PROGRESSIVE FAILURE ANALYSIS OF BUILDING STRUCTURE

Sachin Bhalerao[1*], Rohan Choudhary[2]

[1]*M.tech Student, Department of civil engineering, Sandip University, Nashik*
[2]*Assistant professor, Department of civil engineering, Sandip University, Nashik*

ABSTRACT

Some recent buildings failure showed that structures built according to current design codes were not robust enough under the action of unexpected loads and failed progressively. Progressive collapse is the collapse which is not proportional to the original local damage. Building progressive collapse mitigation became an urgent demand in structural engineering environment. This study aims to provide the designer engineers with wider overview on this topic to minimize the consequences of buildings progressive collapse after the event of column removal scenario. Important researches contributions in building progressive collapse prevention were presented. In addition to that, reporting some important progressive collapse accident, to identify the source and the cause that lead to such collapses. International code writers and many government agencies tried to develop guidelines and recommendations to reduce or prevent the potential of such catastrophic collapses. These guidelines focused on event control, improved local resistance and providing alternate load paths to guarantee that the loss of any key supporting element will not lead to a bigger damage. Also, this paper discussed recent experimental and numerical studies on this issue. Special emphases was focused on reinforcement details as a main factor which governs reinforced concrete RC element behaviour. The collapse behaviour of the whole structures was analysed by different numerical methods (i.e. finite element method, discrete element method and applied element method). Some recommendation for steel, composite and RC structures to insure robust buildings performance after an unexpected event are presented for vulnerable elements i.e. joints in which their failure can lead to elements separation and larger collapses.

Keywords

Progressive collapse, Codes regulations, Experimental studies, Numerical simulations Reinforced concrete RC, Beam- column joint, Reinforcement details

1. Introduction

1.1 General

Progressive collapse is the result of a localized failure of one or two structural elements that lead to a steady progression of load transfer that exceeds the capacity of other surrounding elements, thus initiating the progression that leads to a total or partial collapse of the structure.

The progressive collapse of building structure is initiated when one or more vertical load carrying members (typically column) are removed. Once a column is removed due to vehicle impact, fire, earthquake or any other man made or natural hazards, the building's weight (gravity load) transfer to neighboring columns in the structure. If this columns are not properly design to resist and redistribute the additional gravity load that part of the structure fails.

Failure might thus progress throughout a major part or even all of the structure. After reviewing a couple of failure events, it is outlined why current probability-based design codes are inadequate to prevent progressive collapse.

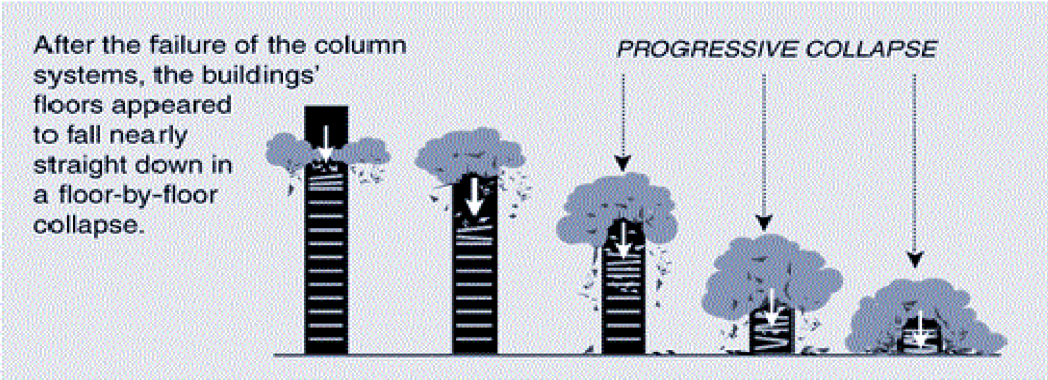
In normal design practice, the abnormal events like, gas explosions, bomb attack, vehicle impacts, foundation failure, failure due to construction or design error etc. are not considered. It is not economical as well to design the structures for accidental events unless they have reasonable chance of occurrence. Considering these aspects, many government authorities and local bodies have worked on developing some design guidelines to prevent progressive collapse. Among these guidelines, U.S. General Services Administration (GSA) and Department of Defense (DOD) guidelines by United Facilities Criteria (UFC) - New York, provide detailed stepwise procedure regarding methodologies to resist the progressive collapse of structure. In this procedure, one of the important vertical structural elements in the load path i.e. column, load bearing wall etc. is removed to simulate the local damage scenario and the remaining structure is checked for available alternate load path to resist the load.

1.2 Type of progressive collapse building

Based on different characteristic features, progressive collapse can be categorized in six different types as described below.

1.2.1 Pancake-type progressive collapse of structure

Failure sequence followed in this type of collapse is initiating event, separation of structural components, release of potential energy and the occurrence of impact forces.



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1.2.2 Domino-type progressive collapse of structure

Mechanism behind this type of collapse is, initial overturning of one element, fall off that element in angular rigid-body motion around a bottom edge, transformation of potential energy into kinetic energy,

1.2.3 Section-type collapse of structure

When a member under bending moment or axial tension is cut, the internal forces transmitted by that part are redistributed in to the remaining cross section.

1.2.4 Instability-type collapse of structure

Instability of structure is characterized by small imperfection which leads to large deformations or collapse.

1.2.5 Mixed-type collapse of structure

This type of collapse can be assigned to the structure where one or more possible failure reasons fall in to different category of progressive collapse.

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1.3 Examples of progressive collapse of building structure

Some failures in past which have presented the world wide opportunities to evaluate the validity of engineering approaches and design procedures.

