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Parametric Study on Behaviour of RCC Flat Slab with Drop Panel and Without Drop Panel Subjected to Sudden Column Removal

[1]Prof. Ashwin G. Hansora (Assistant Professor)
[1]Applied Mechanics Department, L. D. College of Engineering, Ahmedabad, Gujarat, India

[2]Bhavinkumar A. Ribadiya (P.G. Student)
[2]Applied Mechanics Department, L. D. College of Engineering, Ahmedabad, Gujarat, India

Abstract:- Progressive collapse causes the failure of primary structural member to propagate to the adjoining member, thus causing the collapse of the entire structure. The need to mitigate the impact of progressive collapse is necessary as it leads to catastrophic economic loss and causalities. The flat slab buildings are more prone to progressive collapse due to the absence of beams which are used to transfer the load initially resisted by the removed column. The main cause of failure in a flat slab building is the punching shear failure occurring at the slab column connections. The main objective of the analysis is to study the different force acting on building. To Study the progressive behavior of flat slab of G + 10 storey L and C shaped asymmetrical plan building for removal of column from different location (interior, exterior and corner). The progressive collapse analysis was carried out with the help of commercially available software named ETABs 16. The critical members were removed. The analysis was carried out by referring General Services Administration (GSA-2013, Revised 2016) and Unified Facility Criteria - Department of Defense (UFC - DoD-2009, Revised 2016) guidelines. For flat slab without drop panel structure when longer side middle column is removed the maximum vertical deflection in L plan building is around 1/2 of maximum vertical deflection of C plan. Flat slab without drop panel structure when outer corner, inner corner and middle column removed maximum base shear in L plan building is around 1/2 of maximum base shear of C plan. From the analysis results it was found out that L plan and C plan buildings, L plan building performed better.

Keywords:- *Progressive Collapse, RC Frame, Flat Slab, Drop Panel, Linear Static Analysis, ETABS.*

I. INTRODUCTION

The failure of a primary structural element spreads to the adjacent member causing the complete or partial failure of the structure is called progressive collapse. The major reason for progressive collapse is aircraft impact, design/construction error, fire, gas explosions, accidental overload, hazardous materials, vehicular collision, bomb explosions, etc. Flat slabs are reinforced concrete slab building in which the slabs are directly supported on the column without the use of beams. The advantages of providing flat slab structures include ease of construction, reduced storey height and ease of routing of services. The load transferring mechanism of flat slab building is different from the RCC framed building. In the conventional RCC framed building the beam members transfer the load from the slab to the column but flat slab building relies on the slab column connection for the load transfer. During the column removal, the additional load gets redistributed to the adjacent slab column connection and causes punching shear failure at that junction. The failure of the adjacent slab column connection in punching shear causes the load to further redistribute and causes the punching shear failure to spread over a large portion of the structure, leading to the collapse of the entire structure. The General Service Administration (GSA) and Department of Defense (DoD) guidelines are used for the design and analysis of structures subjected to progressive collapse.

II. LITERATURE REVIEW

- *Masoud Ghahremannejad,*

In this paper is to present the findings of a study of the how the number of stories of a RC structure impacts the building when a first-story column is removed instantaneously. Authors classified mainly three categories of building and all of the building same plan, but with varying numbers of floors (3, 5, and 7 floors).The criteria established for comparing the behavior of the buildings when sudden column removal and variations of applied axial forces to the column. The Column Sensitivity Index(β) was utilized to compare the condition of neighboring columns before and after the column removal.In this paper selected plan equal spans in both direction, with a regular and symmetric plan to cover all probable removal locations. This plan was adopted for this study to avoid irregularity of other parameters. The selected plan caused the center and stiffness of the mass to be at the same point. The axial force of columns was researched in this study, and the modeling was done in OPENSEES software.

- *Suyash Garg,*

In This paper progressive collapse behavior of an eight-story RC flat slab building, with and without perimeter beams, by conducting linear static progressive collapse analysis as per the current analytical research GSA guidelines (2016). The first study conducts a linear static analysis to understand the behavior of flat slab building with progressive collapse with initial local damage at specific locations of each floor and evaluates vertical joint displacement at different column removal locations. In the combined displacement of each story of the short edge column, the long edge column and the corner column are removed at the minimum displacement value compared to each story. And the rotation of the short-edged column, the long-edged column, and the other chord rotation of the corner column of each story compared to each story and the result. Progressive collapse resistance increases as we move from the first floor to the final floor. Adding perimeter beams significantly improves the progressive collapse resistance of the flat slab building studied in cases of corner, short edge and long edge column removal.

- *Yi Li,*

This article presents a nonlinear static pushdown analysis to evaluate the progressive collapse-resistance curve of typical RC frames under different deformations. Unlike previous studies in which only a few typical columns, such as columns on the ground floor, have been removed, this study examines the scenario of removing columns for different specific locations from different stories**.** The RC frame structure studied here is an eight storey building. Plan view of RC frame. The bottom ends of the first floor columns are fixed to the ground. This results in two frame models, such as the Model A, designed for the low-seismic-intensity region, and the Model B, designed for the high-seismic-intensity region. All representative columns on each floor, located on the short-edge, long-edge, corner and interior of the plan layout, are individually treated as initially damaged columns.Model A and Model B will break down under three and two column removal scenarios, respectively. This typical planner is derived from a numerical analysis of 3-story and 10-story frames, the results of which cannot accurately describe the nonlinear dynamic effect of all types of frame buildings. This can result in gradual failure of the beam from one floor to the other in the frame system, which differs from the theoretical assumption that the beams are damaged together on different floors. This action also weakens the compressive arch mechanism of the beam, and therefore reduces the relative collapse resistance of the RC frames under the beam mechanism. This is especially true for frames with more stories.

- *Huizhong Xue,*

In this paper a set of progressive collapse resistance, finite-element modeling techniques of RC-flat plates was established. Modeling of the bond-slip behavior between concrete and rebar was particularly highlighted, which has a significant effect on the performance of the flat plate. The author was previously tested on a 2 × 2-two-flat plate substructure and simulated for similar model validation in the literature. An eight-column flat plate substructure with two 2 × 2 bay, missing internal columns was first numerically modeled to simulate their respective progressive collapse experiments. Simulations and comparisons against published pullout tests have confirmed the reliability and effectiveness of the proposed bond-slip model. Progressive collapse behavior of the RC-flat plate structures under interior column removal. Three design parameters, including concrete strength, slab thickness, and reinforcement ratio, were different to measure their effects on the structural behaviors of RC-flat plate substrates with missing internal columns.

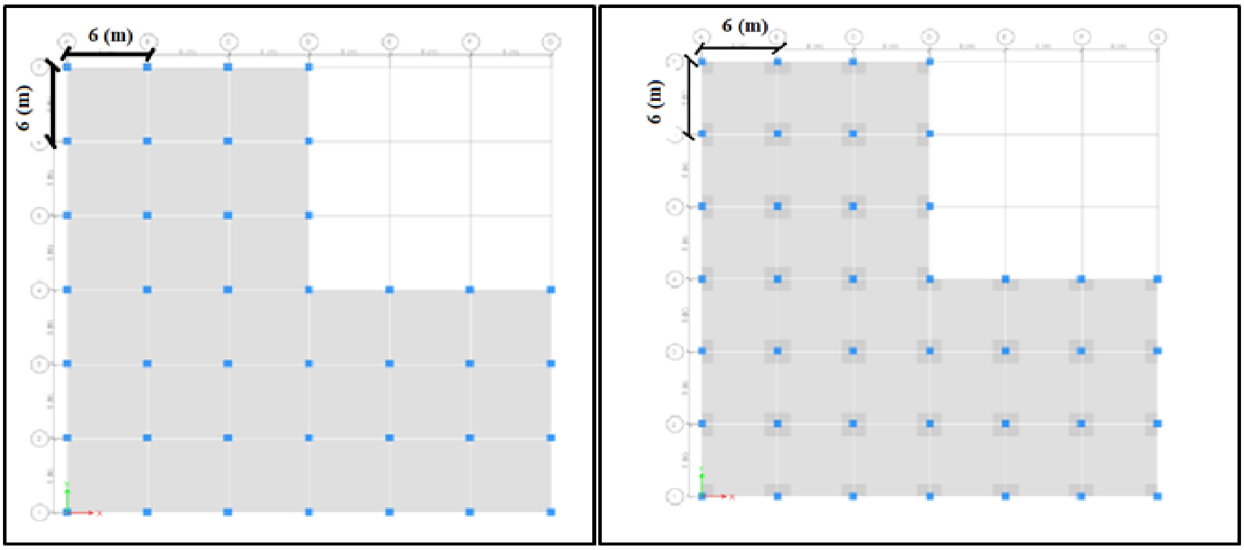
- *Xinzheng Lu,*

In this paper presents the experimental results from two quasi-static large-displacement tests performed on 2×2-bay, RC flat plate substructure subjected to corner column removal scenarios. In this paper Alternate Load Path (ALP) design method, a number of in-depth studies on the progressive collapse resistance of RC structures under a column removal scenario have been conducted analytically, experimentally and numerically. When compared to frame structures, flat plates are naturally susceptible to punching shear failure resulting in the absence of beams which aids in load distribution. In the event of column loss, either due to punching shear failure or normal load, high shear force and bending moments will form adjacent slab-column connections, leading to high stress concentration. In this context, failure can propagate horizontally and vertically. Punching shear failure occurred in the two edge columns adjacent to the removed corner column. Both tests showed full-depth flexural cracks and are located evenly at the cut-off location of the top reinforcing bars of the edge columns adjacent to the removed corner column. 80% to 110% of the applied UDL was removed during the entire tests and the removed corner columns were transferred to adjacent two edge columns.

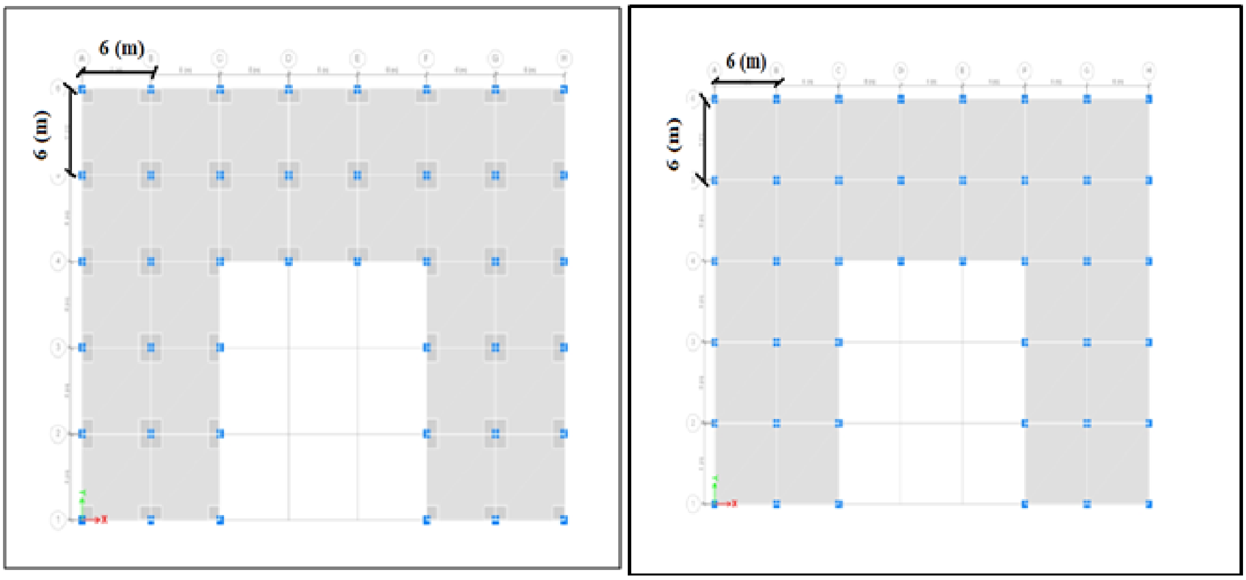
- *Building Modelling*

In this study we take a G+10 storey RC Flat slab building the geometrical parameters of the multi-storey frames is as follows:

- Type of building - SMRF
- Number of stories -11 stories
- Ground Storey Height - 4m
- Remaining Storey Height -3m
- Size of Column -0.6m x 0.6m
- Flat Slab Thickness -0.2m
- Drop Thickness -0.1m
- Drop Panel Size -2 m x 2m
- Grade of Concrete -M30
- Grade of Steel -FE500
- Zone Factor -5
- Soil type -Medium
- Importance Factor - III
- Response reduction Factor -5



(a) (b)
Fig 1 L Plan of Modelled Building a Flat Slab Building b Flat Slab Building with Drop



(a) (b)
Fig 2 C Plan of Modelled Building a Flat Slab Building b Flat Slab Building with Drop

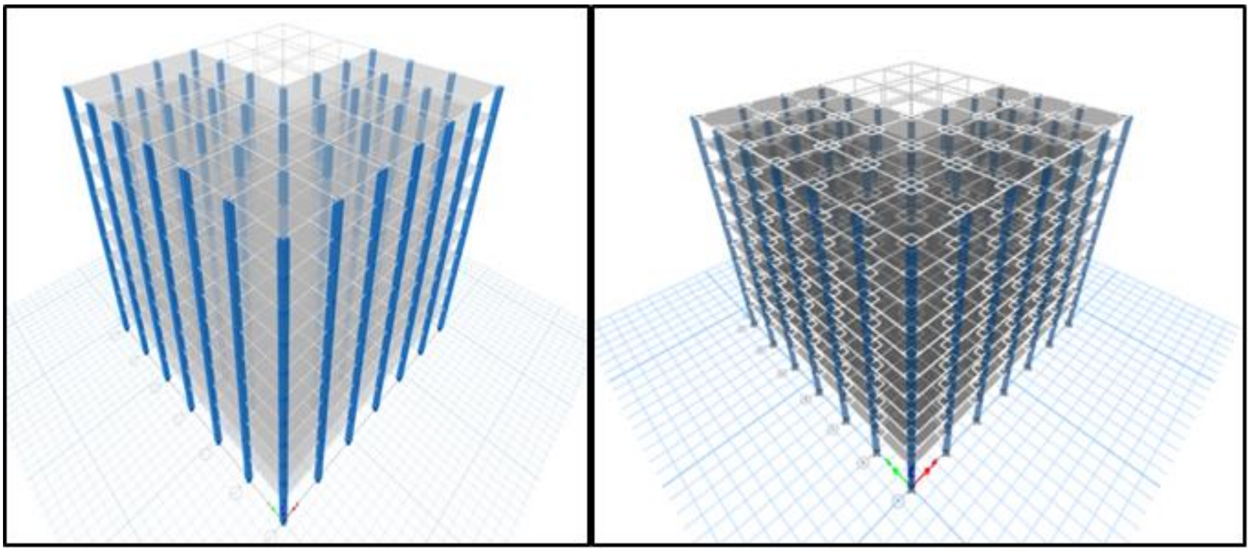


Fig 3 L Plan 3D Rendered view of Flat Slab Building and Flat Slab Building with Drop

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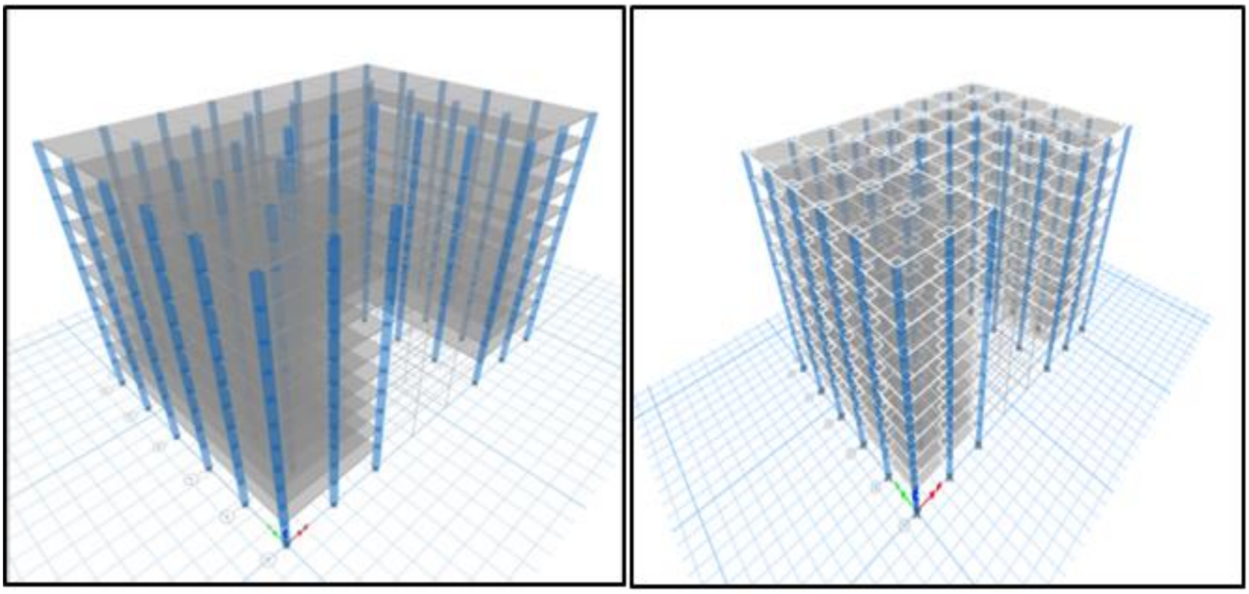

Fig 4 C Plan 3D Rendered view of Flat Slab Building and Flat Slab Building with Drop

➢ *Objctive*

- The main objective of the analysis is to study the different force acting on building.To Study the progressive behavior of flat slab of G+10 storey L and C shaped asymmetrical plan building for removal of column from different location (interior, exterior and corner).
- To study the different parameter such as Vertical Displacement, Axial force, DCR, Base reaction, Joint Displacement, Bending, Storey Drift, Base shear by using ETABS.

➢ *Scope of Work*

Analysis of L and C shaped G+10 storey building with following parameters.

- Flat slab with Drop panel and without drop panel.
- Sudden Removal column from different location in ground, first and second floor (inner corner, outer corner and middle).
- To study the different parameters such as Vertical Displacement, Joint displacement, DCR, Bending, Axial force, Base reaction, Storey Drift, Base shear based on IS:456, IS:875 and IS:1893.

➢ *Load and Load Combinations*

A live load of 4 kN/m2 is applied as per IS:875(Part 2): 1987, a floor finish of 2kN/m2 in applied as per IS:875(Part 1): 1987 and dead load is assigned by the software itself. The GSA guidelines provided load combination for the linear static analysis of a building for progressive collapse

$$2(DL+0.25LL)$$

Where DL is dead load, which includes self-weight of the building and loads due to floor finish; and LL is the live load.

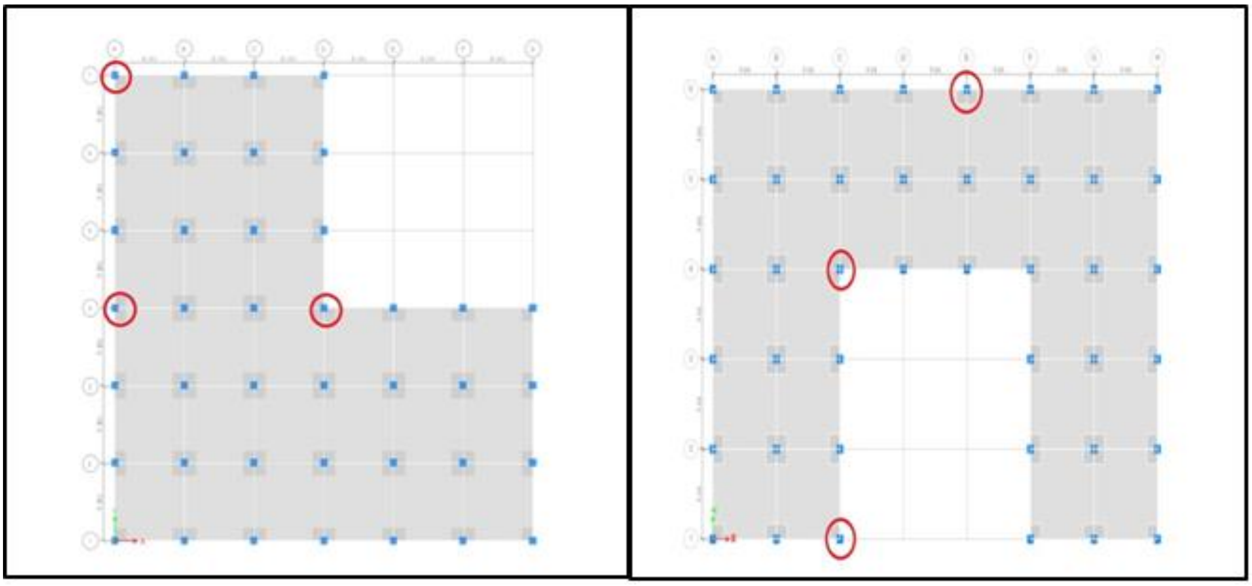

Fig 5 Typical Locations of Column Removal for Both Building Model

➢ *Progressive Collapse Analysis*

In this study, linear static analysis was conducted to analyze the potential of progressive collapse as per the guidelines provided by GSA in the ETABS software. The progressive collapse is achieved by the removal of a critical column and studying its effect on the structure. The criterion for the removal of column is provided by GSA guidelines. In this study, 3 different locations of column removal at the ground floor, first floor and second floor are considered as per GSA guidelines recommendation:

- Inner corner column removal (ICC)
- Outer corner Column removal (OCC)
- Middle column removal (MC)

The Figure 5 shows the locations of column removal considered in study. The different column removal cases are analyzed on separate building models.

III. ANALYSIS AND RESULTS

The linear static progressive collapse analysis on the L plan and C plan building model for the three cases of column removal was done. The results of the study are in terms of Demand Capacity Ratio (DCR), Axial force in the column adjacent to the removed column and the vertical displacement at the location of column removal. The GSA guidelines suggests to have the Demand capacity Ratio of the member to be less than 2 to resist progressive collapse. The Demand capacity Ratio is defined as the ratio of the demand coming to the member after the column removal to be the capacity of the member. The DCR value for the flat slab building is taken in terms of axial forces in the column members. The capacity of the member is calculated form Eq.1 provided IS 456:2000 for the determining the capacity of the column member for axial force.

$$QUE = 0.4 \times Fck \times Ac + 0.67 \times Fy \times Asc$$

Where QUE = Ultimate capacity of column section; Fck = Compressive strength of concrete; Fy = Yield strength of steel; Ac = Area of concrete; Asc = Area of longitudinal reinforcement bars.

The expected ultimate axial force (QUE) for the column is taken as 5306.57 kN.

➢ *DCR*

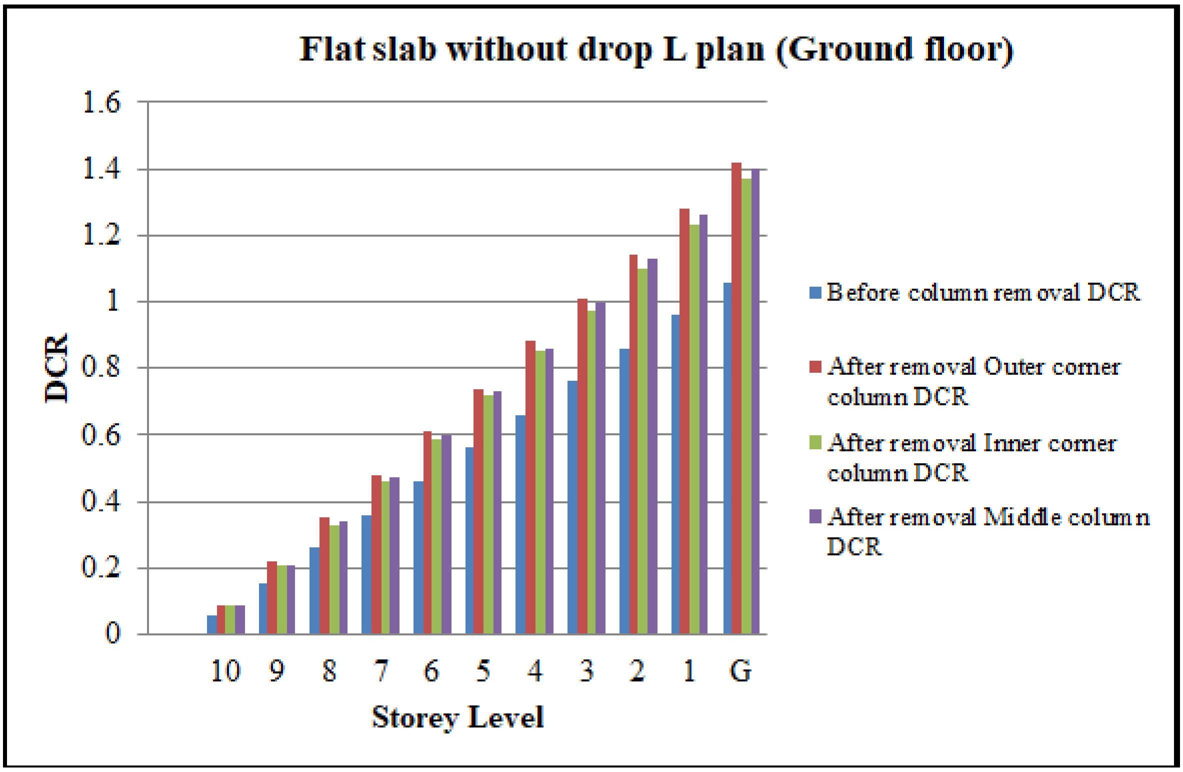

Fig 6 Flat Slab without Drop L Plan (Ground floor)

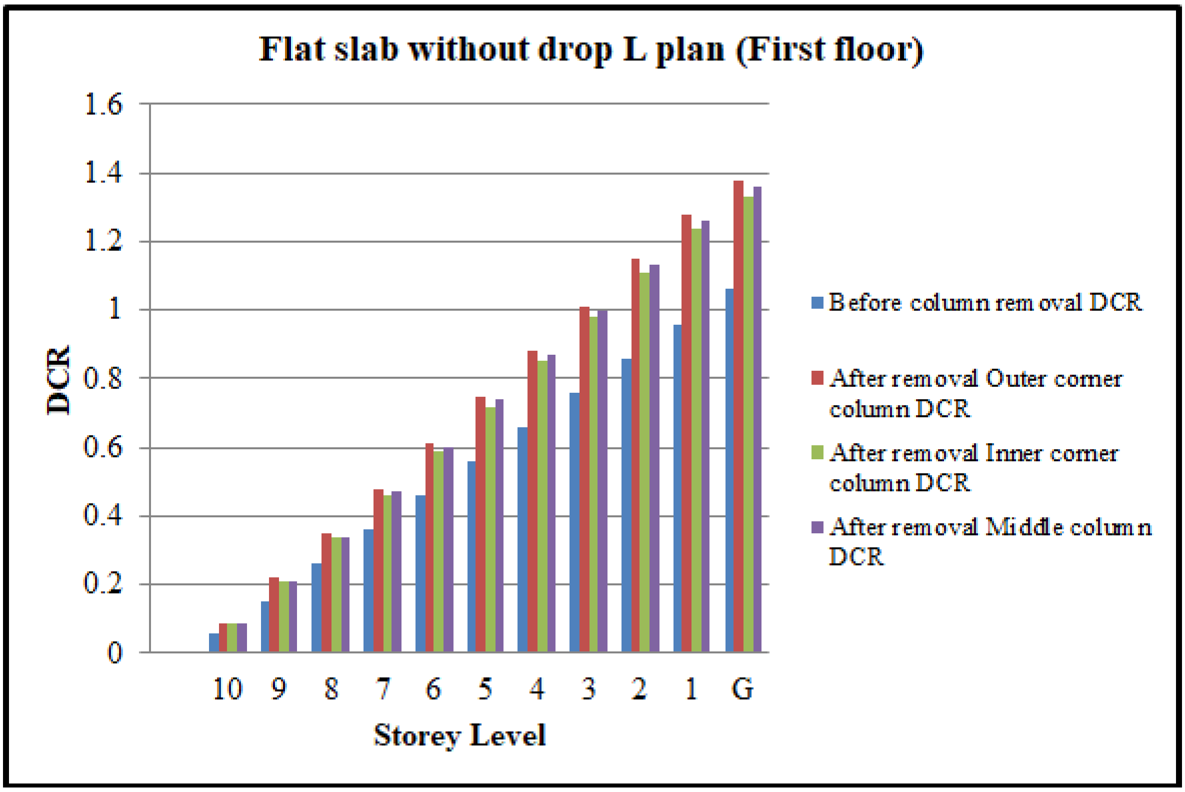

Fig 7 Flat Slab without Drop L Plan (First floor)

