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EVALUATING THE PROGRESSIVE COLLAPSE OF REINFORCED CONCRETE FRAME BY NON-LINEAR DYNAMIC APPROACH

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Abstract: This study has been undertaken to investigate the progressive collapse of reinforced cement concrete building by using nonlinear dynamic approach the present work is carried out on G+10 multistoried building located in zone III. The building is analyzed for three different column eliminating conditions of ground floor such as corner, edge and interior column. And for reducing the potential of progressive collapse V type bracing is provided to the building. This analysis is carried out by nonlinear time history analysis through FEM by using ETABS 2019. The various parameters such as axial force, displacement of column and demand capacity ratios of beams are studied in this work. It has been observed that the elimination of interior column is more threatening than other two conditions. Demand capacity ratio values are also less than 2 for beams after providing the braces to the building.

Index Terms - Modal analysis, Time History Analysis, Progressive Collapse, ETABS, DCR ratio

I. INTRODUCTION

In 1968. one corner of the 22-story Ronan Point dwelling in London. England, collapsed almost completely, following a gas explosion within the kitchen of an apartment on the 18th floor. The building was constructed using precast reinforced concrete panels. and also the explosion blew out an exterior wall paneling. This resulted in an exceedingly loss of support of the stories above, which caused a collapse chain reaction upwards to the roof. Debris falling from the stories above caused the stories below to collapse in a very similar chain reaction almost to the bottom level (figure l.lc). This kind of chain reaction, where failure of members propagates through a significant portion of a structure, following damage to a comparatively small portion of it, bas been termed "progressive collapse

Progressive Collapse, as defined by ASCE 7, is the spread of an initial local failure from a structural element resulting, eventually, in the collapse of an entire structure or a large part of it (just like how a single domino can knock down an entire series of blocks). This phenomenon is also called disproportionate collapse, for the reason that the collapse is out of proportion to the triggering event. The susceptibility of structures to progressive collapse varies to a certain degree and is dependent on many factors. Over the years different investigations and studies have been conducted to further examine its nature. Among the many triggering events considered, the most notable are design or construction errors and extreme loading conditions structures for different failure conditions and then optimize it for various threat scenario. All structures are expected to withstand many kinds of loads without deforming excessively. Most of the time, a bad design does not come as a result of computational errors, but by failure to consider loads that a structure is expected to resist. In addition to this, invalid design assumptions, inaccurate data, and erroneous design drawings are amongst the other causes of design error. Other forms of human error take place during the construction stage. Construction failures can be categorized in terms of performance and materials. errors are associated with poor construction methodologies, deficient assembly, inadequate supervision of construction workers, and non-conformance to the design intent. On the other hand, material deficiencies are caused by production errors and non-conformance to design specifications. During its lifetime, a structure may be subjected to extreme loading conditions that far exceed normal design assumptions, leading eventually to catastrophic consequences. These abnormal loading hazards may be classified as blast, impact, or deformation-related loads. Blast (e.g. gas explosion, bomb detonation) and impact (e.g. vehicular collision, aircraft impact) loads are short in duration and but high in intensity, resulting in unusual structural responses when compared to more conventional dynamic loads such as earthquakes and wind. Furthermore, deformation-related loads include fire (which causes softening of steel) and foundation subsidence (i.e. the process of downward displacement of the supporting ground). Since these potential abnormal loading conditions have a low probability of occurrence, they are not usually considered in the structural design due to economic reasons and inability to accurately predict scenarios.

Objective of the work:

- To calculate the progressive collapse potential of a 10-storey building as per GSA (2013) Guidelines.
- To determine the collapse pattern in the structure due to different failure points.
- To evaluate the variations in stresses due to failure of a column, in the neighbouring structural members.
- To determine the importance of alternate load paths and their role in such failure conditions.
- To understand the international standards for structural safety and evaluate the Demand capacity ratio (DCR).

