Progressive Collapse Resistance Design of G+10 Story Steel Structure

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Abstract- *Progressive collapse is defined as total or remarkable partial collapse of structure following local damage at a small portion of the building. Progressive collapse of structures due to explosion, vehicle impact, fire, or other man-made hazards etc. the main aim of the present study is to assess the behavior of steel structure under accidental load which may lead to progressive collapse of complete structure .a steel structure will be evaluated for sudden column loss. The iteration will be carried out as per the present guideline available for critical column removal like GSA or DOD.*

Secondly to find out the best system to which will have maximum potential to resist progressive collapse of a structure. Two method are used first is increase the beam and column size at critical location due to which progressive collapse is minimize and second way provide bracing system due to bracing system also minimize the progressive collapse. Second method is more effective than first method.

In order to study the behavior of steel building structure on the special moment resting frame (SMRF) under the progressive collapse G+10 structure is modeled in E-Tab (2016).in order to know about progressive collapse and to obtain reliable results, linear static (LS) analyses procedure for single column removal have been implemented in this study for better understanding factors considered in the study. For demand capacity ration (DCR), displacement of removal location, axial load in the column specially columns adjacent to removed column.

Keywords- Progressive collapse, Special moment resistant frame, DCR, LSA, BM, SF, ETABS

I. INTRODUCTION

The term progressive collapse has been used to describe the spread of an initial local failure in a manner analogous to a chain reaction that leads to partial or total collapse of a building. The progressive collapse of building structures is stared when one or more vertical load carrying members (typically columns) is removed .as a column is removed due to a vehicle impact fire earthquake or other manmade or natural hazards the building weight (gravity load) transfers to neighboring column in the structure neighboring column are not properly designed to resist and redistribute the additional gravity load that part of the structure fails the gravity load carrying element of the structure continue to fail until the additional loading is stabilized as a result substation of the structure may collapse causing greater damage to the stricter than the initial impact Progressive collapse is defined by the sequential spread of an initial local failure resulting in a cascade of failure which affects a larger portion of the structure .this type of collapse is mostly of concern to structural engineer if there is a decide disproportion between the initiating event and the resulting collapse in other words if it is a disproportionate collapse**.**

ASCE (2002) defined it is “the spread of an initial failure from element to element eventually resulting in the collapse of an entire structure or disproportionately large part of it”

The general services administration (GSA 2003) offers a specific description of the phenomenon: “progressive collapse is a situation where local failure of primary structure component leads to the collapse of adjoining members in turn leads to additional collapse” [11].

“Progressive collapse can be defined as collapse of all or a large part of a structure precipitated failure or damage of a relatively small of it”

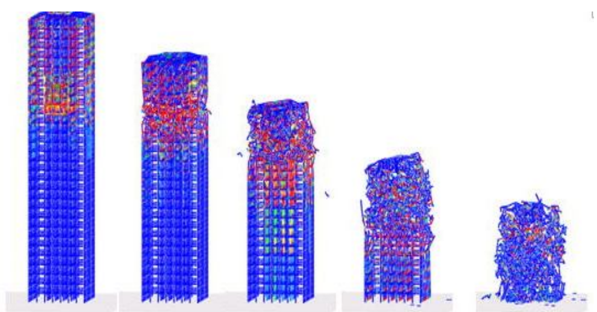


Figure 1. Progressive collapses Fail

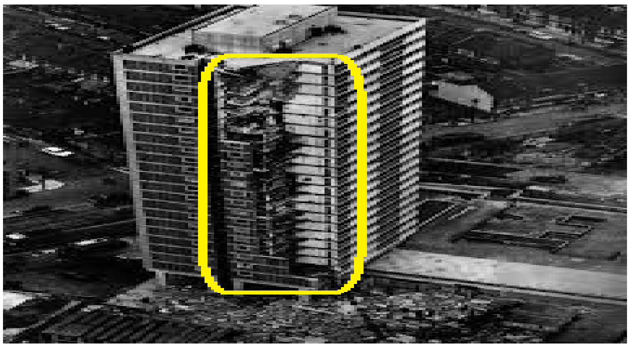


Figure 2. Ronan point Apartment (1968)

Figure .3 World Trade Centre (2001)

II. SCOPE OF STUDY

To achieve mentioned objective we have decided the scope of our work as,

- A typical steel building will be analyses and designed for standard load like dead load ,live load ,wind load and earthquake load as per IS code in a finite based software named ETABS.
- The same structure will be analyses for accidental load though removal of critical column as per the available guideline and its potential to progressive failure will be checked.
- The result like DCR, axial force in column, bending moment in beam, shear force in beam will be compared for both cases of with column and without column
- To find out the best system to which will have maximum potential to resist progressive collapse of a structure.
- The structure further enhanced by providing diagonal bracing system and increases the beam and column size at critical location new structure will be checked for its potential to progressive collapse failure.

III. PREVIOUS WORK

Alireza Ch. Salmasi and Mohammad R. Sheidaii, research, strength of dual steel moment frames equipped with a variety of eccentric bracings against progressive collapse was evaluated by using nonlinear static alternate path method.[1]. Carolos Antonios Vidalis Although research around the subject has been aimed at understanding the mechanics of progressive collapse, little work has been done on translating findings into better guidance on how to ensure adequate resistance without relying on the current prescriptive rules.[2]. Ronald Hamburger investigated steel framing connections must be capable of resisting large tensile demands simultaneously applied with large inelastic flexural deformations and the structure as a whole must be capable of distributing these large tensile demands through a complete load path. Research is needed to identify framing connection technologies capable of reliable service under these conditions.[3]. Rinsha and Biju Mathew studied The structure behave pattern is studied. So middle and corner column was analytically removed from the building to understand the subsequent load redistribution within the building. The axial force and DCR values are studied. By comparing these parameters and conclude that corner column removal in base is more effective in a building using ETAB[4]. Anastasia Vasilieva The purpose of the study was to describe the process of progressive collapse and to find more methods and approaches to design the structure for preventing from this kind of failure. And the last aim was to find Russian norms and standards [5]. Eric Martin, Eric Williamson, Aldo Mckay And Kirk Marchand The state-of-the-art in the design of buildings to resist Progressive Collapse (PC) has Continued to advance, in North America and throughout the world. Recent developments include improved design guidance, cost assessments for implementing PC design requirements, research efforts to understand key structural mechanisms for collapse resistance, and growing experience in using commercially available design tools to better design and analyze progressive collapse events. The goal of this paper is to report upon these recent developments. [6]. Sepideh Fadaei, This study investigates the potential of progressive collapse in steel framed structures using normal I-beams and truss beams in their floor systems. A general Service Administration (GSA) guideline with linear static procedure is used for the analysis of the above mentioned buildings and as a result of the analysis Demand Capacity Ratio (DCR). [7]. Uwe Starossek give the typology and classification of progressive collapse of structures is developed that is founded on a study of the various underlying mechanisms of collapse. Six different types and four classes are discerned, the characteristic features of each category are described and compared, and a terminology is suggested. On this basis, the theoretical treatment of progressive collapse and the development of countermeasures are facilitated because they differ for different types of collapse. Some conclusions drew here concern analogies that should be pursued further, collapse promoting features, and possible countermeasures [8]. R. Shankar Nair After the progressive and disproportionate collapse of the Ronan Point apartment tower in England in 1968, prevention of progressive collapse became one of the unchallenged imperatives in structural engineering, and code-writing bodies and governmental user agencies attempted to develop design guidelines and criteria that would reduce or eliminate the susceptibility of buildings to this form of failure [9]. Victoria Maria Janssens The primary objective of this research is to develop an analysis program that is capable of modeling the complex structural behavior associated with progressive collapse. This program is based on the finite element method of analysis and implements the notional element removal method using three different types of analysis, of increasing complexity: linear static, nonlinear static and nonlinear dynamic analysis [10].

