JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Comparative study of different flat slab structures under progressive collapse

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Abstract: Flat slabs system of construction is one in which beams are not present. The slab directly rests on the column and load from the slab is directly transferred to the columns and then to the foundation. But absence of beam drastically affects the strength of structure, this results in reduction in serviceability. To overcome this, various arrangements are introduced in flat slab system and analysed for different criteria. The initial local failure propagates disproportionately from component to component, eventually leading to the collapse of the entire structure this is called as Progressive Collapse. Progressive collapse occurs for many reasons, such as explosion, vehicle impact, fire, etc.

In this paper to analyse the structure for progressive collapse alternate load path method is used which is the part of direct design method as per GSA guidelines. As per alternate load path method column removal scenario is introduced at various locations in structure. ETABS software is used to model and analyse the reinforced concrete flat slab structures. After obtaining analysis results from ETABS comparative study on different parameters is carried out such as axial load, vertical displacement and demand capacity ratio of the structures. From that comparative study we concluded that using perimeter beam and drop panels helped in improving the performance of structure in Progressive Collapse condition.

Keywords: **RCC flat slab, progressive collapse, perimeter beam, ETABS**

1.INTRODUCTION:

A series of failures termed as progressive collapse are brought on by the sudden loss of one or more vertical load-bearing parts. In the event that a vertical structural element fails, the structure should provide a backup load-bearing channel and shift the loads it was carrying to nearby elements. As a result of internal energy from a member loss, dynamic internal forces in adjacent members rise. Every structural element of the structure sustains a distinct load, including the additional internal forces, once the load has been redistributed across it. Any redistributed load that is greater than the undamaged members capacity may result in another local failure. Such successive failures can eventually affect the entire structure or a disproportionately big section of it as they propagate from element to element.

The first known instance of disproportionate progressive collapse was the fall of the Ronan Point apartment building on May 16 Fig.1, 1968. Situated in Newnham, England, the structure was a 22-story precast concrete bearing wall system. A gas stove leak in an 18th-floor corner kitchen caused the fall. The global structural engineering community was alerted to and concerned about the Ronan Point catastrophe. To prevent progressive collapse, this collapse in particular prompted major modifications to construction rules in Canada and England.

Fig.1. Ronin point

Flat slab:

A flat slab is a two-way reinforced concrete slab without any beams that is directly supported by columns. As a result, the loads are immediately transferred to the supporting columns. The absence of beams creates a plain ceiling and an appealing appearance in flat slab constructions. The flat slab is simpler to build and uses less expensive formwork. Partition walls can be installed anywhere in flat slab constructions, which also have less fire vulnerability than typical slab-beam structures. Building vertical structures is becoming a need for our way of life as a result of the acute shortage of land.

Progressive collapse:

A condition where the collapse commences with the failure of one or a few structural components and then progresses over successive other components. Technically a subsection of the previous case, in this instance the progressive failure mechanism is not arrested and results in the collapse of the structure, or a significant part of it

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2.LITERATURE REVIEW:

Jinrong Liu, Ying Tian, and Sarah L. Orton [1], Used a macromodeling approach and alternate path method, dynamic and static analyses are performed to assess the progressive collapse resistance of a multistorey reinforced concrete flat-plate building lacking structural integrity reinforcement in the slabs. Two loading scenarios, instantaneous removal of an exterior column and interior column, are considered. The dynamic analyses examine the potential of progressive collapse of the building, the dynamic demands on global and local nonlinear deformations, the effects of strain rate in materials, and the development of compressive membrane action. The effectiveness of an energy-based nonlinear static analysis procedure is examined for equivalently estimating the peak dynamic global and local responses caused by sudden column removal. The analyses indicate that older flat-plate buildings are vulnerable to progressive collapse; the combined effects from strain rate and compressive membrane action can significantly increase punching resistance; energy-based nonlinear static analysis can approximate the peak dynamic loading response especially for instantaneous exterior column removal.

