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ROBUSTNESS EVALUATION OF RC BARE FRAME AND INFILLED FRAME BUILDINGS TO PROGRESSIVE COLLAPSE UNDER CORNER AND MIDDLE COLUMN REMOVAL SCENARIO

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ABSTRACT

Progressive collapse occurs when primary structural element fails due to many reasons such as impact, earthquake, abnormal loading etc., resulting in the failure of adjoining structural elements, which in turn causes partial or total collapse of the structure consequently. The present study investigates the comparison behaviour of 2 bay X 2 bay, five storey RC bare frame and infilled frame and to assess the effect of infill to resist the progressive collapse. A linear static analysis is carried out using finite element software using SAP 2000 for corner, and middle column was removed and studied under dead load conditions. In this study and Demand Capacity Ratio (DCR) of a five storey bare frame and infilled frame building was evaluated as per GSA guidelines. Results are bare frame and infilled frames compared and it shows that the presence of infilled frames will delay the progressive collapse when compared to bare frames.

Key words: Progressive collapse, RCC frame, Bare frame, Infilled frame, linear static.

INTRODUCTION

Research in Progressive collapse has gained momentum in 2000. Due to the increase in trigger mechanism such as impact, bomb, earthquake, fire or manmade etc. loss of critical elements leads to increase in moments and stresses which progresses to nearby elements ultimately causing failure of the structure progressively. It is a dynamic process and it is accompanied by large deformation. The system as it collapses transfers the load into an alternate load path. The behaviour is linear static, non-linear static, linear dynamic, non-linear dynamic depending on the condition of initiation of failure or during the collapse

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mechanism. There have been a few worldwide examples for progressive collapse such that Ronan point residential apartment building (London 1968), Alfred P. Murrah federal banking (Oklahoma,1995) after the collapse of World trade centres, many research activities have led to more detailed guidelines on designing and preventing the progressive collapse. The U.S. General Services Administration (GSA)[1] and Department of Defence (DoD)[2] guidelines by United Facilities Criteria (UFC)-New York, provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure

The published researches by various authors on topics that are related to progressive collapse are presented below Infilled masonry walls though not considered in the design, have always imparted rigidity to the structure in cases of simple gravity load to seismic loading. Research in identifying suitable elements or using combination elements for modelling such walls is being carried out. Due to the varied type of materials in masonry and insufficient control in production determining material properties and finalizing a typical the stress strain curve is yet in the research stage. Papers relating to modelling and properties of masonry under Indian condition have also been presented. Izzuddin et al.[3] has proposed suggested a simplified multilevel framework for progressive collapse assessment due to sudden loss of column. The framework considers the floors above the lost column. The analysis considers (1) A non-linear static response of the damaged structure under gravity load. (2) Simplified dynamic assessment to establish the dynamic response under gravity load. (3) Ductility of the connections. The choice of elements is elasto plastic beam column element the beam level and advanced shell element for the slab at floor level. The elements are coupled to the beam element to represent integrated floor response. The proposed framework offers a practical and simple means for assessing the collapse resistant potential under extreme accidental loading at the level concerned especially in multi-storeyed buildings. Hyun-Su Kim et al.[4] have developed integrated software 'Opensees" which carries out the progressive collapse analysis automatically identifying the critical members and remodelling the structure. It conducts the iterative procedure automatically considering plastic hinges before producing the final results. The paper outlines the primary elements of progressive collapse analysis such as damage index nonlinear material model. Analytical model for failed members analytical model for sudden removal of column. On the contrary "Opensees" carries out the above steps successively before the final deformations are produced as output. The software uses GSA and DOD guidelines and is capable of handling different nonlinear material model. It uses two models for the failed material, plastic hinge and separation of nodes. Mehrdad Sasani[5] on paper 'Response of a reinforced concrete infilled-frame structure to removal of two adjacent columns' analyses the response of a six storeyed RC infilled frame of a building "Hotel San Diego. The building was constructed in 1914 with non-ductile reinforced concrete (RC) frame structure with hollow clay tile exterior infill walls. The floor system consisted of one-way joists running in the longitudinal direction. The analysis simulates the removal of two exterior adjacent columns. The frame was studied using Fem and modified FEM model and verified experimentally. The beams and columns were modelled with Bernoulli's beam element plastic hinges were assigned at points were yielding occurs. An iterative procedure by determining the cracking regions and using modified section properties were carried out. The infilled walls were modelled in two types 2D shell elements and compression struts. A cracked location of the infilled walls nodes was introduced. The internal forces of the removed column were replaced as external loads along with the permanent loads. In the applied FEM model the elements were modelled as the cubical sub elements and spring triples. The connections of the infills were modelled interface mortar elements. The analysis was done using the software ELS. The results were verified experimentally. It was concluded that the infilled walls offered support and constraints to the beam and act as mechanism for redistribution of loads. Hemant B Kaushik et al.[6] has conducted research on uniaxial compressive stress strain model for clay brick masonry. The paper outlines the stress strain relationship for masonry for the Indian construction conditions extending into the non-linear range. 84 masonry prisms were tested. Hand moulded bricks from four manufacturers were considered. Three grades of mortar (cement lime sand by volume) 1:0:6, 1:0:3, 1: ½:4 ½ were considered for each set of bricks. The specimens were tested till failure. From the test results a stress strain co relation was developed for each of the mortar type. The value of E was also co related as a function of failure strain and presented as E = 550 fm. A numerical model was developed using 6 control points at various stain levels in order to develop a stress strain curve. To use this model, the compressive strength of bricks alone is required. A simplified tri linear stress strain response was also idealized for the above developed numerical curve.