IV. METHODOLOGY

Progressive collapse design criteria depend upon identifying three approaches for overcoming the effect of progressive collapse.

i) Specific local résistance.
ii) Prescriptive design rule
iii) Alternate path method

In first approach key vertical load carrying member are designed to carry foresees events like blest, fire etc. While in second approach there are some thumb rule like providing continues reinforcement, minimum joint resistant and ductility ,redundant structure system and many more in last approach we design the structure in such way that stresses in overstressed member transfer to adjacent undamaged member this APM approach was selected by GSA &UFC standards . In the present study this approach is used and various analysis are done ranging from linear static to nonlinear static &linear dynamic to nonlinear dynamic.

A) Linear static

GSA 2013guidline were developed to provide least requirement for evaluating possibilities of progressive collapse for building structure less 10 or equal to stories though structure show dynamic behavior under the effect of column removal condition this method is used .in this method a load increase factor (LIF) equal to 2 is used for regular steel structure which is including of dead load plus 25% of the imposed load (love load) these guideline also allow to find out DCR>1 to take into effect of dynamic deformation .this method is used to find DCR .THE GSA and DoD provide step procedure for performing this analysis .this analysis requires less complicated software and experience .sometime linear static analysis results may also cause the dynamic effect too but the main drawback of this method is that it cannot consider redistribution of forces p-delta instability nonlinear effect of geometric or material also it cannot permit to develop plastic hinges when subjected to column removal factored load .to overcome this drawback more precise and accurate nonlinear analysis should be performed which consider membrane effect as in inelastic stress hardening based upon type of material used in construction .

Load combination

Case 1. $GLF = \Omega_{LF} [1.2 D + 0.5 L]$
Case 2. $GLF = [1.2 D + 0.5 L]$

Where,

G_{LF} = Increased gravity loads for force-controlled actions for Linear Static analysis.
D = Dead load
L = Live load
Ω_{LF} = Load increase factor for calculating force-controlled actions for Linear Static analysis

B) Nonlinear static

These analysis include geometric nonlinearity resulting due to large deformation caused by column removal scenario .as the column is removed there is increase in load in the column next to it which represents deformation of structure as single degree of freedom (SDOF) to consider this dynamic effect caused by sudden increased in load we consider DIF (Ω_N) in the analysis which is depending upon plastic rotation and yield rotation of member AISC 4-10. The GAS(2013) guideline permits NLS analysis as an alternate option to LS analysis both geometric and martial linearity are considered .in this analysis loads are increased by DIF which account only inertia effects .this is then applied to the model once column is removed deformation limits according to performance level are compared with corresponding member deformation from the ductile action ,while in brittle action member strength doesn't change so it is directly compared with maximum internal member action

Case 1. $G_N = \Omega_N [1.2 D + 0.5 L]$
Case 2. $G_N = [1.2 D + 0.5 L]$

Where G_N = Increased gravity loads for Nonlinear Static Analysis

D = Dead load
L = Live load
Ω_N = Dynamic increase factor for calculating deformation-controlled and force controlled actions for Nonlinear Static analysis.

GSA Guideline (2013).

After remarkable cases of progressive collapse in Unite state there is need of some design change in exiting design which resist progressive collapse for this US invent GSA guideline which named as progressive collapse analysis and design guideline for new federal office building and major modernization projects (June 2013) the main motive of GSA guideline is

1) To minimize the effect of progressive collapse in already existing structure as well as ongoing new federal government buildings.
2) To assist in development of potential upgrades for progressive collapse.

A guideline allow use of linear analysis for 10 building and lesser which includes static as well as dynamic linear statics finite analysis .nevertheless for high rise building like greater than 10 story level we should go for nonlinear dynamic analysis which can consider the material and geometrical non-linearity.

The guideline starts with the discussion about the exemption of the particular building from the valuation for potential of building to progressive collapse .decision about the whether the building is exempted from the analysis or not depends on certain point as,

Acceptance Criteria

An examination of the linear elastic analysis results shall be performed to identify the magnitudes and distribution of potential demands on both the primary and secondary structural elements for quantifying potential collapse areas. The magnitude and distribution of these demands will be indicated by **D**emand-**C**apacity **R**atios (*DCR*). These values and approaches are based, in part, on the methodology presented in the following references

Acceptance criteria for the primary and secondary structural components shall be determined as:

$$DCR = Q_{UD}/Q_{CE}$$

Where,

Q_{UD} = Acting force (demand) determined in component
Q_{CE} = Expected ultimate, un-factored capacity of the component

Exterior consideration:

Analysis for the instantaneous loss of a column for one floor above grade located at or near the middle of the short and long side of the building.

Analysis for the instantaneous loss of a column for one floor above grade located at the corner of the building.

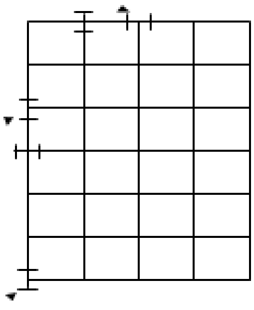


Fig.4.Plan view columns to be for assessment

Interior Considerations:

Analyze for the instantaneous loss of 1column that extends from the floor of the underground parking area or uncontrolled public ground floor area to the next floor (1 story). The column considered should be interior to the perimeter column lines.

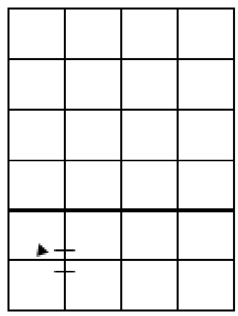


Fig.5.Plan view showing columns to removed interiorly

Model Configuration

10 story 3D models using SMRF system are used in this study each plane is composed of 10spans with the length of 4m .the story height is 3m, NO parking is included in the model .the LL on the floor is 2.5KN/m^2 and floor finish is

1.25KN/m^2 .material used M20and Fe 415, depth of slab 150mm. box hot rolled steel section are used in this model. these models are used for LS analysis .Occupancy category is III& structure is placed in II seismic zone. APM approach is used to choose member to check their capacity for progressive collapse resistance .the columns and beam are design with yield stress Fy=345Mpa .in this study columns are remove as per GSA guideline on various floor and for each removal of column 1analysis are performed to study progressive collapse effect on these models, later on diagonal Bracing are provided to reduce the effect of progressive collapse (prevention method) and again analysis are performed .this the focus of the paper.

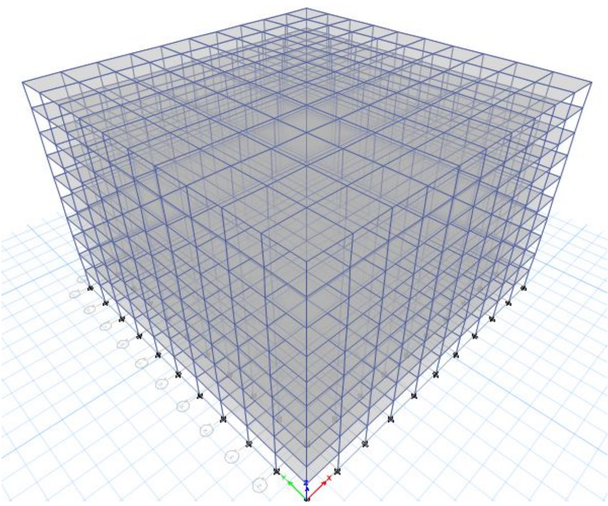


Fig.6.3D view of G+10 E-Tab Model

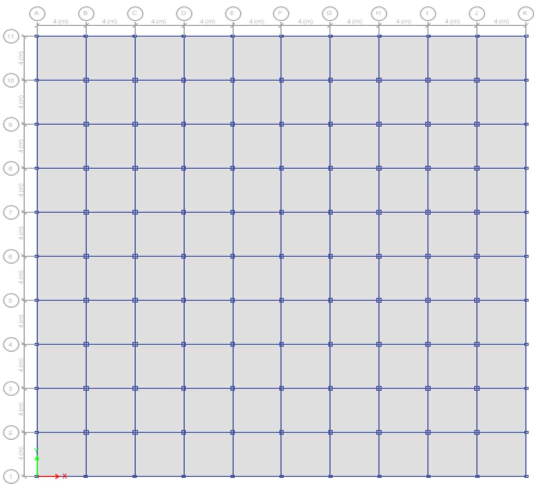
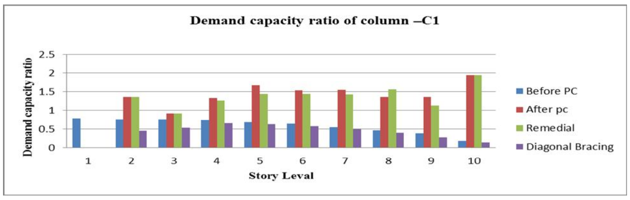


