



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 9.935

Volume 15, Issue 8, August 2026

Design of Disproportionate Collapse Resistance of Typical RC Frame Structure with Respect to Grade of

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ABSTRACT: Disproportionate collapse results from small damage or minor accident, leading to collapse of large portion of the structure. Such collapse may result in severe financial losses and human casualties. Therefore, ensuring a structure have structural robustness under accidental loading conditions is very important. At present study investigates the disproportionate collapse resistance of a typical reinforced concrete frame structure with respect to variation in concrete grades.

The structure was initially designed as per relevant Indian Standards. Performance-based collapse assessment was carried out as per procedure recommended in GSA guidelines. Exterior column removal scenarios including corner and edge column failures were considered to evaluate structural reliability, force redistribution, and alternate load path development under accidental loading conditions.

Three different concrete grades, namely M30, M35 and M40 with Fe500 reinforcement were studied to understand the influence of concrete strength on collapse behaviour and reinforcement demand. The behaviour of adjacent beams and columns after column removal was evaluated in terms of bending moment, load redistribution, and reinforcement requirement.

The results indicated that increase in reinforcement demand under collapse loading due to cantilever action, flexural redistribution, and alternate load path formation. Corner column removal produced severe localized effects. The study further showed that increasing concrete grade significantly reduced reinforcement demand in columns due to increased compressive strength. However, beam reinforcement demand remained near about same for all concrete grades, indicating that disproportionate collapse resistance in beams depends primarily on ductility, continuity, and redistribution capacity rather than concrete compressive strength alone.

KEYWORDS: Disproportionate collapse, Structural Robustness, GSA guidelines, Column removal, Alternate load path Load redistribution.

I. INTRODUCTION

As India is a growing country our economy and population are increasing day by day. Town planning is observed in the cities to avoid land shortage. To land shortage we have to build highrise projects in which there can be regular or irregular type of building. Under dynamic loads, these buildings develop torsional irregularities that cause high lateral drift and instability. In today's world designing a seismic resistant building is a challenge for the structural engineers. Moreover the buildings are prone to failure if not addressed properly, which may lead to progressive collapse. Progressive collapse is the event where the compromise of a primary structural element triggers the total or partial structural system failure, regardless of initial and final damage. Disproportionate collapse occurs when small damage leads to collapse of relatively large part of the structure. Disproportionate collapse are progressive, but progressive collapse cannot be disproportionate. The possibility of structural collapse is very less, any such event would lead to irrevocable loss. The initial cause for such structural failure can be manmade (e.g Bombs, explosions, Vehicular Impact)

or natural (Earthquakes). Ronan point apartment building in london and Murrah federal building in Oklahoma are example of structure failures. World trade centre disaster event played a wide role in the development of disproportionate collapse guidelines.

As per IS800:2007, the structure should be stable and have alternate load paths to prevent disproportionate, overall collapse under accidental loading(22). As per IS16700:2023, Key elements are members, whose failure would result in a disproportionate deterioration of the building and whose presence is vital to ensure ductile behaviour of the building. Vertical and lateral resistance of key elements shall be improved in many ways, including by the use of higher partial safety factors for loads and materials, to ensure that they do not yield before designated ductile elements. Elements adjoining key elements should be capable of providing an alternative load transfer path, shall be suitably designed and detailed(29).

Stepwise techniques have been recommended by several guidelines like U.S. General Service Administration (GSA 2016) suggest step by step procedure for linear static, non linear static and non linear dynamic analysis. Among the techniques available in GSA, the alternative path method (APM) is the most preferable. In this method Key element of the structure is removed and alternative path analysis is performed as part of the linear static procedure and design requirements. The GSA guidelines specify a dynamic amplification factor of 2 to account for dynamic effect in static computations for both reinforced and steel structures.

II. LITERATURE SURVEY

Researchers have done several investigations on various type of structures for progressive collapse behaviour.

P Neeraja, K Anish 2021: The researcher have studied Stiffness Irregular RCC framed structures having variance in storey height. As per author collapse occur due to failure of primary load carrying members subjected to abnormal loads during its life or during earthquake. The load transfer pattern of overloaded element changes which leads to failure. Stiffness of irregular RCC frame structure having difference in height is considered to examine the potential ability of seismically designed buildings against Progressive collapse and compared them with nominal model. Analysis is done using static method for following cases: 1) short side middle column removal. 2) Longside middle column removal. 3) Corner column removal 4) Interior column removal. Finally the comparison is done in regular and stiffness irregular building. Results concluded that DCR of the beam elements in critical region associated with column removal seems to fail both in shear and flexure. To avoid failure amount of reinforcement is to be increased slightly than required to limit DCR values.

Suyash Garg, Vinay Agrawal 2021: The researcher have shown that RC flat slab building with no perimeter beams are more prone to progressive collapse. As per author collapse could lead to financial losses and casualties. Flat slab buildings are more prone to progressive collapse than moment frame. As there is no beams for redistribution of loads that the loss of column can be restricted. Linear static progressive collapse analysis is performed as per GSA guidelines. Therefore strengthening methods are adopted using **different sized beams** for progressive collapse resistance(2,7).

Saeed Panahi, Seyed Mehdi Zahrai 2021: They studied typical concrete building under progressive collapse, plan are typically square and rectangular in shape. Method of analysis as per GSA are of four types in case of APM, nonlinear dynamic analysis provides closest to actual response. Load combination form of DL+0.25LL should be exerted on the building an selected load bearing element should be removed. As per author corner column plays a huge role in progressive collapse. Results concluded that square building performs better in progressive collapse resistance other factors like column location and framing are also important for progressive collapse resistance.

