removal scenarios. The load redistribution mechanisms among columns were signifi-cantly influenced by the overturning action and bracing effects. The ceiling beam in the lower module and the floor beam in the upper module form a double beam sys-tem. The column section, beam section, arrangement of bracings and number of stories significantly influence the robustness of the modular structure. [4]

P Neeraja, K Anish (2021) examined the potential ability of seismically designed buildings against Progressive Collapse and compared them with nominal model. They considered G + 12 reinforced concrete framed regular and various models of Stiffness irregular structures in their study to analyze Progressive collapse of buildings. Results of their analysis determined the intensity of structural damage caused under column removal. Calculation of DCR'S of the beam elements in critical region associated with column removal seems to fail both in Flexure and Shear. [5]

Divyansh Singh Thakur, Murlidhar Chourasia (2021) have done direct static inves-tigation for dynamic breakdown opposition assessment of a 12 storey RC building for four column removal case namely corner, short edge, long edge and interior as per GSA 2013. Column has been removed at ground floor and DCR proportions for Beams in flexure just as shear and PMM values sections were assessed and intro-duced as bar diagrams. They found out that Interior column removal case was the most critical (since values of PMM are nearer to limiting value i.e. 2.0) and corner column removal case was least critical. [6]

Ahmad Shehada et. al. (2021) discussed the resistance of RC framed structure to progressive collapse due to column exclusion from the viewpoint of numerical model-ling issues using fibre element approach. The numerical results using fibre element approach were compared with a reported database of ten test RC framed buildings. Their study showed that developing a simple numerical model, as an alternative to destructive tests, based on the fibre element approach with few elements and proper-ly selected model parameters to adjust can accurately predict the resistance of struc-tures subjected to interior column removal with minimal computational time and effort, and can be utilized in lieu of performing difficult advanced geometric and material nonlinear finite element computations. [7]

Andrey Nikolaevich Dmitriev and Vladimir Vladimirovich Lalin (2021) study is mainly based on the methods outlined in the current Russian standard (linear static (LS) pulldown, nonlinear static (ND) pulldown, and nonlinear dynamic), but also includes LS and NS pushdown procedures suggested by the American guidelines and linear dynamic procedure. They found that correct results for both RC structures can only be found using a nonlinear dynamic procedure, and the mismatch with the test data do not exceed

7%. Compared to static pulldown methods, LS and NS pushdown methods are more accurate and differ from the experiment by 28% and 14%, respec-tively. This relative accuracy is provided by more correct load multipliers depending on the structure type. [8]

Mayank Sundriyal, Vinaykumar C H (2020) had checked the resistance of a cho-sen building model to the phenomenon of Progressive Collapse as per the new GSA 2016 guidelines. They investigated the potential of progressive collapse by perform-ing Linear Static Analysis on the chosen RCC structure. The chosen structure was subjected to Indian Standard Loading as per IS 875 & IS 1893 both the central & edge column of the shorter side of the structure with the help of FEM software ETABS. The static analysis revealed the Resistance of the structure to Progressive Collapse. The structure had been checked for Force and Deformation Controlled actions as well as for the Redundancy requirements of location, strength and Stiff-ness.3. Accordingly Alternate Load path. They concluded that after removal of a particular column load redistribution took place within the structure with maximum Load redistributing to the adjacent columns and this redistribution of load decreases as we move up to higher stories. Maximum load got redistributed to the column which was closest to the removed column. DCR for Columns decreases as they go higher storey wise. Damage due to progressive Collapse is localized and restricted to the bays immediately surrounding the removed column and varies across the height of the building for different cases. [9]

2.1 Objectives of Investigation

1. To review the strength of structure with seismic load for progressive collapse for different types of irregularities.
2. To study the result of unexpected removal of columns on building globally.
3. To compare the effects for Steel-RCC column and RCC column for progressive collapse.
4. To suggest the suitable remedies for irregular building due to progressive col-lapse.

III. METHODOLOGY

For the current study, earthquake analysis is conducted for RC.C. Building with 26 floors situated in seismic zone IV. The analysis is conducted using commercial soft-ware ETABS.