In the absence of more accurate data this relationship is a handy tool for analysing masonry structures in the non-linear range. Ivo calio et al.[7] on the paper 'A macro-element modelling approach of Infilled Frame Structures' has proposed a plane discrete element for the infilled walls. The element is articulated quadrilateral with rigid edges connected by four hinges and 2 diagonal nonlinear springs perpendicular and parallel to the panel sides. The sides of the quadrilateral can interact with the elements by the nonlinear springs. The interface is also modelled by non-linear springs The beams and columns are modelled using concentrated plasticity beam–column elements. The collapse mechanism such as flexural failure diagonal shear failure and sliding shear failure were obtained. The infilled frames with and without central openings were studied using these elements. The calibration of the springs was based on C and F of the interface. Modal discretisation of the infill was also carried out. The top displacement of the model was compared with the experimental results. The research studies reported above either confine to the framed structures under progressive collapse or response of in filled wall under static and dynamic loading. Studies on the effect of infilled walls during progressive collapse are very limited. Further the effects of seismic loading have not been considered under progressive collapse. Very few researches has been carried out in determining masonry properties under Indian conditions, hence it is it is inevitable to use these properties for the material modelling of masonry. Varied elements are being used for the infills but the choice of a suitable element will have to be made for a obtaining b a more accurate result. Further the GSA and DoD guidelines have to be incorporated in the analysis. Though a software, which automatically caries out the iterations for progressive collapse analysis, its validation and use is yet to be established. Hence it is better to use standard software for the analysis in order to obtain more realistic results.

Need for present work

A number of researches have been done in progressive collapse of various RC building frames, beam column assemblages, beam column joint detailing using GSA and DOD guidelines. Similarly work has been carried out in masonry infill frames under various types of loading including seismic loads. Since masonry infills impart stiffness to the frame, it is necessary to study effect of infills in progressive collapse of RC frames.