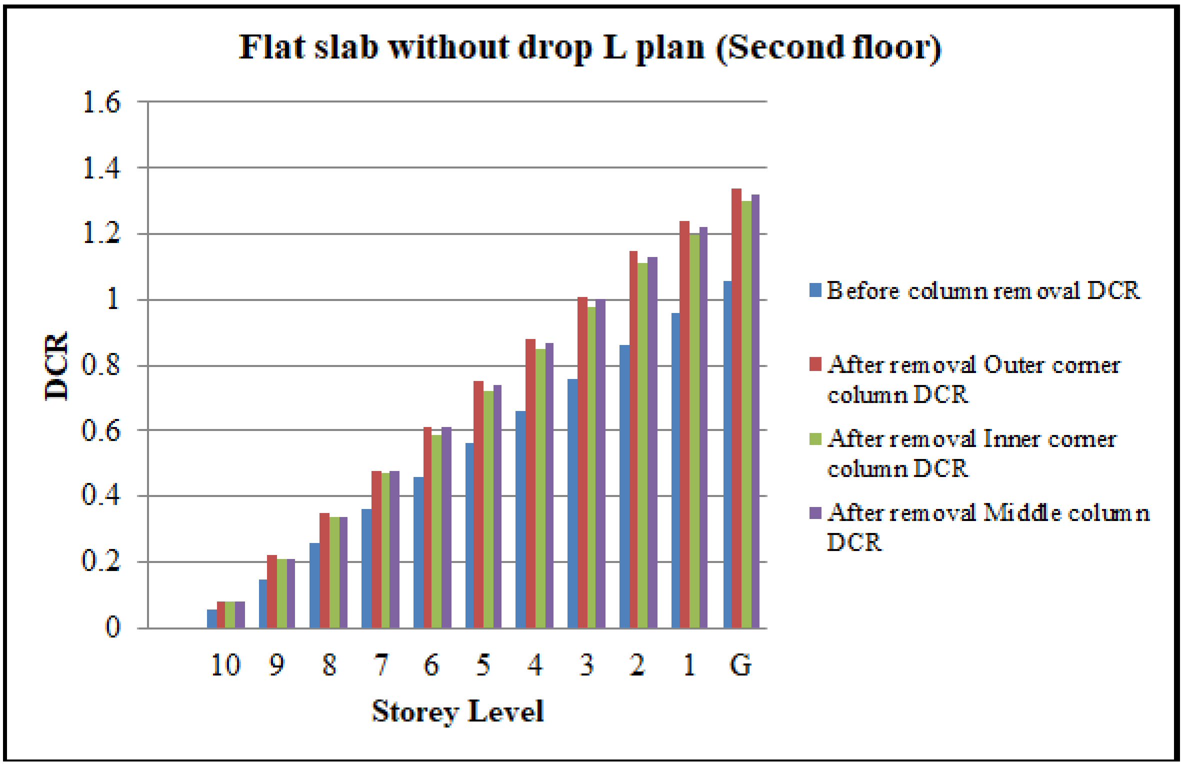

Fig 8 Flat Slab without Drop L Plan (Second floor)

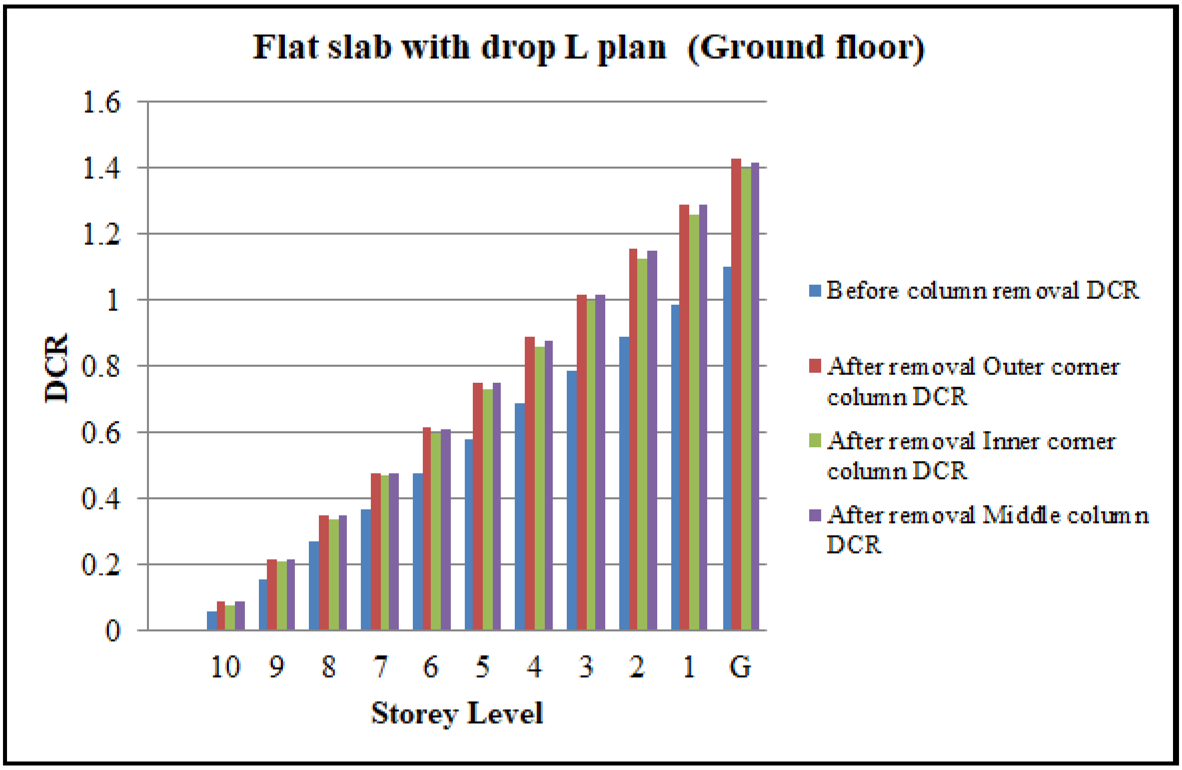

Fig 9 Flat Slab with Drop L Plan (Ground floor)

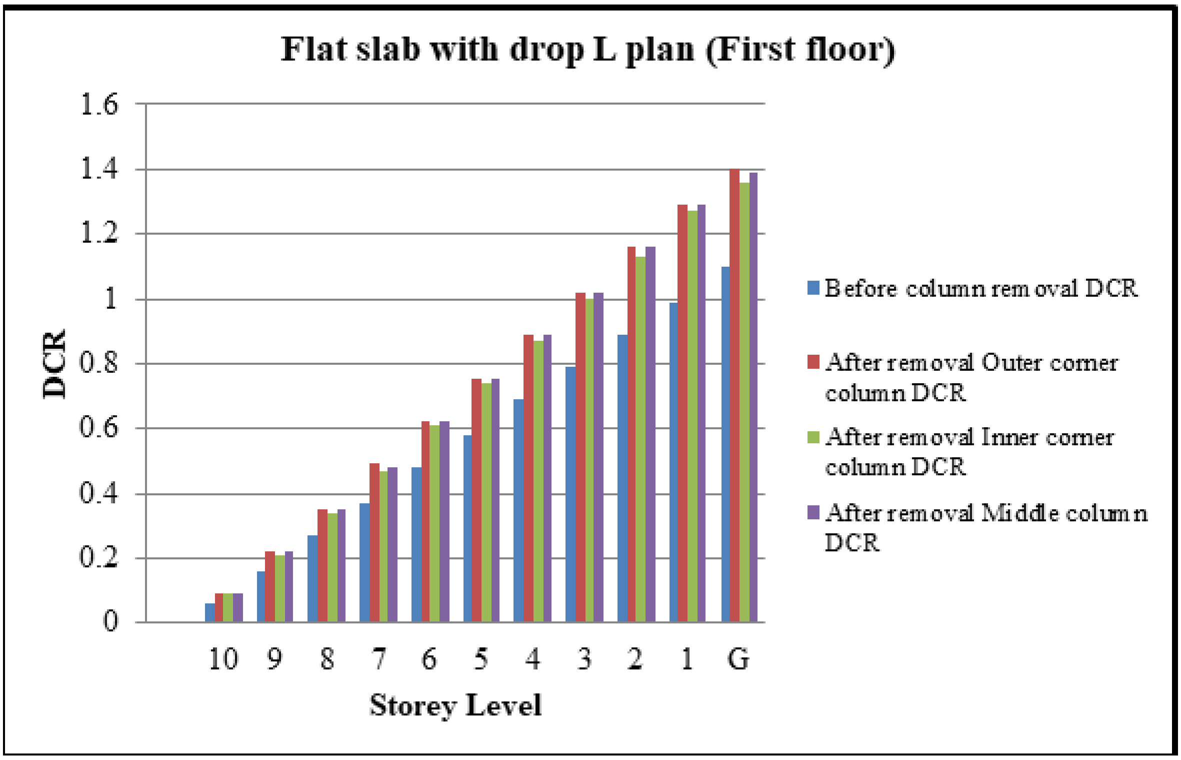

Fig 10 Flat Slab with Drop L Plan (First floor)

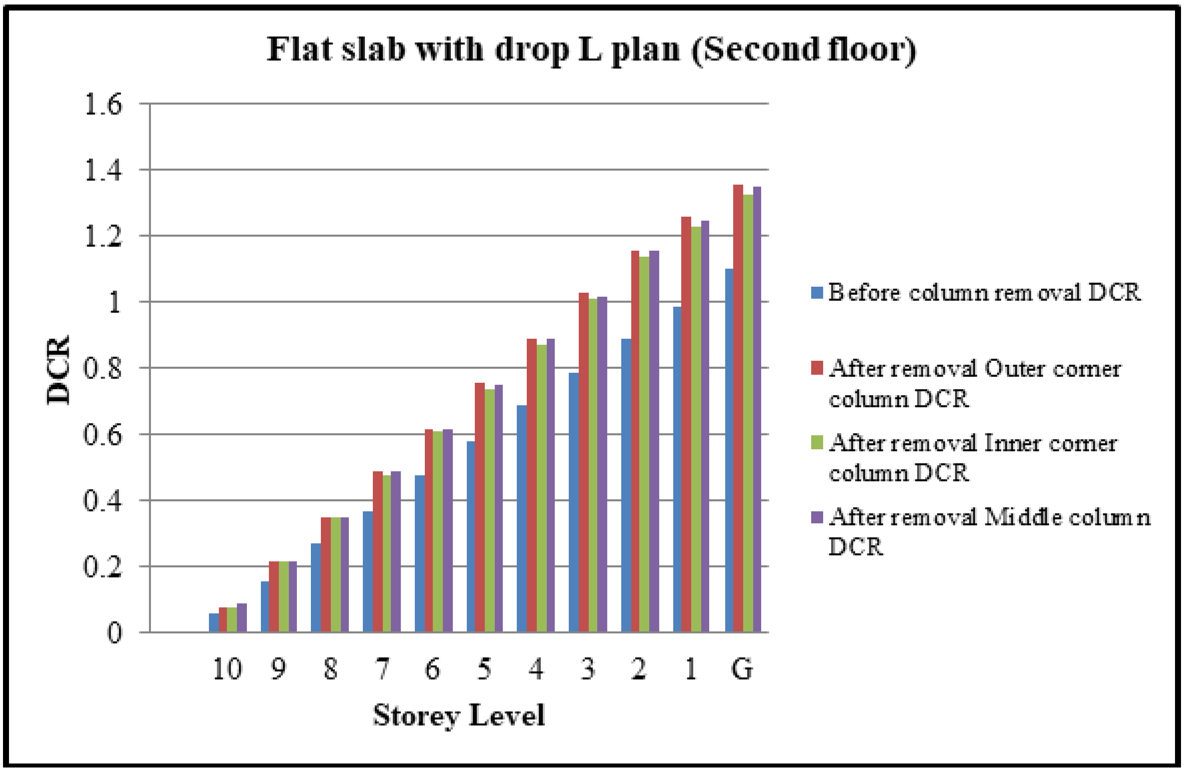

Fig 11 Flat Slab with Drop L Plan (Second floor)

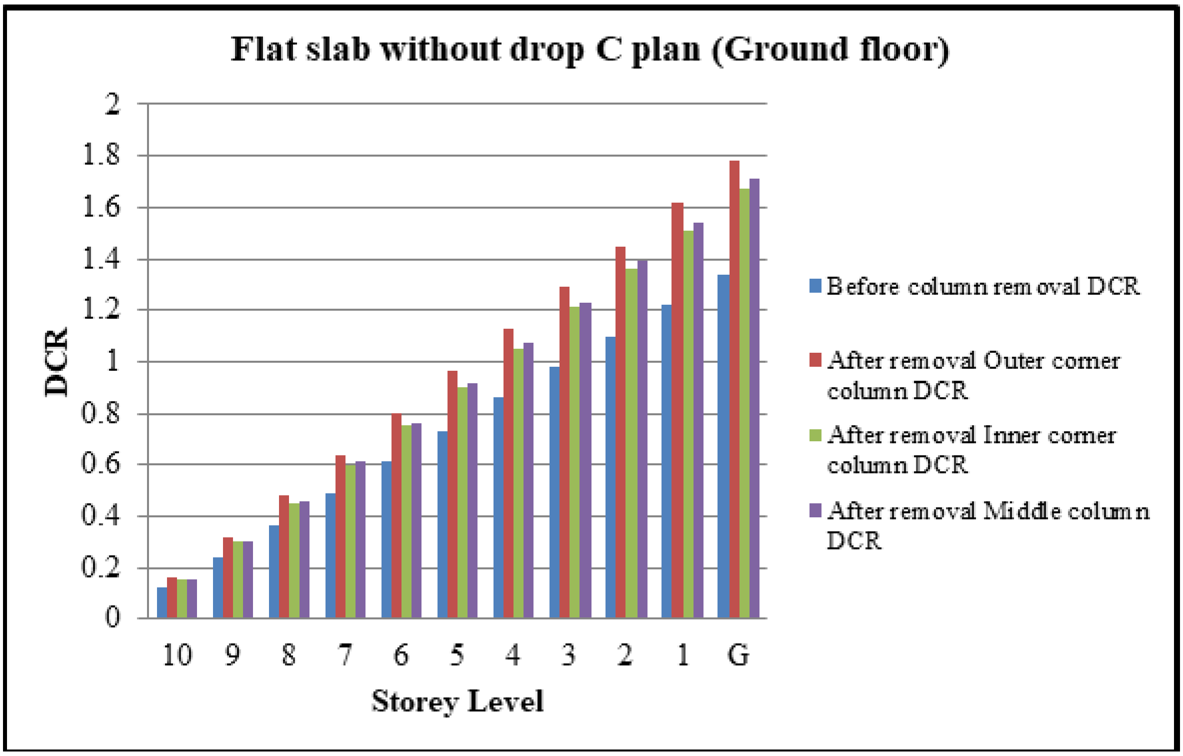

Fig 12 Flat Slab without Drop C Plan (Ground floor)

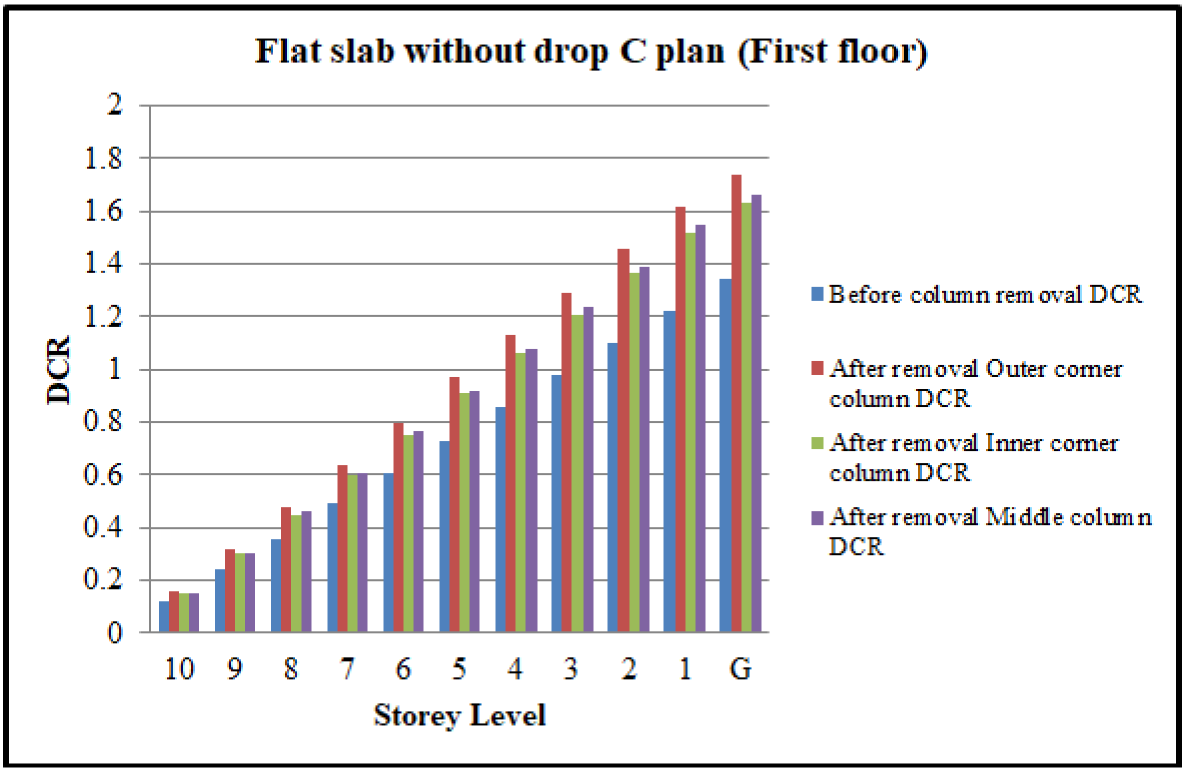

Fig 13 Flat Slab without Drop C Plan (First floor)

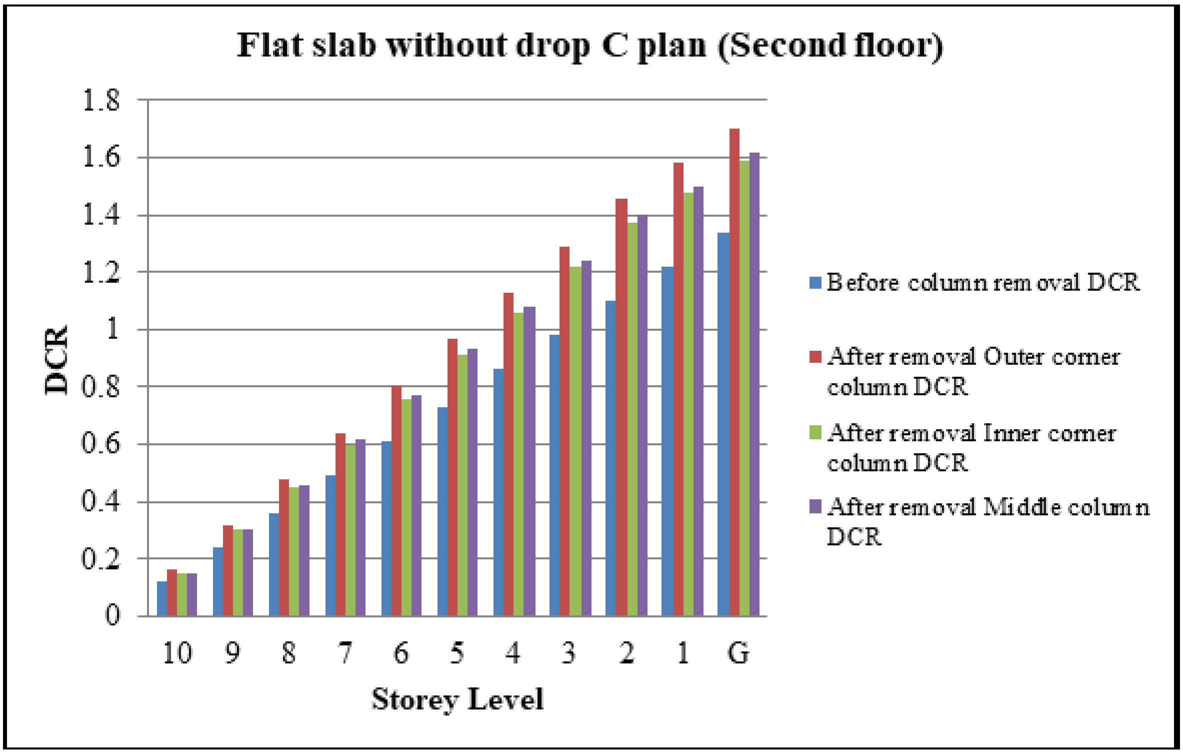

Fig 14 Flat Slab without Drop C Plan (Second floor)

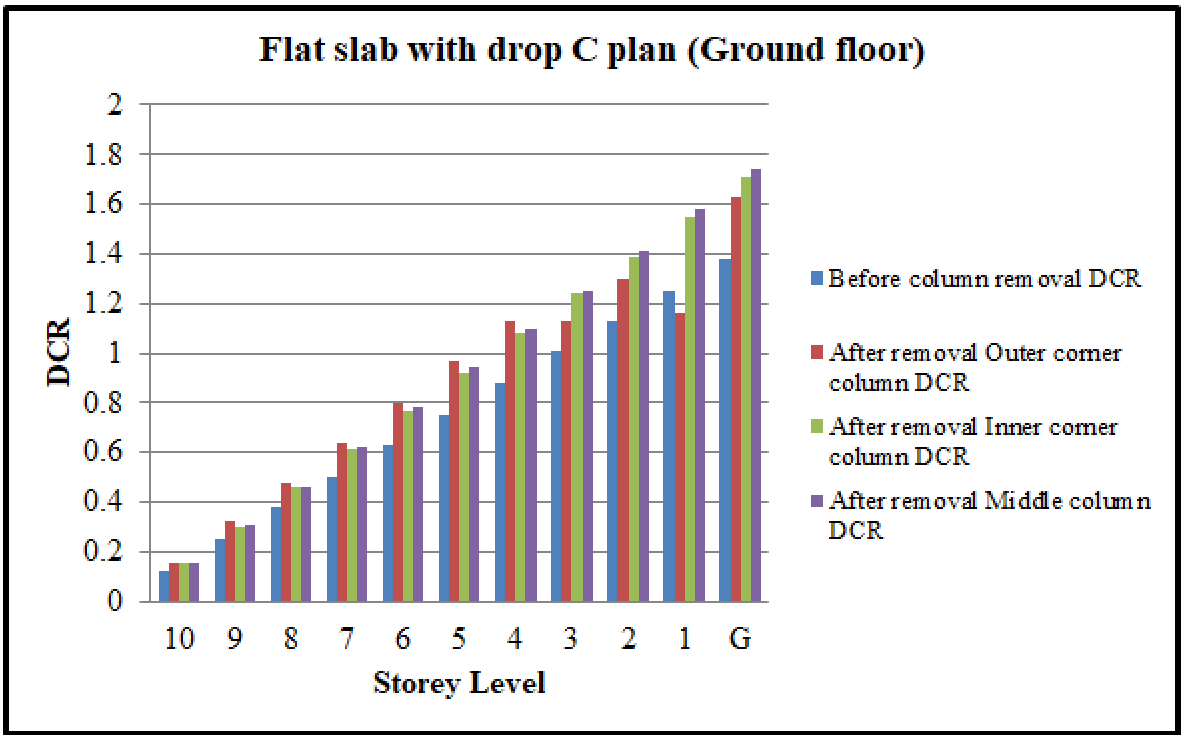

Fig 15 Flat Slab with Drop C Plan (Ground floor)

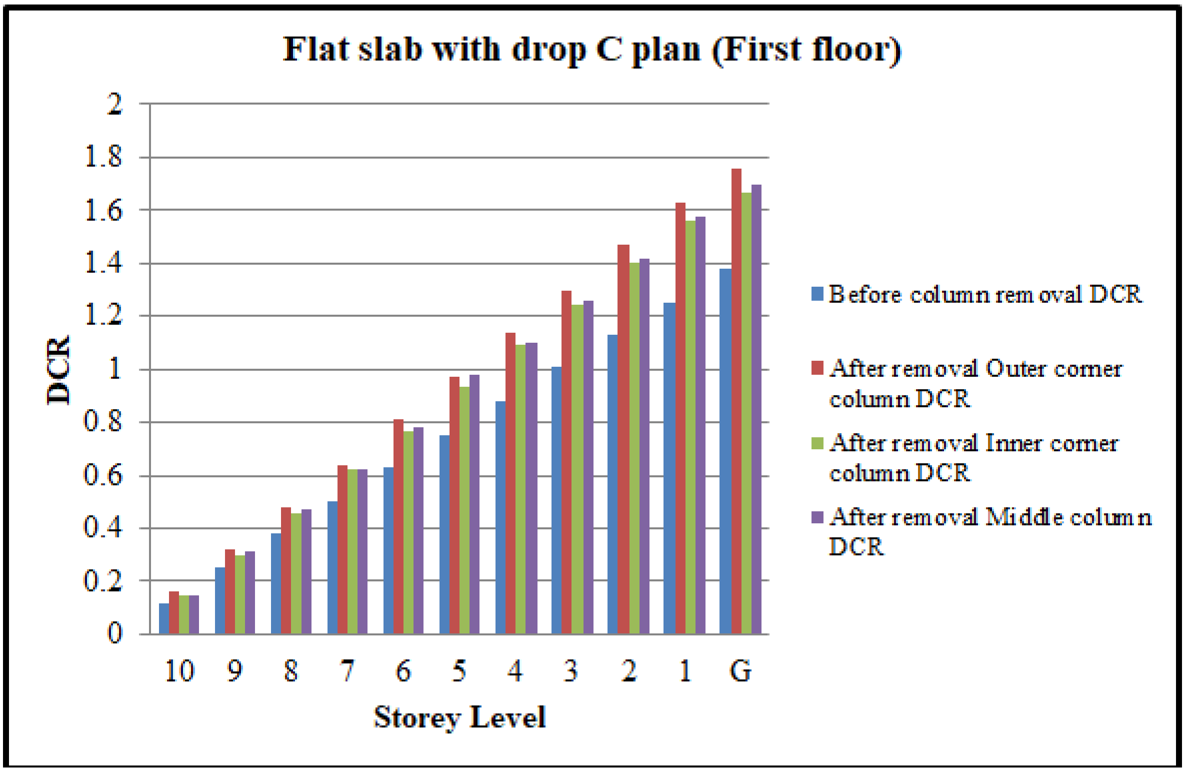

Fig 16 Flat Slab with Drop C Plan (First floor)