Fig.7. Plan view of G+10 E-Tab Mode

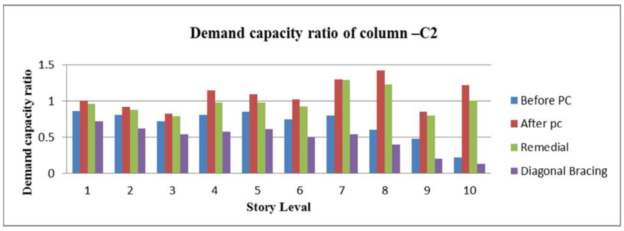
V. RESULTS AND DISCUSSONS

Case 1 :(C1) analysis for the sudden loss of a column situated at the corner of building

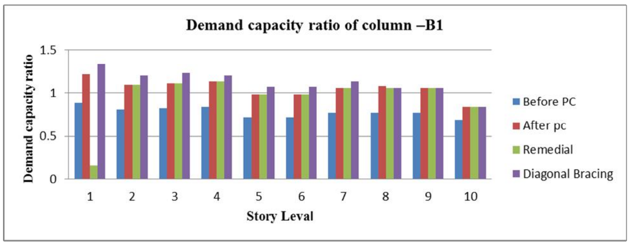
Case 1a: C1 remove at ground floor



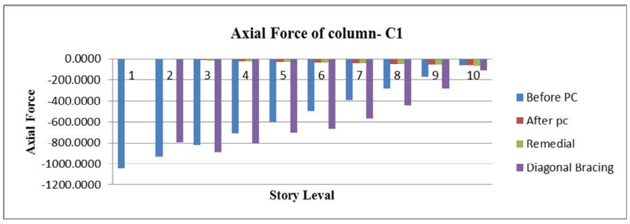
a .Demand capacity ratio of column –C1



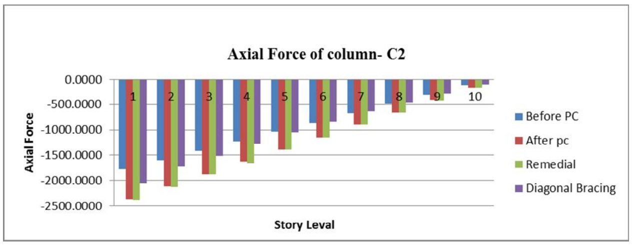
b. **Demand capacity ratio of column –C2**



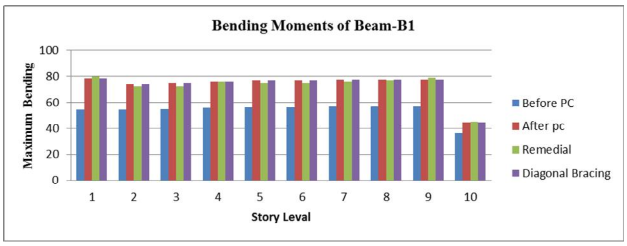
c.Demand capacity ratio of beam-B1



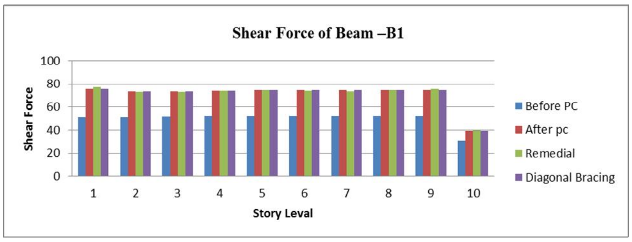
d. Axial Force of column- C1



e. Axial Force of column- C2



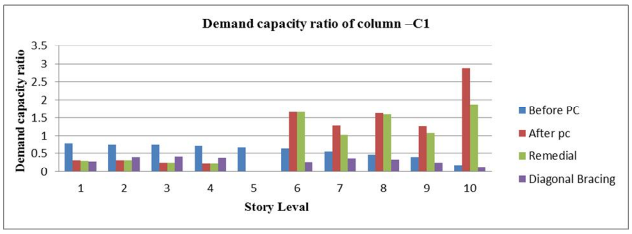
f. Maximum Bending Moments of Beam-B



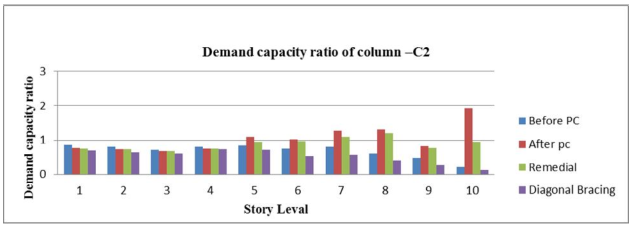
g. Shear Force of Beam –B1

Graph 1. (a-g) comparisons of various parameters for removal of column C1 at ground level