The subsequent cases are considered, and software models has been created ac-cordingly:

1. Removal of central RCC column
2. Removal of peripheral corner RCC column
3. Removal of peripheral center RCC column
4. Removal of central Equivalent Steel-RCC column
5. Removal of peripheral corner Equivalent Steel-RCC column
6. Removal of peripheral center Equivalent Steel-RCC column

All above cases will be studied for different types of irregularities as per IS1893 given below:

- Regular G+26 RCC building
- RCC Building with soft story (Stiffness irregularity) at ground floor.
- RCC Building with heavy loads at ground floor slab (Mass irregularity)
- RCC Building with floating columns.

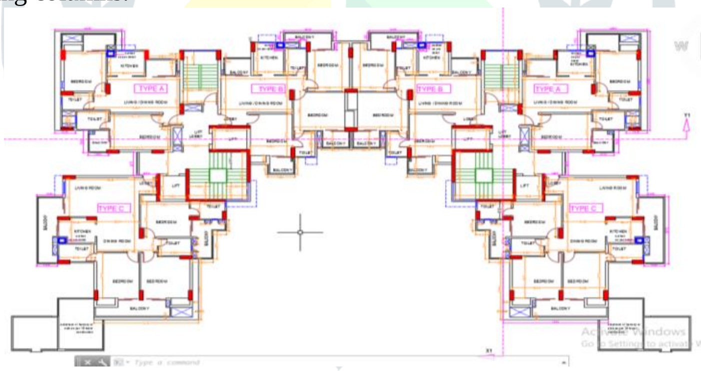

Fig. 2. Top view of the Building in AutoCAD

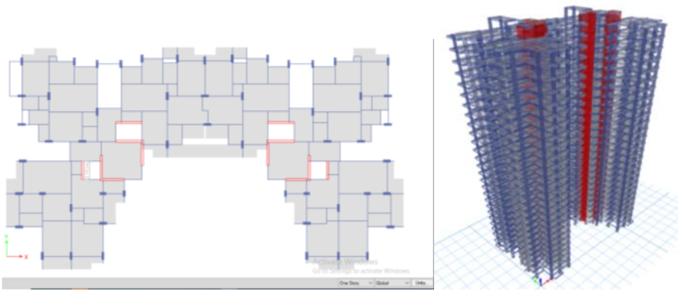

Fig. 3 top view and 3d view of the Building in ETABS

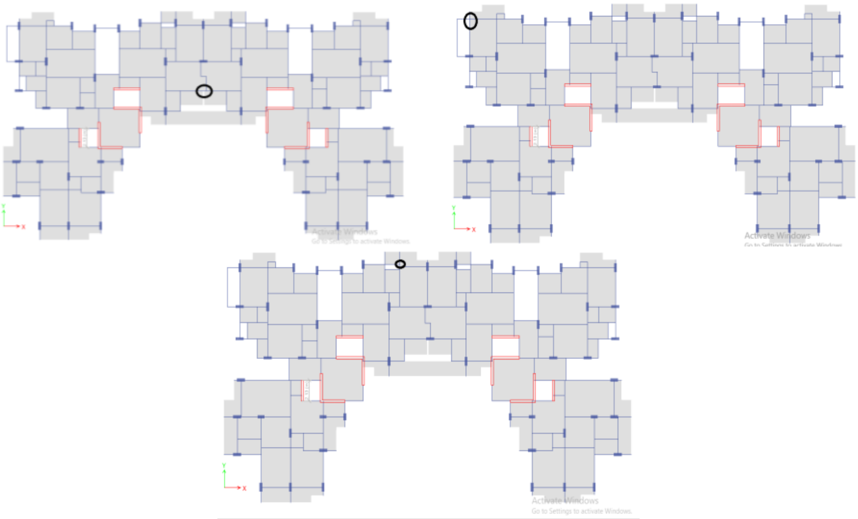

Fig. 4 Removal of columns form various positions

IV. Results and Discussions

The response spectrum analysis is conducted as stated previously and results are presented by figures.