Meng-Hao Tsai, Tsuei-Chiang Huang 2011: The researchers have considered effect of three common types of exterior non-structural RC walls in RC buildings under sudden column loss, Linear and Non linear static analysis are carried out for RC frames with and without non-structural walls. Three types of walls were considered parapet type, Wing type and panel type. Wall is modelled as equivalent strut between the floor beams. Load combination considered (DL+0.25LL) is considered for the design. Their research concluded that wing type wall showed better performance in collapse resistance(8,17).

Mohammed El-desoqi et.al 2020: In this paper researcher have researched on precast reinforced concrete beams using applied element method. The conclusion was that a bare frame model will result in a vulnerable structure, The analysis

showed a partial collapse for the structure. Location of the column removal affects the beam behaviour. The different span beam influence appeared in the resisting mechanism. As the cross-section dimension increases in both edge and corner column removal, the compression arch resisting forces increases as well.

Hamed Yavari. Et al 2019: A group of researcher have performed investigation on torsional Irregular buildings located in different seismic zones, This paper evaluates effects of Torsional Irregularity (TI) and Inplane discontinuity in Vertical lateral force resisting element Irregularity (IDVLI) together with seismic strength of the building on progressive collapse potential of steel special moment resisting frames which were designed based on common seismic codes. They concluded that building located in higher seismic hazard level have more resistance to progressive collapse(11)

Objectives of the study : To study the disproportionate collapse resistance of typical RC frame structure with different grade of concrete M30, M35, M40 and same reinforcement grade of Fe500. Incase of failure of column, additional load and moments are transferred on adjacent structural members, due to which there is an increase in reinforcement in beams and columns. So we are researching does increasing the grade of concrete in beams and columns increases the capacity of the section and reinforcement reduces.

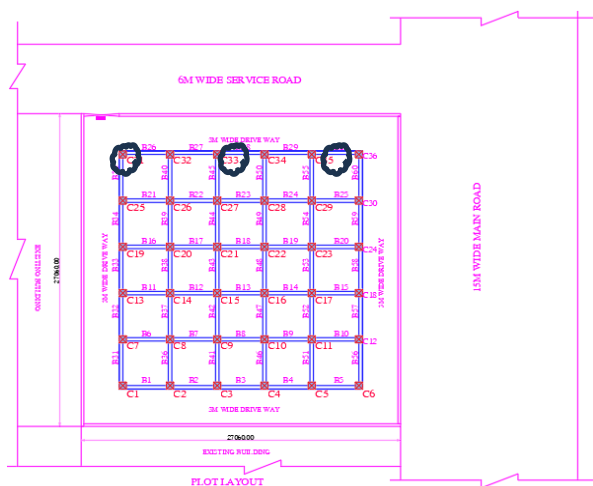


Fig. 1 Plan of the 18 storey RC framed structure building. Marked columns are the important columns of the structure.

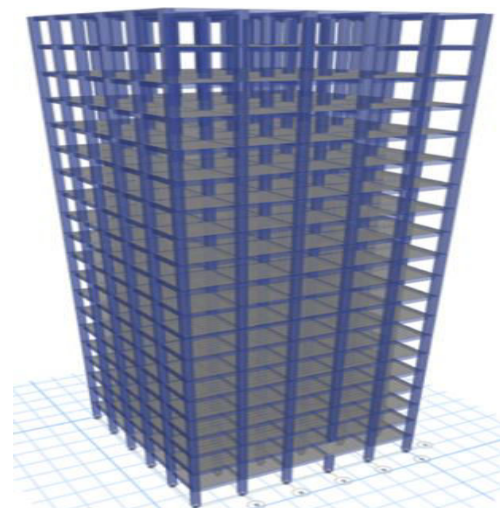


Fig. 2 3D view of 18 storey building of RC framed structure building.

III. METHODOLOGY

Loadings considered in the models are as per Indian standards, Live load is 2KN/sq.m for different area elements as per IS875 part 2. Floor finish is considered as 75mm which is super dead load of 1.5KN/sq.m with the density of material as 20KN/cu.m as per IS875 part 1. Wall load is taken as 7.0KN/m from 150mm thick wall with height of 2.4m and density of material 20 KN/cu.m on all beams at every floor. For earthquake loading parameters considered are as per IS1893:2016. For Zone III $Z=0.16$, Importance factor=1.2 for more than 200 person and Response reduction factor $R=5$ for Ductile design. Soil type considered is type II. % Imposed load considered is 25% of live load, as the live load is less than 3KN/sq.m

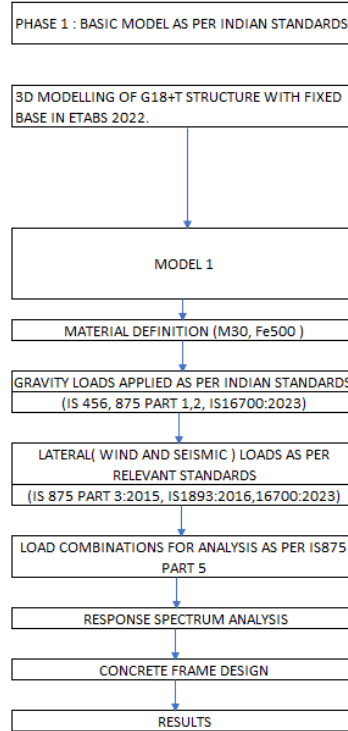


Fig.3 Flow chart of Phase I analysis and design of G+18+Terrace storey building of RC framed structure.