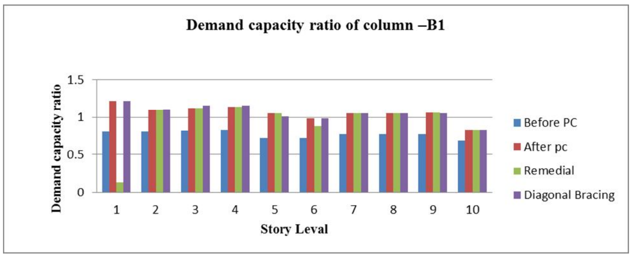
Case 1b: C1 remove at fifth floor



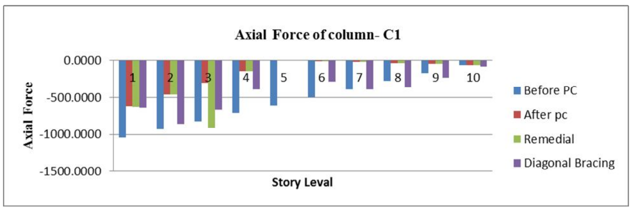
a. Demand capacity ratio of column –C1



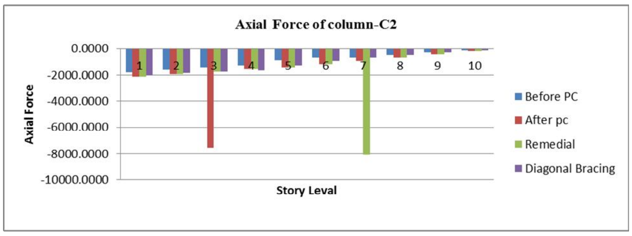
b. Demand capacity ratio of column –C2



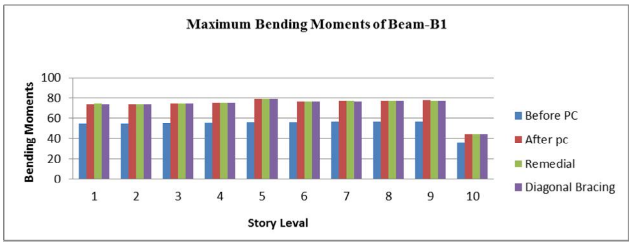
c. Demand capacity ratio of Beam –B1



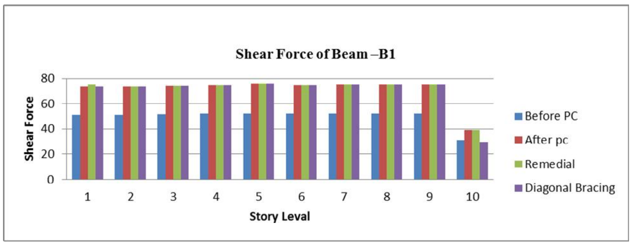
d. Axial Force of column- C1



e. Axial Force of column- C2



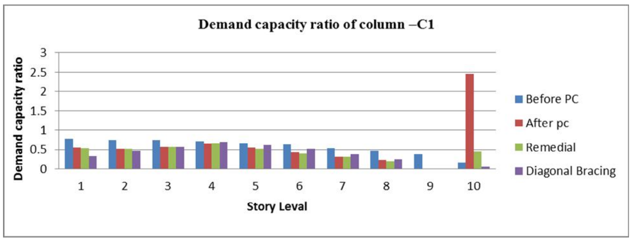
f. Maximum Bending Moments of Beam-B1



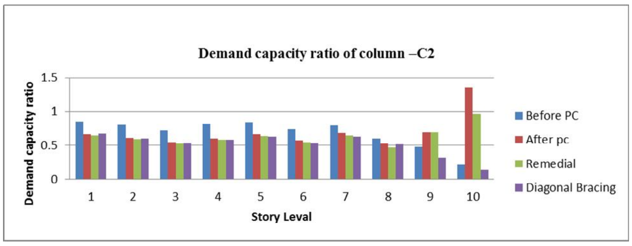
g. Shear Force of Beam –B1

Graph.2 (a-g) comparisons of various parameters for removal of column C1 at ground level

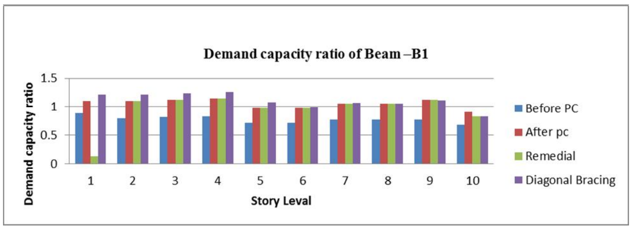
Case 1c: C1 remove at ninth floor



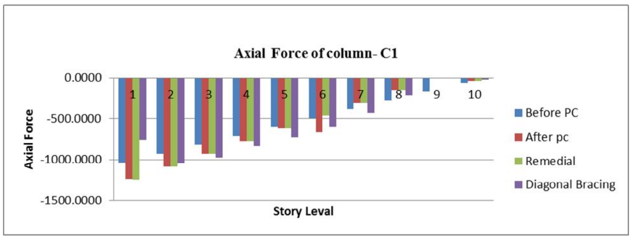
a. Demand capacity ratio of column –C1



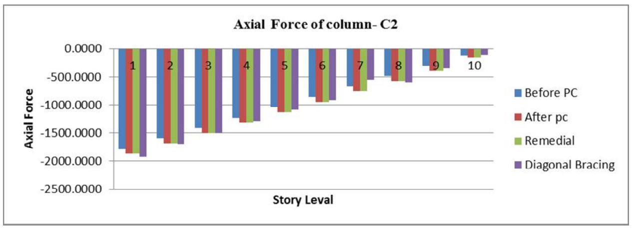
b. Demand capacity ratio of column –C2



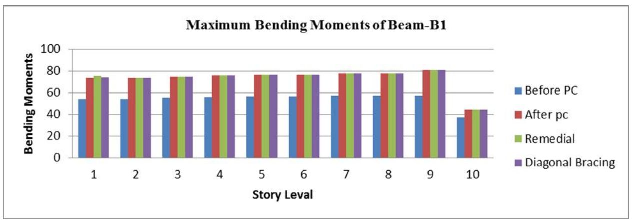
c. Demand capacity ratio of Beam-B1



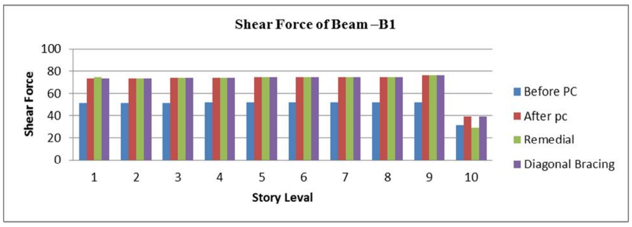
d. Axial Force of column- C1



e. Axial Force of column- C2



f. Maximum Bending Moments of Beam-B1

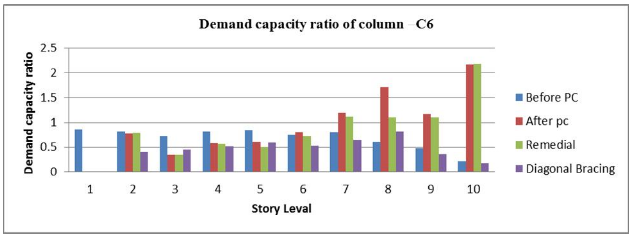


g. Shear Force of Beam –B1

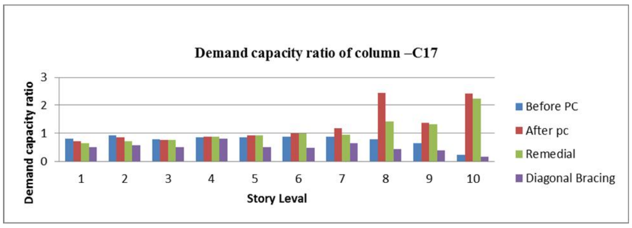
Graph.3 (a-g) comparisons of various parameters for removal of column C1 at ground level

5.4 Case: 2 analyses for the sudden loss of a column situated at the middle of the one of building

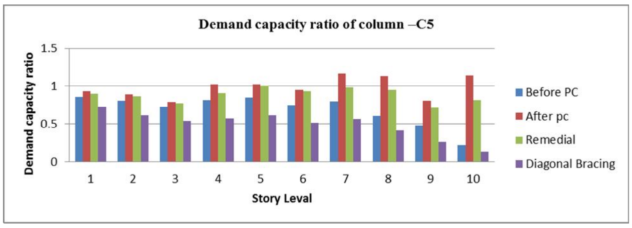
Case 2.a: Column C6 Remove at ground floor