Zhonghua Peng, Sarah L. Orton, Jinrong Liu, and Ying Tian [2], have presented experimental results of dynamically removing an interior column in a single-story, 2-bay-by-2-bay reinforced concrete flat plate substructure. The test specimen represented pre-1971 designed flat-plate buildings. The specimen was loaded with dead weight at a load level equal to 78% of the unfactored design load and the support under the interior column suddenly removed by means of a collapsing jack. The test specimen experienced punching failures at four neighbouring slab-column connections, but did not fully collapse due to post punching capacity.However, the slab rotation at punching was consistent with predicted rotation capacity and previous test data. The measured lateral expansion of the specimen indicated the presence of compressive membrane forces in the slab at the time of punching failure. The experimental results validated a macro model developed for simulating the behaviour of plate-plate structures.

Leila Keyvani, and Mehrdad Sasani [3], have experimentally and analytically evaluated progressive collapse resistance of an actual posttensioned parking. An interior column was removed by explosion and the structure resisted progressive collapse with a permanent maximum vertical displacement of about 61 mm (2.4 in.). Analytical models of the garage are developed using computer software and nonlinear dynamic analyses are performed. The interaction between the tendon and the slab is modeled explicitly. The analytical results show that despite the fact that the slab around the removed column had no bottom reinforcement and the tendons were placed close to the top of the slab, pushing the slab down, the compressive membrane forces developed in the slab helped increase the flexural strength of the slab sections. The gravity load redistribution is discussed and characterized.

Zhonghua Peng, Sarah L. Orton, Jinrong Liu and Ying Tian,[4] has documents the findings from a dynamic collapse experiment carried out on a single-story two-by-two bay reinforced concrete flat-plate substructure. The test specimen had a 0.4 scale, represented older flat-plate buildings designed without structural integrity reinforcement in slabs, and was subjected to an instantaneous removal of an exterior supporting column. Tests were conducted three times with different levels of gravity load until a progressive collapse occurred. The specimen survived a gravity load corresponding to 42% of the normal loading capacity defined by the direct design methods but collapsed at a load of 49% of the design loading capacity. The tests also indicated that a slab-column connection without continuous slab bottom reinforcement through the column has limited post-punching resistance. The experiment indicated that an older flat-plate building is vulnerable to a progressive collapse when it is subjected to a sudden exterior column removal. Numerical simulations of the experiments using a macromodel were conducted and its effectiveness was confirmed.

Wei-Jian Yi, Fan-Zhen Zhang, and Sashi K. Kunnath, [5] has performed a series of experiments on two identical large-scale models, an interior, exterior, and corner column of the structure were replaced by mechanical jacks during the fabrication of the structure. In collapse-resistant design of structures, understanding primary structural failure-mechanisms and alternative load paths under accidental extreme loads is important. A quasi-static experimental method is used to simulate the sudden loss of a column in a single story concrete flat slab-column structure.. After application of uniform loads of increasing intensity, the jack representing the lost column was unloaded. In the first model test wherein an interior column was removed, a downward concentrated load was also applied on the upper end of the interior column until the structure collapsed. Elastic behaviour, yield-line mechanisms, and compressive and tensile membrane actions in the flat slab-column structure were observed during the collapse tests. The results provide valuable information on the load transfer mechanisms in a flat slab-column structure when critical columns are removed.

J.M. Russella, J.S. Owenb , I. Hajirasoulihac [6] has analyzed the nonlinear dynamic response of a structure after dynamic column loss event is considered, including the redistribution of loads and displacement profile. These results are then compared to equivalent static cases in order to determine the Dynamic Amplification Factor (DAF). For the range of structures, they considered, the DAF was calculated as between 1.39 and 1.62 for displacements, with lower factors associated with a higher nonlinear response or slower column removal. Additionally, the shear forces in remaining columns may exceed 200% of their fully supported condition, with a different associated DAF. The effects of increasing the tensile strength of concrete due to high strain rates are also considered. They did experiment on FE displacements results against time with different removal times compared to the experimental results. Four different times (0, 20, 50 and 100 MS) are used to reduce the reaction force provided by the temporary support. In this work study is applied experimentally The dynamic response of RC flat slab structures after a column loss demonstrates that a sudden removal can considerably increase the peak displacements and the shear forces compared to the static condition. The DAF for displacement values is related to the extent of damage and nonlinearity within the force displacement response.