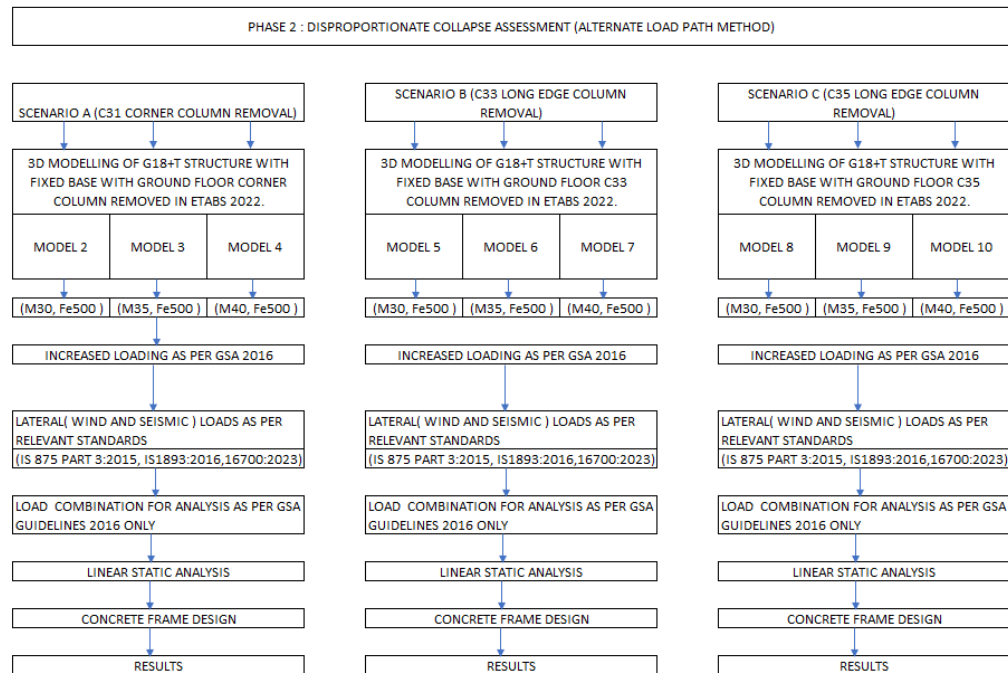


Fig.4 Flow chart of Phase II analysis and design of Disproportionate collapse resistance of G+18+Terrace storey building of RC framed structure with Different grade of concrete

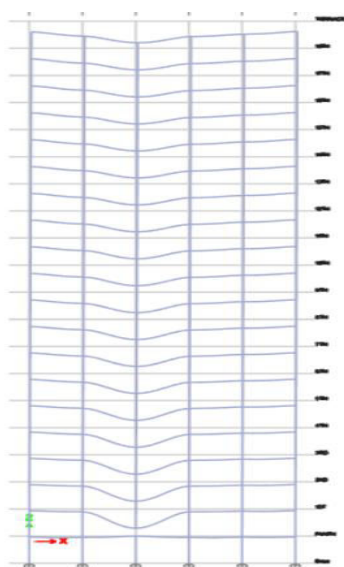


Fig.5 Deformed shape on removal of corner column C31

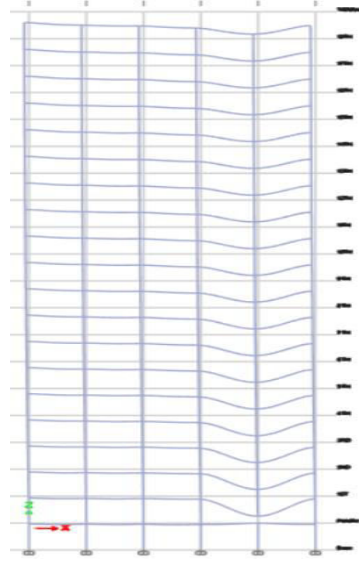


Fig.6 Deformed shape on removal of long edge column C33

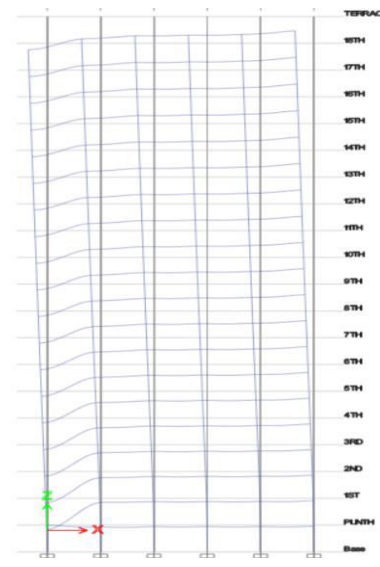


Fig.7 Deformed shape on removal of long edge column C35

Above Figure 5,6,7 shows the deformed shape of the building in case of column failure.

Analysis is done using linear static method for removal of corner column(C31)/ long edge column(C33) and Column beside corner column (C35), All the inputs for analysis are given as per GSA methodology. Only one column can be removed at a time as per GSA guidelines. Load combination of $2(1.2 \text{ DL} + 0.5 \text{ LL})$ To represent dynamic response in progressive collapse factor 2 is used as a dynamic magnification factor in linear static analysis. Marked columns C31,C33 and C35 (refer Fig.1)are removed on ground floor, each at a time for disproportionate collapse analysis and checked for M30,M35 and M40 grade of concrete.