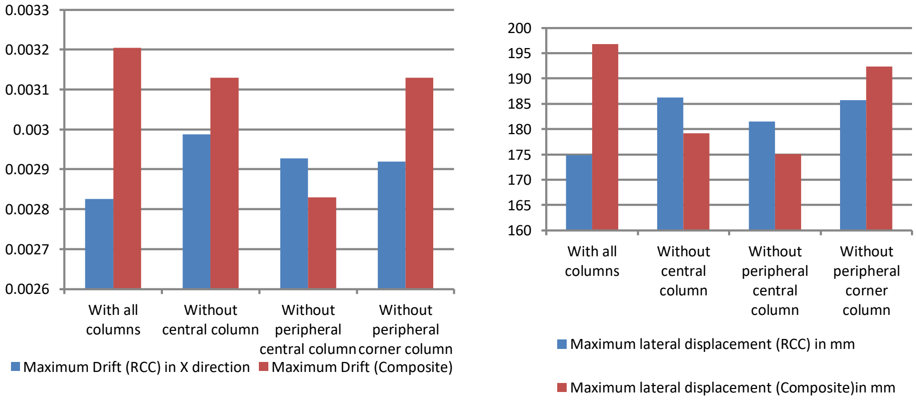

Fig. 5 Variation of maximum story drift and maximum lateral displacement for RCC Columns and with Steel-RCC Columns for regular building

According to Fig. 5, as compared to buildings with all columns, the value of story drift for typical buildings rises to about 5-6% after the removal of columns from different places, with the central column showing the greatest amount of drift. Additionally, when compared to buildings with all columns, the maximum lateral displacement for typical buildings increases by about 5-7% with the removal of columns from different positions, and greatest lateral displacement is seen when the centre column is removed.

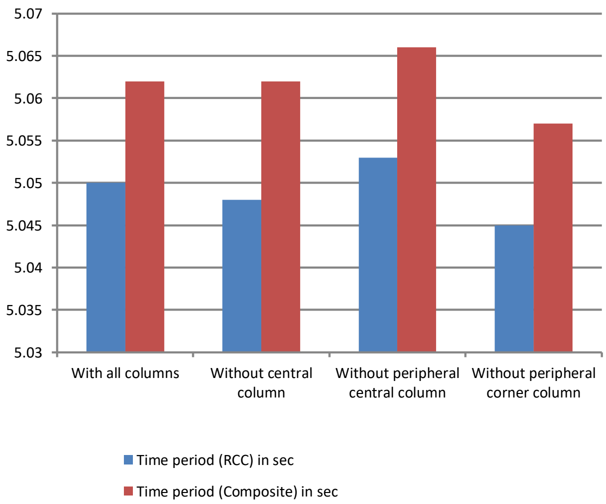

Fig. 6 Variation of maximum time period for RCC Columns and with Steel-RCC Columns for regular building

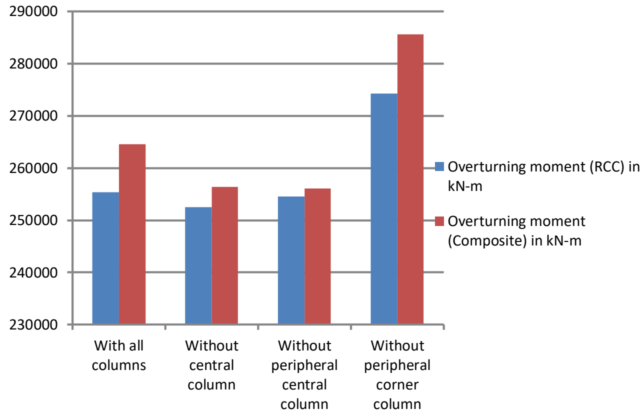

Fig. 7 Variation of maximum overturning moment for RCC Columns and with Steel-RCC Columns for regular building