G. Anandakrishnan , Jiji Antony [7] have investigate the performance of a multistoried flat slab buildings subjected to progressive collapse. Also, the study investigates the effect of drop panel on the progressive collapse of the building and also the impact of progressive collapse of structure designed based on Indian codes for different locations of column removal. The linear static progressive collapse analysis of the flat slab building is done using ETABS.

Suyash Garg, Vinay Agrawal, Ravindra Nagar [8] assesses the progressive collapse behaviour of eight-storey R.C flat slab building, with and without perimeter beams, by conducting linear static progressive collapse analysis as per the GSA guidelines (2016). This research explores the column removal situations for various typical positions on each storey, unlike earlier studies where only certain typical columns on the first storey are removed. The results are analyzed for each scenario in terms of joint vertical displacement and chord rotation at column removal locations, and thus the susceptibility of the building to progressive collapse is calculated in compliance with the relevant accepted criteria laid down in the DoD Guidelines (2009). The results showed that the incorporation of perimeter beams in flat slab 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 increased gravity loads.

3. ANALYTICAL STUDY:

3.1. Progressive collapse analysis:

The linear static analysis procedure is performed under loading condition in which combination of service loads are multiplied by amplifying factor 2. Service load combination includes dead load and live load. However, it is limited to relatively simple structures where both nonlinear effects and dynamic response effects can be easily and intuitively predicted. The loading is taken as per G.S.A. guidelines that is [DL+0.25LL] for before column removal and 2[DL+0.25LL] for after column removal case. The design has been done as per IS:456 code using ETABS software. Response of structure for given loading condition is evaluated by demand to capacity ratios DCR, which shall not exceed than 2.

Where, DL= Dead Load, LL= Live Load

The progressive collapse is achieved by the removal of a critical column and studying the effect on the structure. The criterion for the removal of column is provided by G.S.A. guidelines, In this study, 2 different locations of column removal at the ground floor are considered.

CASE I Corner Column Removal.
CASE II Edge Column Removal.

The load considered in the study is live load of 4 kN/m^2 is applied as per IS:875(Part 2) a floor finish of 2 kN/m^2 is applied as per IS: 875 (Part1) and dead load is assigned by software.

3.2. Building Description:

In this work, four models of RC flat slab building is considered for understanding the effect of progressive collapse which are given in the table 3.1. In the study, analysis of G+10 flat slab building with strengthening method is carried out, building of a plan area of 25m x 25m, the total height of the building models is 30m. 3D model is prepared for G+10 multi-story building using ETABS software. Table 3.2 includes structural details and properties of simple flat slab building.

Table 1: Building models

BUILDING MODEL	DISCRIPTION
1.	Simple flat slab Building
2.	Flat slab building with drop panel
3.	Flat slab building with perimeter beam
4.	Flat slab building with drop panel and perimeter beam

Table 2: Structural Details and Properties of simple flat slab building

No. of stories	G+10
Base floor	3 m
Floor to Floor ht.	3 m
Concrete grade	M25
Steel grade	Fe415
Rebar	HYSD 415
Size of the slabs	300 mm
Column size	700 mm X 700 mm

3.3 Building models:

In this study four models of flat slab building is considered as shown in table 3.1 that are as simple flat slab building, flat slab with drop panel, flat slab with perimeter and flat slab with drop panel and perimeter beam. The respective models of structure are shown below.