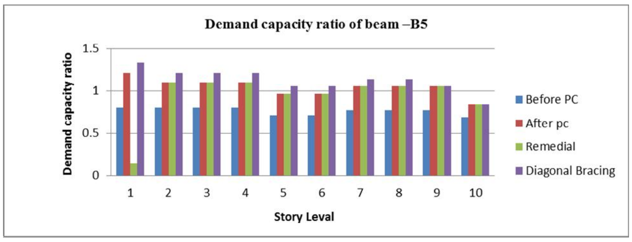
a. Demand capacity ratio of column –C6



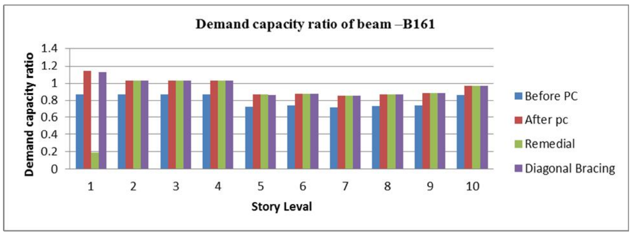
b. Demand capacity ratio of column –C17



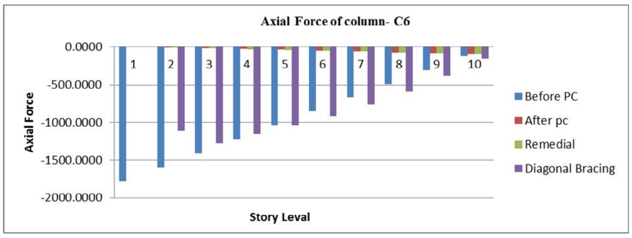
c. Demand capacity ratio of column –C5



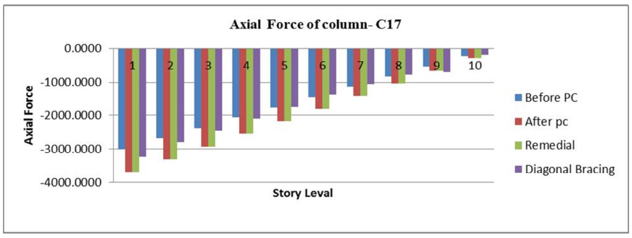
d. Demand capacity ratio of beam –B5



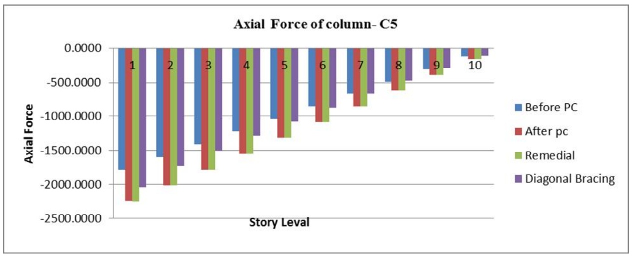
e . Demand capacity ratio of beam –B161



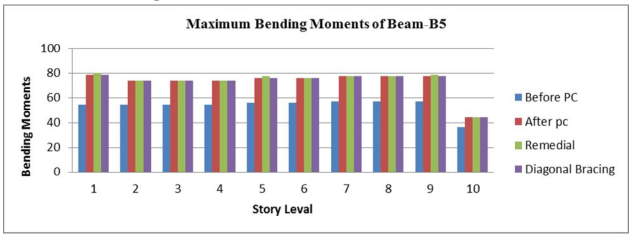
e. Axial Force of column- C6



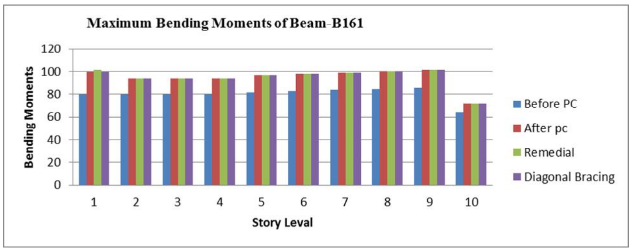
f. Axial Force of column- C17



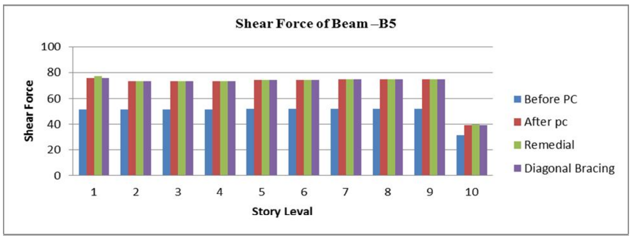
g. Axial Force of column- C5



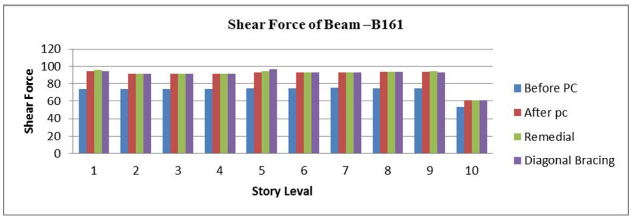
i . Maximum Bending Moments of Beam-B5



j . Maximum Bending Moments of Beam-B161



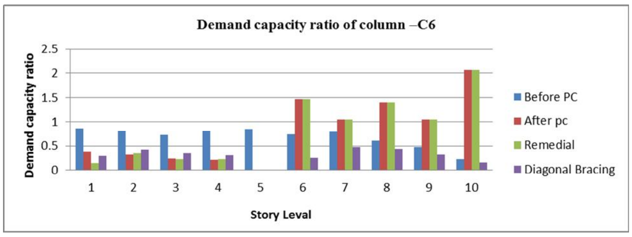
k. Shear Force of Beam –B5



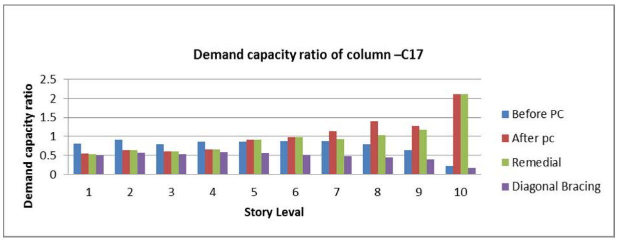
l. Shear Force of Beam –B161

Graph.4 (a-l) comparisons of various parameters for removal of column C6 at ground floor

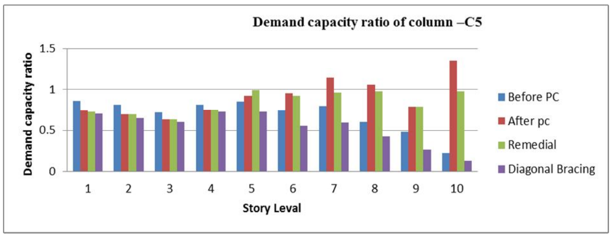
Case 2.a: Column C6 Remove at fifth floor