II. LITERATURE REVIEW:

Ibrahim M.H. Alshaikha et.al conducted a study on progressive collapse as it is a structural failure caused by abnormal loads It starts as a local failure, followed by a sequential reaction that may result in massive portion failure or even progressive collapse of the entire structure. paper says that interest of researchers increases in structural integrity and resistance to progressive collapse after the collapse of the Ronan Point Apartment in England in 1968. This paper summarizes previous studies on the progressive collapse of RC structures and focuses on experimental studies on various types of structures, such as beam–column and beam–slab sub-assemblies, planar frame structures, and large-scale buildings. Numerous aspects, including general overview, progressive collapse resistance mechanisms, review of previous experimental tests in terms of alternate load path approach, types of testing procedure, the effects of boundary conditions, additional reinforcing rebar's, seismic detailing, structure retrofitting, in filled walls, contribution of RC slabs and transverse beams, demolished building, multi-hazard, new mitigation schemes for precast frames, and alteration of concrete mixture materials. Some of the conclusions are made after the experimental results are came out from the paper that the Pre stressed RC members (beams and slabs) are used in long-span situations, so the risk of progressive collapse is higher than that for RC buildings. Most previous studies conducted progressive collapse tests on monolithic RC frame structures, but this paper studied on precast concrete whole building structures which is rare. He also concluded that further research is required to search for a new innovative design of beam–column joints that can provide adequate continuity to resist progressive collapse.

Moinul Haq and Ashish Agarwal (2019) Progressive collapse analysis is carried out for regular and irregular buildings .the irregularity of the building is steeped type geometry in elevation along shorter bay .3 buildings of G+20 storey with and without atrium is taken and analyzed in SAP2000 software. The methodologies that are taken for analysis are linear elastic and nonlinear static .each method of analysis is completely investigated and DCR values are quantified. for comparing the study the GSA2003 guidelines are used .the purpose of this research is that to give the economical design of structure and to study the behavior of structure under the linear and nonlinear methods .the study was carried out by taking various factors such as different structural geometry, different position of column as well as different methods of analysis. He concluded that high rise RC frame structure is more stable and offer more resistance to progressive collapse, he also examined the hinges formation in building due to the gravity load of building. The ultimate goal of this study is to give insight into ways to help prevent progressive collapse of structures. It is observed that high rise RC frame structures has more tendencies to redistribute moments after collapse and consequently offer more resistance to progressive collapse.

Yara M. Mahmoud, et.al (2018)[7] studied Assessment of progressive collapse of steel structures under seismic loads, best practical advice to reduce the potential of progressive collapse is to consider performance-based design practices and to avoid local damage failures that may affect the whole structure. Meanwhile, the conducted work can be extended through comparing forces developing at interface between beams and floor supporting slabs, investigating progressive collapse behavior of different bracing systems such as cross bracing and eccentric bracing configurations, and examining the behavior of steel structures with irregular layouts, different heights, spans, and loads.

III. METHODOLOGY:

Time history method

Time-History analysis is a step-by-step procedure where the loading and the response history are evaluated at successive time increments. During each step the response is evaluated from the initial conditions existing at the beginning of the step (displacements and velocities and the loading history in the interval). In this method, the non-linear behavior may be easily considered by changing the structural properties (e.g. stiffness, k) from one step to the. Therefore, this method is very effective to determine the non-linear response, however, in linear time history analysis, the structural properties are assumed to remain constant, and a linear behavior of structure is assumed during the entire loading history. As a consequence, the mode superposition method as already discussed in previous section is applicable