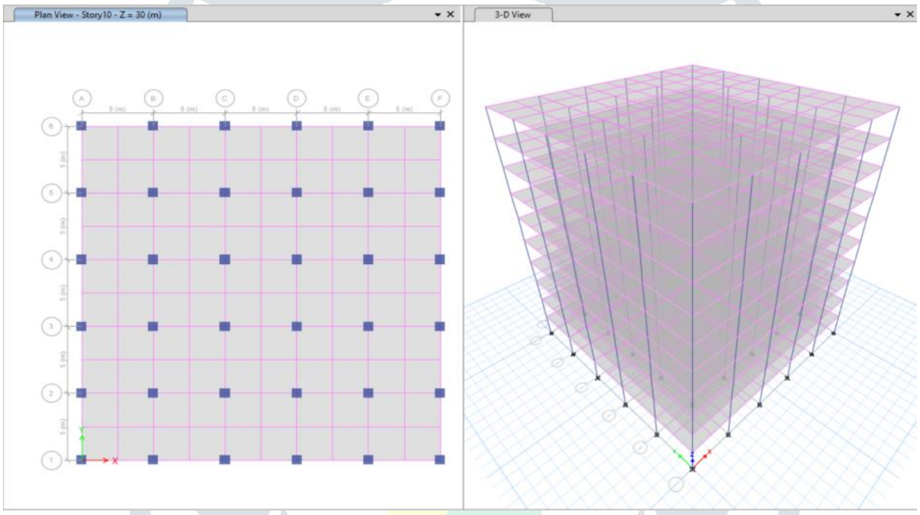

Figure. 2. Plan and 3-D View of flat slab structure

The above fig.2 shows the plan and 3D view of simple flat slab building of G+10 storey with fixed end at bottom the load is transferred from slab to directly on column and then to foundation as slab is rest on column.The centre-to-centre distance between column is 5m.

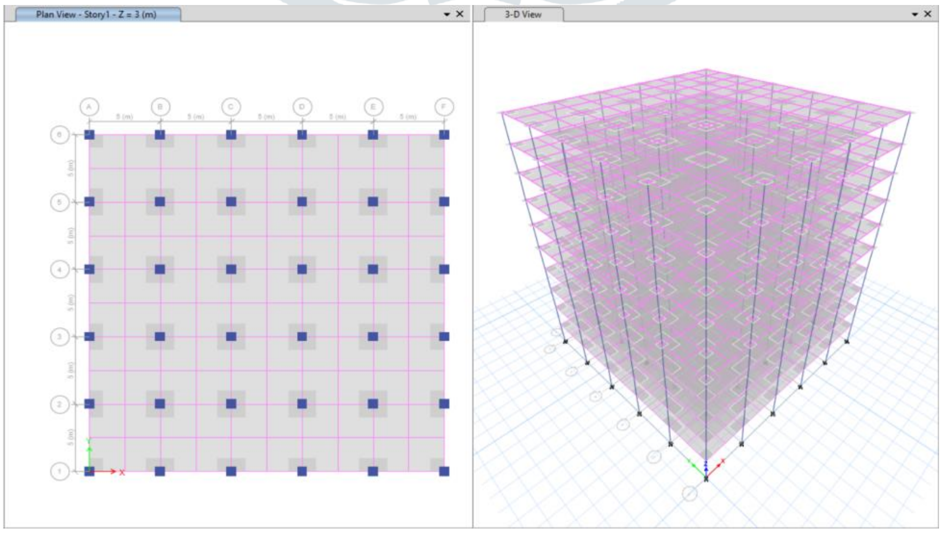

Figure.3. Plan and 3-D View of flat slab structure with drop panel

Figure 3. shows the plan and 3D view of reinforced concrete flat slab wit drop panel building with fixed end at bottom. The size of the drop panel is 2000X2000mm and 100mm thickness is provided.