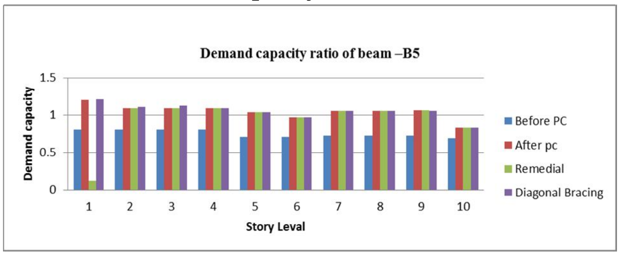
a. Demand capacity ratio of column –C6



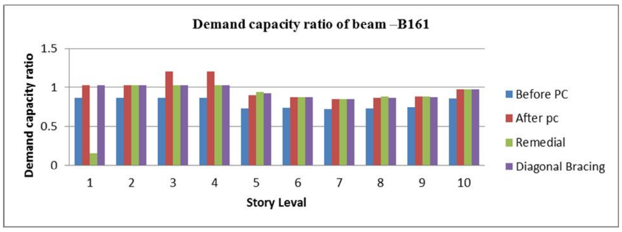
b. Demand capacity ratio of column –C17



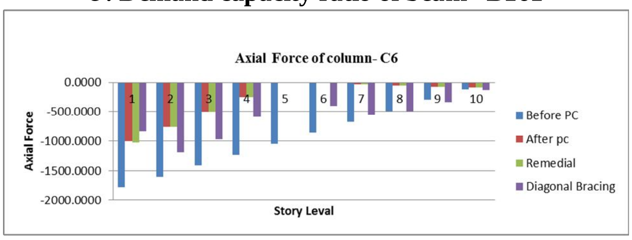
c. Demand capacity ratio of column –C5



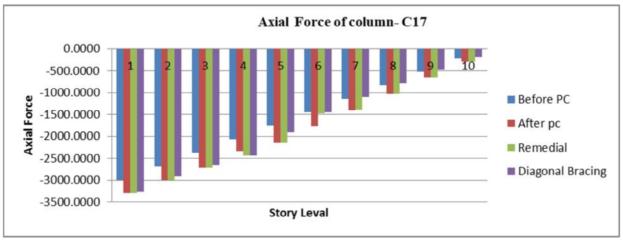
d. Demand capacity ratio of beam –B5



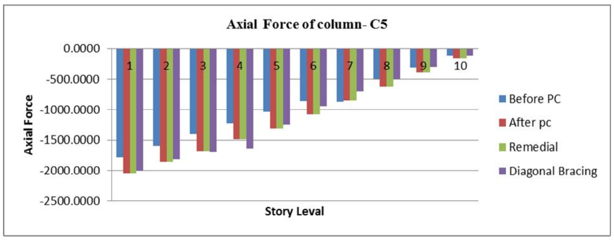
e . Demand capacity ratio of beam –B161



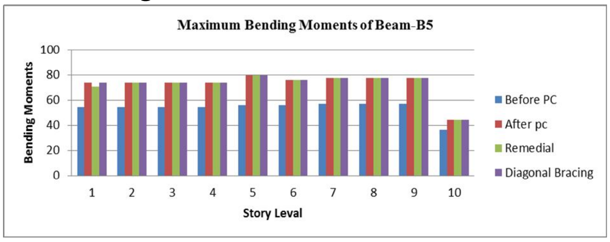
e. Axial Force of column- C6



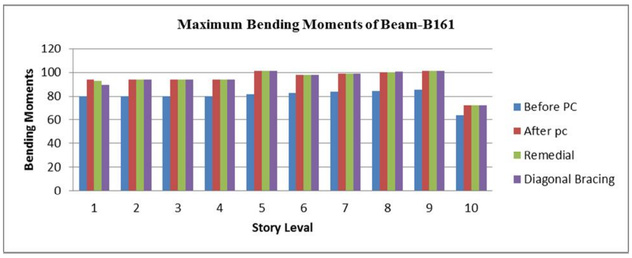
f. Axial Force of column- C17



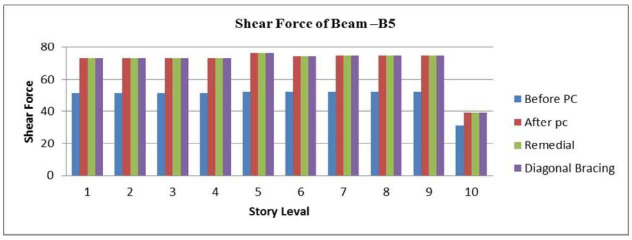
g. Axial Force of column- C5



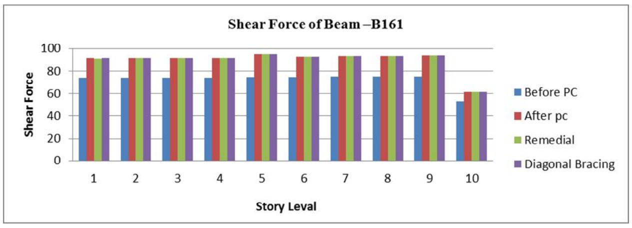
i . Maximum Bending Moments of Beam-B5



j . Maximum Bending Moments of Beam-B161



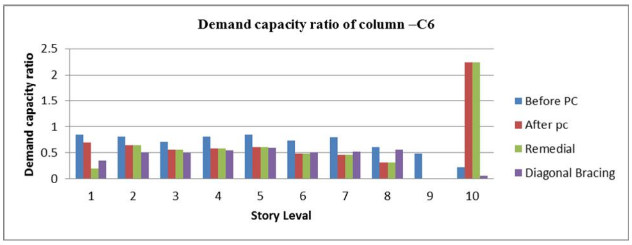
k. Shear Force of Beam –B5



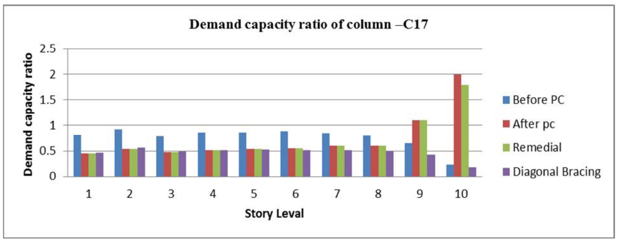
l. Shear Force of Beam –B161

Graph.5 (a-l) comparisons of various parameters for removal of column C6 at ground floor

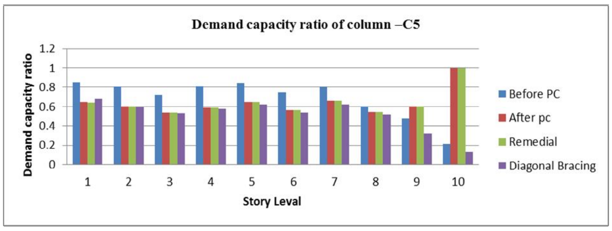
Case 2.a: Column C6 Remove at ninth floor