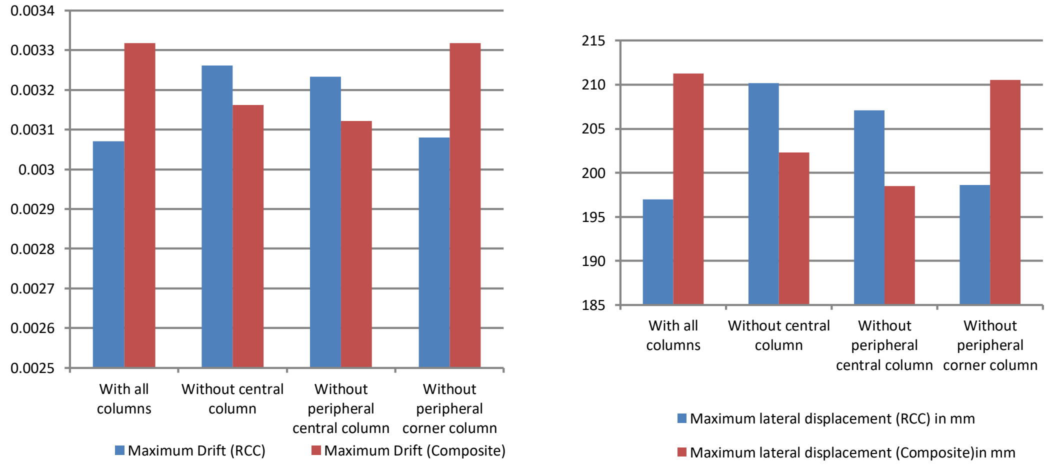

Fig. 8 Variation of maximum story drift and maximum lateral displacement for RCC Columns and with Composite Columns for irregular building with soft story

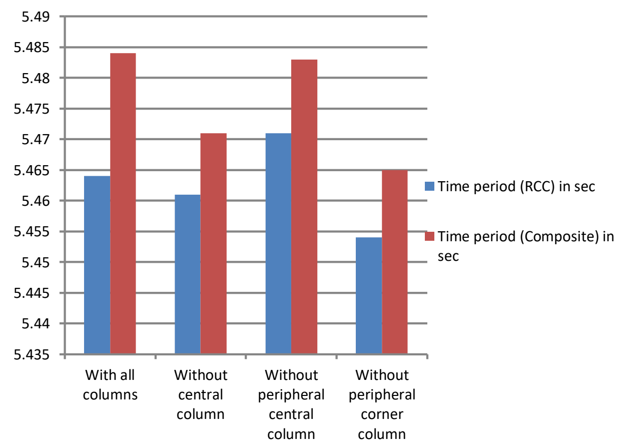

Fig. 9 Variation of maximum time period for RCC Columns and with Composite Columns for irregular building with soft story

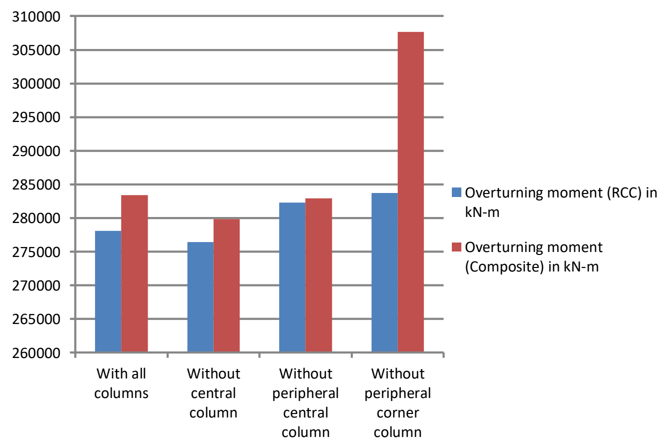

Fig. 10 Variation of maximum overturning moment for RCC Columns and with Composite Columns for irregular building with soft story

The value of the building's time period does not considerably alter following the removal of columns from various sites, according to Fig. 9. Due to a modest increase in the building's ductility, there is a slight lengthening of time in the case of structures with composite columns. Overall maximum time period increases by 15-20% in the case of soft-storey irregularities at basement level as compared to regular buildings. From Fig. 10, it is found that the value of the overturning moment is almost the same when the central column and peripheral central column are removed but increases by around 7% when the peripheral corner column is removed. There is around a 4% increase in overturning moment in the case of building with composite columns as compared to building with R.C.C. columns. Overall maximum overturning moment increases by 8–10% in the case of soft-storey irregularities at basement level as compared to a regular building.