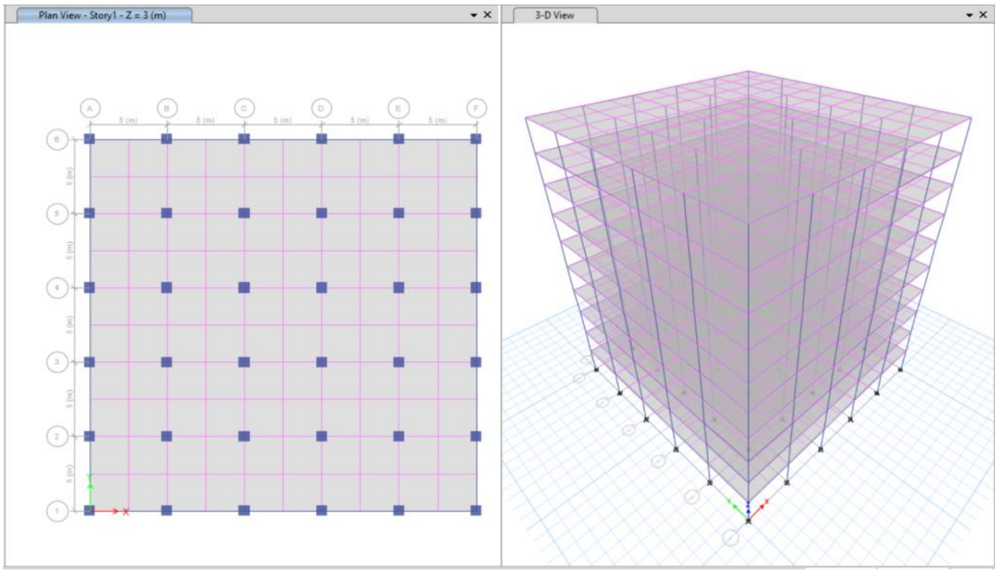

Figure. 4: Plan and 3-D View of flat slab structure with perimeter beam

Figure.4 shows the plan and 3D view of reinforced concrete flat slab with perimeter beam building with fixed end at bottom. The perimeter beam is provided at the periphery of the structure and the size of the beam is 300mmX550mm.

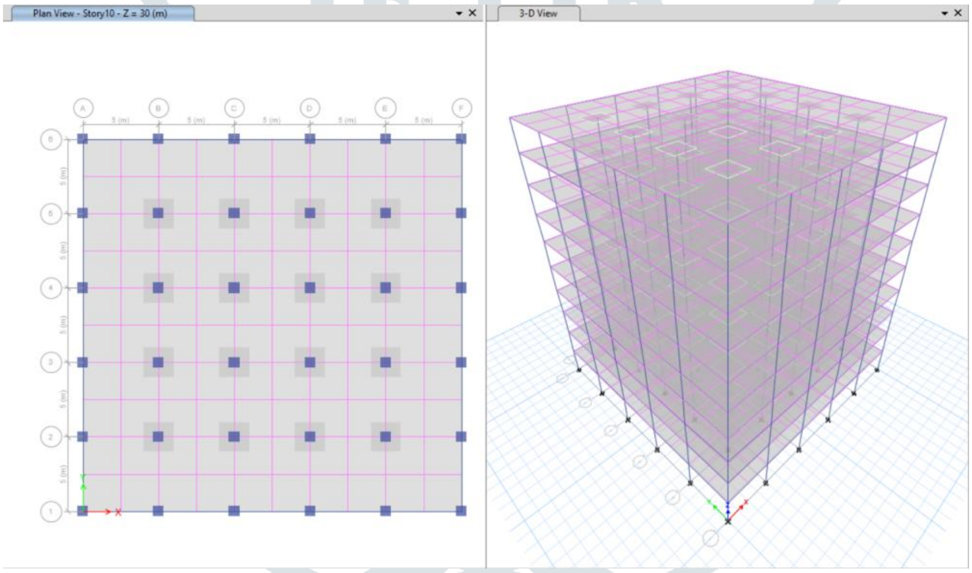

Figure. 5: Plan and 3-D View of flat slab structure with perimeter beam and drop panel

Figure.5 shows the plan and 3D view of reinforced concrete flat slab with perimeter beam and drop panel building with fixed end at bottom.