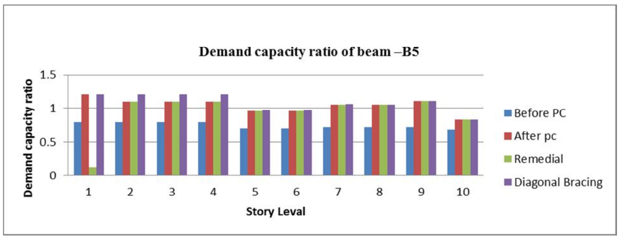
a. Demand capacity ratio of column –C6



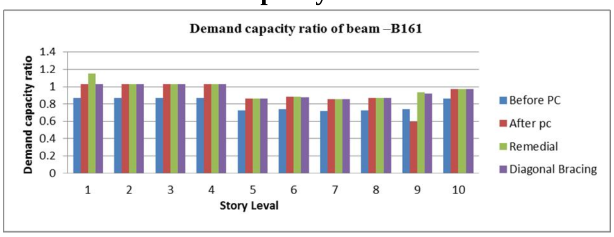
b. Demand capacity ratio of column –C17



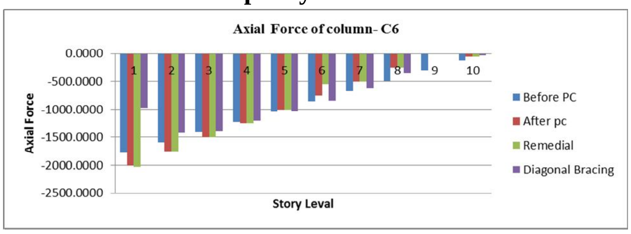
c. Demand capacity ratio of column –C5



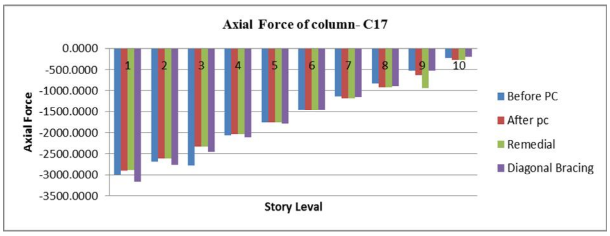
d. Demand capacity ratio of beam –B5



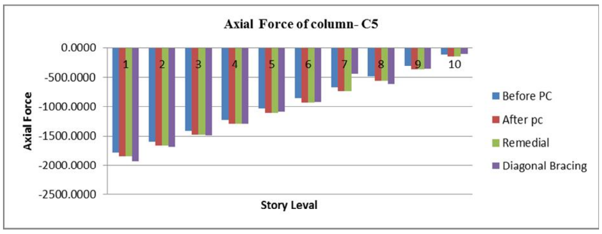
e . Demand capacity ratio of beam –B161



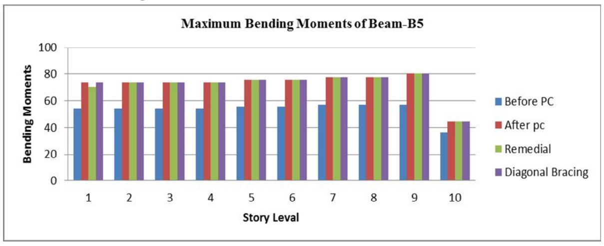
e. Axial Force of column- C6



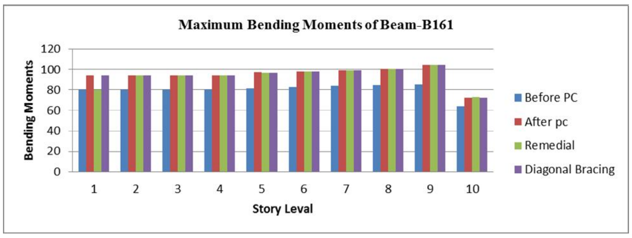
f. Axial Force of column- C17



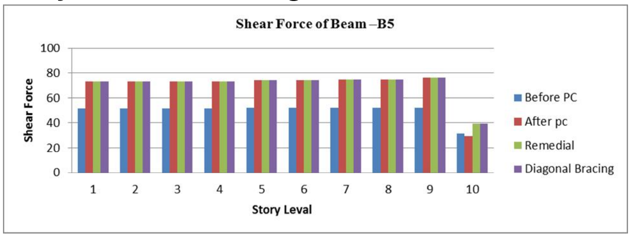
g. Axial Force of column- C5



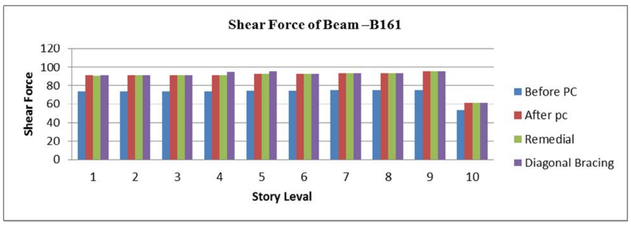
i . Maximum Bending Moments of Beam-B5



j . Maximum Bending Moments of Beam-B161



k. Shear Force of Beam –B5

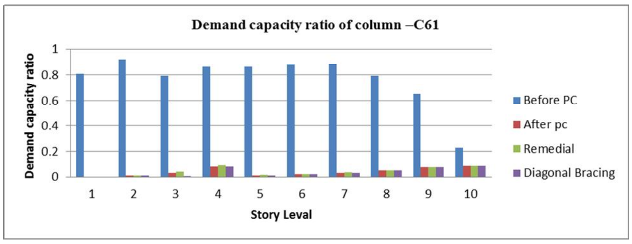


l. Shear Force of Beam –B161

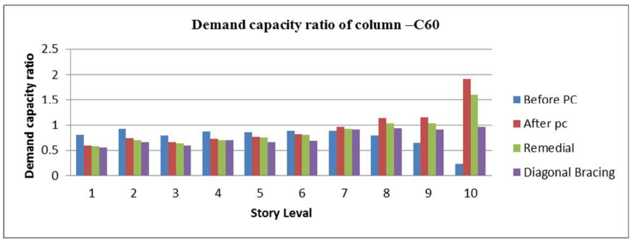
Graph.6 (a-l) comparisons of various parameters for removal of column C6 at ground floor

Case:3 analyses for the sudden loss of a column situated at or near middle removal at any suitable location should be carried out for building .in these case column next to middle position.

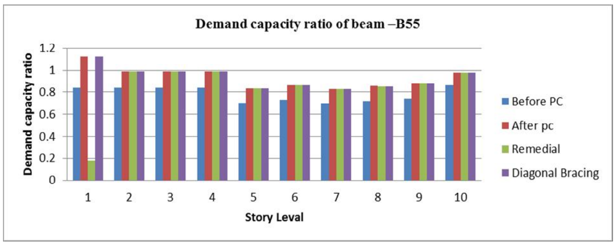
Case 3.a: Column C61 Remove at ground floor



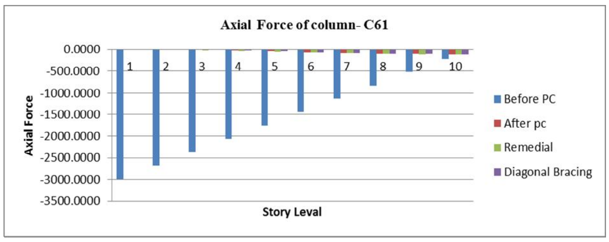
a. Demand capacity ratio of column –C61



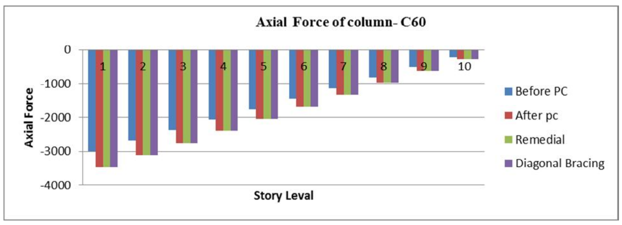
b. Demand capacity ratio of column –C60



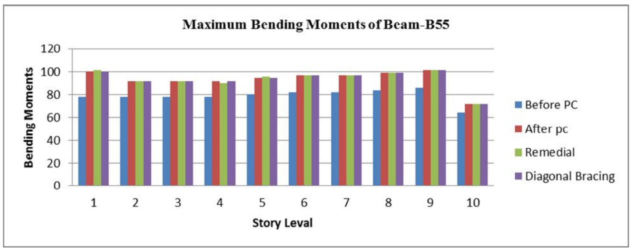
c. Demand capacity ratio of beam –B55



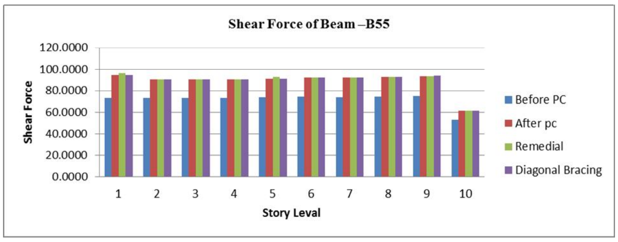
d. Axial Force of column- C61



e. Axial Force of column- C60



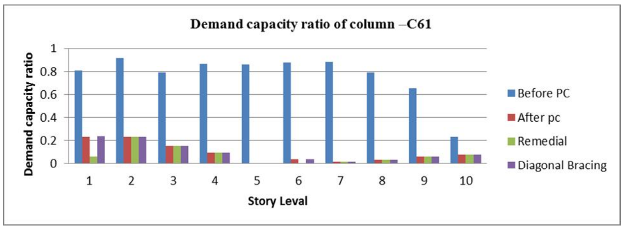
f. Maximum Bending Moments of Beam-B55



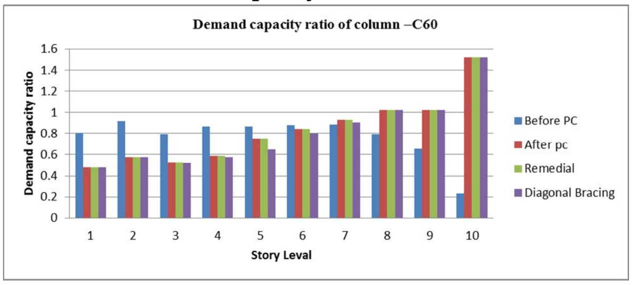
g. Shear Force of Beam –B55

Graph .7 (a-f) comparisons of various parameters for removal of column C61 at ground floor

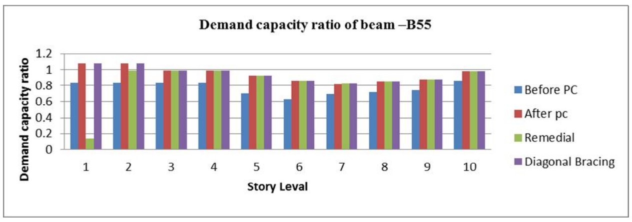
Case 3.b: Column C61 Remove at fifth floor