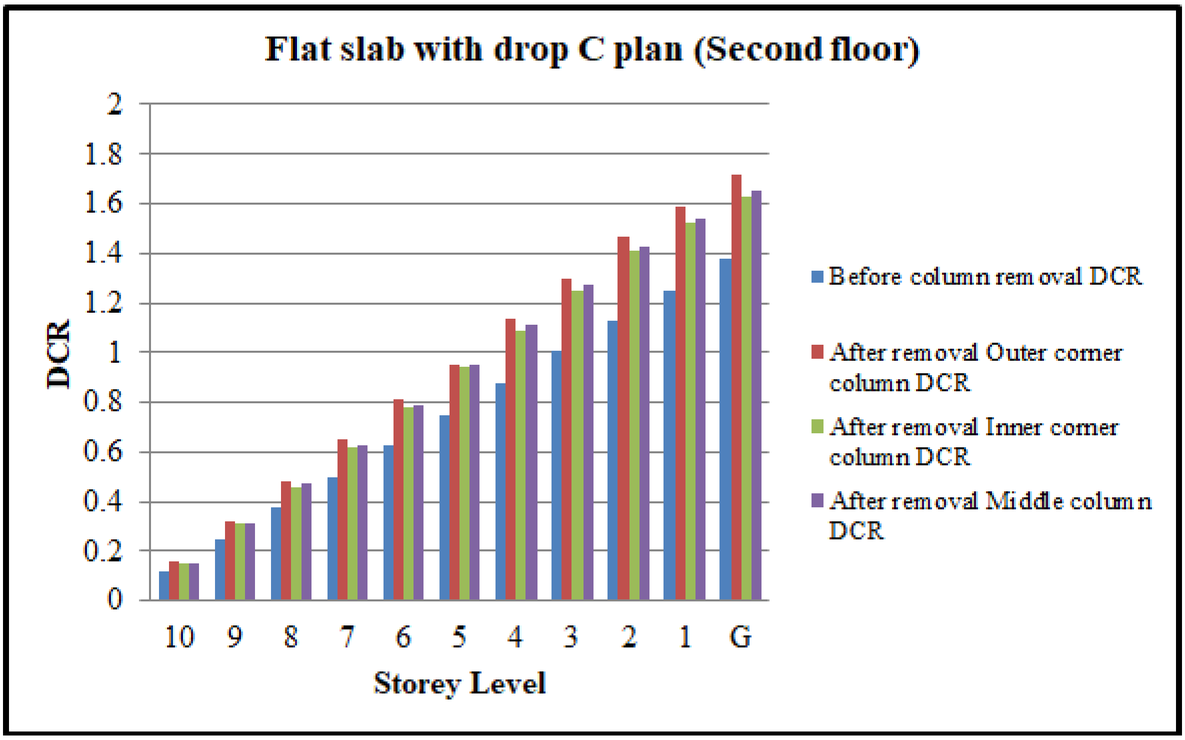

Fig 17 Flat Slab with Drop C Plan (Second floor)

- *Storey Drift*

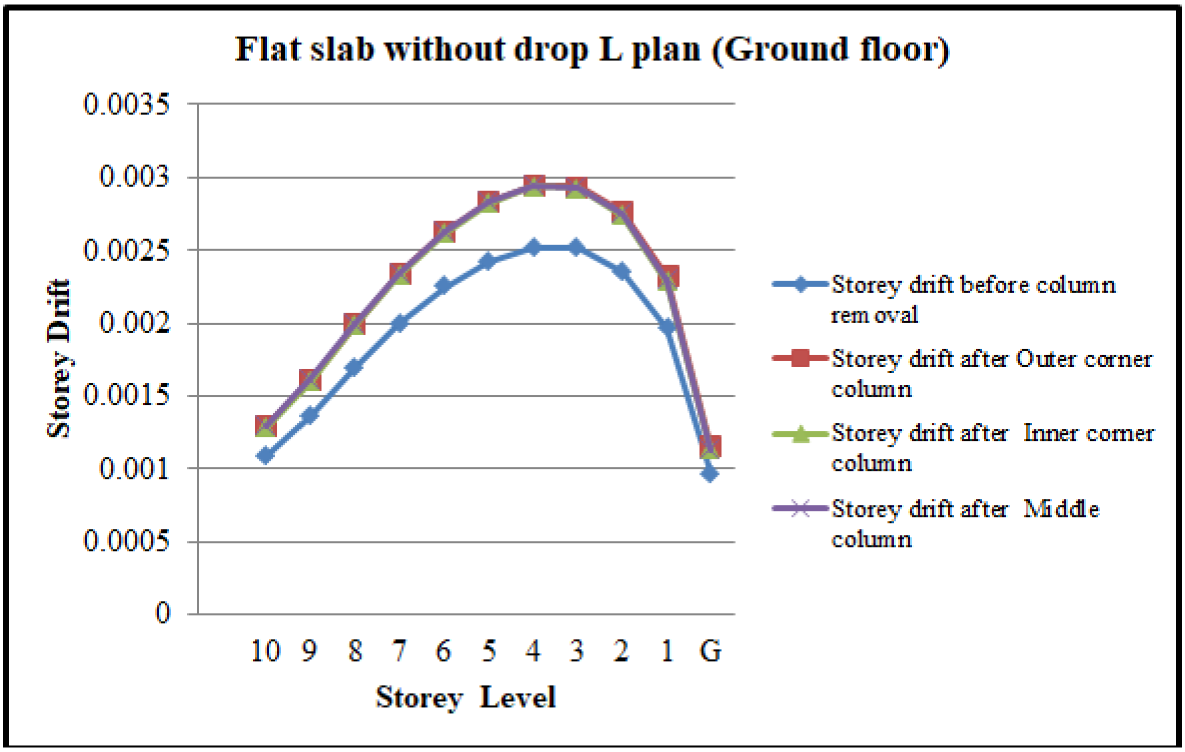

Fig 18 Flat Slab without Drop L Plan (Ground floor)

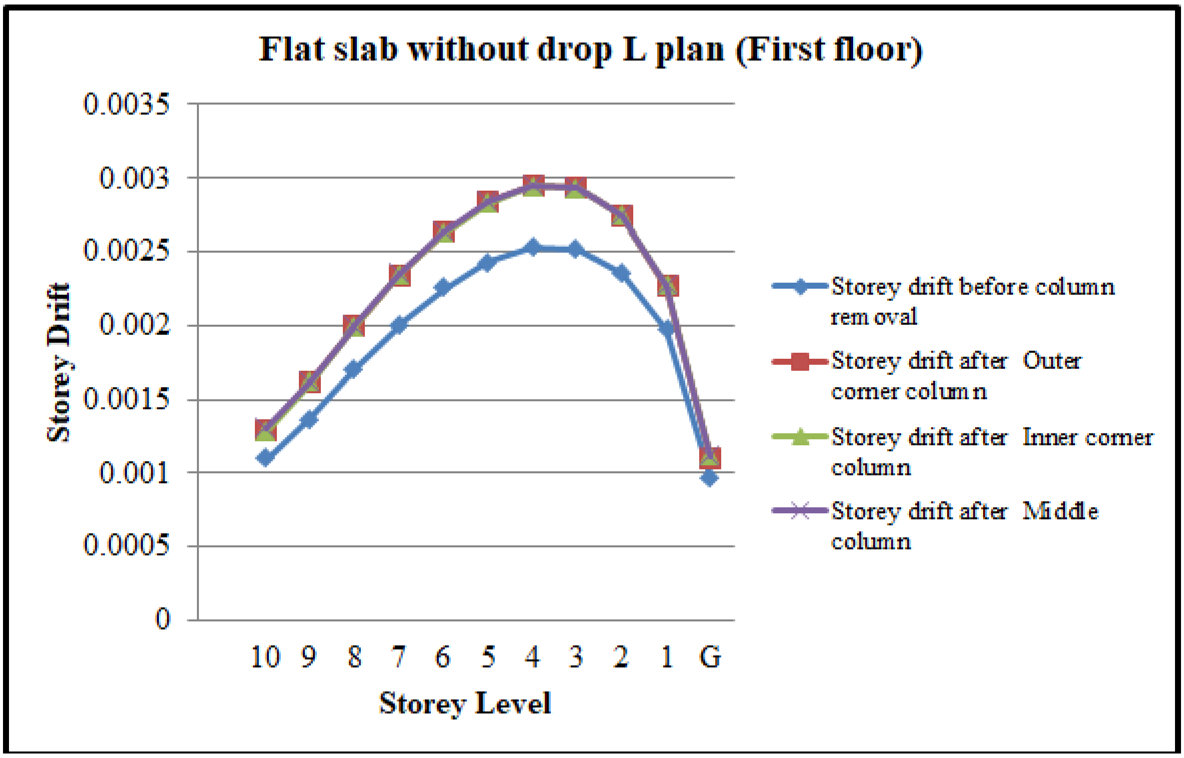

Fig 19 Flat Slab without Drop L Plan (First floor)

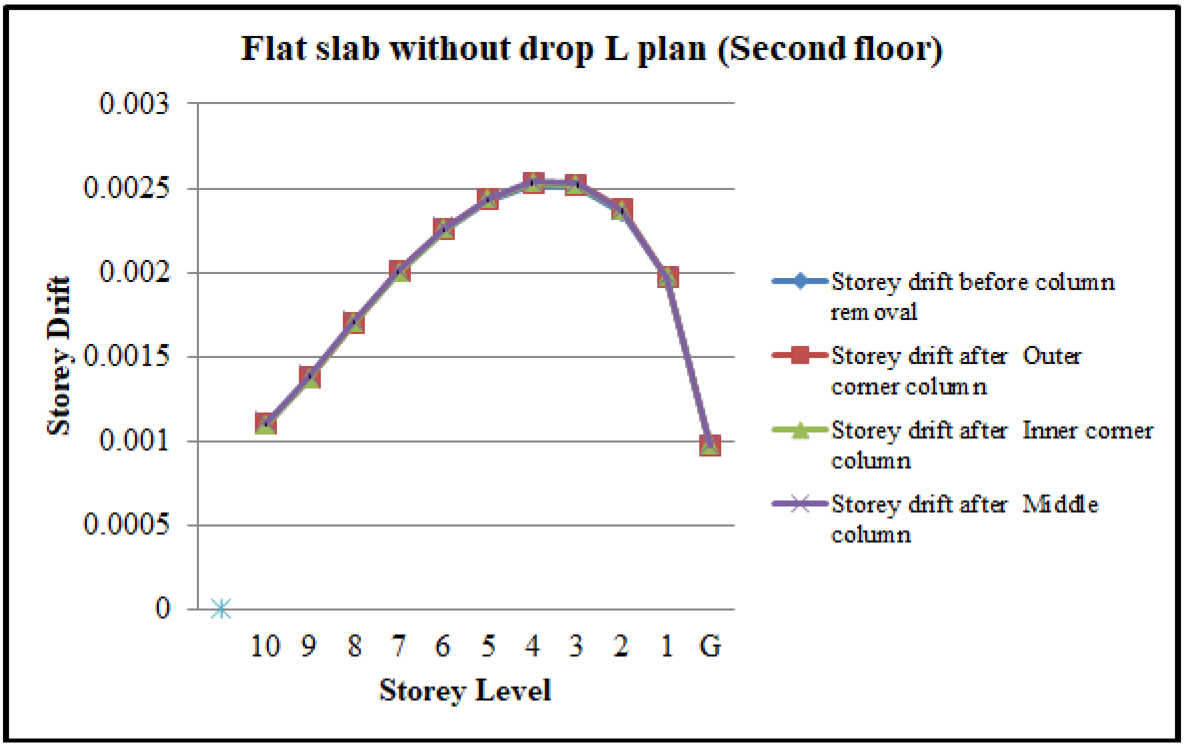

Fig 20 Flat Slab without Drop L Plan (Second floor)

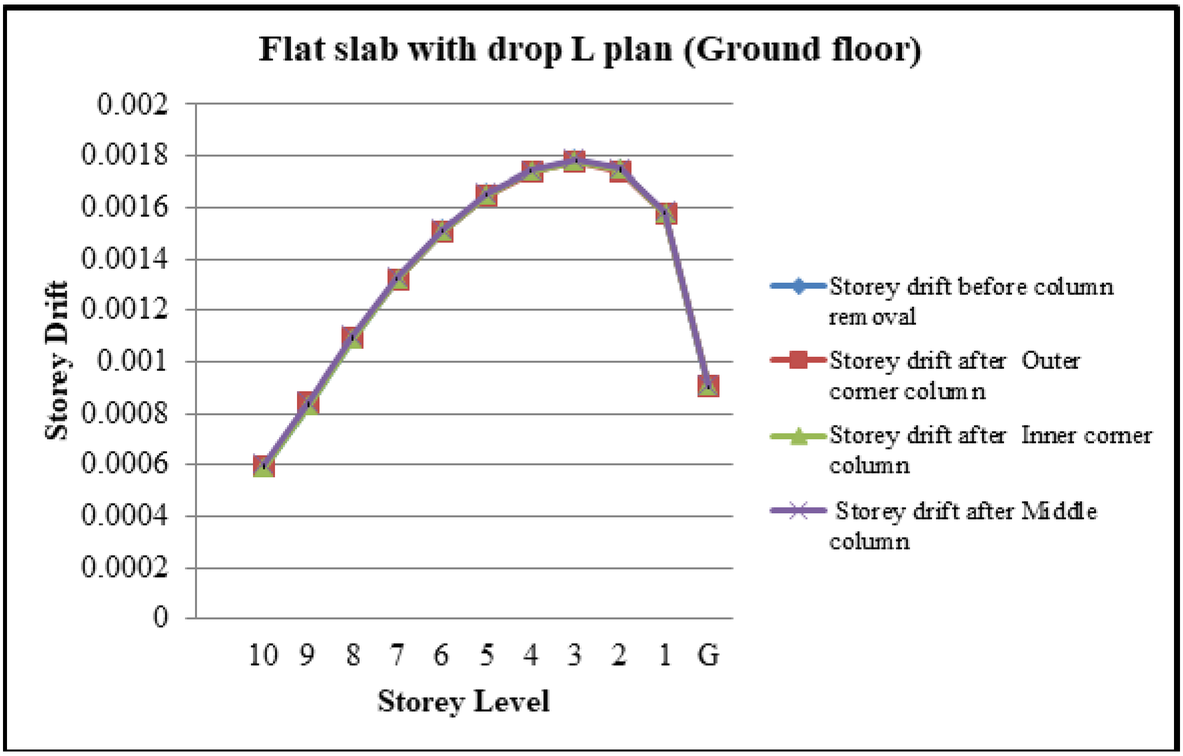

Fig 21 Flat Slab with Drop L Plan (Ground floor)

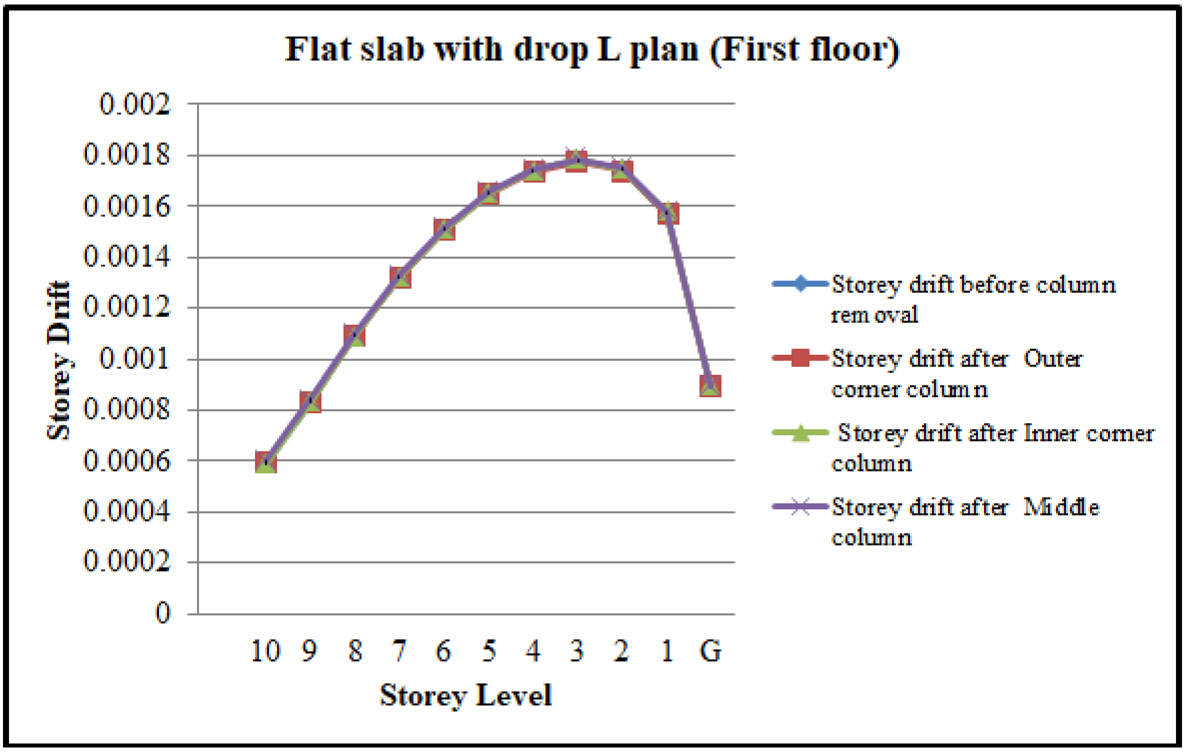

Fig 22 Flat Slab with Drop L Plan (First floor)

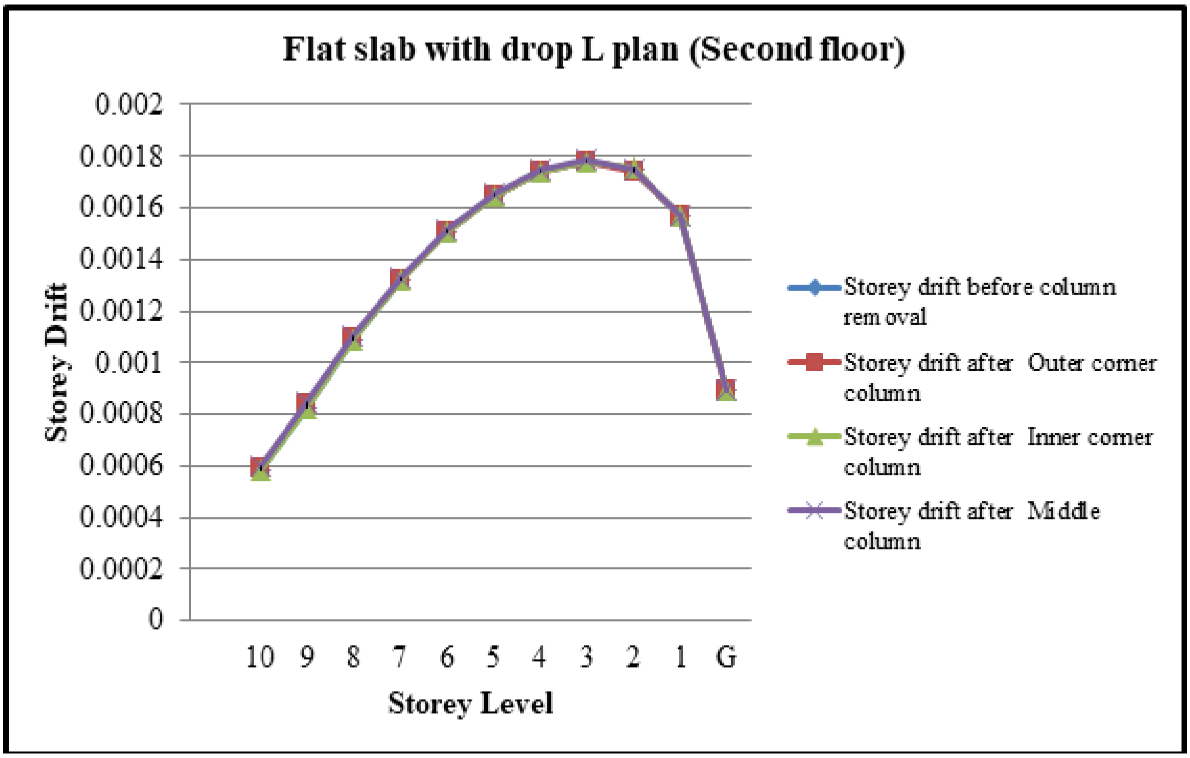

Fig 23 Flat Slab with Drop L Plan (Second floor)

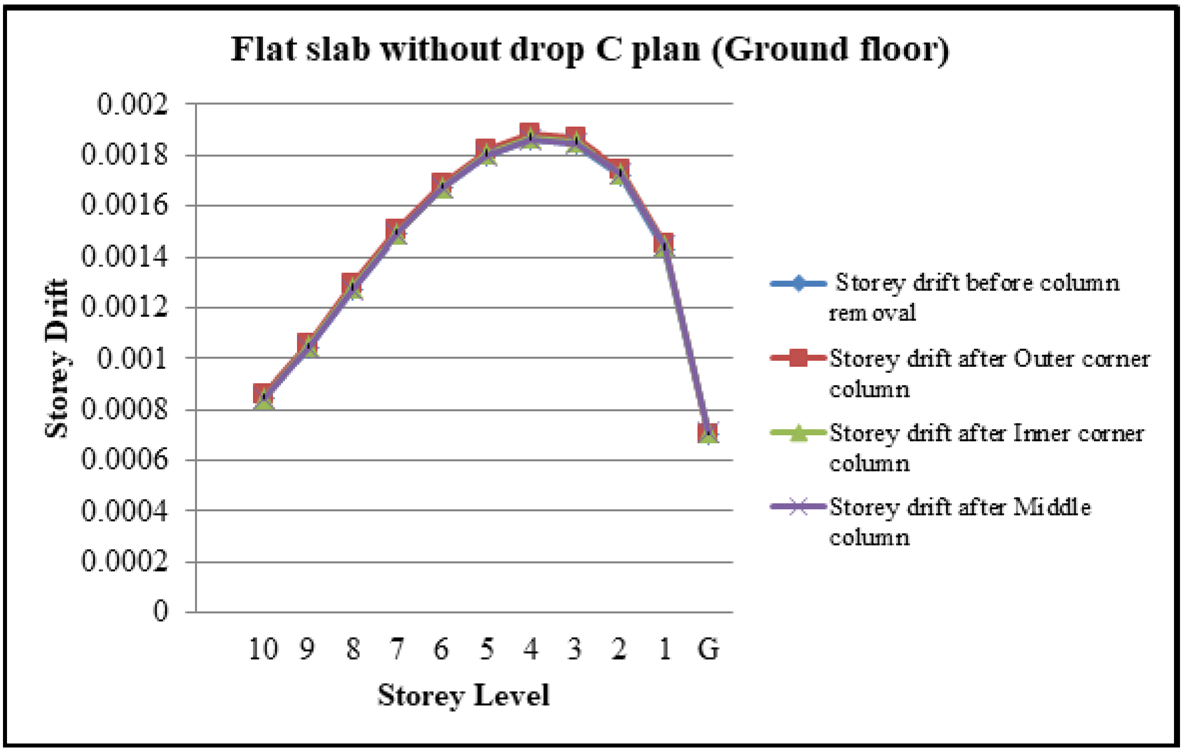

Fig 24 Flat Slab without Drop C Plan (Ground floor)

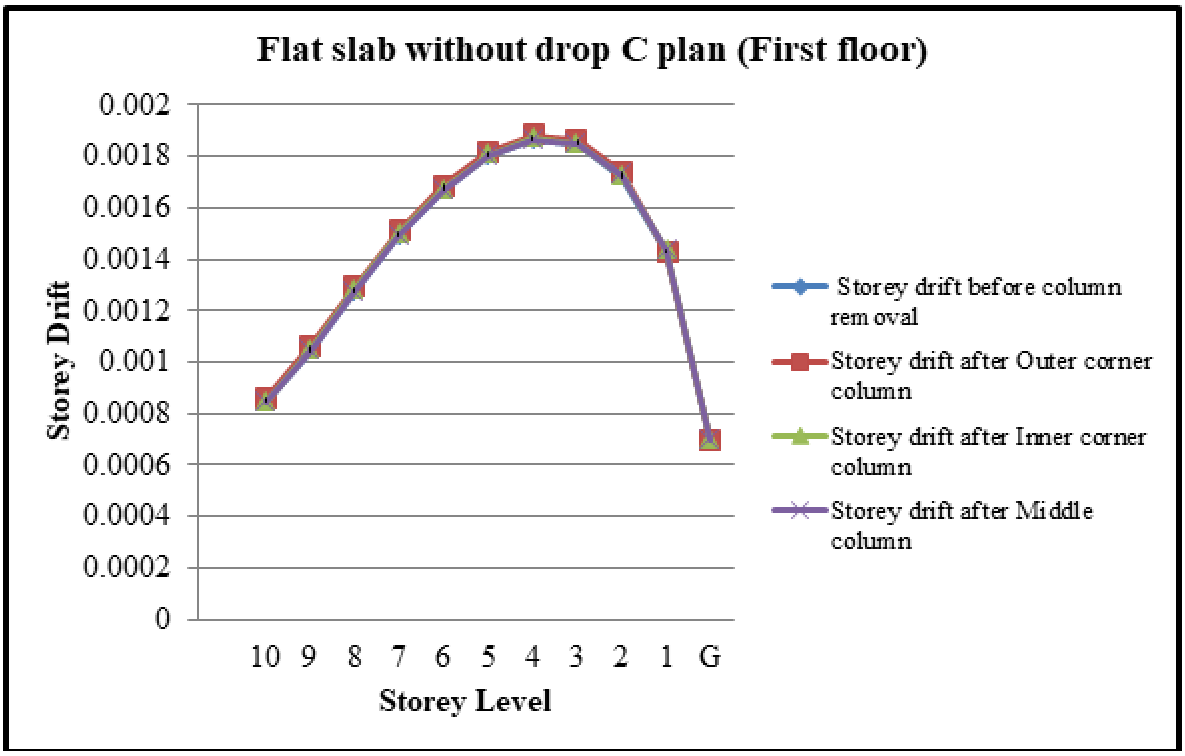

Fig 25 Flat Slab without Drop C Plan (First floor)

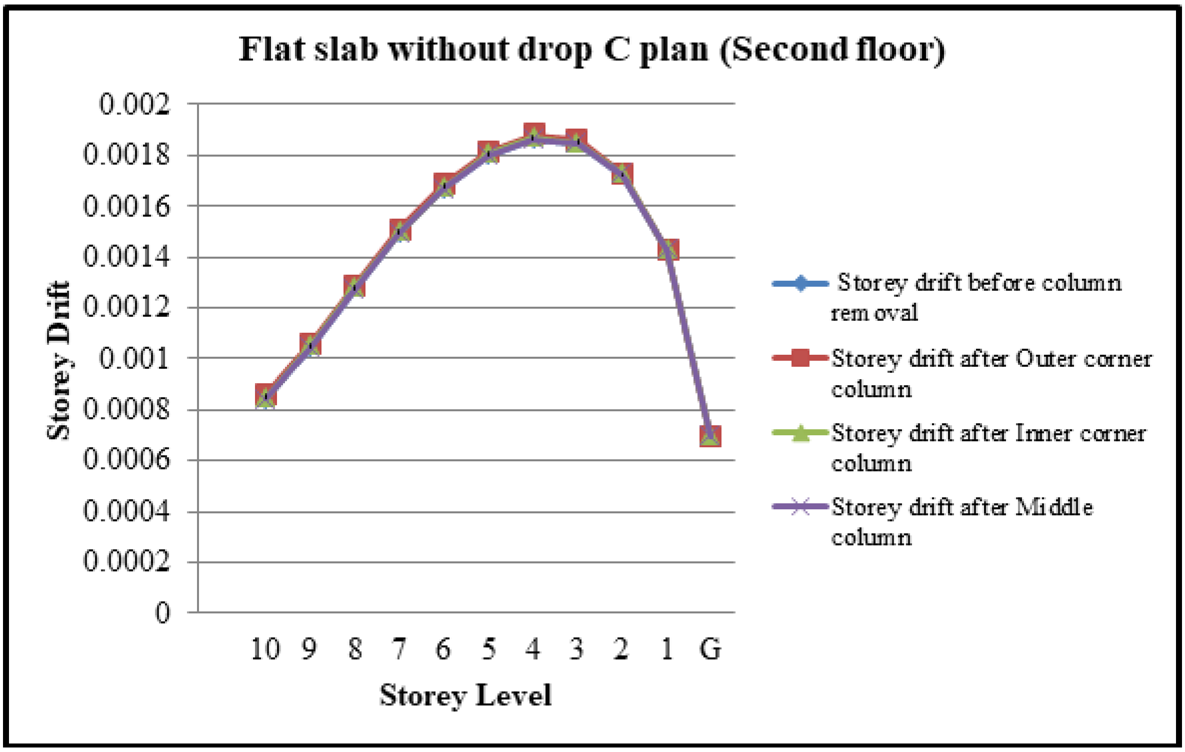

Fig 26 Flat Slab without Drop C Plan (Second floor)