Non-Linear dynamic analysis

In this method, the seismic response of the structure is evaluated using step-by-step time history analysis. The main methodology of this procedure is almost similar to the static method of analysis. However, this approach differs in the concept that the design displacements are not established using the target displacement; but, are estimated through dynamic analysis by subjecting the building model to an ensemble of the ground motions. The calculated seismic response is very sensitive to the ground motion characteristics, and the analysis is carried out for more than one ground motion record. To perform the non-linear dynamic analysis, the equation prescribed by the Newmark‟s method (Chopra 2001; Cook 1988 and Humar 1990) can be suitably extended. Based on review of analytical methods, the non-linear dynamic analysis method is adopted for the analytical study due to its accuracy and efficiency in determining the inelastic seismic response of a system subjected to the ground motion data. The review of previous research works show that the past research works have adopted static methods in majority for simplicity. However, the present research works in majority have adopted dynamic analysis (especially non-linear dynamic analysis) to achieve better accuracy to estimate the realistic seismic demands. Moreover, different seismic design codes prescribe dynamic analysis for medium and tall structures and it has been used by recent researchers as well (Karavasilis et al. 2008 a,b; Panda and Ramachandra 2010). Therefore, non-linear dynamic analysis method has been adopted in the present study to determine the seismic response of the building models.

About software ETABS

ETABS is the Acronym of EXTENDED THREE-DIMENSIONAL ANALYSIS OF BUILDINGSYSTEMS, is software developed by Computers and Structures, Inc. (CSI); California based engineering software company named Berkeley was established in 1975. For the purpose of analyzing and designing the multi-storey buildings utilizing grid-like geometry, different analysis methods and solution techniques, including various load combinations, an engineering software product ETABS is used.

The humongous and most intricate building models can be handled by ETABS, along with an extensive variety of nonlinear behaviors, which makes it the structural engineer's best tool of choice in the construction industry. In the analysis and design of building structures, ETABS can be productively used which may consists structural members such as beams, columns, slabs, shear walls etc., Easy application to different construction materials and different structural members like reinforced concrete, steel etc., is possible with ETABS.

For the purpose of design of buildings and structural analysis, an integrated software package "ETABS" is considered as superlative. ETABS provides an unprecedented 3D object- based modeling and tools of visualization, splendidly quick linear and nonlinear analytical power, exceptional and comprehensive design proficiency for a extensive variety of materials, displays, reports, insightful graphic displays and schematic drawings that permits users to swiftly and effortlessly interpret and perceive design and analysis results. Since beginning of design conception via production of schematic drawings, ETABS combines each and every feature of the engineering design process. Establishment of models has never been uncomplicated - instinctive commands of drawing permits for the quick generation of floor and framing of elevation. Computer Aided Designs can be transformed directly into ETABS models or can be utilized as templates over which ETABS objects can be overlaid. The SAP Fire 64-bit solver permits exceptionally huge and complicated models which are examined quickly and upholds modeling techniques which are nonlinear such as time effects and construction sequencing (e.g., shrinkage and creep).

Composite columns, steel joints, steel and concrete frames design (with computerized optimization), shear walls of concrete and masonry are incorporated, as is the check for capacity of base plates and steel connections. Models can be pragmatically depicted, and the outcome can be showcased straightaway on the structure. Extensive and customizable reports are accessible for all the design output and design, schematic construction drawings of framing plans, details, schedules and cross-sections can be developed for steel and concrete structures

Models used in study

- Modeling is done in ETABS for a regular building and the behavior such as storey drift variation, Base Shear, Moments and base reactions are to be analysed.
- Model of a structure is done by using Indian Standard Code Book IS 1893:2016 (Part 1).
- Plan size = 25m x 20m
  Column size: 300 x 700 mm
  Beam size: 300 x 400 mm

  Slab thickness:150 mm Grade of concrete: M25
  Grade of reinforcement: Fe 550
  Providing bracing of ISNB 100 M ,125L,135L (from GF to Top story)