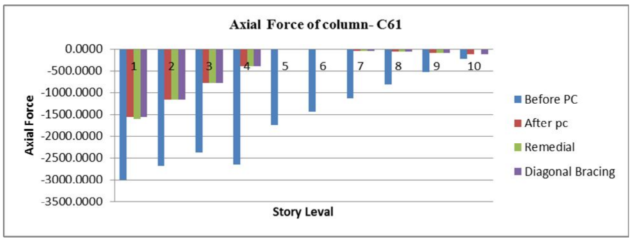
a. Demand capacity ratio of column –C61



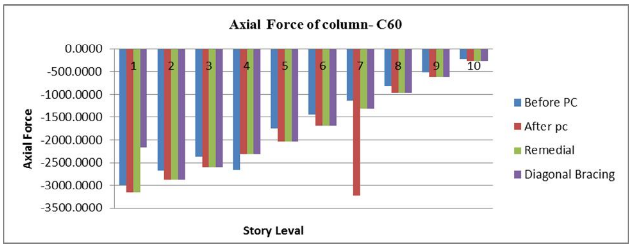
b. Demand capacity ratio of column –C60



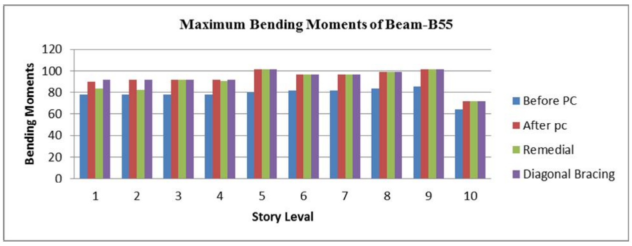
c. Demand capacity ratio of beam –B55



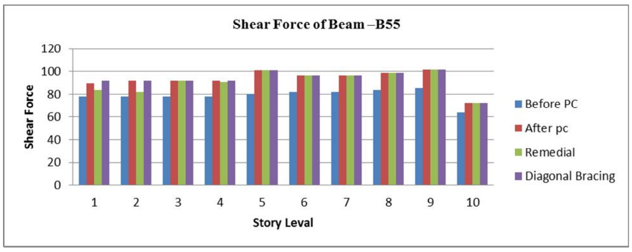
d. Axial Force of column- C61



e. Axial Force of column- C60



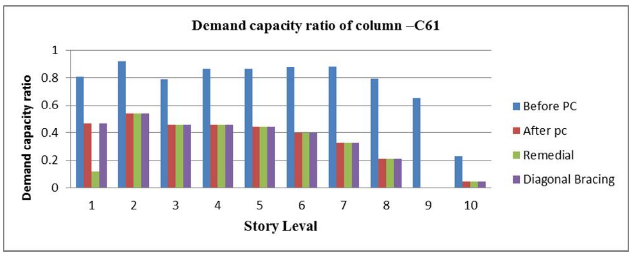
f. Maximum Bending Moments of Beam-B55



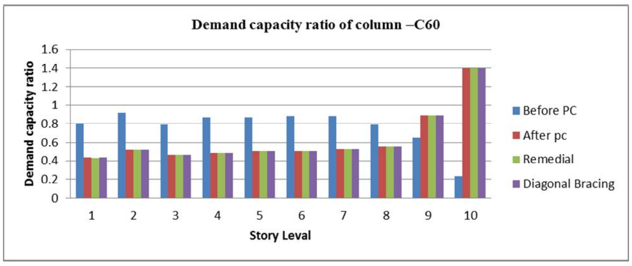
g. Shear Force of Beam –B55

Graph 8. (a-g) comparisons of various parameters for removal of column C61 at ground floor

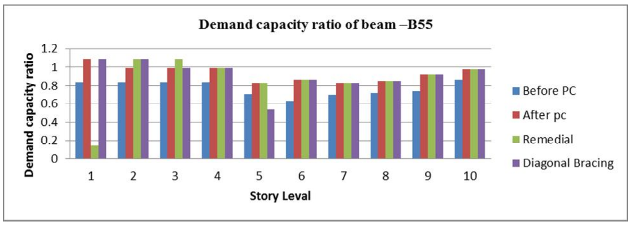
Case 3.a: Column C61 Remove at ninth floor



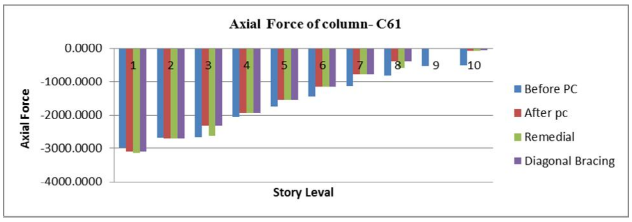
a. Demand capacity ratio of column –C61



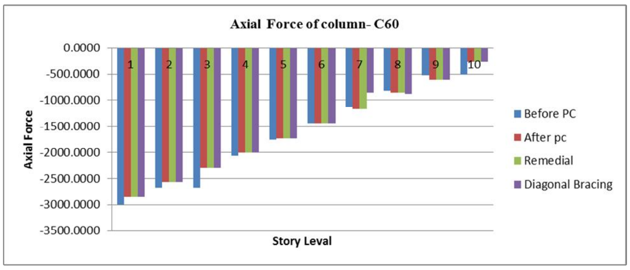
b. Demand capacity ratio of column –C60



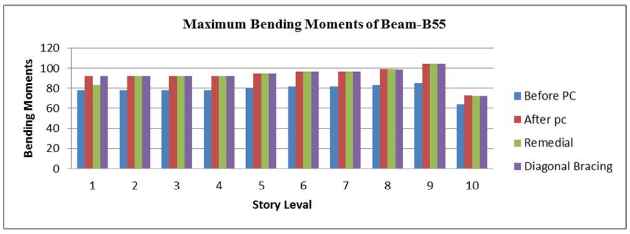
c. Demand capacity ratio of beam –B55



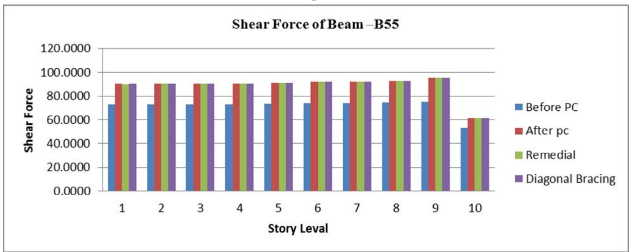
d. Axial Force of column- C61



e. Axial Force of column- C60



f. Maximum Bending Moments of Beam-B55



g. Shear Force of Beam –B55

Graph 5.7 (a-g) comparisons of various parameters for removal of column C61 at ground floor

In the present study progressive collapse by linear static analysis is performed .to find out the behavior of various frame system under progressive collapse analysis is done by removing column as stated in GSA(2013).here in this section case of removal of column C1 at ground floor is discussed DCR values of models are compared .we can see that the red color member show DCR values more than 1 which means these member are failed .also to reduces this effect of progressive collapse bracing and increase the beam and column size at critical location .after increase the beam and column size and providing diagonal bracing this value of DCR can be reduce . this indicate diagonal braced system have higher strength as compared to increase the beam and column size at the critical location .this procedure for removal of column is done on various floor e.g. ground ,5th and 9th and then DCR ,Axial forces in column, displacement ,moments in beam are find out .

VI. SUMMARY AND CONCLUSION

The study focus on the relive measure to reduce to the risk of progressive collapse of high rise steel building .two different method are use reduce the collapse first increase beam and column size at critical location and second using diagonal bracing .A 3-dimentional symmetrical G+10 model in finite element based ETABS 2016 Software tool for sudden column loss at different location at different levels along the height of structure by using alternate path method approach is prepared these frame structure systems are examine under various column removal condition as stated in GSA such as exterior & interior location .In exterior location column C1 located at corner of the building . C6 located at middle of the building and interior location C61 is removed which is located at the center of the building.

- In the present study we have consider SMRF system which is design for lateral as well as gravity load and performed progressive collapse analysis from results it is conclude that the effect of progressive collapse in diagonal braced system is best as compared to increase the beam and column size at critical location system .
- Number of story increases effect of progressive collapse decreases since the numbers to members for taking distributed load are more and hence DCR values of beams go decreasing for upper levels beam which shows the more failure occurs in nearby area of removed column.
- DCR values of beam go on decreasing towards upper levels but DCR values of column go on increasing towards upper level.

- It is observed that effect of progressive collapse was more when corner column was suddenly removed, as the number of story increases effect of progressive collapse decreases since the number of members for taking distributed load is more.
- It is the increase in bending moment of beam due to redistribution of loading on removed area location which leads to failure may be partial or fully but not shear fore (strong column &weak beam)
- Because of removal of column there is increase in load on the nearby column but loss of strength of same column on succeeding levels and same effect is more hazardous when sudden column loss occurs on higher levels
- In any multi story high rise building stiffness and strength are more important so to stiffness and strength are more important so to improve this characteristic of the structure it is possible to provide bracing.
- Progressive collapse can be minimized by using bracing hot rolled section

VII. FUTURE STUDY

In the present study we have consisted seismic zone III and finite element based E-Tabs software for analysis .similar analysis can be done by considering different seismic zone. In E-Tabs software tool and results thus obtained are to be compared with literature available and graphs are to be plotted

VIII. ACKNOWLEDGMENT

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