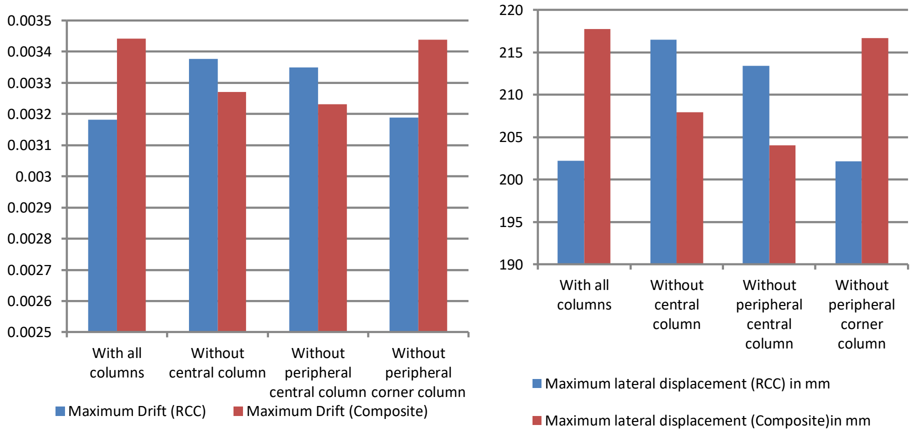

Fig. 11 Variation of maximum story drift and maximum lateral displacement for RCC Columns and with Composite Columns for irregular building with floating column

According to Fig. 11, the maximum story drift value rises to about 5-6% after columns are removed from different positions compared to a building with all columns, and the greatest drift is shown when a central column is removed. In cases with floating column abnormalities at basement level, the overall maximum story drift is increased by 15% as compared to a standard building. Maximum lateral displacement is seen when a central column is removed, and it is discovered that the value of maximum lateral displacement increases by about 5-7% after columns are removed from various locations compared to a building with all columns. Overall maximum lateral displacement increases by 17–18% in cases of floating column irregularity at basement level as compared to a regular building.

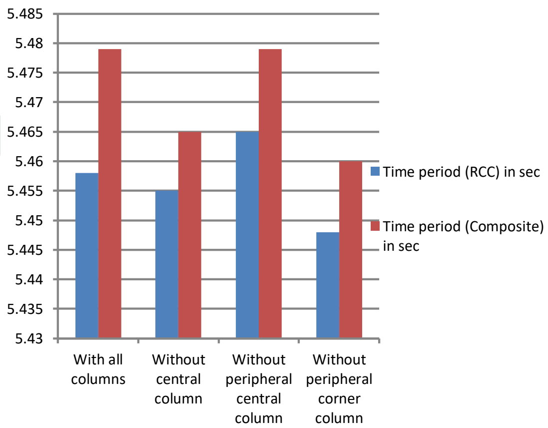

Fig. 12 Variation of maximum time period for RCC Columns and with Composite Columns for irregular building with floating column

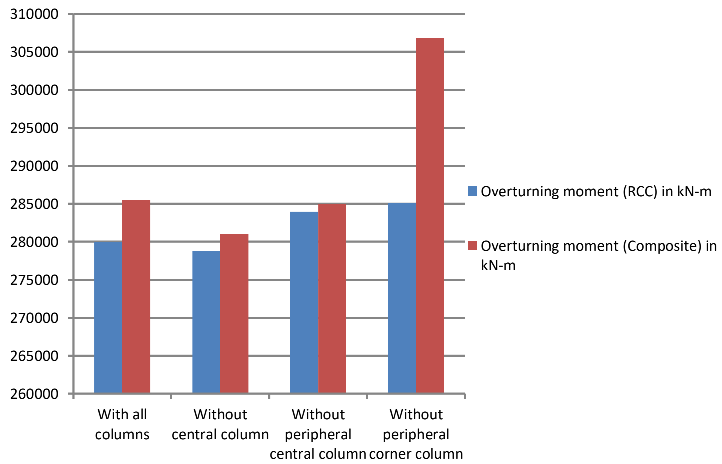

Fig. 13 Variation of maximum overturning moment for RCC Columns and with Composite Columns for irregular building with floating column