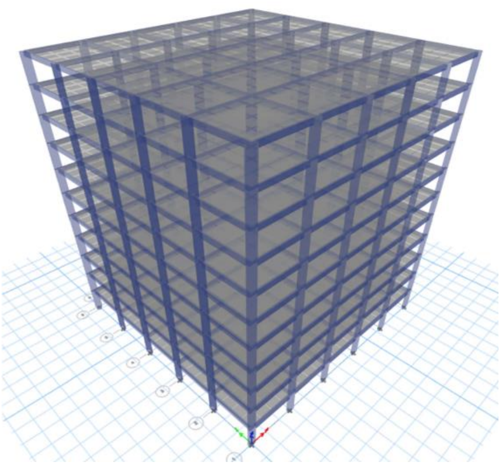
Fig 3.1 Isometric view of building

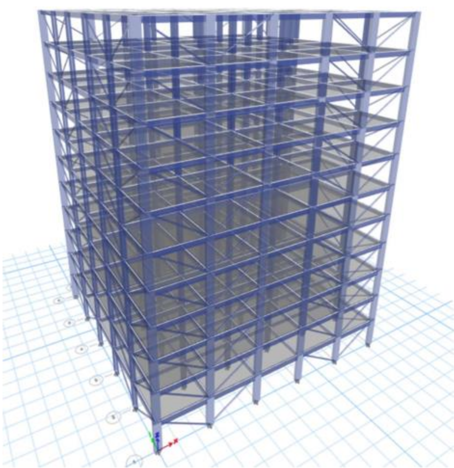
Fig 3.2 Isometric view of building with V braces

Loading details

Live load – 3 kN/m^2
Super dead load-1.0kN/m^2
Wall Load -11 kN/m
Member loads - as per structure configuration
IS 1893 (Part 1):2016 - Seismic load
Location - INDIA
Zone III - 0.16
Importance factor – 1.2
Response Reduction factor – 5
IS 456:2000 and IS 1893 (Part 1):2016 - Load combinations
Both serviceability and strength combinations were considered