4. RESULTS AND DISCUSSION:

The linear static progressive collapse analysis on all the building model for the two cases of column removal are performed. The results of the study are in terms of vertical displacement at the location of column removal, axial force and demand capacity ratio (DCR) in the column adjacent to the removed column. Demand capacity ratio is defined as the ratio of the demand coming to the member after the column removal to the capacity of the member.

4.1 For Case I: Corner column Removal

The first case considered is the corner column removal at the ground floor of simple flat slab building, flat slab with drop panel building, flat slab with perimeter beam building and flat slab with drop panel and perimeter beam building models.

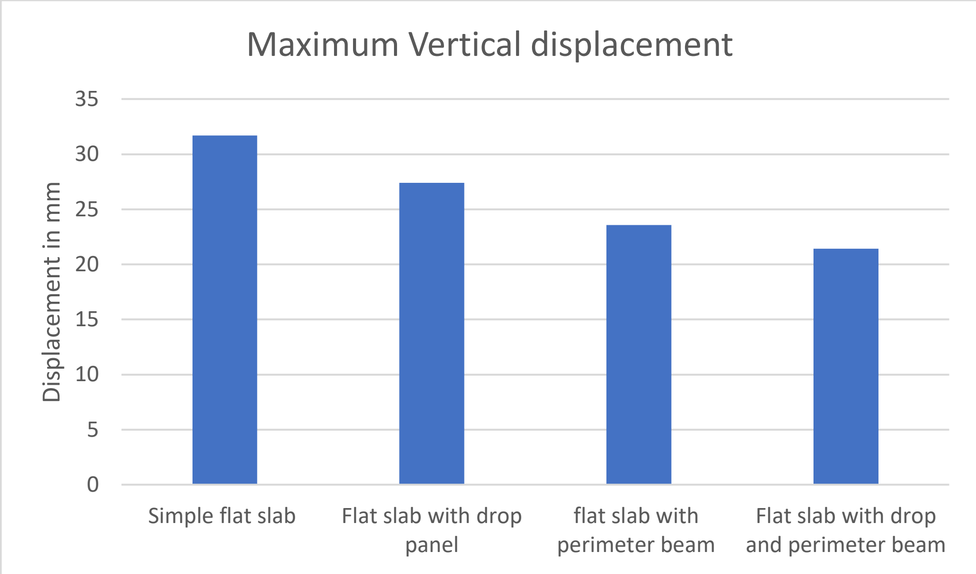

Fig.6: Maximum vertical displacement for all building models For Case I

The above figure.6. shows the comparison of maximum vertical displacement of all the models after removal of corner column at the ground floor. The maximum vertical displacement for simple flat slab building is 31.7mm, for Flat slab with drop panel is 27.393mm, for flat slab with perimeter beam is 23.569mm and for flat slab building with drop and perimeter beam is 21.419mm. It can be observed that the incorporation of the drop panel and perimeter beam tends to decrease the vertical displacement at all the stories above the removed column.