IV. EXPERIMENTAL RESULTS

Assessment of Disproportionate collapse behaviour under corner (C31) column removals

In this section we have addressed the findings of the modelled buildings. This sections examines the behaviour of normal building and column removal condition. i.e. Incresase in reinforcement of beams and columns, Lateral Displacement of the buildings, Deflection in beams. Incase of normal design as per Indian standards, flexural reinforcement required in beams are approximately 0.68% of beam size, where as incase of columns the reinforcement required for columns of normal design of peripheral and internal columns is 0.8% which is minimum reinforcement of column as per IS456:2000. Base shear, storey drift and lateral displacements are well within the limits as per Indian standards like IS456:2000, IS1893:2016, IS16700:2023.

Refer Fig. 1 for better understanding of the results discussed below. Incase of removal/failure of C31 there are two columns and two adjacent beams on which major load will be transferred.

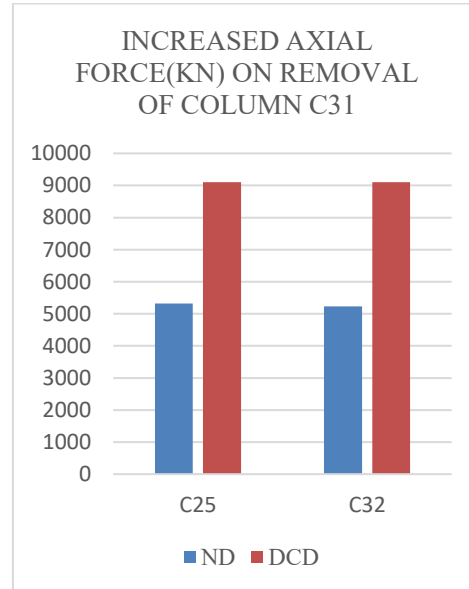


Fig.8 Comparison of Axial force for Normal design (ND) and C31 column removal Disproportionate collapse design (DCD)

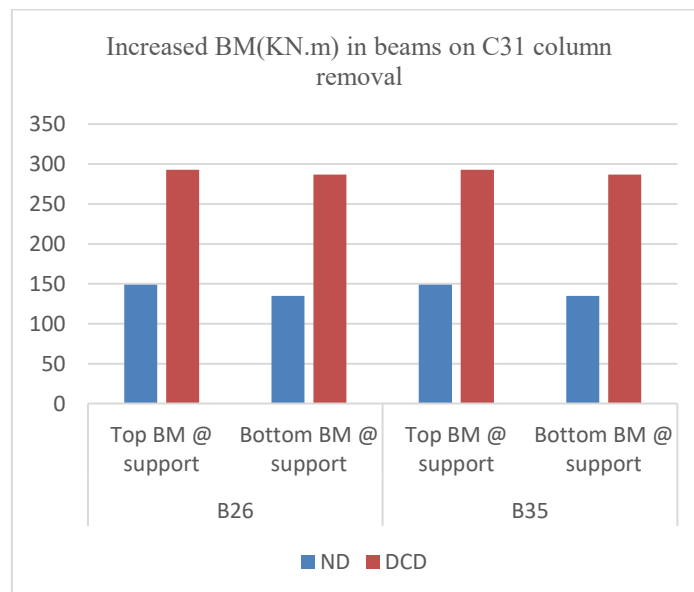


Fig.9 Comparison of Bending moment for Normal design (ND) and C31 column removal Disproportionate collapse design (DCD)

Fig 8 compares the axial force in the model 1(ND) with model 2 (DCD C31 M30) for collapse assessment of C31 failure(corner column removal). i.e. The increase in Axial load in columns, Similarly Fig 9 compares the bending moment in the model 1(ND) to model 2 (DCD C31 M30) for collapse assessment of C31 failure(corner column removal). i.e. The increase in bending moments at support due to failure of the corner column there will be increased loads in the adjacent beams and adjacent columns. In this comparison we have observed that there is an increase in bending moment by 96% in beams(Refer fig.9) at support in case of corner column removal and in adjacent columns there is increase in axial force by approximately 70%. Therefore there will be requirement of additional reinforcement/ additional concrete strength in beams and columns for disproportionate collapse resistance.

So we have checked the design for same grade of concrete M30 which we have used for Normal design as per Indian standards. In results we have observed that there is very high demand for reinforcement in beams and columns to increase the capacity of the section to resist disproportionate collapse. Therefore study is done with the increase in grade of concrete we can prevent disproportionate collapse in RCC frame structure.

Fig 11,12,13 reflects that by increasing the grade of concrete there is a sudden increase in capacity of the column member which reduces the requirement of the reinforcement required in columns. In fig 11 on removal of corner column it is observed that the reinforcement to prevent disproportionate collapse with the same grade of concrete M30 which we have used for normal design has increased approximately 2.5-3 times the actual design requirement. Similarly beams will also need the extra reinforcement to resist disproportionate collapse. The study concludes that by using 1 higher grade of concrete (M30 to M35) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 29% and by using 2 higher grade of concrete (M30 to M40) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 55%. In beams the study concludes that using higher grade of concrete controls deflection in beams, maximum storey displacement and storey drift, but it hardly reduces the reinforcement required to prevent disproportionate collapse by 50 sq.mm. Therefore it is better to use higher grades of concrete in columns and additional reinforcements in beams to prevent disproportionate collapse.