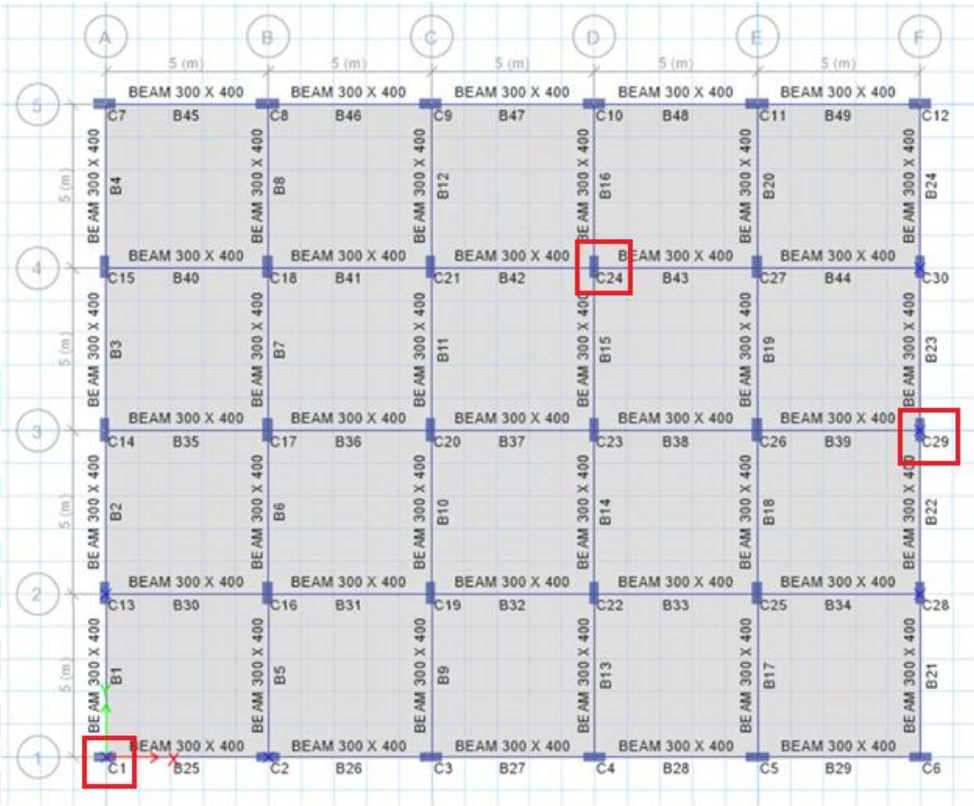

Fig 3.3 Column removal position

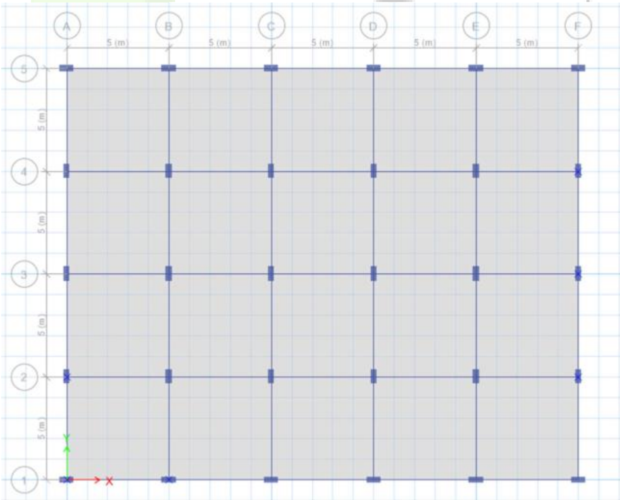

Fig 3.4 Plan of the building

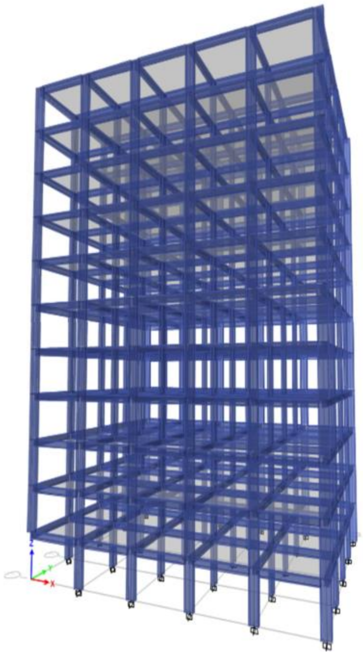

Fig 3.4 corner column removal

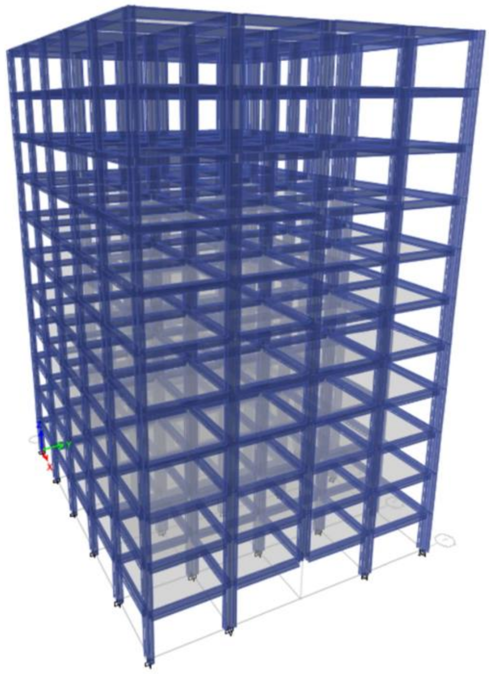

Fig 3.5 Edge column removal

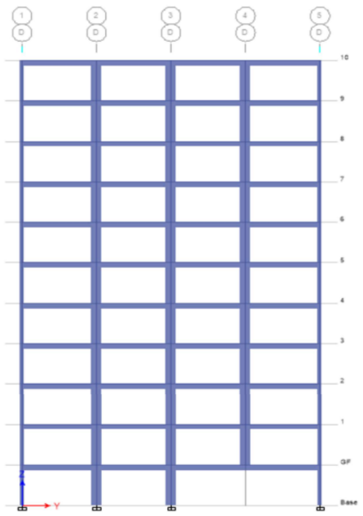

Fig 3.6 Centre column removal

IV. RESULTS AND DISCUSSION

The response of G+10 storey buildings having structural systems like moment resisting frame (OMRF), frame consist of bracing system. The behavior of these all the buildings are studied and compared. To understand the efficacy of all these structure, the demand capacity ratio (DCR) of the structure are incorporated from the nonlinear dynamic analysis using ETABS 2019 and performing time history analysis. These results obtained from the model analysis and discussed in detail in this. Further these results have been used for the understanding of the performance of these structures under the effects of earthquake loads

Demand Capacity Ratio's (DCR):

Table 4: DCR ratio for beam 25

No of floors	Bending moment in beam B25 after removal of column C1 in KNm	Ultimate moment of beam B25 in KNm	DCR ratio
10	198.5	156	1.27
9	235.22	156	1.50
8	255.36	156	1.63
7	250.69	156	1.60
6	278.6	156	1.78
5	285.6	156	1.83
4	296.6	156	1.90
3	300.2	156	1.92
2	325.2	156	2.08
1	330.5	156	2.11
GF	345.2	156	2.21

Table 5 : DCR ratio for beam25 after bracing

No of floors	Bending moment in beam B25 after removal of column C1 in KNm	Ultimate moment of beam B25 in KNm	DCR ratio
10	140.45	156	0.90
9	156.5	156	1.00
8	185.6	156	1.18
7	205.6	156	1.31