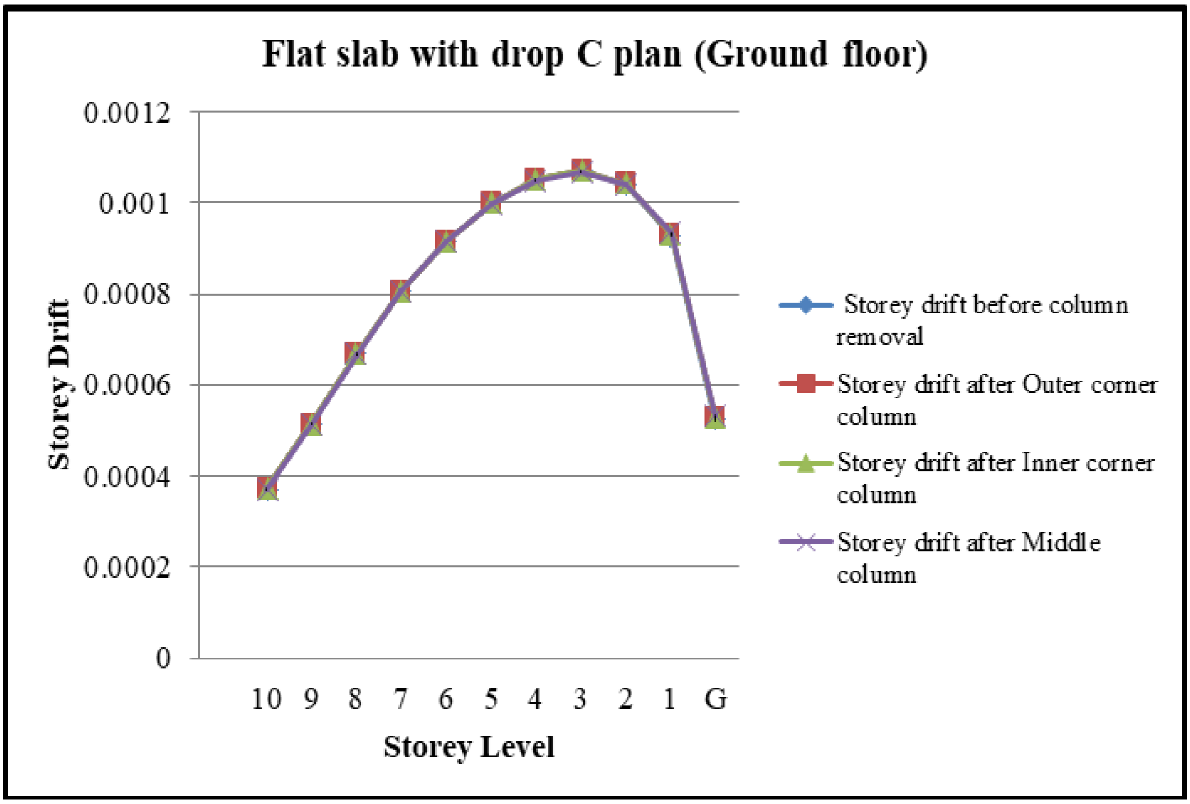

Fig 27 Flat Slab with Drop C Plan (Ground floor)

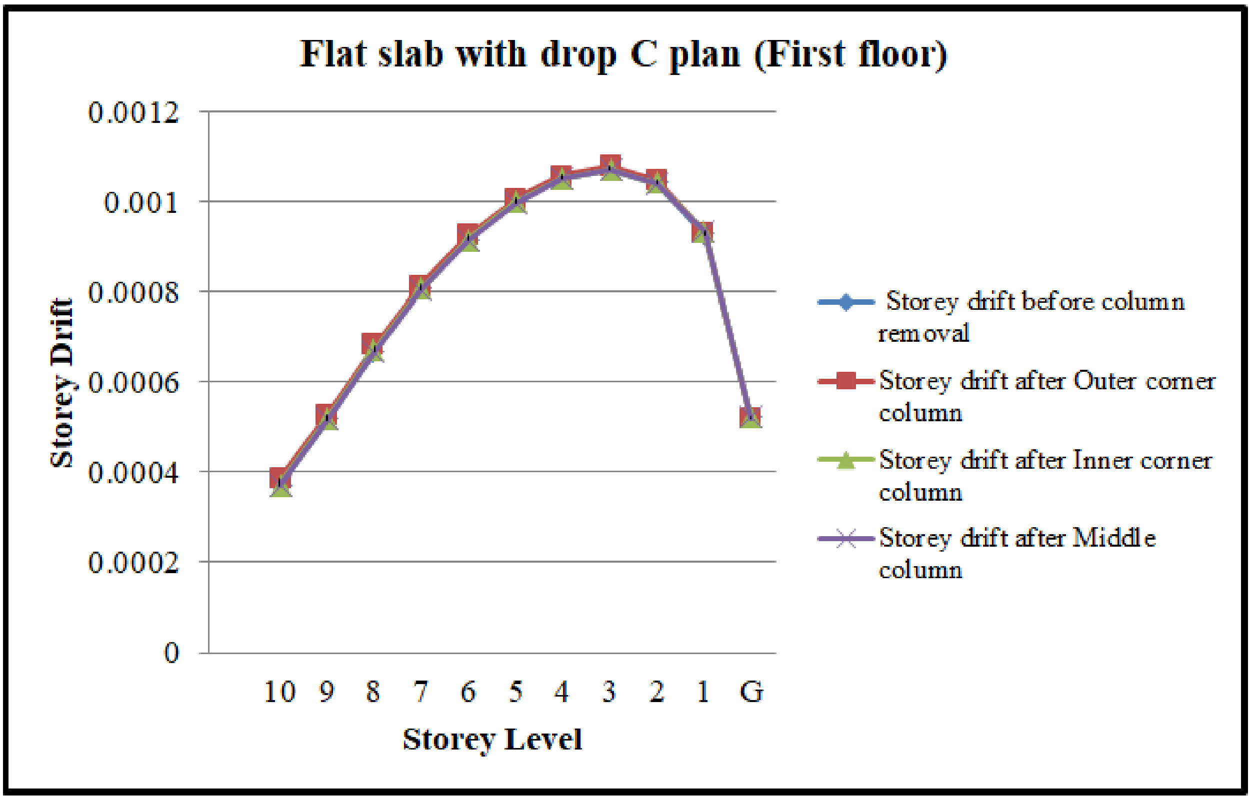

Fig 28 Flat Slab with Drop C Plan (First floor)

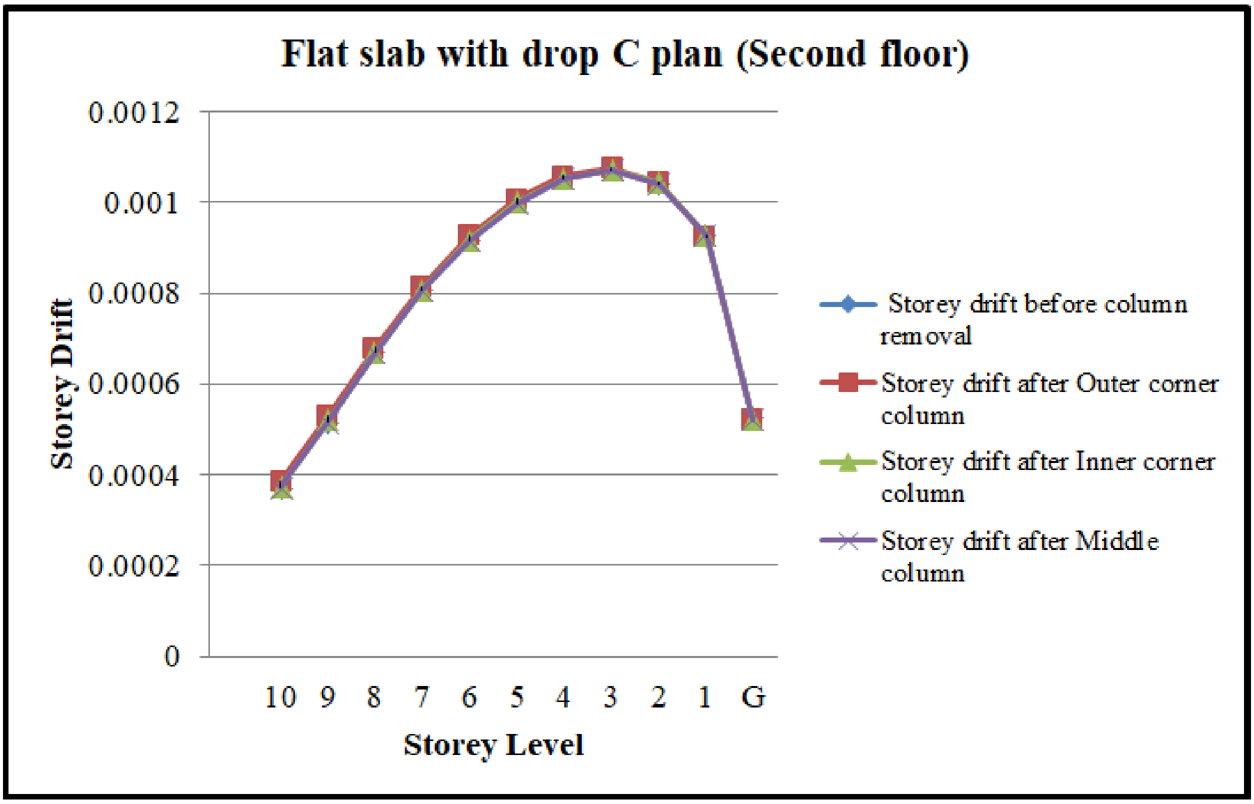

Fig 29 Flat Slab with Drop C Plan (Second floor)

➢ *Vertical Displacement*

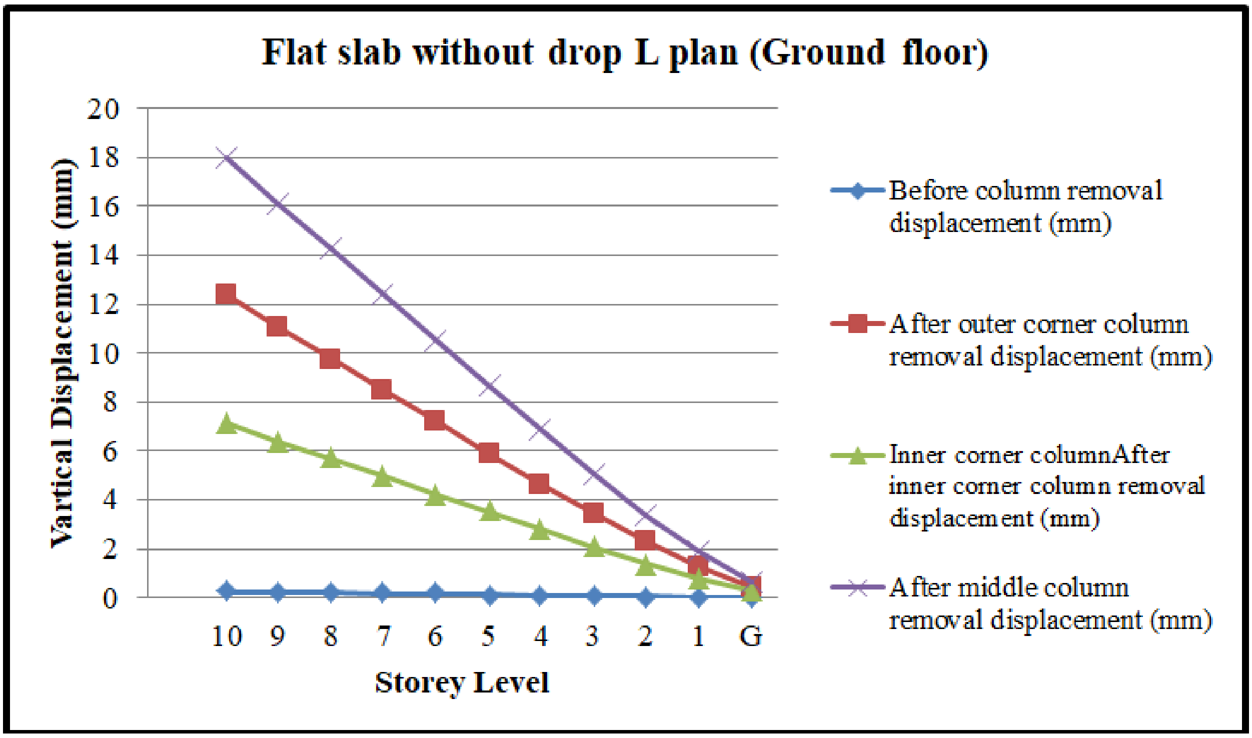

Fig 30 Flat Slab without Drop L Plan (Ground floor)

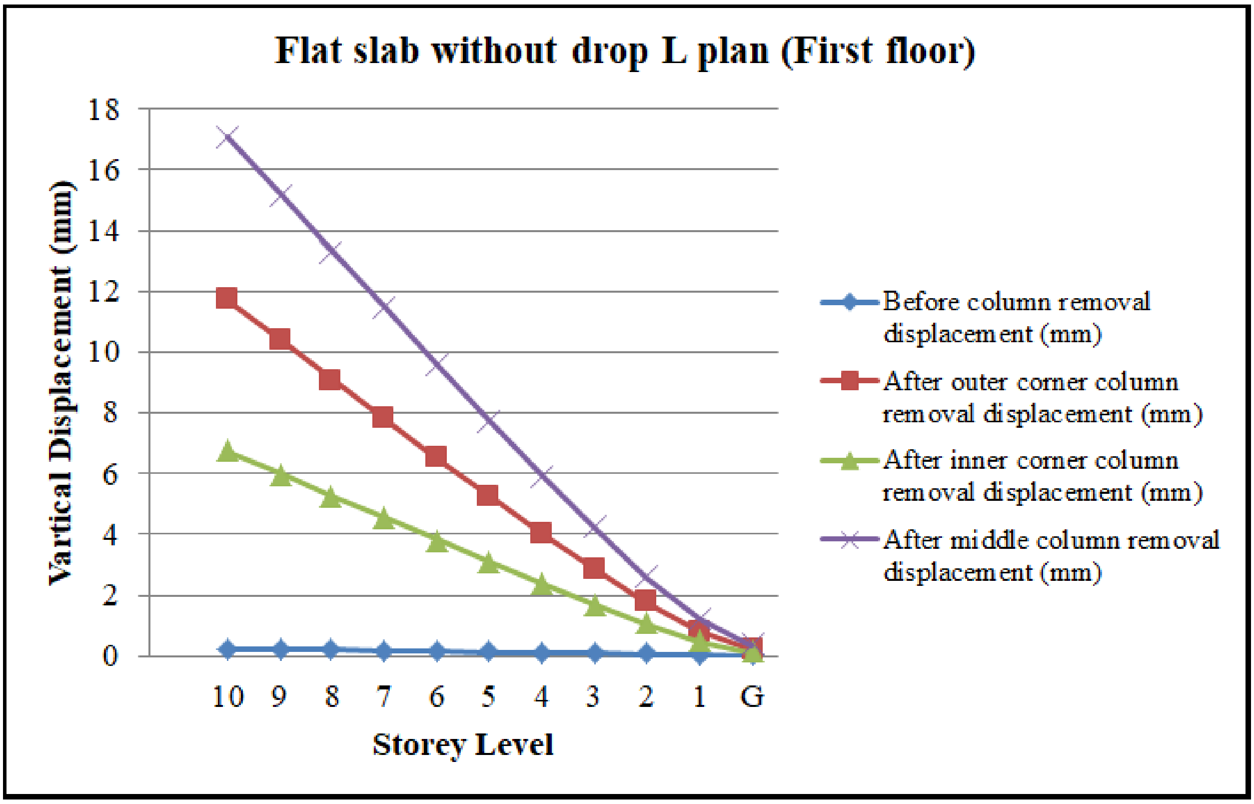

Fig 31 Flat slab without drop L plan (First floor)

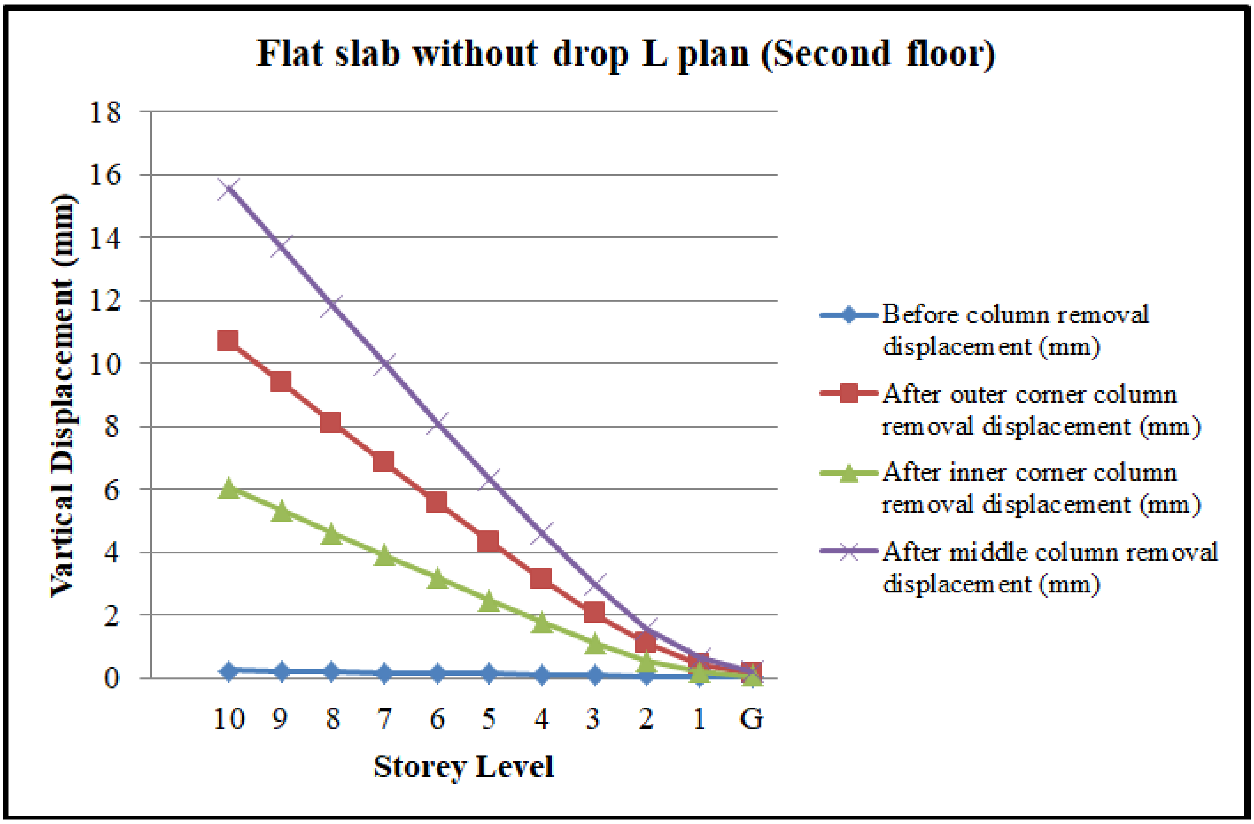

Fig 32 Flat Slab without Drop L Plan (Second floor)

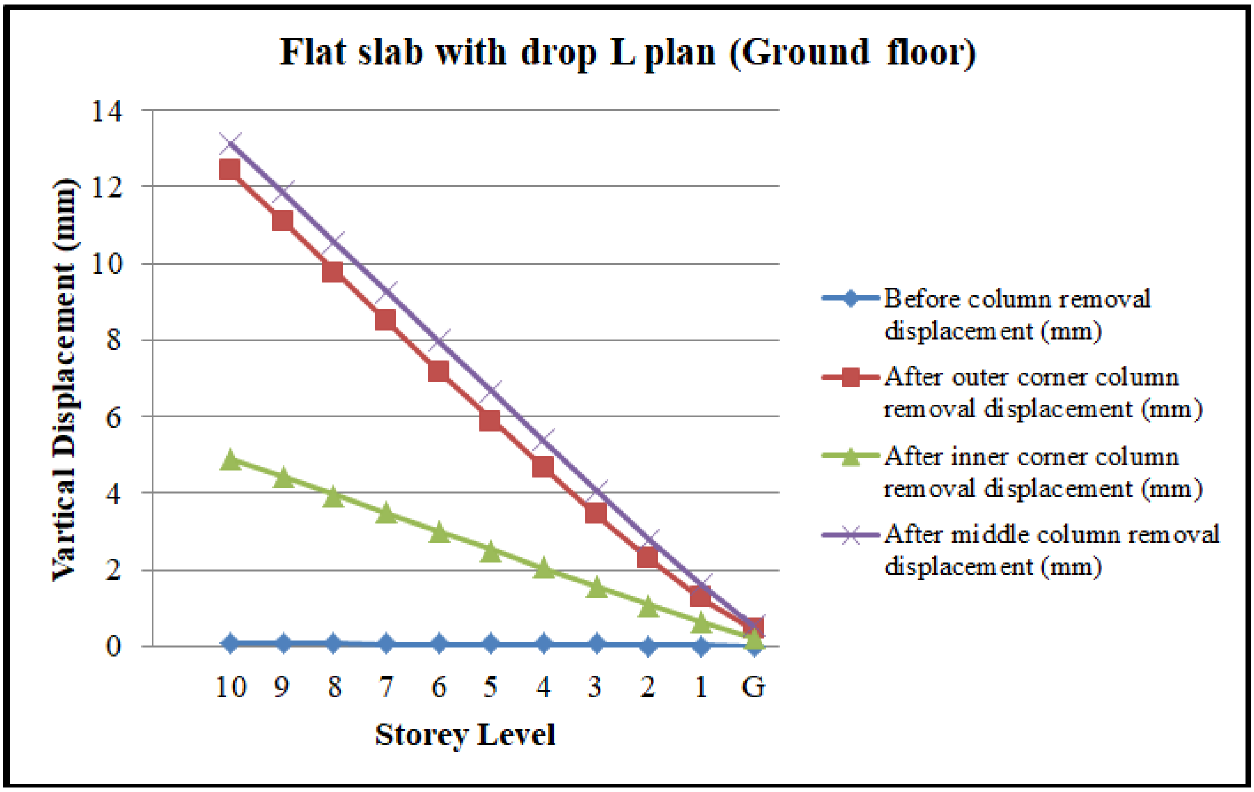

Fig 33 Flat Slab with Drop L Plan (Ground floor)

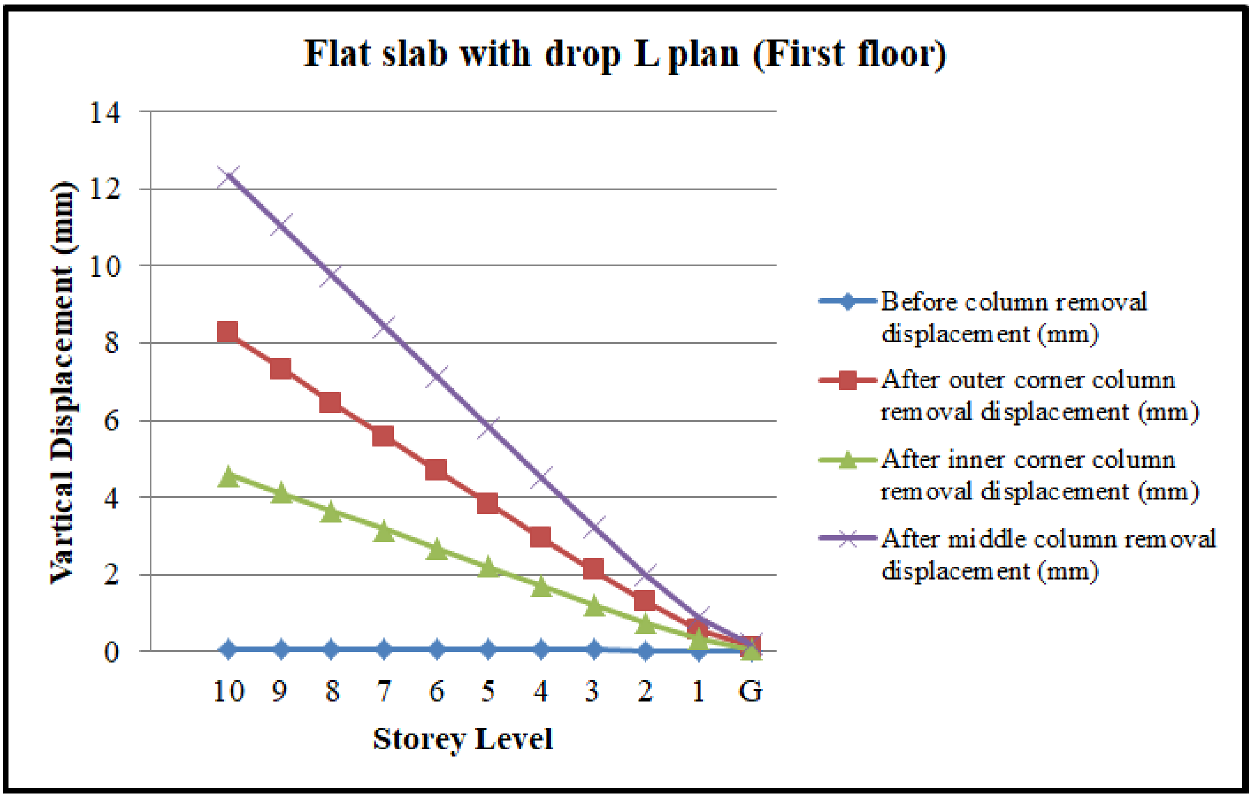

Fig 34 Flat Slab with Drop L Plan (First floor)