Assessment of Disproportionate collapse behaviour under edge (C33) column removals

Fig 10 compares the axial force in the model 1 (ND) to model 5 (DCD C33 M30) for collapse assessment of C33 failure (edge column removal). i.e. The increase in Axial load in columns. Similarly Fig 11 compares the bending moment in the model 1 (ND) with model 5 (DCD C33 M30) for collapse assessment of C33 failure (edge column removal). i.e. The increase in bending moments at support due to failure of the edge column there will be increased loads in the adjacent beams and adjacent columns. In this comparison we have observed that there is an increase in bending moment by 200% in beams at support in case of corner column removal and in adjacent columns there is increase in axial force by approximately 65-75%.

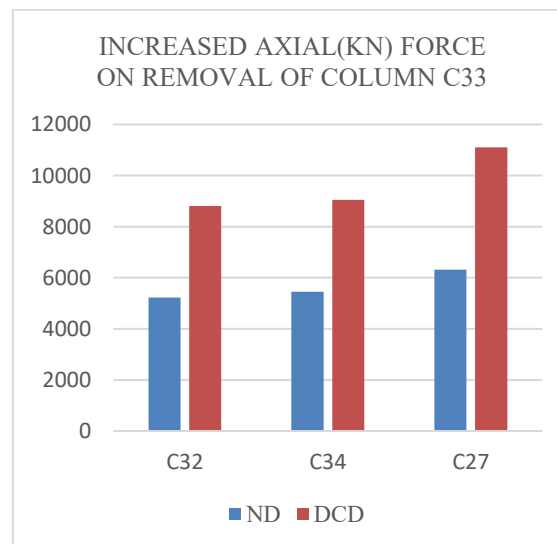


Fig.10 Comparison of Axial force for Normal design (ND) and C33 column removal Disproportionate collapse design (DCD)

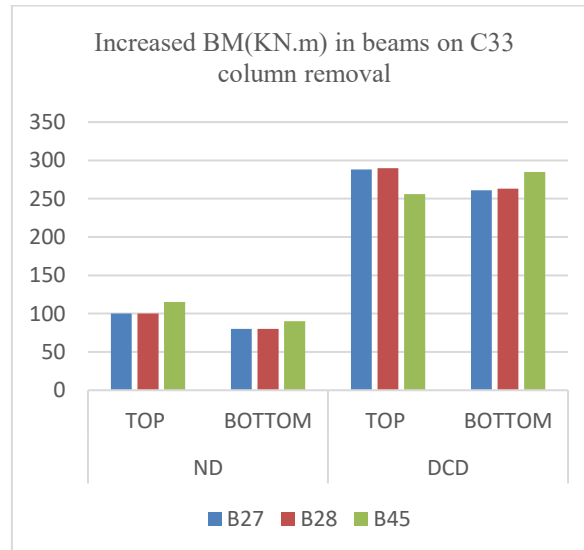


Fig.11 Comparison of bending moment for Normal design (ND) and C33 column removal Disproportionate collapse design (DCD)

Fig 15,16,17 reflects that by increasing the grade of concrete there is a sudden increase in capacity of the column member which reduces the requirement of the reinforcement required in columns. In fig15 on removal of corner column it is observed that the reinforcement to prevent disproportionate collapse with the same grade of concrete M30 which we have used for normal design has increased approximately 2-2.5 times the actual design requirement for edge column and 4 times for internal column. Similarly beams will also need the extra reinforcement to resist disproportionate collapse. The study concludes that by using 1 higher grade of concrete (M30 to M35) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 45% and by using 2 higher grade of concrete (M30 to M40) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 70% for edge columns. For internal columns reinforcement reduces by 30% by using 1 higher grade and further by using two higher grades the reinforcement reduces by 44%. In beams the study concludes that using higher grade of concrete controls deflection in beams, maximum storey displacement and storey drift, but it hardly reduces the reinforcement required to prevent disproportionate collapse by 50 sq.mm. Therefore, it is better to use higher grades of concrete in columns and additional reinforcements in beams to prevent disproportionate collapse.

Assessment of Disproportionate collapse behaviour under column besider corner (C35) column removals.

Fig 12 compares the axial force in the model 1(ND) with model 8 (DCD C35 M30) for collapse assessment of C35 failure (column adjacent to corner column removal). i.e. The increase in Axial load in columns. Similarly Fig 13 compares the bending moment in the model 1(ND) to model 8 (DCD C35 M30) for collapse assessment of C35 failure (column adjacent to corner column removal). i.e. The increase in bending moments at support due to failure of the edge column there will be increased loads in the adjacent beams and adjacent columns. In this comparison we have observed that there is an increase in bending moment by 95-100% in beams at support in case of corner column removal and in adjacent columns there is increase in axial force by approximately 65-85%.

Fig 15,16,17 reflects that by increasing the grade of concrete there is a sudden increase in capacity of the column member which reduces the requirement of the reinforcement required in columns. In fig17 on removal of corner column it is observed that the reinforcement to prevent disproportionate collapse with the same grade of concrete M30 which we have used for normal design has increased approximately 2.5-3 times the actual design requirement for edge column and 4 times for internal column. Similarly beams will also need the extra reinforcement to resist disproportionate collapse.