6	235.6	156	1.51
5	230.6	156	1.47
4	266.89	156	1.71
3	270.6	156	1.73
2	250.6	156	1.60
1	255.96	156	1.64
GF	266.3	156	1.70

Table 3 : DCR ratio for beam22

No of floors	Bending moment in beam B22 after removal of column C29 in KNm	Ultimate moment of beam B25 in KNm	DCR ratio
10	140.45	156	1.32
9	156.5	156	1.38
8	185.6	156	1.59
7	205.6	156	1.76
6	235.6	156	1.85
5	230.6	156	1.92
4	266.89	156	2.22
3	270.6	156	2.56
2	250.6	156	2.88
1	255.96	156	2.30
GF	266.3	156	2.35

Table 4: DCR ratio for beam22 after bracing

No of floors	Bending moment in beam B22 after removal of column C29 in KNm	Ultimate moment of beam B25 in KNm	DCR ratio
10	139.6	156	0.894
9	170	156	1.08
8	182.08	156	1.167
7	184.16	156	1.180
6	196.896	156	1.262
5	214.832	156	1.377
4	222.68	156	1.427
3	235.896	156	1.512
2	252.376	156	1.617
1	256.464	156	1.644
GF	271.32	156	1.739

Table 5: DCR ratio for beam15

No of floors	Bending moment in beam B15 after removal of column C24 in KNm	Ultimate moment of beam B15 in KNm	DCR ratio
10	167.52	156	1.073
9	204	156	1.306
8	218.496	156	1.400
7	220.992	156	1.416
6	236.2752	156	1.514
5	257.7984	156	1.652
4	267.216	156	1.812
3	283.0752	156	1.914
2	315.276	156	2.021
1	362.70	156	2.325
GF	377.520	156	2.420

Table 6: DCR ratio for beam15 after bracing

No of floors	Bending moment in beam B15 after removal of column C24 in KNm	Ultimate moment of beam B15 in KNm	DCR ratio
10	150.768	156	0.966
9	183.6	156	1.176
8	196.6464	156	1.260
7	198.8928	156	1.274
6	212.64768	156	1.363
5	232.01856	156	1.487
4	240.4944	156	1.541
3	254.76768	156	1.633
2	272.56608	156	1.747
1	276.98112	156	1.775
GF	293.0256	156	1.878