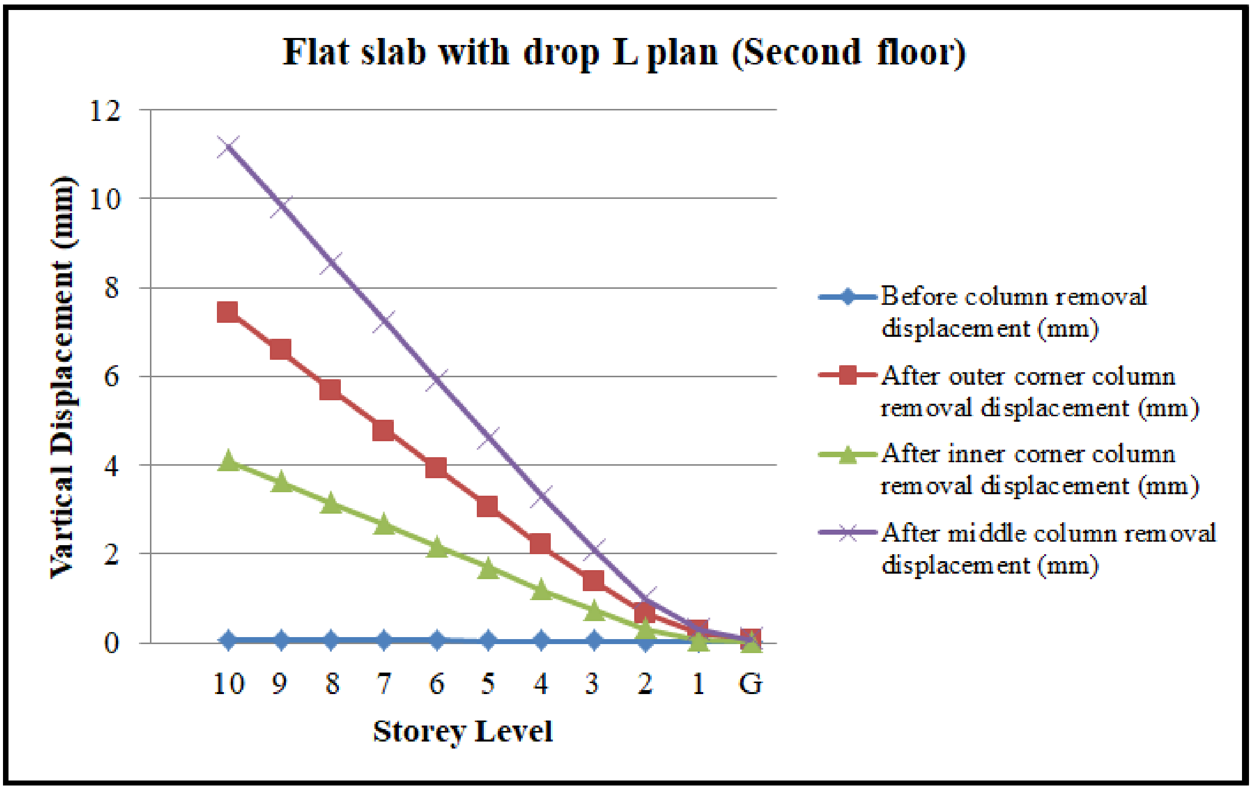

Fig 35 Flat Slab with Drop L Plan (Second floor)

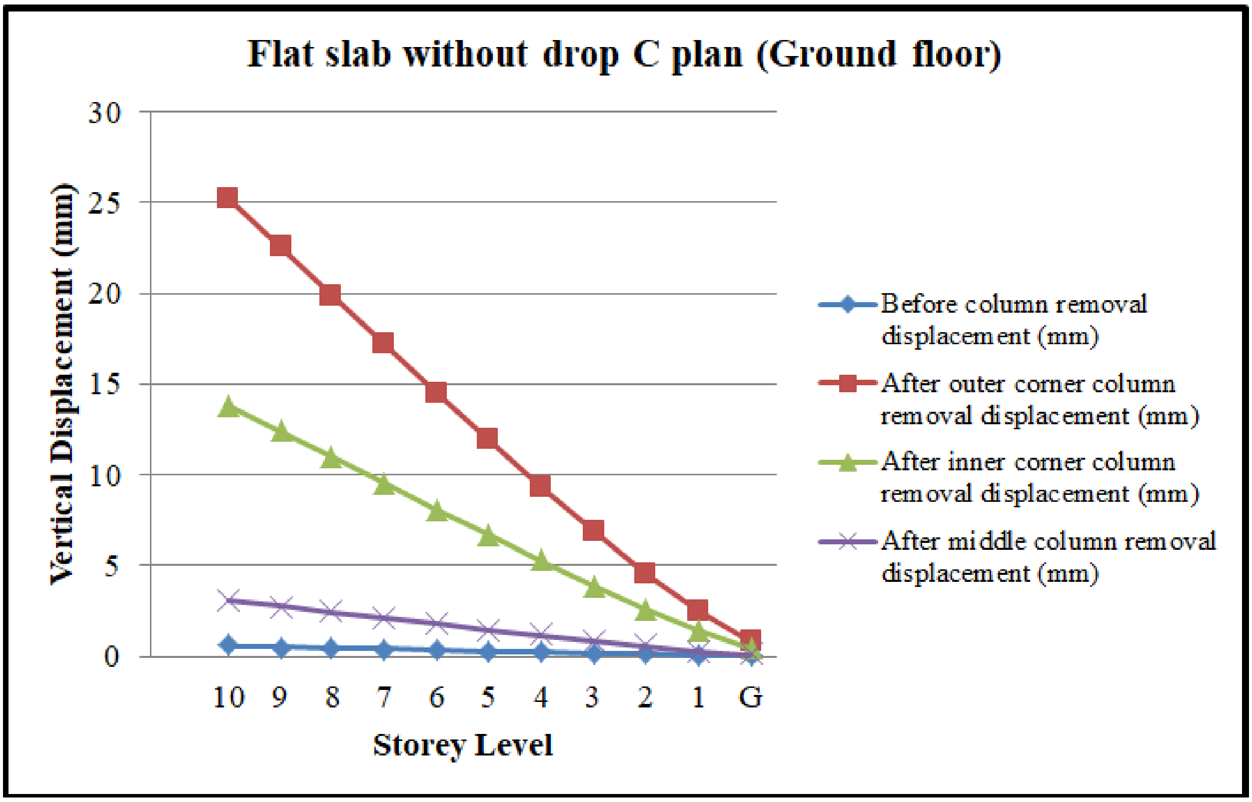

Fig 36 Flat Slab without Drop C Plan (Ground floor)

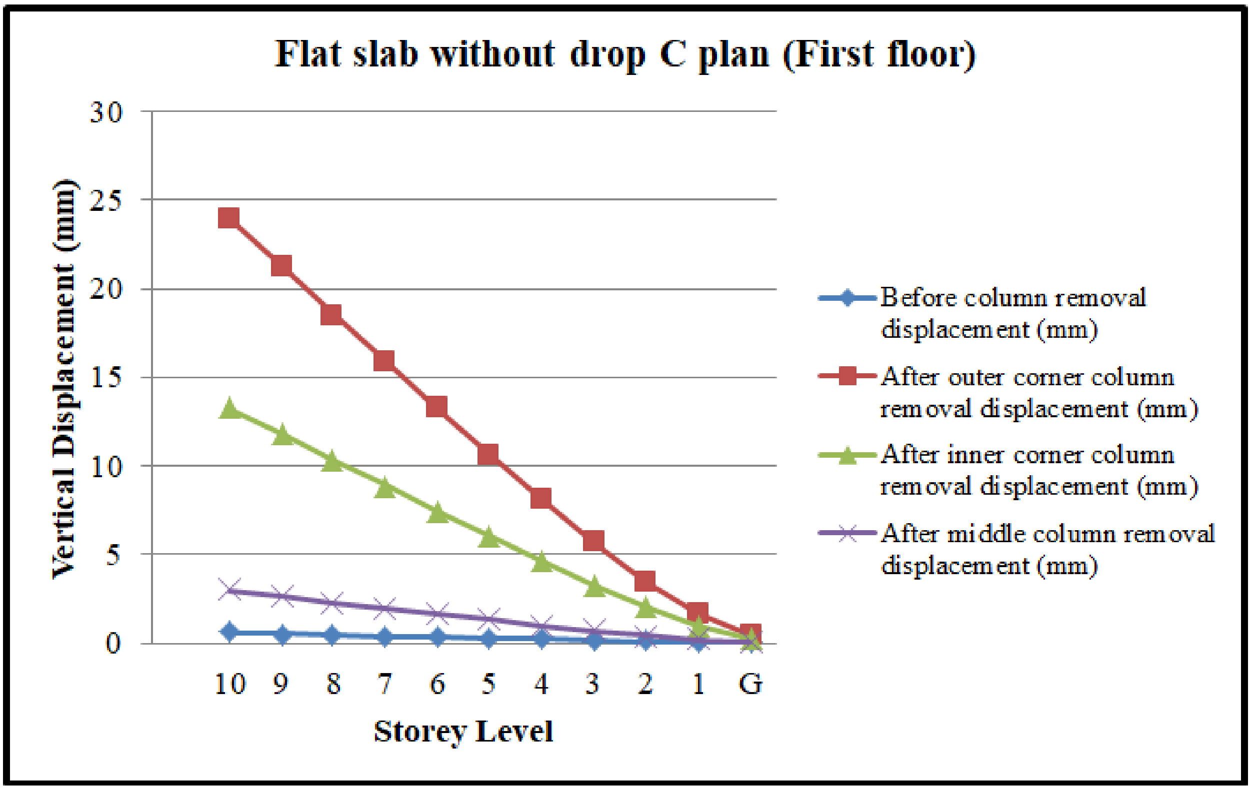

Fig 37 Flat Slab without Drop C Plan (First floor)

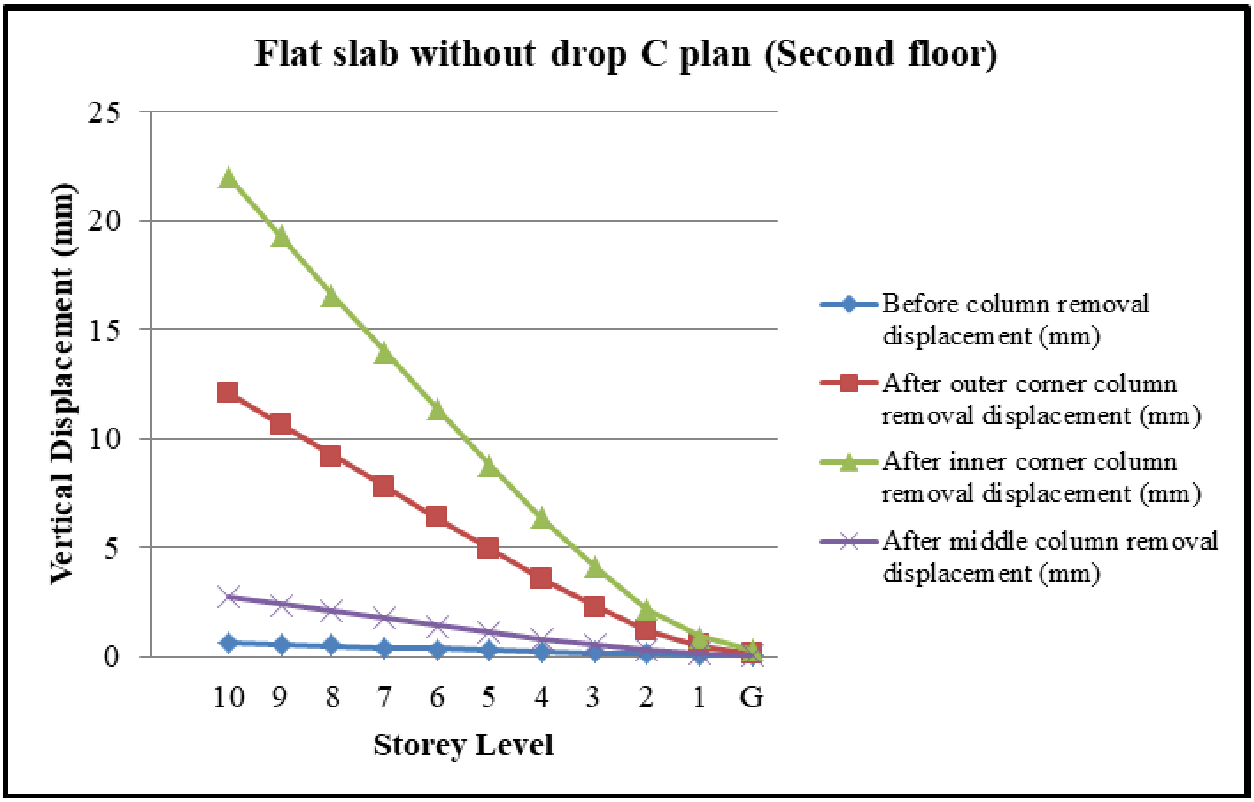

Fig 38 Flat Slab without Drop C Plan (Second floor)

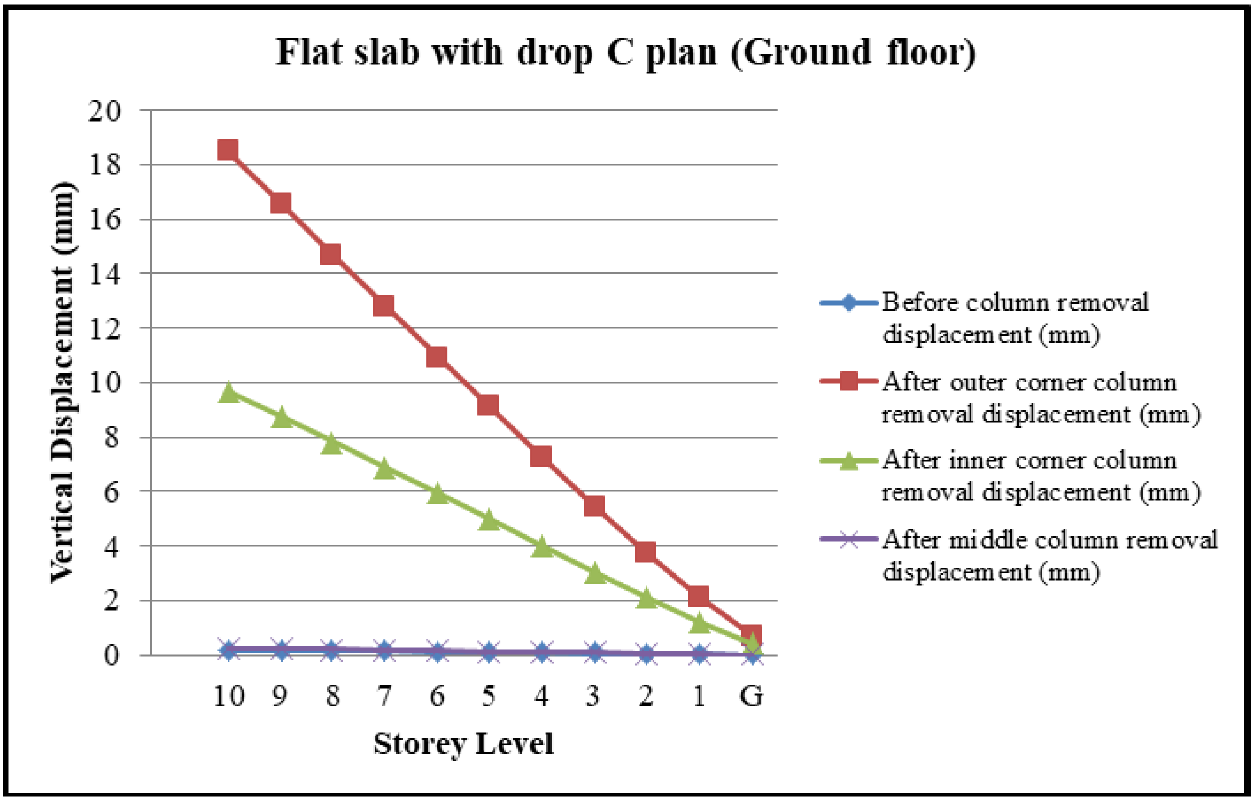

Fig 39 Flat Slab with Drop C Plan (Ground floor)

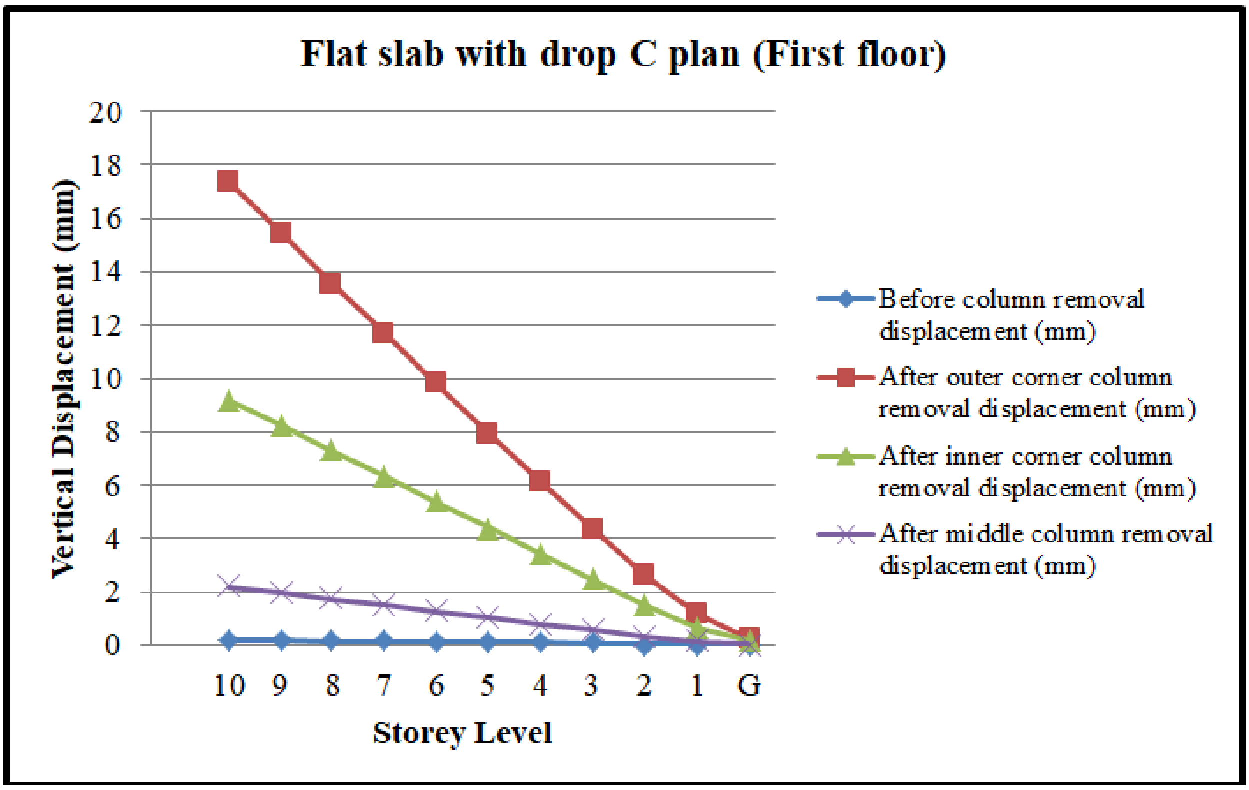

Fig 40 Flat Slab with Drop C Plan (First floor)

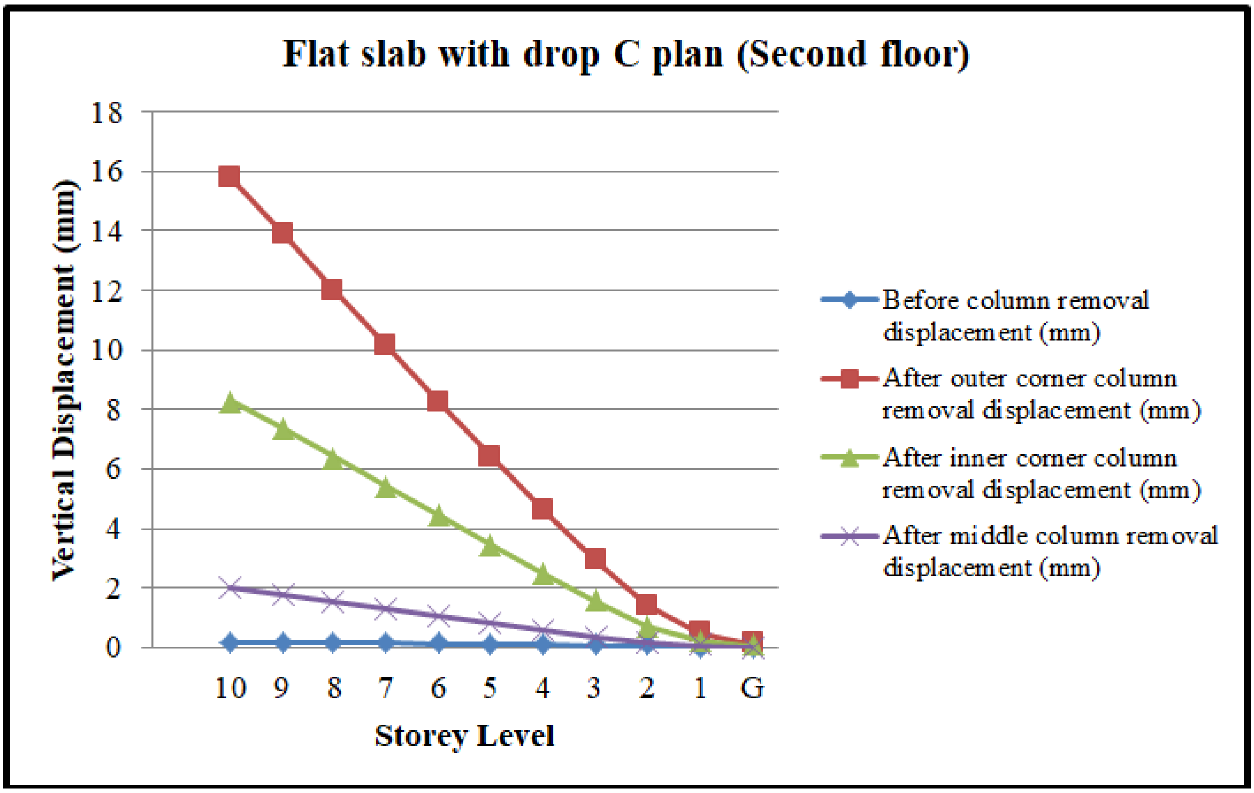

Fig 41 Flat Slab with Drop C Plan (Second floor)

- *Base shear*

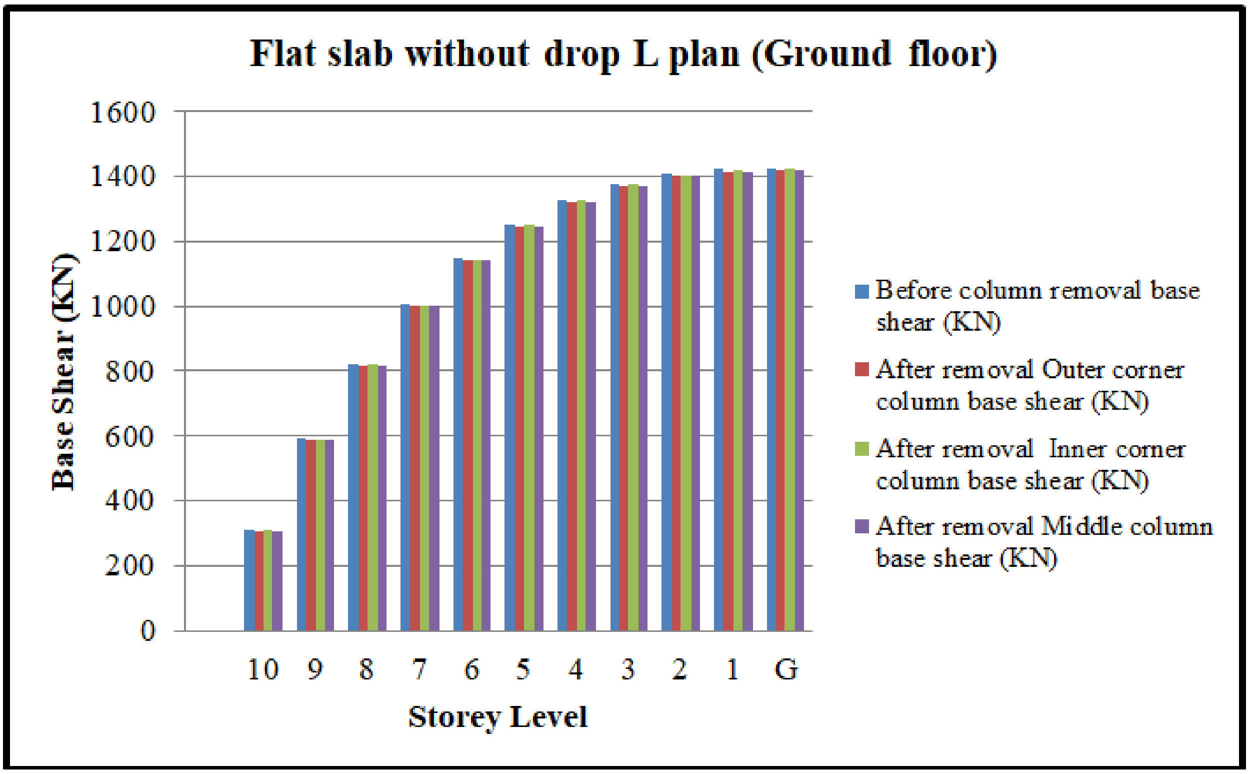

Fig 42 Flat Slab without Drop L Plan (Ground floor)

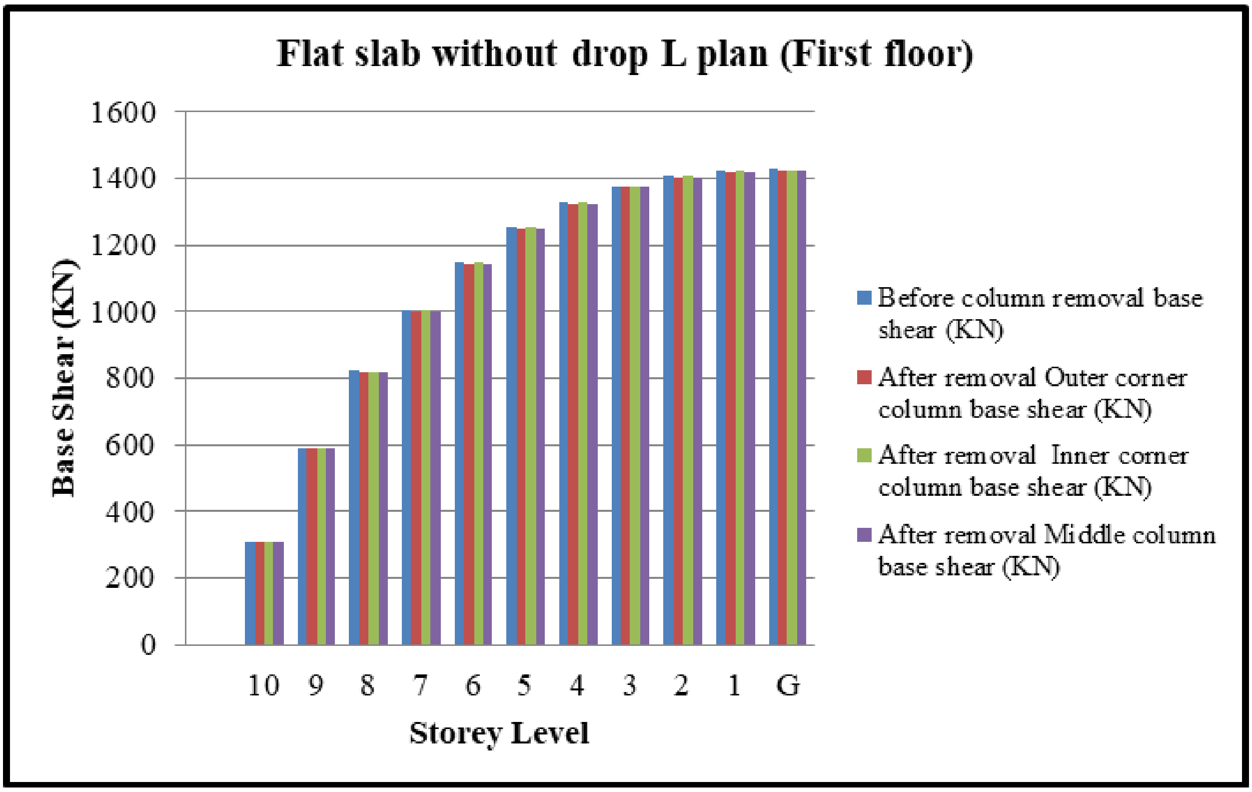

Fig 43 Flat Slab without Drop L Plan (First floor)