The value of the building's time period does not considerably alter following the removal of columns from various sites, according to Fig. 12. Due to a modest increase in the building's ductility, there is a slight lengthening of time in the case of structures with composite columns. Overall maximum time period increases by 12–15% in cases of floating column irregularity at basement level as compared to a regular building. From Fig. 13, it is found that the value of the overturning moment is almost the same when the central column and peripheral central column are removed but increases by around 7% when the peripheral corner column is removed. There is around a 4% increase in overturning moment in the case of building with composite columns as compared to building with R.C.C. columns. Overall maximum overturning moment increases by 9–11% in cases of floating column irregularity at basement level as compared to a regular building.

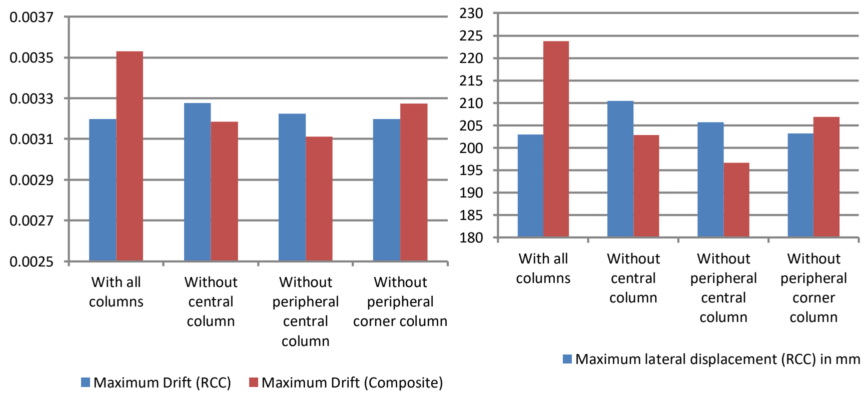

Fig. 14 Variation of maximum story drift and maximum lateral displacement for RCC Columns and with Composite Columns for irregular building with mass irregularities

According to Figure 14, the maximum story drift rises to about 5-6% after columns are removed from different positions compared to a building with all columns, and the greatest drift is shown when the centre column is removed. In situations of mass irregularity at basement level, the overall maximum story drift rises by 16–17% as compared to a regular construction. Additionally, it is discovered that when a central column is removed, maximum lateral displacement is seen. This value increases by about 5-7% after the removal of columns from various positions compared to a building with all columns. Overall maximum lateral displacement increases by 18–20% in cases of mass irregularity at basement level as compared to a regular building.

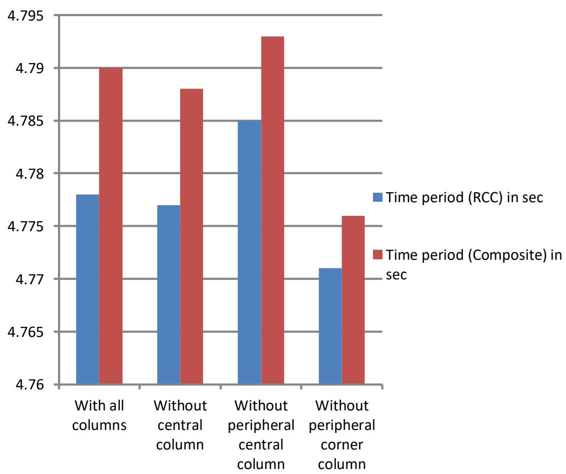

Fig. 15 Variation of maximum time period for RCC Columns and with Composite Columns for irregular building with mass irregularities