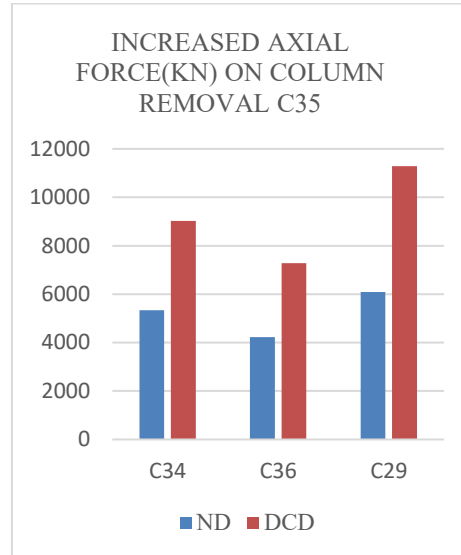


Fig.12 Comparison of Axial force for Normal design (ND) and C35 column removal Disproportionate collapse design(DCD)

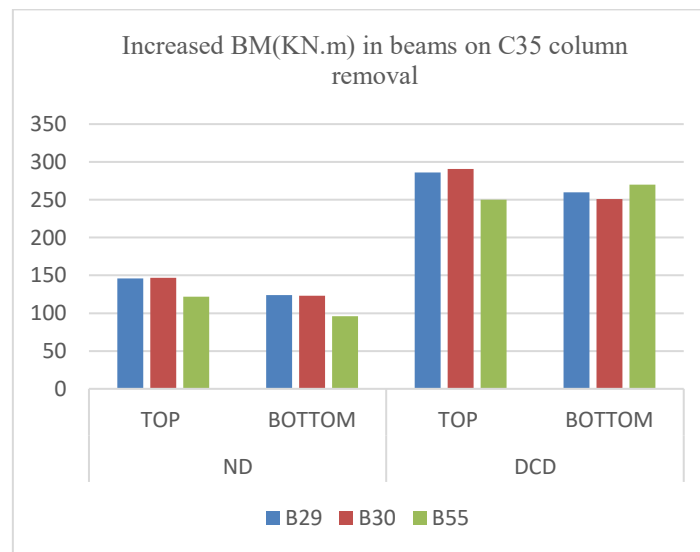


Fig.13 Comparison of Bending moment Normal design (ND) and C35 re column removal Disproportionate collapse design(DCD)

The study concludes that by using 1 higher grade of concrete(M30 to M35) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 20-30% and by using 2 higher grade of concrete(M30 to M40) in columns the capacity of the section increases and it reduces the reinforcement to prevent disproportionate by 60% for column beside corner columns. For internal columns reinforcement reduces by 20% by using 1 higher grade and further by using two higher grades the reinforcement reduces by 40%. In beams the study concludes that using higher grade of concrete controls deflection in beams, maximum storey displacement and storey drift, but it hardly reduces the reinforcement required to prevent disproportionate collapse by 50 sq.mm. Therefore it is better to use higher grades of concrete in columns and additional reinforcements in beams to prevent disproportionate collapse.

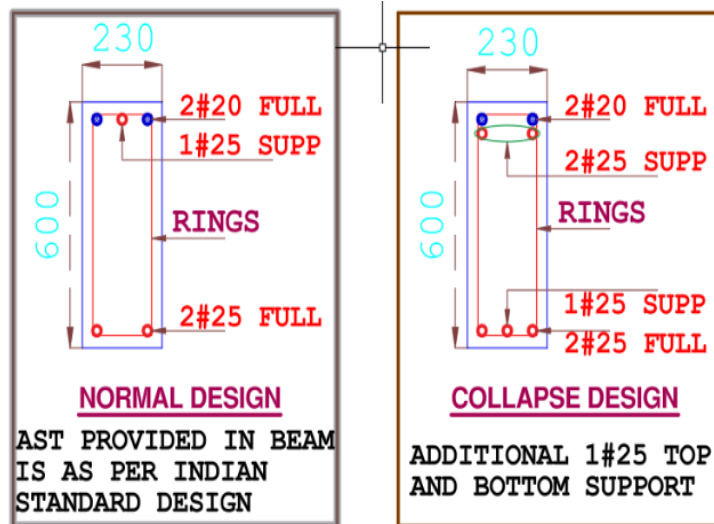


Fig.14 Standard beam design and collapse mitigation for beams

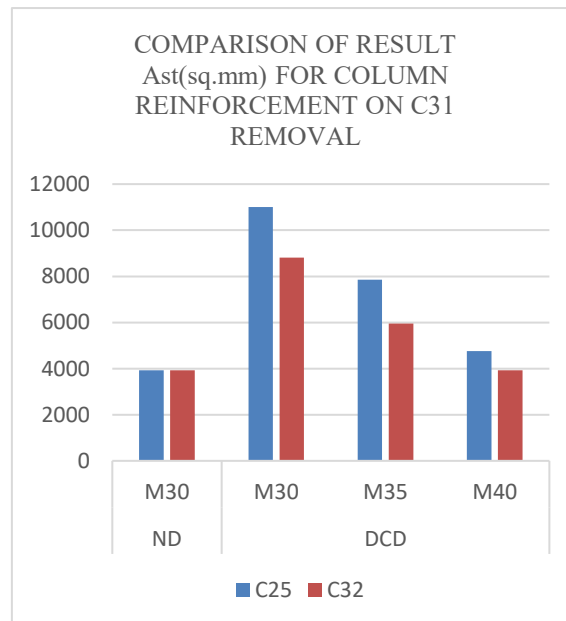


Fig.15 Reduction in Ast required as we increase the grade of concrete for Chart Area in removal Disproportionate collapse Design (DCD) with Normal design (ND)