Research significance

Although progressive collapse is generally a rare incident in developing countries but effect on building is very dangerous and costly. Without significant consideration of adequate continuity, ductility and redundancy, the progressive collapse cannot be prevented in addition; the researches on the progressive collapse resistance of reinforced concrete structures are gradually increasing with the improvement of modern material, technology, and methods particularly in the developing countries. So it is proposed to study the behaviour of 5 storeys of reinforced concrete (RC) frames under progressive collapse on removal of critical column and to study a bare frame and masonry infill wall to assess its effect on the frame to resist the progressive collapse.

Objective of this study

This study aims to a quantitative comparison between progressive collapse potential of symmetrical buildings with bare frame and infilled frame. The results will be compared from the point of structures vulnerability to progressive collapse and analysed by linear static procedure based on GSA 2003 Guidelines. The main objectives of this study, to assess the susceptibility of bare frame and infilled frame to progressive collapse. To calculate DCR for Beam and column and to make the comparison between the bare frame and infilled frame with two different column removal scenario regarding to progressive collapse incident.

Description of structure

A Structure was five story, 2 bay x 2 bay was selected to perform progressive collapse analysis. The building has two spans in both longer and shorter direction. The storey height is 3 m. The building plan is showing with dimension is given in Fig. 1. The bean sizes are (300 mm x 300 mm) and column sizes are (400 mm x 300 mm) are considered for the building. The wall having 100 mm thickness is present on all the beams. The characteristic compressive strength of concrete M30 grade and Fe 415 steel are used. The walls are proposed in brick masonry in 1:6 mortars. In absence of proper data in available codes of practices the material properties of masonry are taken from a research article listed in the reference [4]

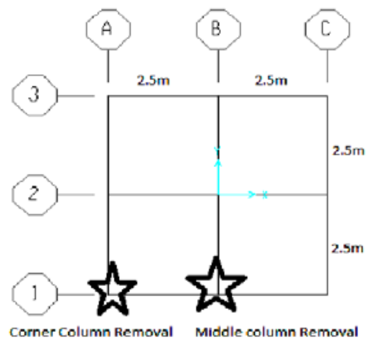

Fig. 1: The plan of the building

The longitudinal direction has considered as a front elevation and transverse direction has considered as side elevation and it is shown in Fig. 2 & 3.

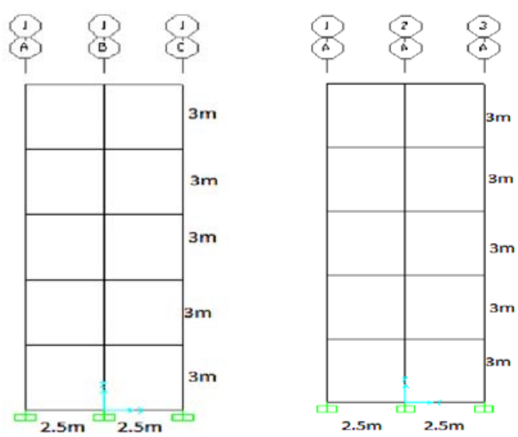

Fig. 2: Front and side elevation of the building

Loading combinations

For static analysis purposes the following vertical load shall be applied downward to the structure under investigation:

$$\text{Load} = 2(\text{DL} + 0.25\text{LL})$$

For dynamic analysis purposes the following vertical load shall be applied downward to the structure under investigation:

$$\text{Load} = \text{DL} + 0.25\text{LL}$$

Where, DL = Dead load

LL = Live load (higher of the design live load or the code live load

Although the GSA and DoD guidelines [1,2] recommended by applying the combination of dead load and live load in structural analysis, in this research paper only the self-weight only considered to be able to compare the numerical results with the experiments, but in this research paper only linear static analysis results only discussed.

Column removal scenario

In this present study corner and middle column was removed along the longitudinal direction and it is shown in Fig. 3.