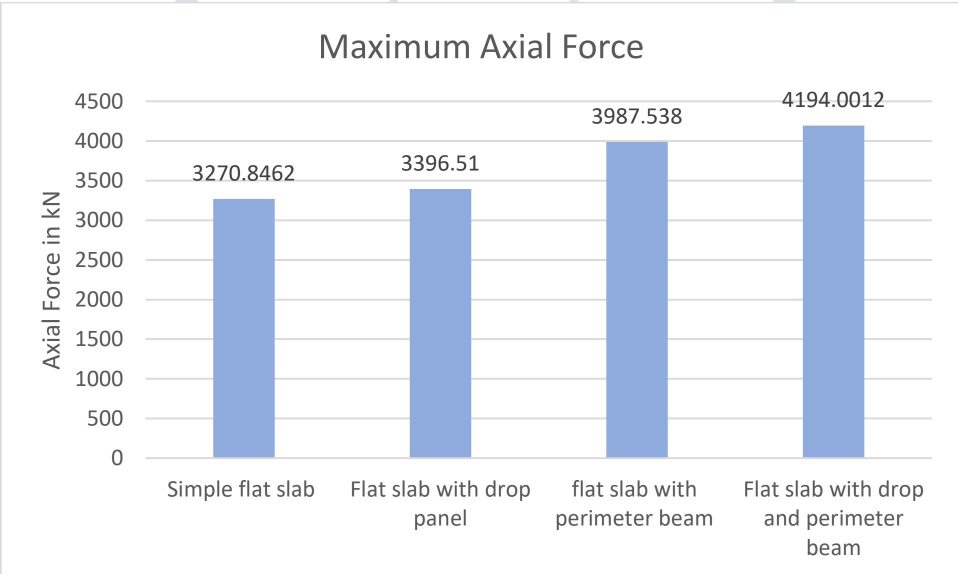

Fig.7: Maximum Axial Force For Case I

Figure.7 shows the comparison of maximum axial force obtained in all the building models. The axial force obtained is in the adjacent column of removed column. These results are obtained after the removal of corner column.

4.2 For Case II: Edge Column Removal

The second case considered is the edge column removal at the ground floor of simple flat slab building, flat slab with drop panel building, flat slab with perimeter beam building and flat slab with drop panel and perimeter beam building models.

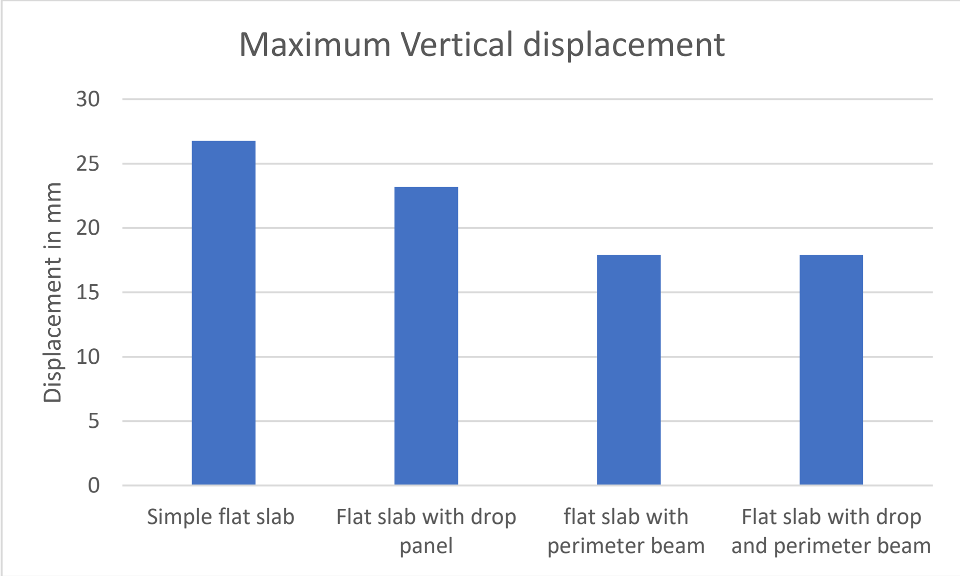

Figure.8: Maximum vertical displacement for all building models For Case II

The above figure.8. shows the comparison of maximum vertical displacement of all the models after removal of Edge column at the ground floor. The maximum vertical displacement for simple flat slab building is 26.778mm, for Flat slab with drop panel is 23.182mm, for flat slab with perimeter beam is 17.929mm. It can be observed that the incorporation of the drop panel and perimeter beam tends to decrease the vertical displacement at all the stories above the removed column.