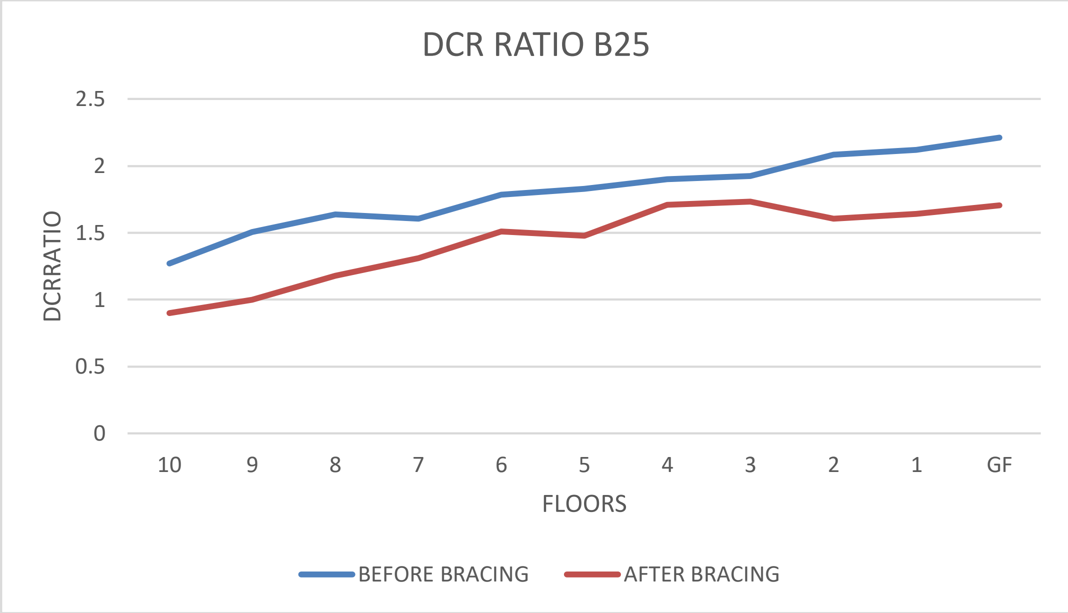

Figure 4.1: DCR ratio graph for beam 25

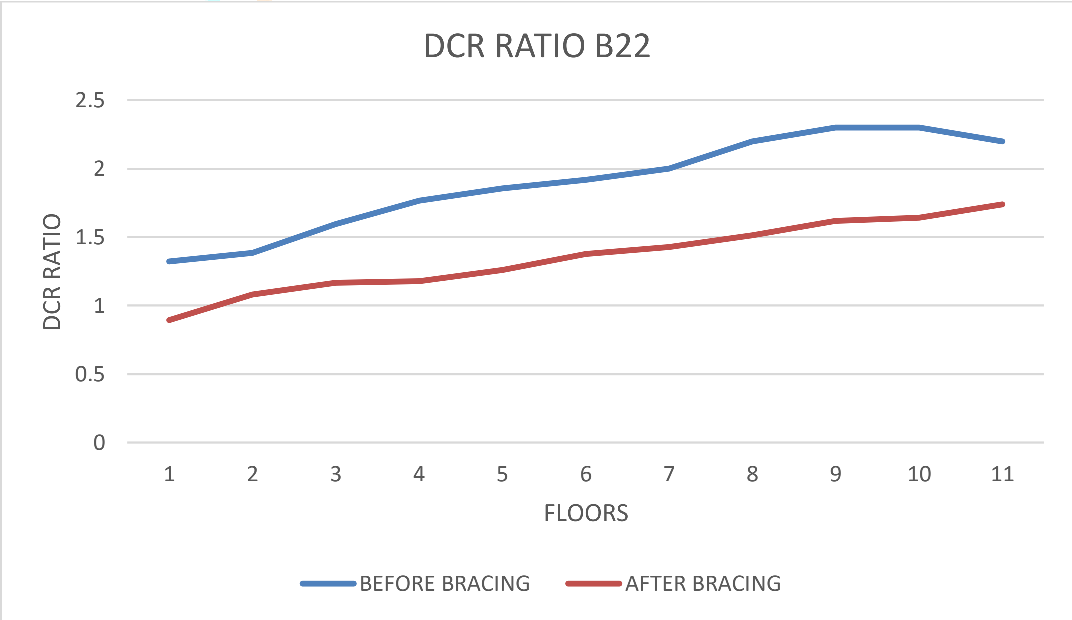

Figure 4.2: DCR ratio graph for beam 22

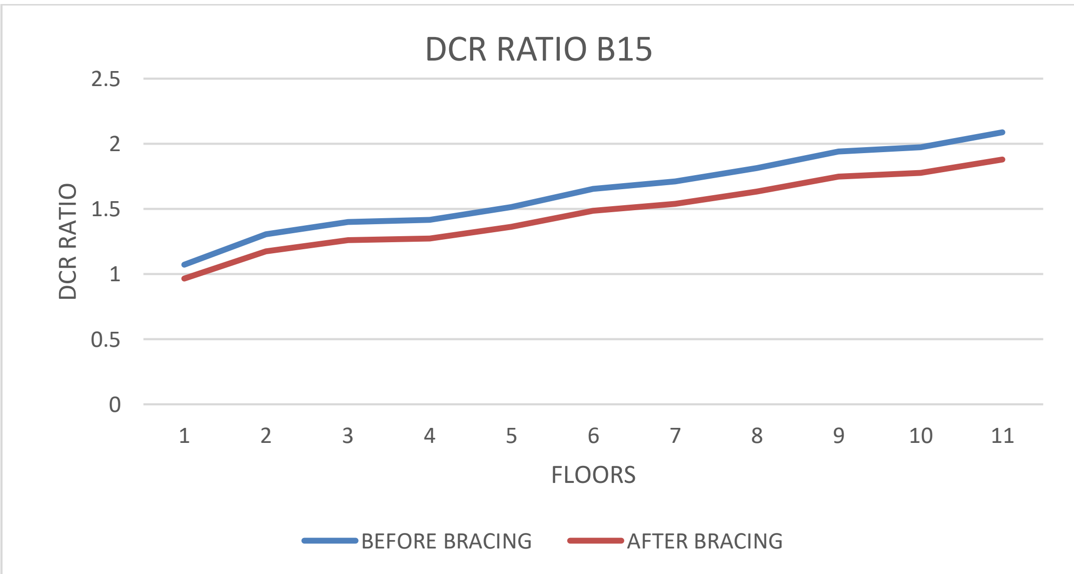

Figure 4.3: DCR ratio graph for beam 15

The above tables and graph shows the demand capacity ratio of beams which are adjacent to the removed column .The graphs clearly shows that the values are less than 2 after providing bracing to the building. The x direction represents the floors of the building and y directions represent the DCR ratio.

V. CONCLUSION:

The beam adjacent to the removed column has experienced increase in bending stresses, increment was more than times of its ultimate moment and it is likely to undergo collapse.

DCR (demand capacity ratio) for the beams for the following cases

- Interior column removal case is 2.42
- Corner column removal case is 2.21
- Edge column removal case is 2.35
-

DCR (demand capacity ratio) for the beams after applying periphery bracing for the following cases

- Interior column removal case is 1.87
- Corner column removal case is 1.70
- Edge column removal case is1.87

From this we can conclude that providing bracing will increase the resisting capacity of progressive collapse

Scope for future study:

1. To understand the behavior of structures with multiple structural systems.
2. Assessing the work with composite material, since steel in general has higher ductility when compared to concrete.
3. Removing different floor column instead of ground floor column only.

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