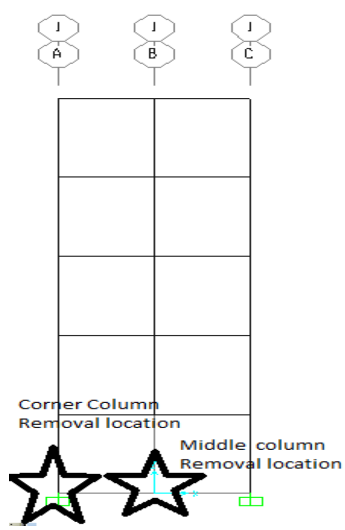

Fig. 3: Diferent column removal location

Finite element model analysis

In this research study, a finite element model of the analysed structure has been created by SAP2000 and it contains 54 nodes and 105 frame elements and 68 infill elements the elements and nodes are shown in Fig. 4.

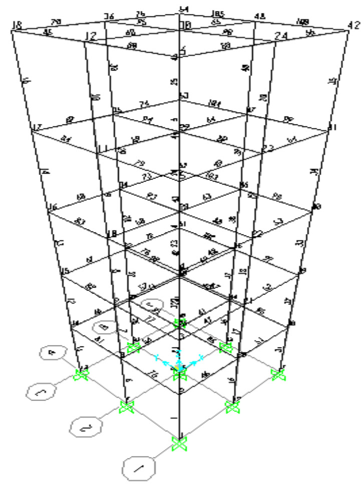

Fig. 4: Nodes and beams nos of the building

In this work two column removals have been considered in bare frame and infill frame: sudden column removal at left corner column and middle column of grid 1.

Linear static analysis

In this present study, static computations are compared with the structural resistances using so called demand-capacity ratio (DCR) is computed for each of the structural members in the building.

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

Where Q_{UD} = Force (bending moment, axial force, shearforce) determined in a component or connection from the analysis

Q_{CE} = Expected ultimate factored capacity (bending moment, axial force, shear force) of the component or connection.

Using the DCR criteria, structural members and connections that have DCR values greater than 2.0 are considered to be severely damaged or collapsed [GSA 2003]. In the case of shear forces, failure is imminent when the DCR value exceeds 1.0. Once the DCRs have been computed, the extent of damage or collapse can be determined. While the linear static analysis is relatively simple, it approximates to the behaviour of the actual building performance and may sometimes mask hazardous dynamic effects. The linear static analysis cannot account for the redistribution of forces, nonlinear material properties, and the development of membrane modes of resistance. Thus, this approach, in general, would produce conservative designs

Linear static analysis results

Linear static analysis of the two models (Bare frame and infill frame) was carried out under the action of dead load and corresponding DCR are calculated for beam and columns. The analysis is also carried for the same models with corner, middle, and intermediate column was removed. Comparison results was performed both bare and infill frame.

Axial force

According, to Fig. 5(a) to 5(d), Axial force of DCR for longitudinal side of five storey bare and infill frame building when corner, middle and intermediate column is removed. At Bare Frame shows the Maximum DCR of 0.225 is present near the affected corner column, the middle and intermediate column removal shows lesser than the bare and infill frame. All the frame shows the $_{\text{DCRaxial}}$ is less than 2, which shows that the susceptibility of structure for occurrence of progressive collapse is low. Furthermore, in these frame, the computed axial stress is less than the allowable Euler stress (fa < Fe) too. Therefore, the columns could bear the existing axial force and progressive collapse will happen

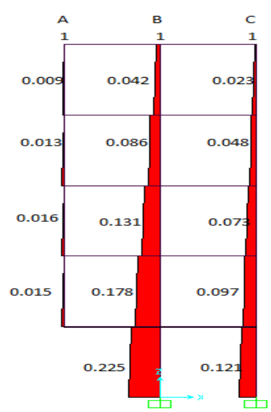

Fig. 5(a): Demand capacity ratio axial (DCR) for longitudinal side of five-story bare frame building (Corner column removal scenario)