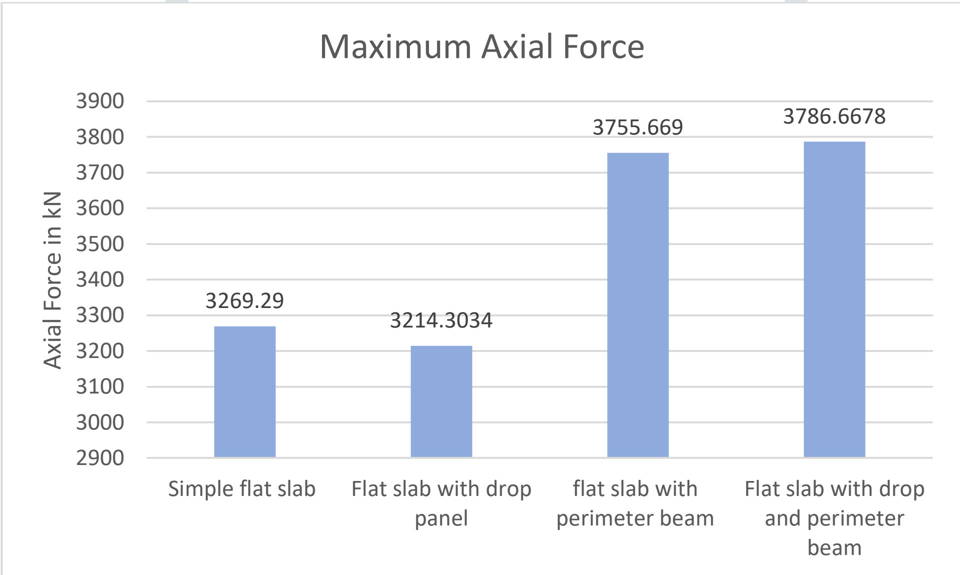

Fig.9: Maximum Axial Force For Case II

Figure.9. shows the comparison of maximum axial force obtained in all the building models. The axial force obtained is in the adjacent column of removed column. These results are obtained after the removal of Edge column.

5. CONCLUSION

After conducting the linear static progressive collapse analysis on all four flat slab building models. The following conclusion can be made from the study.

5.1 Effect on Vertical displacement:

For Corner Column removal case the vertical displacement value of flat slab structure with drop panel is decreased by 14.60%, for flat slab with perimeter beam the value is decreased by 26.30%, for flat slab building with drop panel and perimeter beam the vertical displacement is decreased by 33.25% compared to simple flat slab building

For Edge Column removal case the vertical displacement value of flat slab structure with drop panel is decreased by 18.22%, for flat slab with perimeter beam the value is decreased by 35.65%.

From the results it can be concluded that the flat slab building with perimeter beam improves the resistance to vertical displacement at greater extend because incorporation of perimeter beam enhances the stiffness of structure which improves the performance under progressive collapse condition.

5.2 Effect on Axial force:

For corner column removal case the maximum axial force for flat slab building with drop panel is 3396.51 kN, the maximum axial force for flat slab building with perimeter beam is 3987.538 kN, and the maximum axial force for flat slab structure with drop panel and perimeter beam is 4194.001 kN.

For the case of edge column removal, the maximum axial force for flat slab building with drop panel is 3214.303 kN, the maximum axial force for flat slab building with perimeter beam is 3755.669 kN, and the maximum axial force for flat slab structure with drop panel and perimeter beam is 3786.667 kN.

The axial force is increasing in the adjacent column after column removal as the strengthening methods are used as they act as the alternate path for efficient load transfer.

5.3 Effect on Demand Capacity ratio:

From the DCR values the RC flat slab building for all model was resistant to progressive collapse as all the members have the DCR value less than 2

The Corner column removal is the most critical in all building as the maximum DCR values was obtained at removal of corner column.

5.4Future Scope for study:

1. Reduction of potential for progressive collapse in new and renovated federal buildings.
2. In present study Static analysis is performed, it is necessary to perform dynamic analysis for progressive collapse condition.
3. In present study symmetrical building is been studied, unsymmetrical building is needed to be studied for better understanding.

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