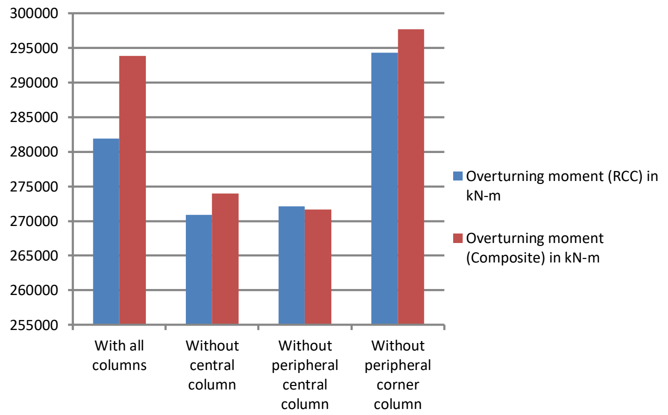

Fig. 16 Variation of maximum overturning moment for RCC Columns and with Composite Columns for irregular building with mass irregularities

The value of the building's time period does not considerably alter following the removal of columns from different sites, according to Fig. 15. Due to a modest increase in the building's ductility, there is a slight lengthening of time in the case of structures with composite columns. Overall maximum time period is reduced by 20–25% in cases of mass irregularity at basement level as compared to a regular building. From Fig. 16, it is found that the value of the overturning moment is almost the same when the central column and peripheral central column are removed but increases by around 7% when the peripheral corner column is removed. There is around a 4% increase in overturning moment in the case of building with composite columns as compared to building with R.C.C. columns. Overall, the maximum overturning moment increases by 9–11% in cases of mass irregularity at basement level as compared to a regular building.

V. Conclusion

According to the findings, story drift value increases after columns are removed from various positions, but this increase is contained within a limited range and won't result in the collapse of the structure as a whole. Composite columns instead of RCC columns have varied effects; for all columns and for peripheral corner columns removed, case story drift increases, and for centre columns and peripheral central columns removed, case story drift decreases with composite columns. Irregular buildings with mass irregularities and floating column story drift have the maximum drift as compared to regular buildings with soft story irregularities. From the results, after removing columns from various positions, it is discovered that the maximum lateral displacement value increases. However, this increase is only 10%, meaning that the building won't collapse as a whole. Composite columns instead of RCC columns have varied effects; for all columns and for peripheral corner columns removed, maximum lateral displacement increases, and for centre columns and peripheral central columns removed, maximum lateral displacement decreases with composite columns. Buildings with mass irregularities and floating columns have maximum lateral displacement as compared to regular buildings and buildings with soft-story irregularities. It is also found out that the value of the maximum time period after the removal of columns at different locations does not change much. The time period of the buildings changes drastically for floating column and soft story irregular buildings as compared to regular buildings, with a maximum 10-12% increase for buildings with soft story irregularities. The time period for building with mass irregularities decreases by approximately 5–7%. There is very little change of 1-2% with composite column cases as compared to RCC columns, and It is discovered that removing a column from a peripheral corner greatly raises the value of the overturning moment, necessitating strengthening of the foundation structure to lessen the building's overturning. There is an increase of 7–10% in overturning moments for buildings with irregularities as compared to regular buildings. There is a slight increase of 2–3% in overturning moment with composite column cases as compared to RCC column cases due to the increase in weight of the member. The removal of columns from different locations should generally cause local failure, not global failure. Results from the above study show that there is a significant increase in bending moment, shear force, and deflection in surrounding beams due to the removal of columns. So proper retrofitting should be done in that area to make it serviceable again for public use. There is no significant effect on the local building due to the irregularity of the building.

VI. Recommendations

Identifying the critical location of the building and local strengthening of that area by adding steel girders Shear walls can be used to control the global effect of the removal of any local column. Also, steel bracing can be used to reduce the effect of lateral loading to control horizontal shear on the building, and by conducting a structural audit, the weak areas of the building should be identified and preventive measures taken in advance.

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