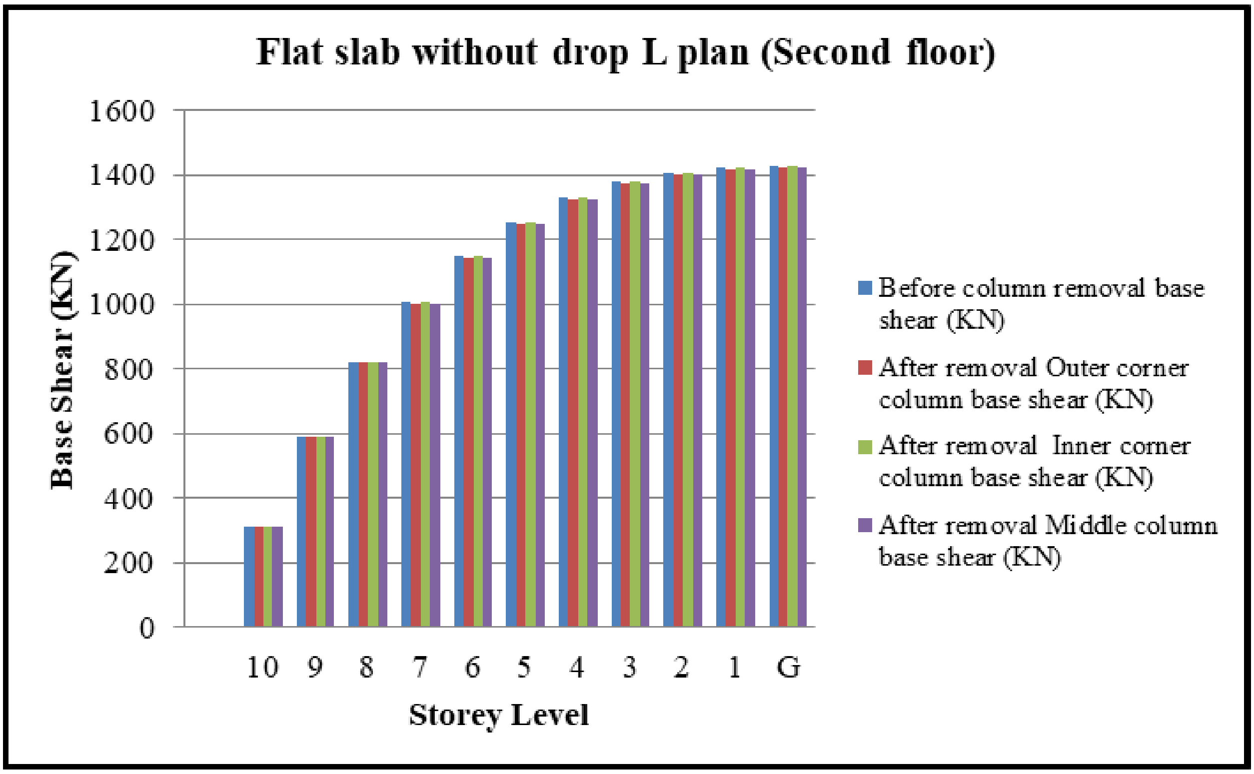

Fig 44 Flat Slab without Drop L Plan (Second floor)

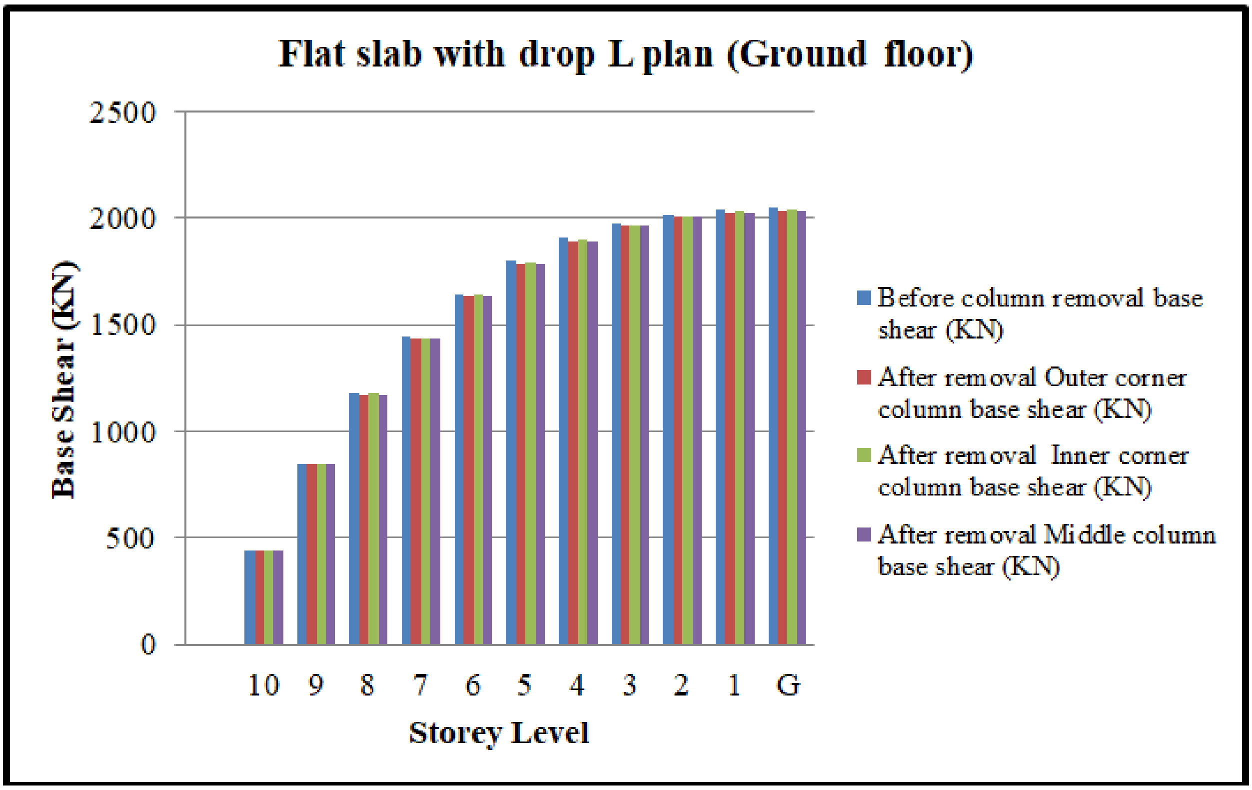

Fig 45 Flat Slab with Drop L Plan (Ground floor)

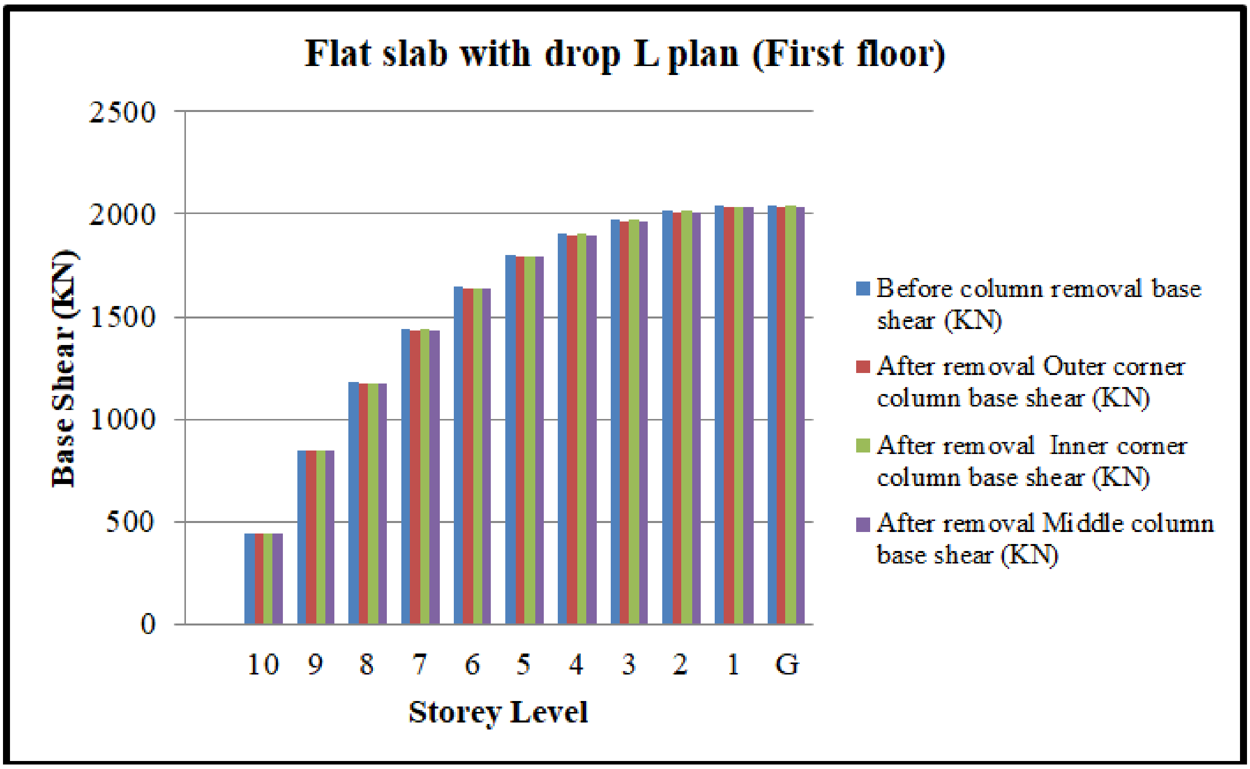

Fig 46 Flat Slab with Drop L Plan (First floor)

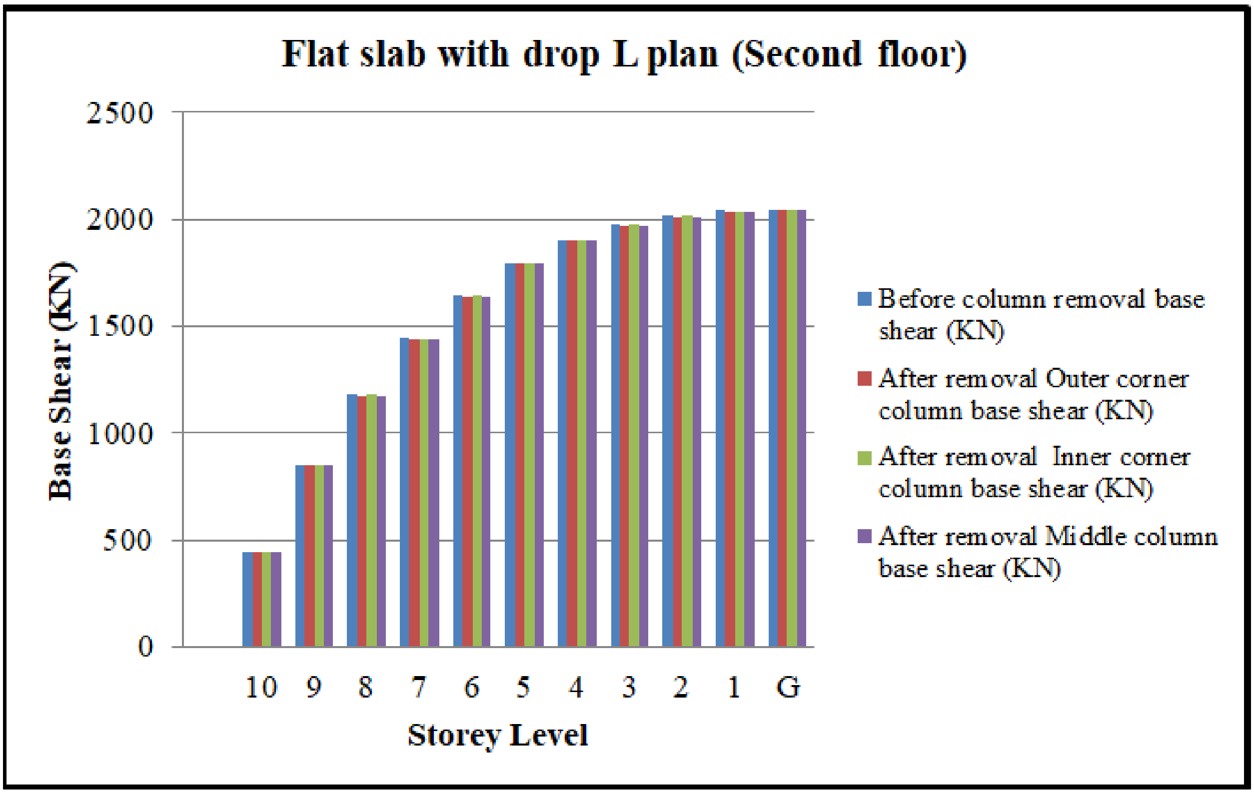

Fig 47 Flat Slab with Drop L Plan (Second floor)

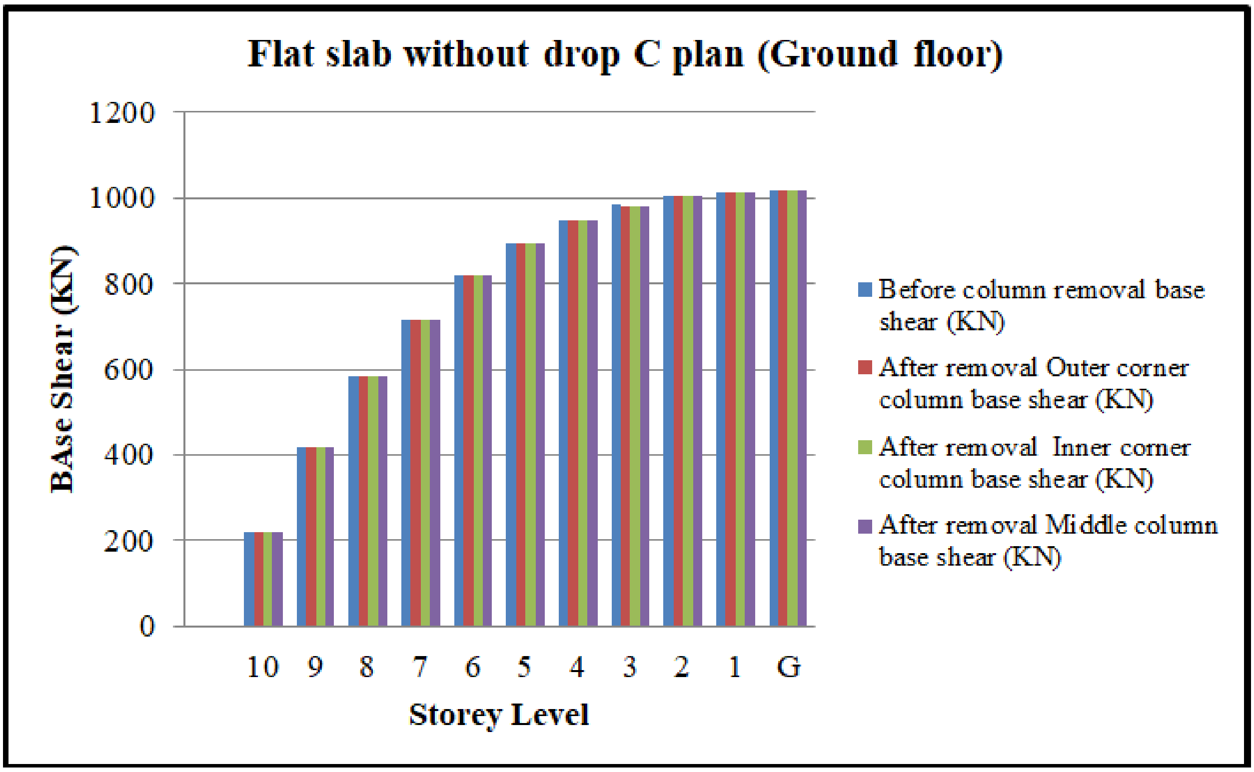

Fig 48 Flat Slab without Drop C Plan (Ground floor)

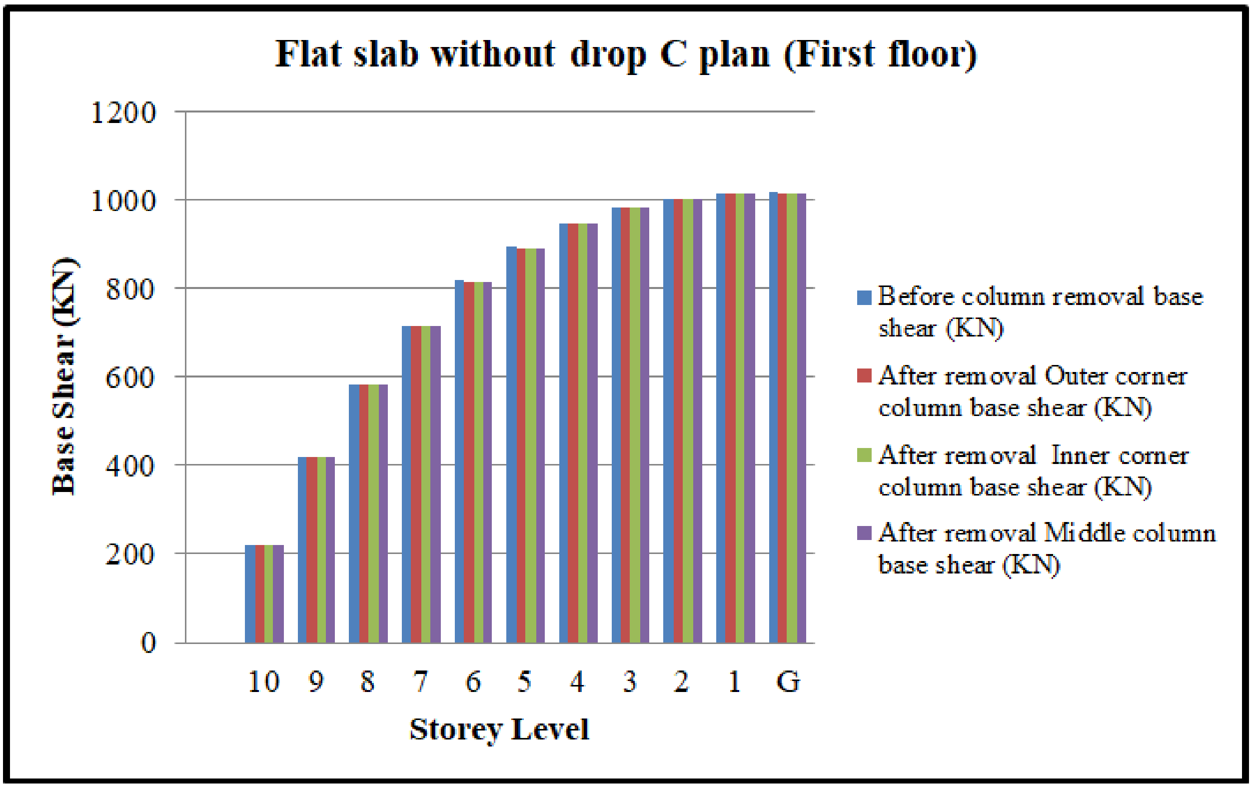

Fig 49 Flat Slab without Drop C Plan (First floor)

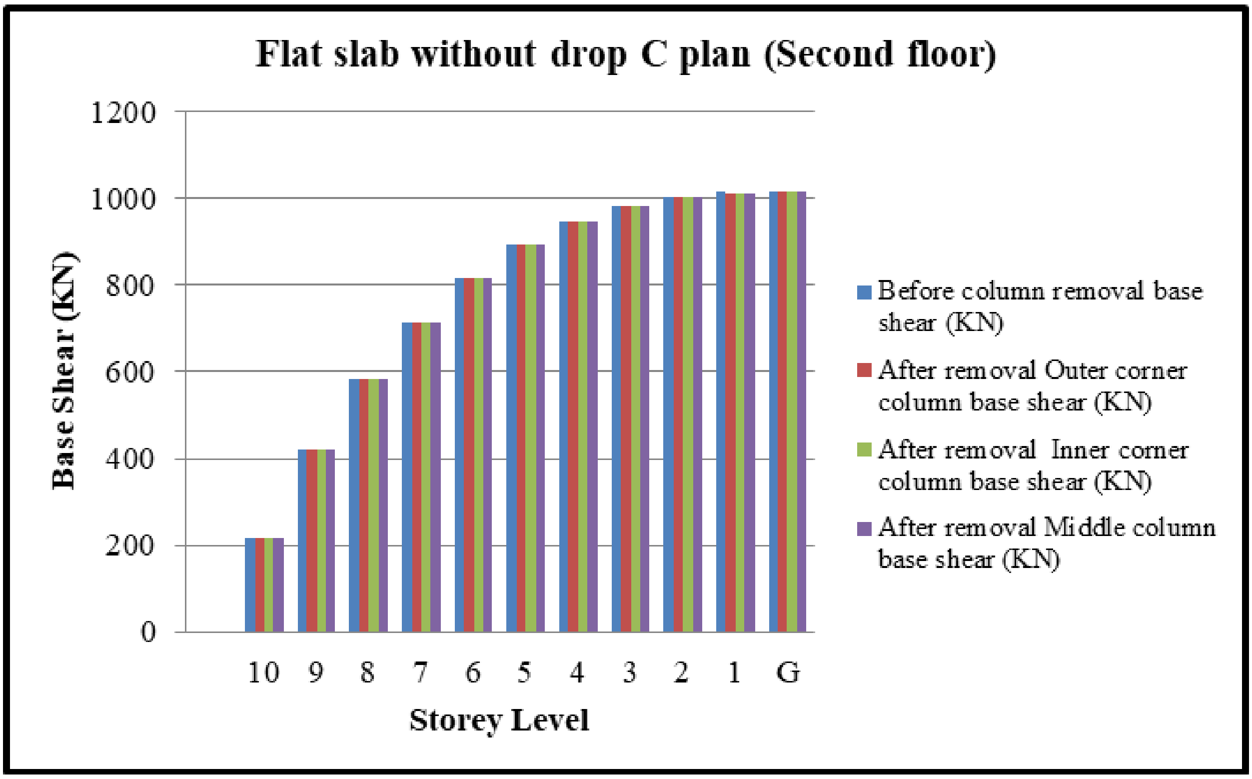

Fig 50 Flat Slab without Drop C Plan (Second floor)

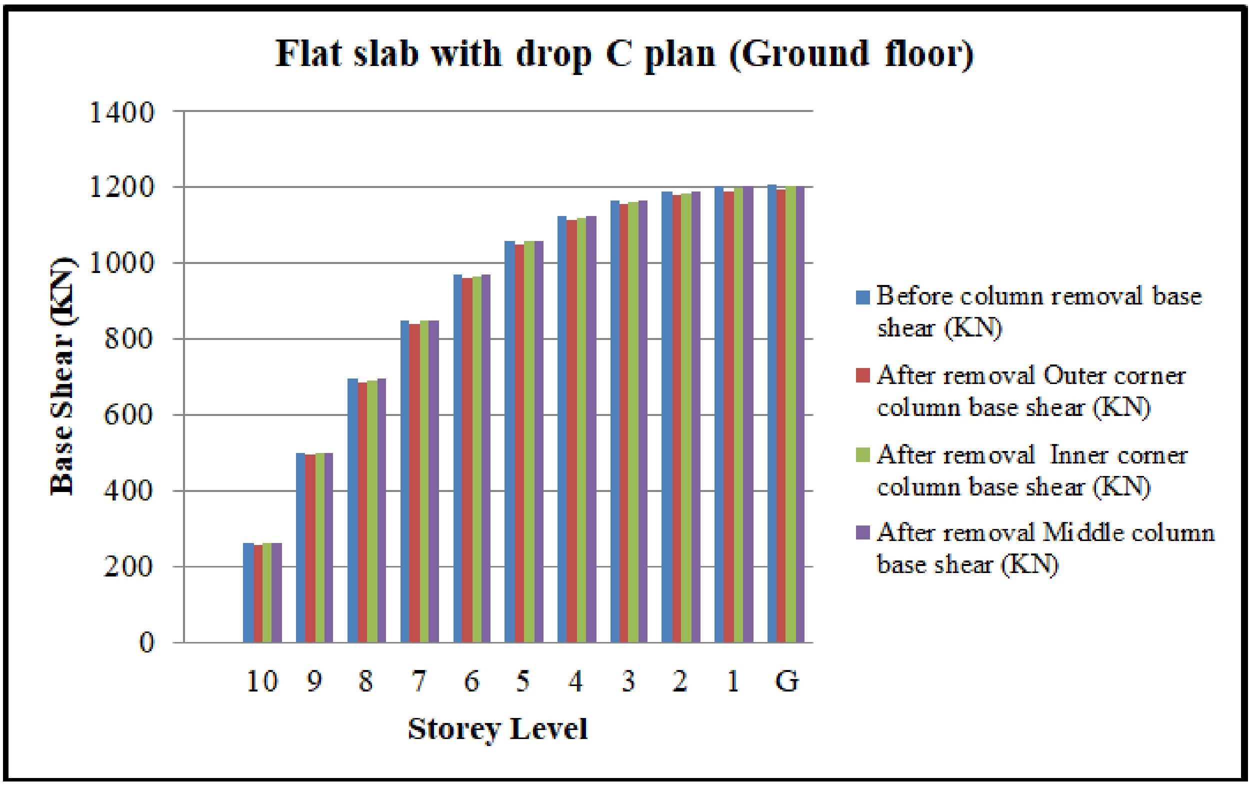

Fig 51 Flat Slab with Drop C Plan (Ground floor)

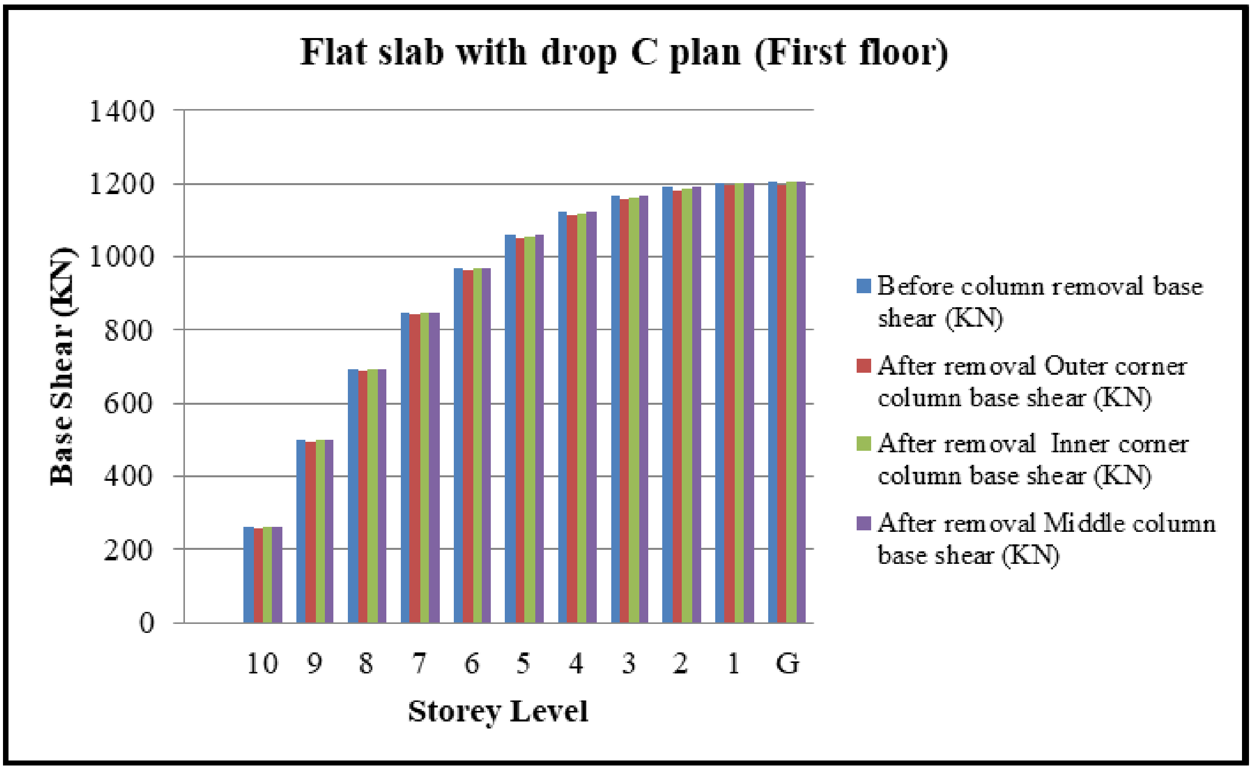

Fig 52 Flat Slab with Drop C Plan (First floor)