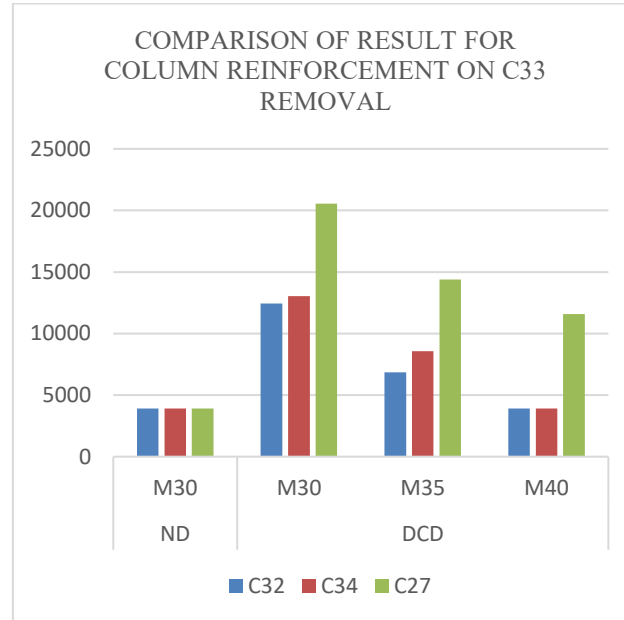


Fig.16 Reduction in Ast required as we increase the grade of concrete for C33 column removal Disproportionate collapse design (DCD) with Normal design (ND)

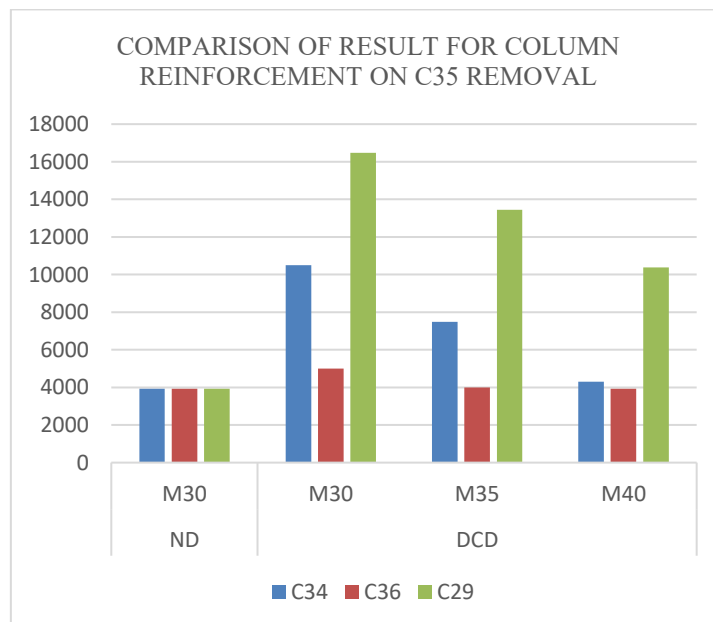


Fig.17 Reduction in Ast required as we increase the grade of concrete for C35 column removal Disproportionate collapse design (DCD) with Normal design (ND)

Assessment of storey drift in Disproportionate collapse behaviour under different column removals and different concrete grades

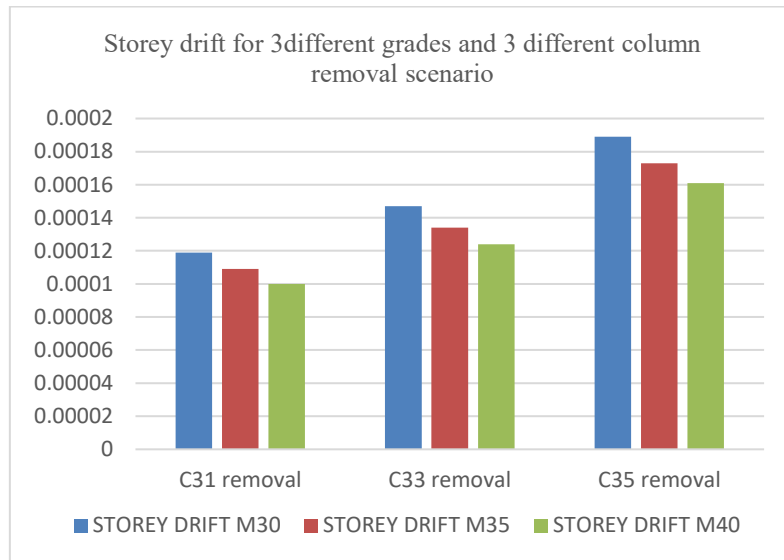


Fig.18 Storey drift in the building during the disproportionate collapse.

Fig 18 compares the model 2,3,4 to model 5,6,7 to model 8,9,10 for storey drift in case of removal of columns at 3 different locations. Removing each column at a time. It is observed that maximum drift is observed on the removal of column C35 and lowest storey drift is observed in removal of column C31. The results concluded that increasing the grade of concrete reduces the storey drift by 7% using 1 higher grade of concrete (M30 to M35) and storey drift reduces by 15% by using 2 higher grade of concrete (M30 to M40). Therefore study concludes that increasing the grade of concrete reduces the storey drift in the structure.