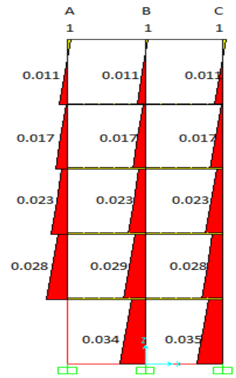

Fig. 5(b): Demand capacity ratio axial (DCR) for longitudinal side of five-story with infill frame building (Corner column removal scenario)

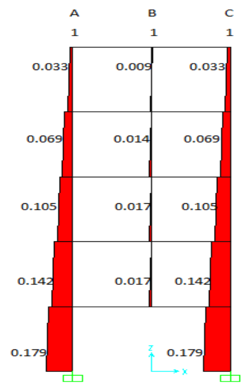

Fig. 5(c): Demand capacity ratio axial (DCR) for longitudinal side of five-story bare frame building (middle column removal scenario)

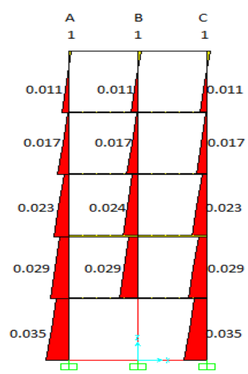

Fig. 5(d): Demand capacity ratio axial (DCR) for longitudinal side of five-story with infill frame building (middle column removal scenario)

Bending moment

Referring to Fig. 5(e) to 5(h), shows that DCR flexure for longitudinal side of five storey bare and infill frame building when corner, middle and intermediate column is removed. When corner column eliminated at bare Frame has reached to an outstanding high number 0.300 is present near the affected corner column, the middle and intermediate column removal shows lesser value than the bare and infill frame. All the frame shows the $_{\text{DCRMoment}}$ flexure is less than 2, which showing the progressive collapse may not happen in this case.

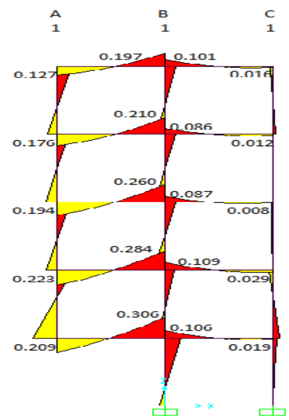

Fig. 5(e): Demand capacity ratio bending moment (DCR) for longitudinal side of five-story bare frame building (Corner column removal scenario)

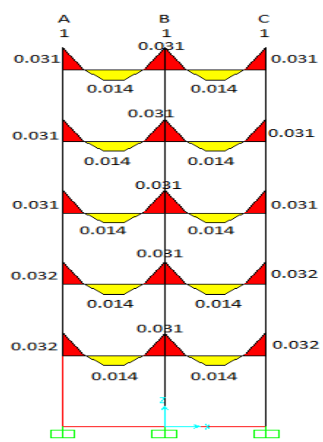

Fig. 5(f): Demand capacity ratio bending moment (DCR) for longitudinal side of five-story with infill frame building (Corner column removal scenario)

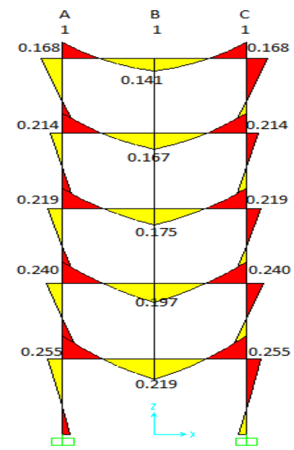

Fig. 5(g): Demand capacity ratio bending moment (DCR) for longitudinal side of five-story bare frame building (middle column removal scenario)

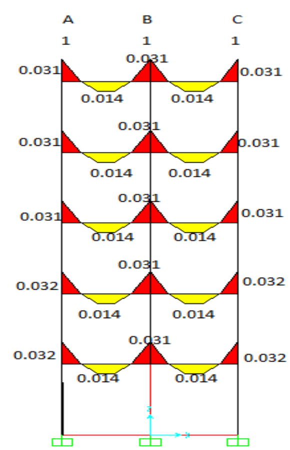

Fig. 5(h): Demand capacity ratio bending moment (DCR) for longitudinal side of five-story with infill frame building (middle column removal scenario)