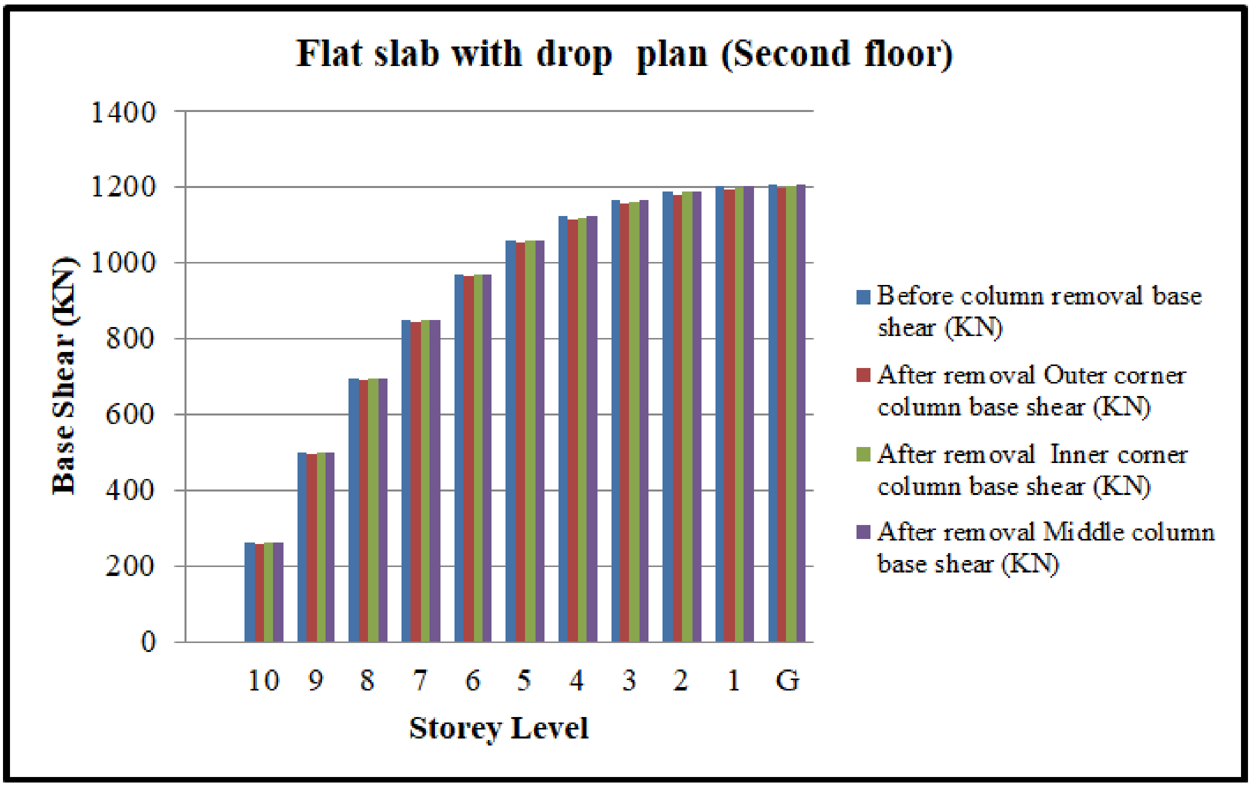

Fig 53 Flat Slab with Drop Plan (Second floor)

- *Axial Force*

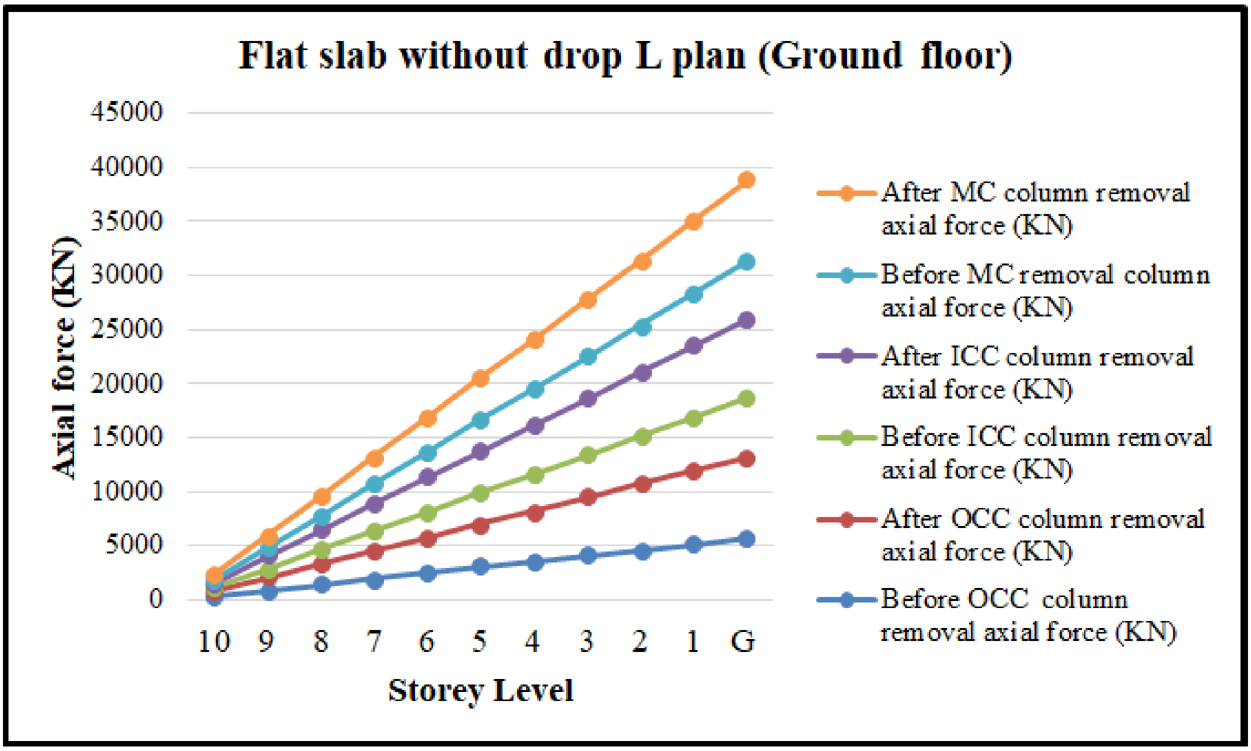

Fig 54 Flat Slab without Drop L Plan (Ground floor)

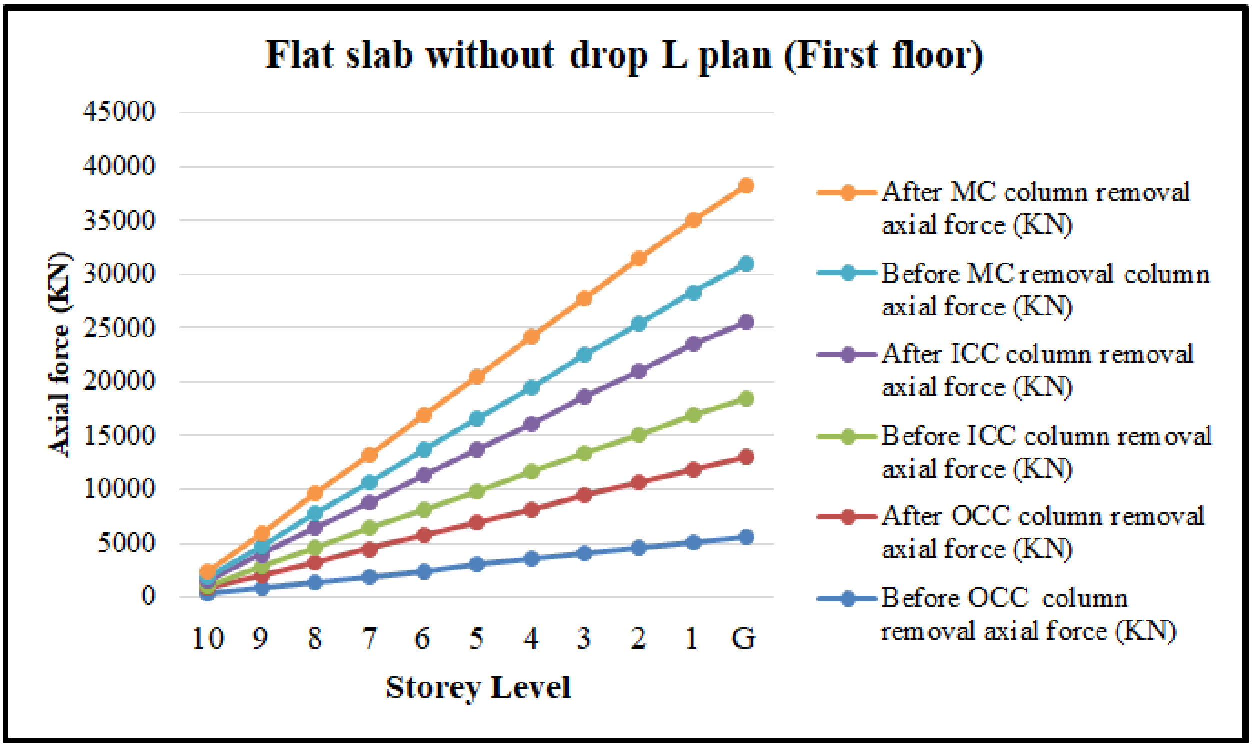

Fig 55 Flat Slab without Drop L Plan (First floor)

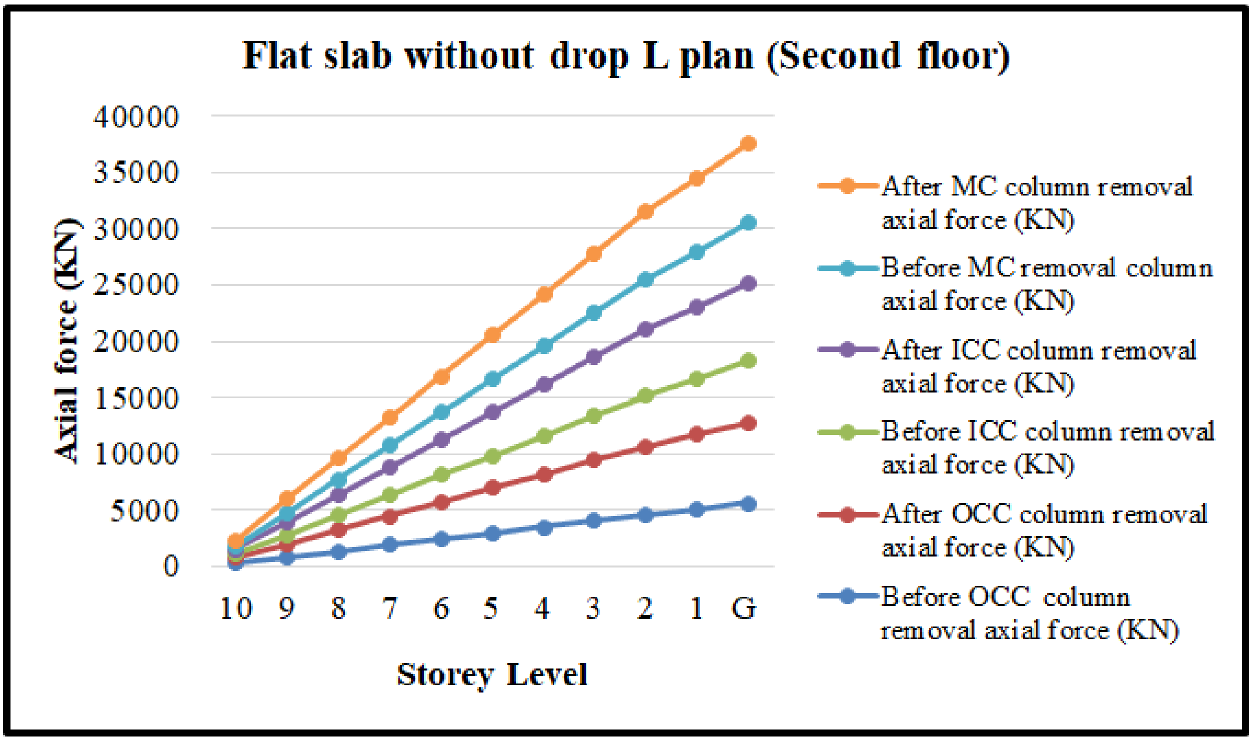

Fig 56 Flat slab without drop L plan (Second floor)

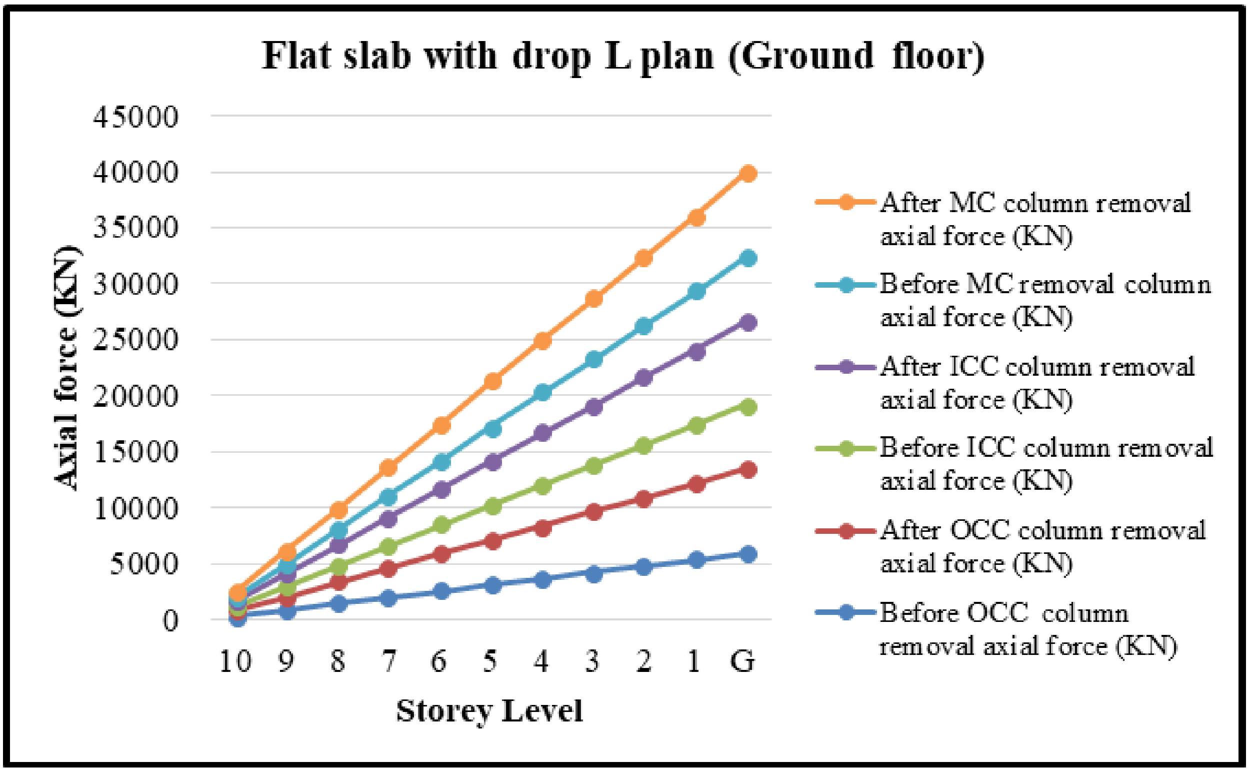

Fig 57 Flat Slab with Drop L Plan (Ground floor)

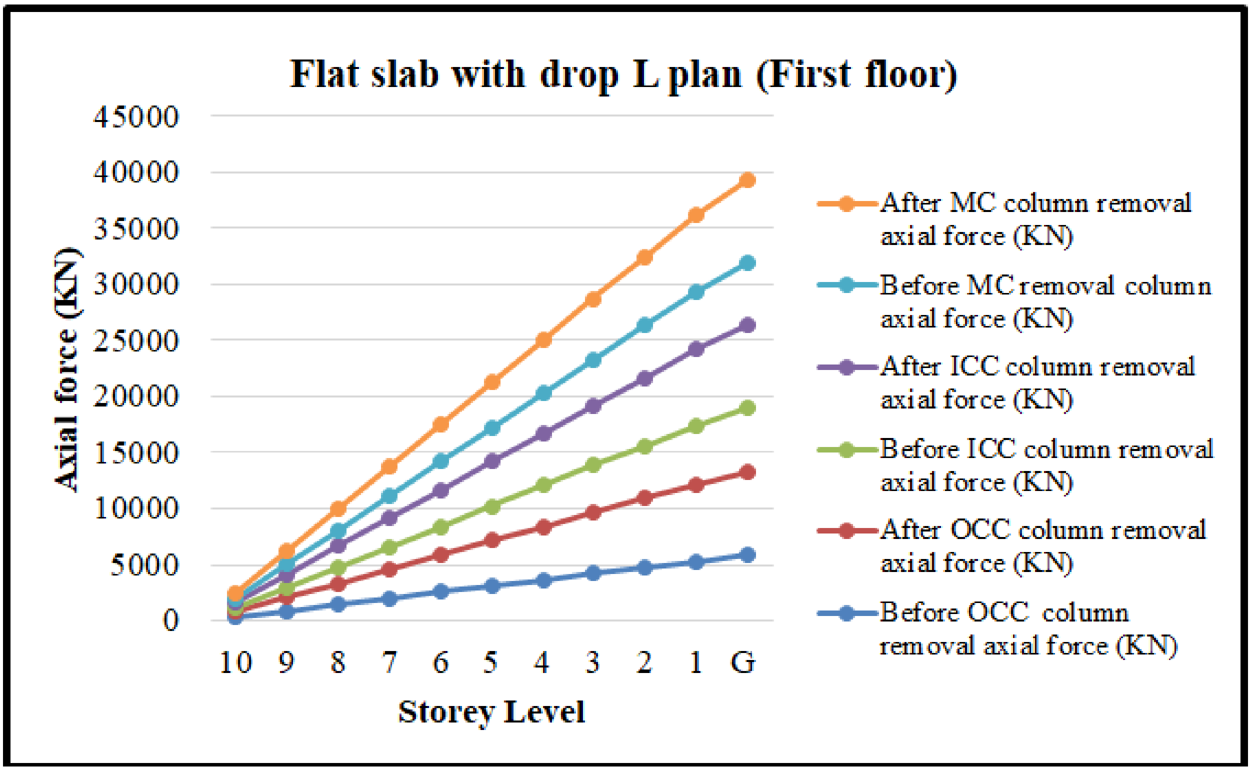

Fig 58 Flat Slab with Drop L Plan (First floor)

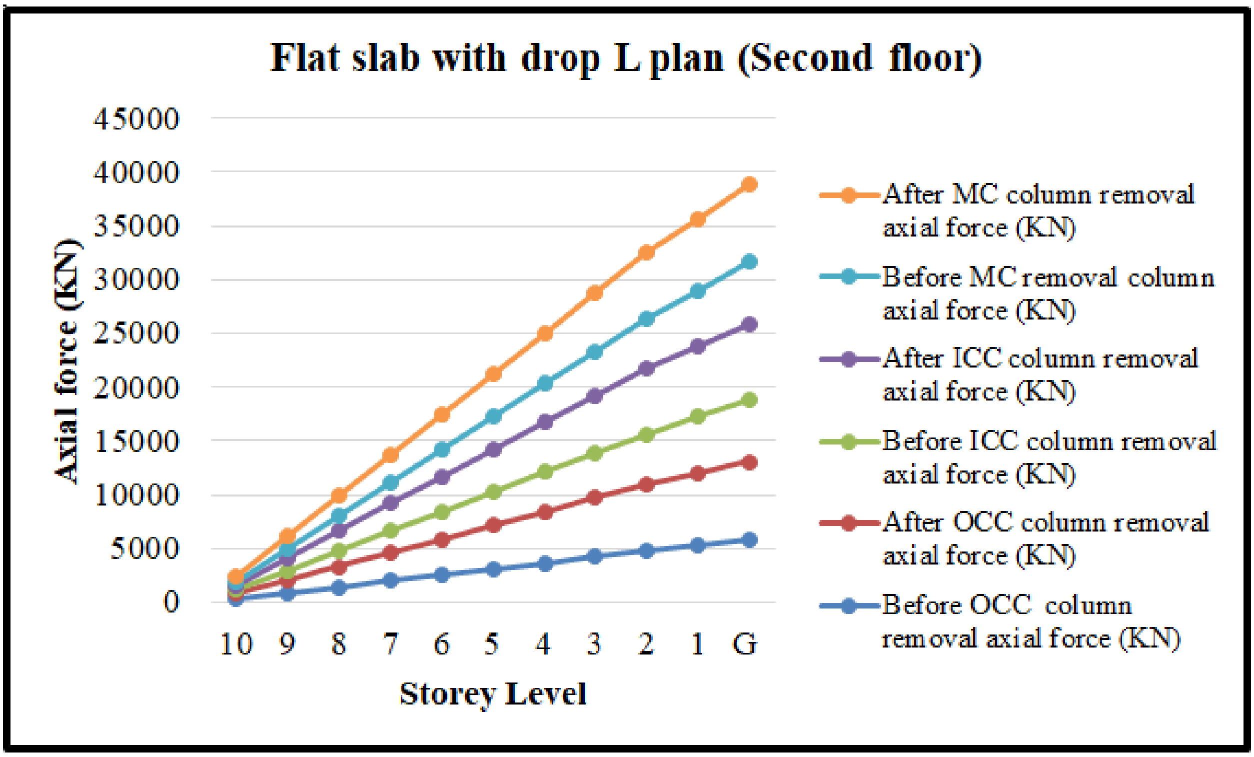

Fig 59 Flat Slab with Drop L Plan (Second floor)

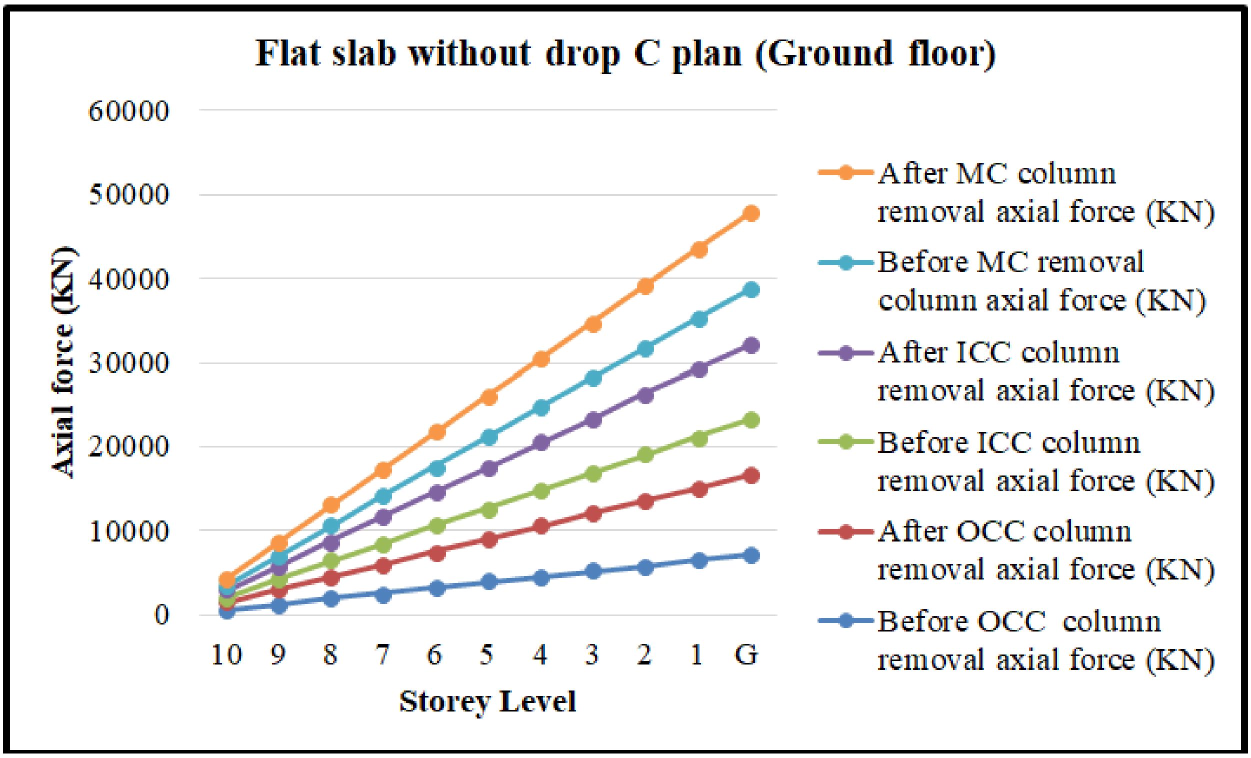

Fig 60 Flat Slab without Drop C Plan (Ground floor)

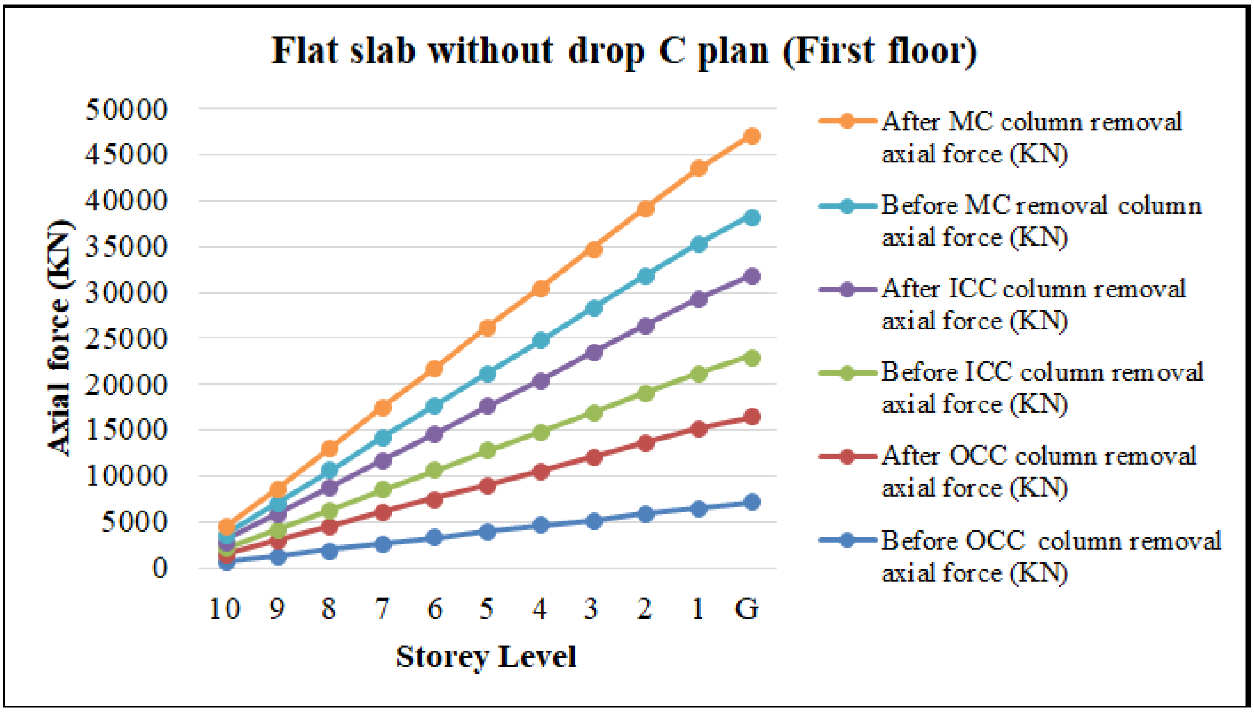

Fig 61 Flat Slab without Drop C Plan (First floor)