Assessment of lateral displacement in Disproportionate collapse behaviour under different column removals and different concrete grades

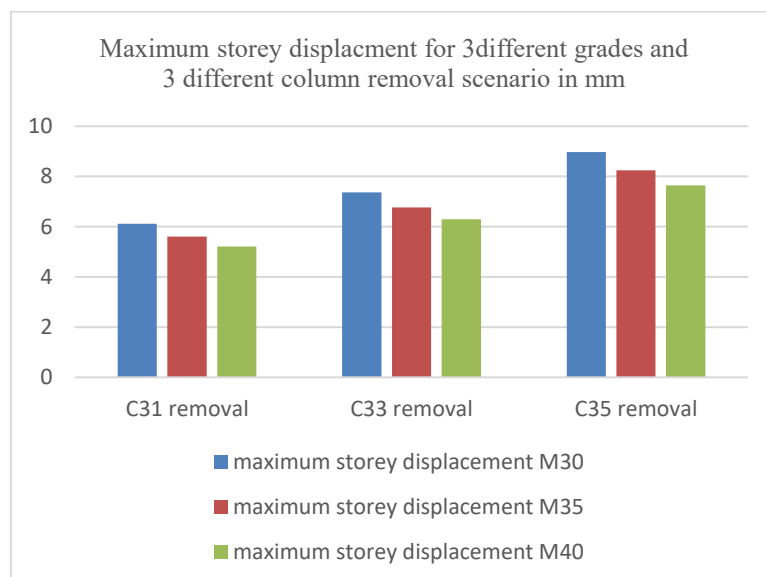


Fig.19 Maximum storey displacement in the building during the disproportionate collapse

Fig 19 compares the model 2,3,4 to model 5,6,7 to model 8,9,10 for maximum lateral displacement in case of removal of columns at 3 different locations. Removing each column at a time. It is observed that maximum lateral displacement is observed on the removal of column C35 and lowest lateral displacement is observed in removal of column C31. The results concluded that increasing the grade of concrete reduces the maximum storey displacement by 8% using 1 higher grade of concrete (M30 to M35) and storey displacement reduces by 15% by using 2 higher grade of concrete (M30 to M40). Therefore study concludes that increasing the grade of concrete reduces the storey displacement in the structure.

Assessment of deflection in beams in Disproportionate collapse behaviour under different column removals and different concrete grades

Fig 20 compares the model 2,3,4 to model 5,6,7 to model 8,9,10 for deflection in case of removal of columns at 3 different locations. Removing each column at a time. It is observed that maximum deflection is observed on the removal of column C31 and lowest deflection is observed in removal of column C35. The results concluded that increasing the grade of concrete reduces the deflection by 8% using 1 higher grade of concrete (M30 to M35) and storey displacement reduces by 15% by using 2 higher grade of concrete (M30 to M40). Therefore study concludes that increasing the grade of concrete reduces the storey displacement in the structure.

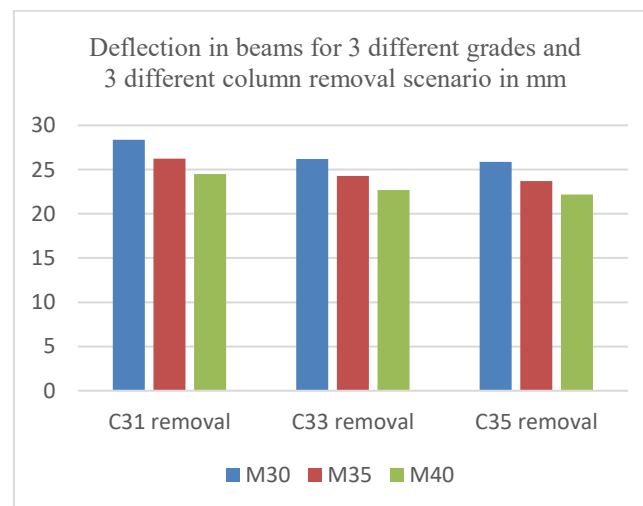


Fig.20 Deflection in the building during the in case of column failure

V. CONCLUSION

As the technology is increasing day by day, we are designing a structures with different techniques and methods to meet the architectural and structural requirements. In recent years researchers have done numerous studies for collapse resistance, Various factors can help to avoid expansion of the damage, one of which is material. In this study the effect of RC frame structure with typical plans and different concrete grade was studied using alternate load path method. The results indicated that

- 1) Using higher grade of concrete for design of column for disproportionate collapse resistance will help in the increasing the capacity of the RCC structural column members.
- 2) It is observed that bending moment of beams adjacent to removed columns is higher than the building designed with Indian standards. Therefore additional reinforcement should be provided at support in beams to resist additional bending moments at the event of disproportionate collapse.
- 3) The results indicate that the columns are good in compression, therefore use of higher grade of concrete would be beneficial and beams should be provided with extra reinforcement at support. It should be noted that factors such as regularity and irregularity of plan, number of stories, location of beam, walls and column plays an important role in the event of disproportionate collapse.

- 4) Future scope: Disproportionate collapse resistance has a wide scope for future studies. On this topic deep research can be conducted with a range of variables and their characteristics. After the completion of Disproportionate collapse resistance with respect to grade of concrete, there are a lot of avenue that can be analysed and designed in detail which are listed below:

For future research different studies can be carried out for disproportionate collapse resistance.

- The studies can be carried out for Vertical and Horizontal Irregular buildings.
- The study can be carried out for different increased height of the building.
- Studies can be carried out for different loadings at different levels.
- The study can be carried out for different load resisting systems.
- Two different systems can also be studied in same building.
- Introduction to other methods like bracing, providing shear walls, spandrel beams can be used for disproportionate collapse resistance.

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