Shear force

According, to Fig. 5(i) to 5(l), shear force of DCR for longitudinal side of five storey bare and infill frame building when corner, middle and intermediate column is removed. At bare frame shows the maximum shear force DCR of 0.311 is present near the affected corner column, the middle and intermediate column removal shows lesser value than the bare and infill frame. So in this case building has enough resistance against progressive collapse.

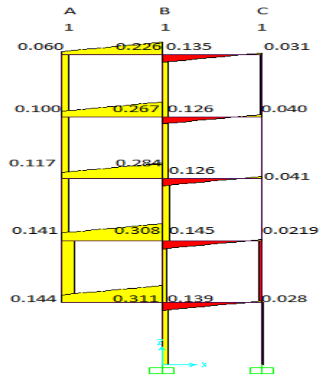

Fig. 5(i): Demand capacity ratio shear force (DCR) for longitudinal side of five-story bare frame building (Corner column removal scenario)

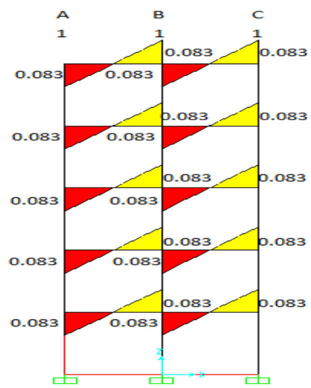

Fig. 5(j): Demand capacity ratio shear force (DCR) for longitudinal side of five-story with infill frame building (Corner column removal scenario)

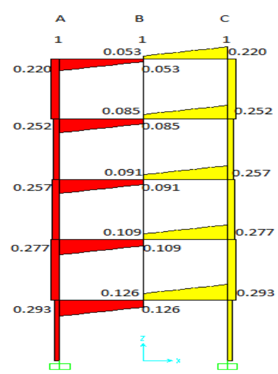

Fig. 5 (k): Demand capacity ratio shear force (DCR) for longitudinal side of five-story bare frame building (middle column removal scenario)

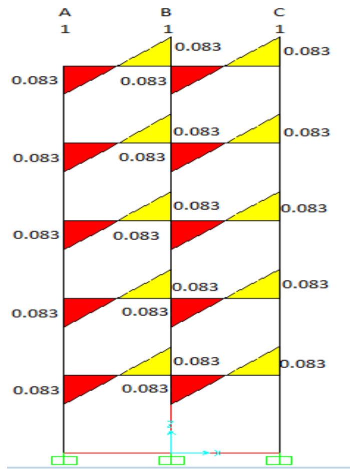

Fig. 5(l): Demand capacity ratio shear force (DCR) for longitudinal side of five-story with infill frame building (middle column removal scenario)

CONCLUSION

There is numerous serious threats which could cause the progressive collapse that may result in loss of lives. After the incident in Oklahoma Murrah building and the recent terrorist attack, such as WTC (World Trade Centre) in 2001, demands in assessing progressive collapse have become more necessary.

To assess the susceptibility of building to progressive collapse, linear static analysis (elastic behaviour) which is simple and conservative method has been used.

(i) Linear static analysis of the two model such as Bare frame and infilled frame was carried out under the action of dead load, the maximum axial force of DCR was found 0.225, Maximum flexure DCR was found out 0.300 and Maximum Shear DCR was found out 0.311in bare frame and it shows that the enough resistance against progressive collapse in the bare frame and infill frame.

(ii) In five storey building bare frame and infilled frame building had a low vulnerability towards progressive collapse when column is removed from the corner middle and middle column removal of the building

(iii) Infilled frame system, the resistance of structure against progressive collapse is comparatively much greater and better than the bare frame system.

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