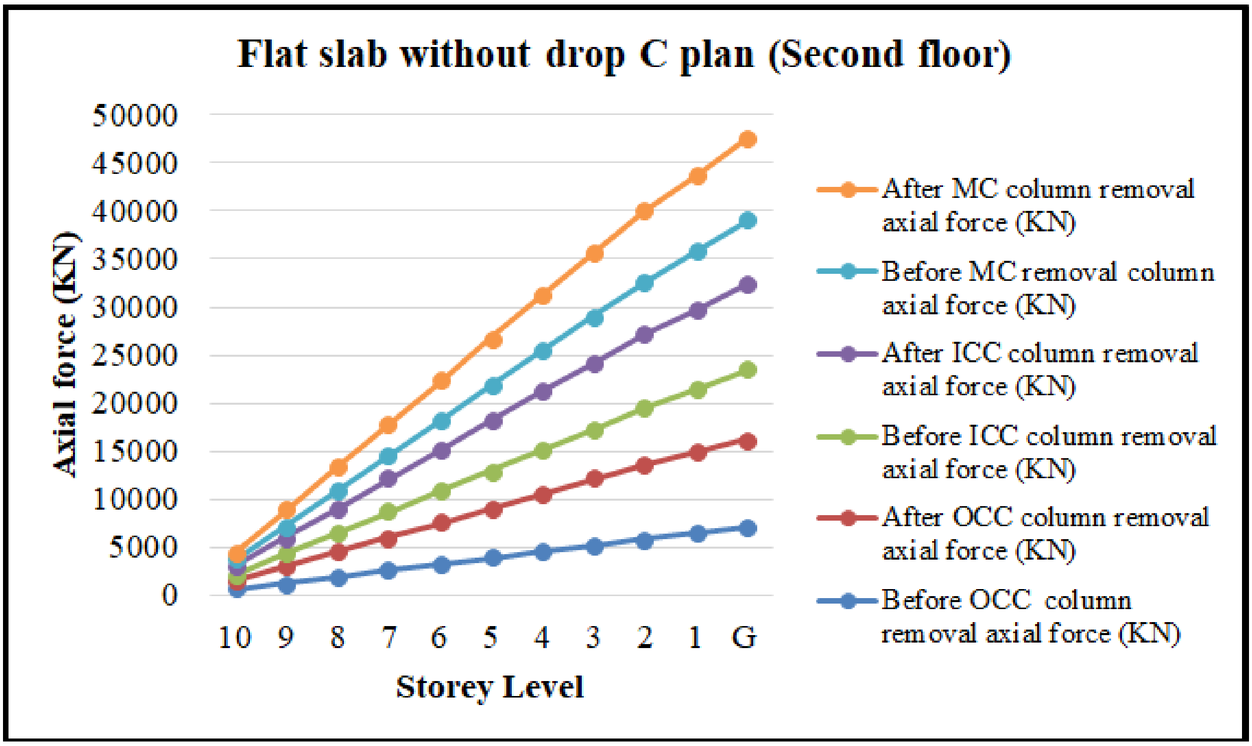

Fig 62 Flat Slab without Drop C Plan (Second floor)

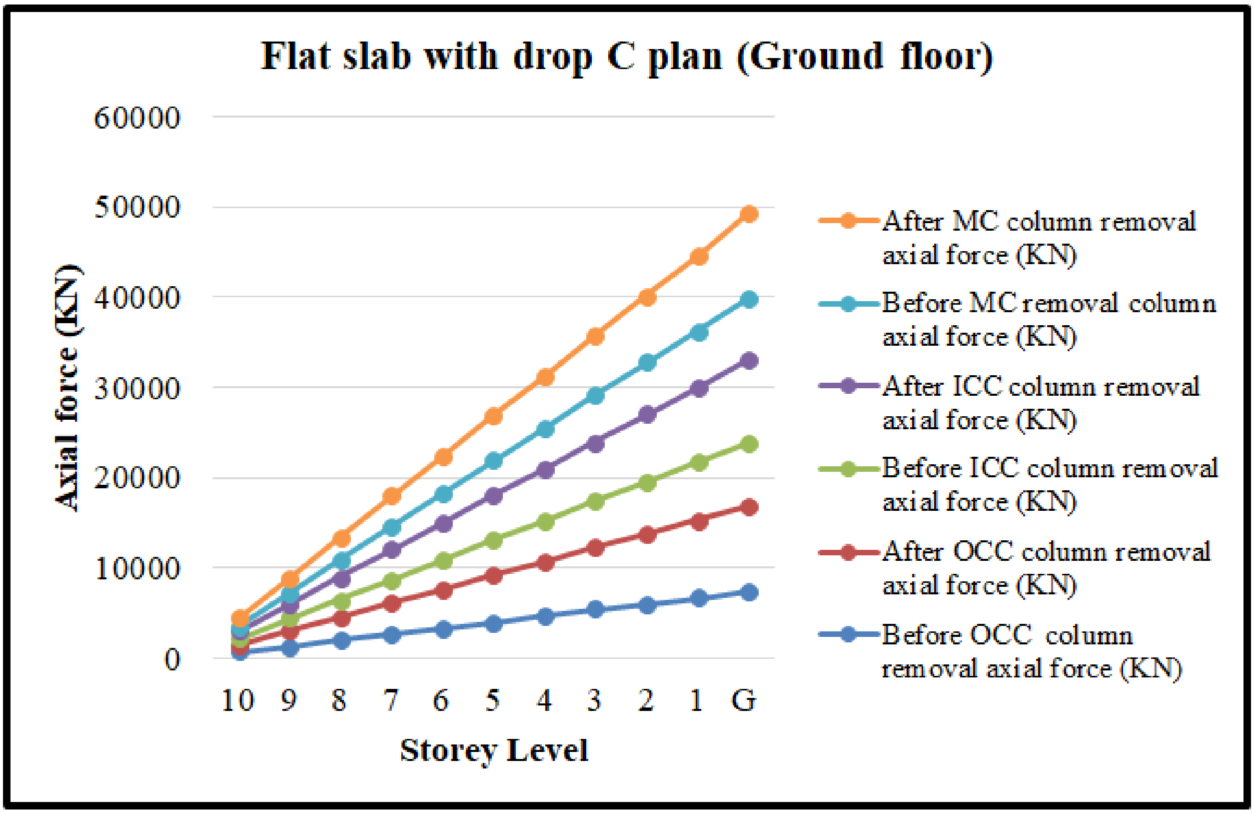

Fig 63 Flat Slab with Drop C Plan (Ground floor)

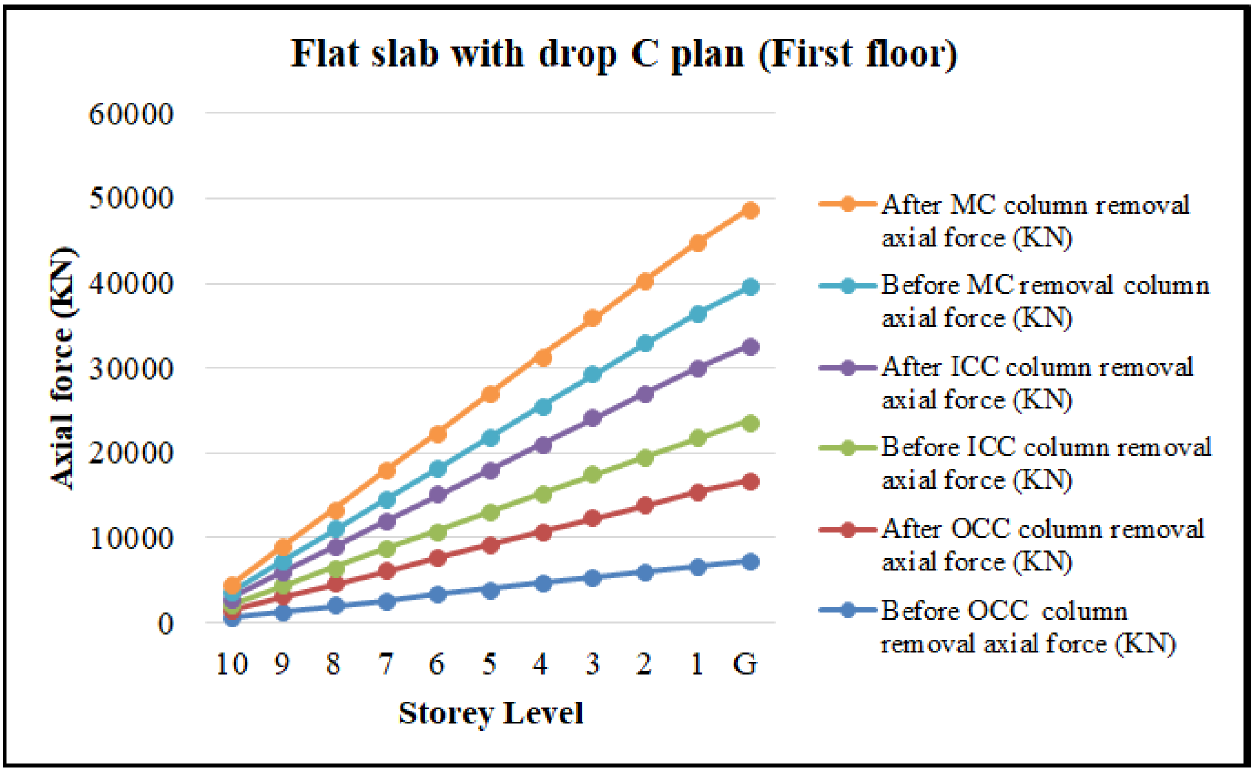

Fig 64 Flat Slab with Drop C Plan (First floor)

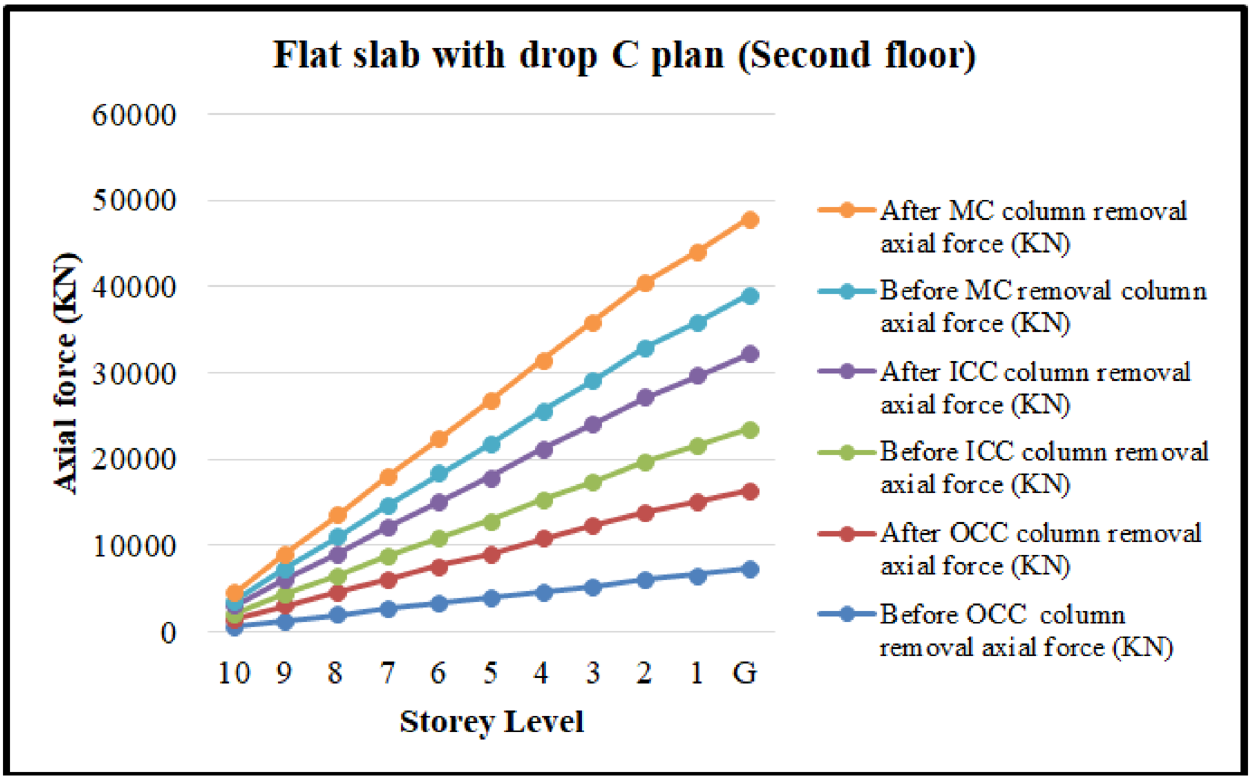

Fig 65 Flat Slab with Drop C Plan (Second floor)

➢ *Bending*

- The maximum Bending is found 328.44 kN.m for the case of middle column removal in flat slab with drop (L plan building).
- The maximum Bending is found 560.28 kN.m for the case of outer corner column removal in flat slab without drop (C plan building).

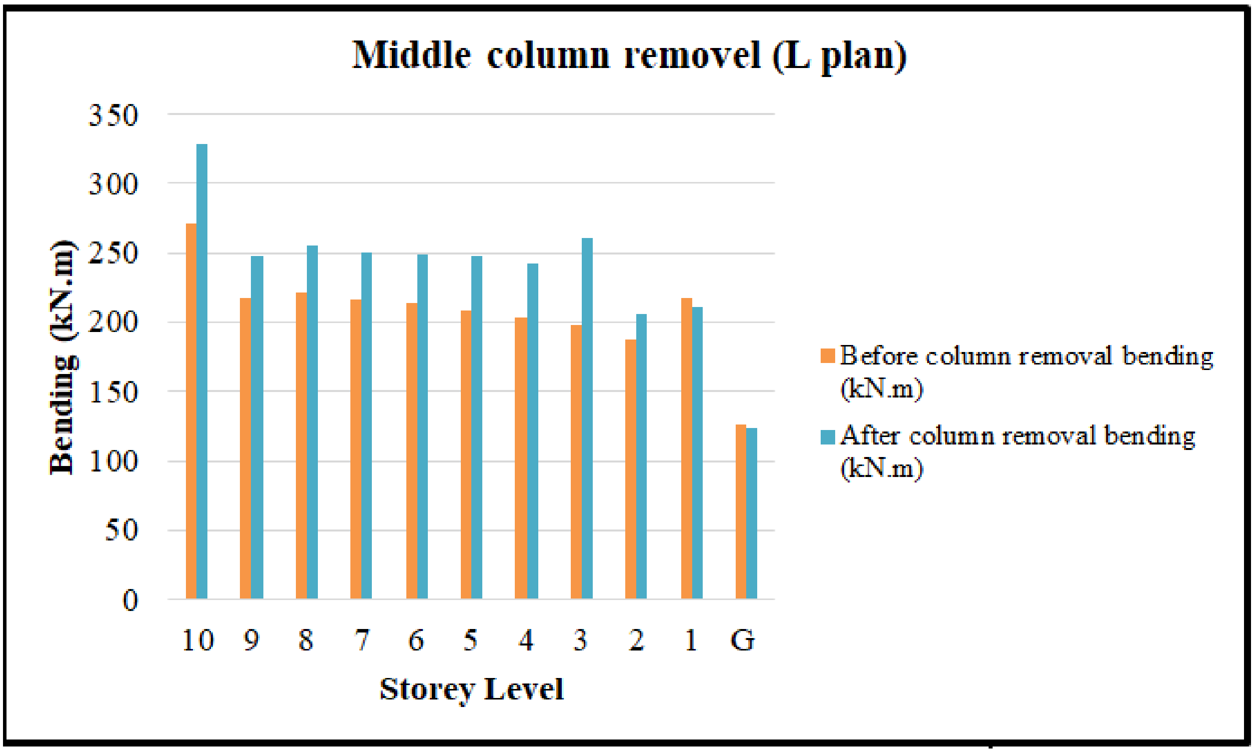

Fig 66 Middle Column Removel (L plan)

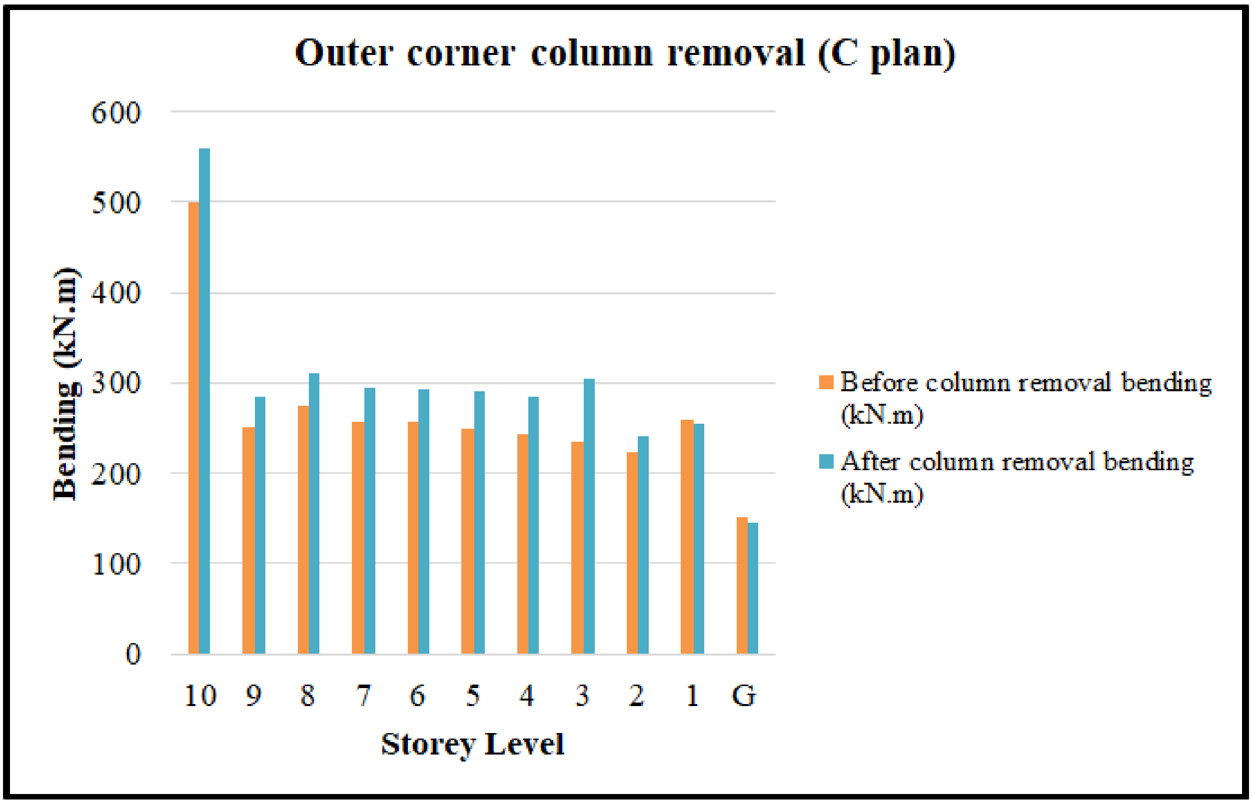

Fig 67 Outer Corner Column Removal (C plan)

➢ *Joint Displacement*

- The maximum joint displacement is found 95.53mm for the case of outer corner column removal in flat slab without drop (L plan building).
- The maximum joint displacement is found 118.50mm for the case of outer corner column removal in flat slab without drop (C plan building).

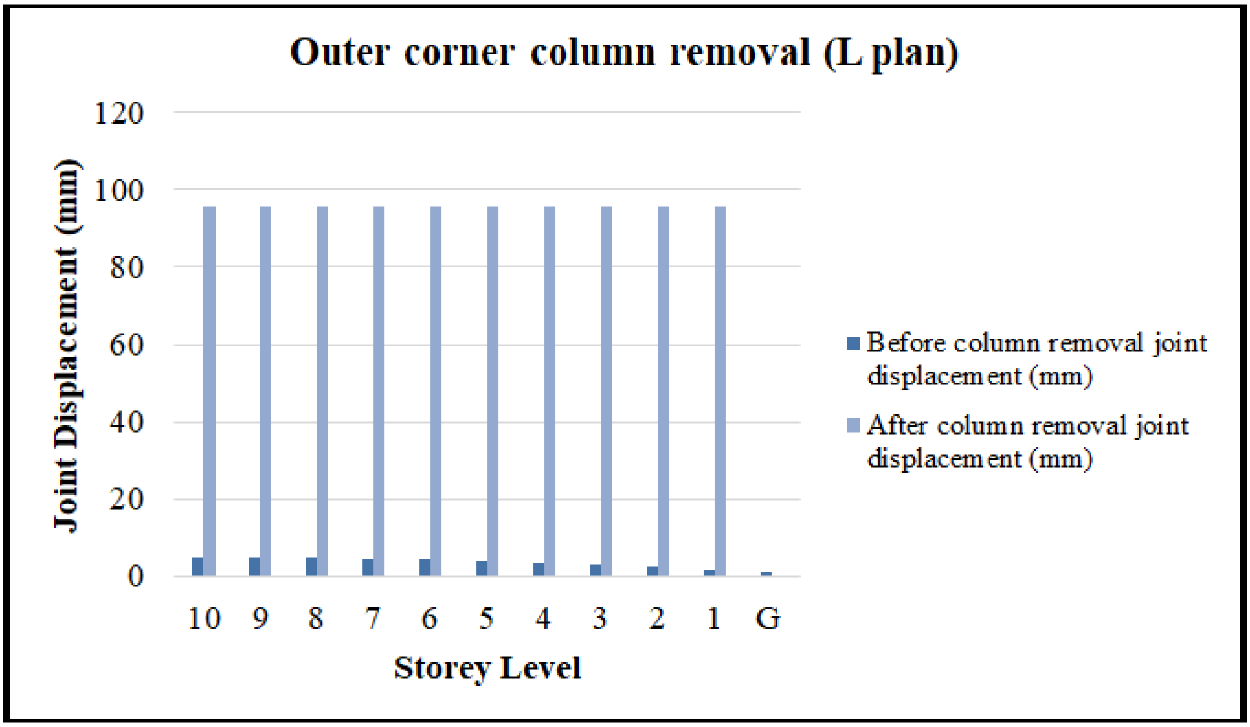

Fig 68 Outer Corner Column Removal (L plan)

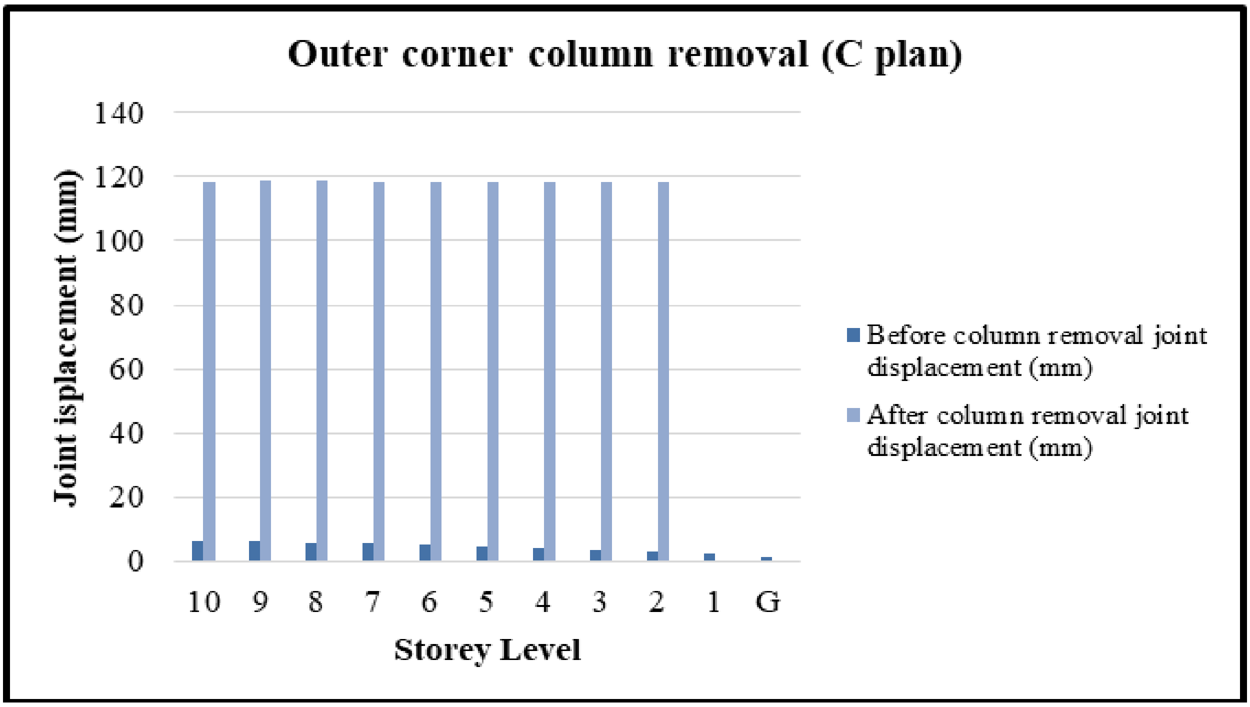

Fig 69 Outer Corner Column Removal (C plan)

IV. CONCLUSION

➢ *The Linear Static Progressive Collapse Analysis on a G+10 Flat Slab Building was Conducted. the following Conclusions are Derived Present Study:*

- The flat slab building with and without drop is able to resist the progressive collapse as the highest value of DCR of the member was found 1.74 which is less than 2.
- In case of the outer corner column removal for the both configuration (with and without drop) DCR value is more compared to column removal from the other location.
- The outer corner column removal is most critical column removal case in both the building s maximum DCR value was obtained for outer corner column removal.
- The axial force in the adjacent column is increased by 0.93, 2.24, and 2.04 % for column removal at the outer corner, inner corner and middle long side (L plan building).
- The axial force in the adjacent column is increased by 0.65, 2.46, and 1.99 % for column removal at the outer corner, inner corner and middle long side (C plan building).
- The flat slab with drop attracts 42.90, 45.27 and 36.67% more bending than flat slab without drop for column removal at the outer corner, inner corner and middle long side (L plan building).
- The flat slab with drop attracts 39.94, 41.25 and 36.8% more bending than flat slab without drop for column removal at the outer corner, inner corner and middle long side (C plan building).
- The flat slab with drop absorbed 43.33, 43.23 and 43.27% more base shear then flat slab without drop for column removal at outer corner, inner corner and middle long side (L plan building).
- The flat slab with drop absorbed 17.99, 18.41 and 18.58% more base shear then flat slab without drop for column removal at outer corner, inner corner and middle long side (C plan building).
- The maximum vertical displacement is found 12.40mm for the case of longer side middle column removal in flat slab without drop (L plan building).
- The maximum vertical displacement is found 25.25mm for the case of longer side middle column removal in flat slab without drop (C plan building).
- The addition of drop in building tends to decrease the vertical displacement at the removal location.
- The maximum joint displacement is found 95.53mm for the case of outer corner column removal in flat slab without drop (L plan building).
- The maximum joint displacement is found 118.50mm for the case of outer corner column removal in flat slab without drop (C plan building).
- For flat slab without drop panel structure when longer side middle column is removed the maximum vertical deflection in L plan building is around 1/2 of maximum vertical deflection of C plan.
- Flat slab without drop panel structure when outer corner, inner corner and middle column removed maximum base shear in L plan building is around 1/2 of maximum base shear of C plan.
- From the From the analysis results it was found out that L plan and C plan buildings, L plan building performed better.

FUTURE SCOPE

- The structure behaviour different Seismic zones and its behaviour of buildings having flat slab with and without drops.
- The structure can be analysed with effect of shear wall.

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