1.3.1 Ronan Point Apartment Building - London

Ronan Point Apartment building, 22-storey tower block in Newham, East London was named after Harry Louis Ronan (a former Chairman of the Housing Committee of the London Borough of Newham).

The tower was built by Taylor Woodrow Anglian, using a technique known as Large Panel System building or LPS. This involved casting large concrete prefabricated sections off-site, then bolting them together to construct the building.

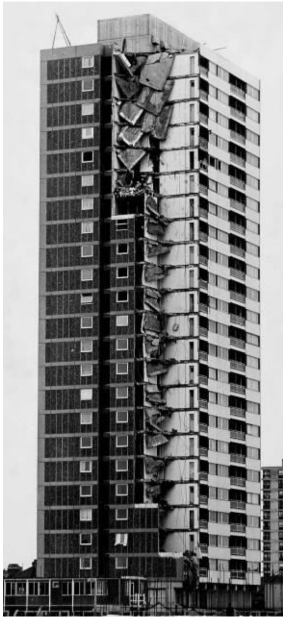

Fig.1.2 Ronan Point, 1968 –Collapse due to gas explosion

On 16th May 1968, a gas explosion took place on 18th floor that knocked out load bearing precast concrete panels near the corner of the building which caused the floors above to collapse [fig 1.2]. This impact set off a chain reaction of collapses all the way to the ground. The ultimate result was collapse of the corner bay of the building from top to bottom. It is believed that the weakness was in the joints connecting the vertical walls to the floor slabs

1.3.2 Skyline Plaza – North Virginia

Skyline Plaza was a large complex located in Bailey's Crossroads, Virginia which included eight apartment buildings, six office buildings, a hotel, and a shopping center. The building that collapsed was to have contained 468 condominium apartments.

In the midst of construction on March 2, 1973, progressive collapse occurred during construction of 24^{th} floor. The collapse involved the full height of the tower, and the falling debris also caused horizontal progressive collapse of an entire parking garage under construction adjacent to the tower [fig 1.3]. The incident occurred at around 2:30 in the afternoon and resulted in the death of 14 construction workers and the injury of 34 others. The most likely cause of the collapse was a punching shear failure of the 23rd floor slab. The two factors that contributed to this were premature removal of shores below the 23rd floor slab, and the low strength of the 23rd floor concrete in the area supporting the weight of the 24th floor slab.

Skyline Plaza, 1973 –Premature formwork removal

1.3.3 Murrah Federal Building, Oklahoma City

Alfred P. Murrah Federal Building in Oklahoma City was the target of terrorist attack in 1995. The truck bomb explosion caused extensive damage to the exterior columns. Suspended transfer girder resting on the exterior columns failed due to loss of support which triggered the progressive collapse of upper stories [fig1.4]. It was the most destructive act of terrorism on American soil until the September

11, 2001 attacks. The Oklahoma blast claimed 168 lives, including 19 children under the age of 6 and injured
more than 680 people. The blast destroyed or damaged 324 buildings within a sixteen-block radius destroyed or burned 86 cars and shattered glass in 258 nearby building.

Murrah Federal Building, 1973

1.3.4 World trade center, NY, U.S.A.

The twin towers of World Trade Center1 and 2 collapsed on Sept. 11, 2001 following this sequence of events: A Boeing 767 jetliner crashed into each tower at high speed; the crash caused structural damage at and near the point of impact, and set off an intense fire within the building (Fig.1.5); the structure near the impact zone lost its ability to support the load above it (Fig.1.6) as a result of some combination of impact damage and fire damage; the structure above collapsed, having lost its support; the weight and impact of the collapsing upper part of the tower (Fig.1.7) caused a progression of failures extending downward all the way to the ground. Clearly, this was a "progressive collapse" by any definition. But it cannot be labelled a "disproportionate collapse." It was a very large collapse caused by a very large impact and fire. And unlike the case with the Murrah Building, simple changes in the structural design that might have greatly reduced the scale of the collapse have not yet been identified.

Structural damage and set off intense fire after crashing

Impact zone lost the ability to support above load

Loss of support creates in stability ad failure of structure.

1.3.5 Saptashringi building at Tarwala Nagar, Nashik

Saptashringi building located at tarwala nagar on dindori road nasik has 15 flats and eight shops. Among eight shop front side middle shop was using for storage of chemical of fire crackers. On June 8 2011 blast took place in that shop because of miss handling explosive chemical. In this blast 3 people were killed and 4 others seriously injured.

The blast was so powerful that it blew off the upper slab of this shop. It also blew of the surrounding wall and column. Even though, it blew of the column and upper slab (fig 1.8) structure wasn't collapse. Surrounding structural element were bear and pass the excessive load safely hence structure remain safe from collapse. The design of building is safe for progressive collapse. Because of this, people who residing in upper floor were not get injured. Three people were killed because they were working in shop. Progressive collapse resisting structure saved the life of residing people.

Due to lack of analysis and study of progressive collapse of structure, this structure is considered as a fail structure and it is demolished. Constructing new structure also costs high. Therefore, study of progressive collapse of structure is necessary.

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Saptashringi building at Tarwala Nagar, Nashik, June 8, 2011

1.4 Aims and objective

For many new and existing construction projects, now we faced with the task of performing progressive collapse analysis that considers the loss of portions of the structure in numerous "missing column" and "missing beam" scenarios. To remain economically viable, this additional design requirement must typically be incorporated without substantial increases in the cost of the structural system. By studying

Past hazards of progressive collapsed, we must now use their creativity to find cost-effective solutions that will make buildings more resilient to both natural and man-made hazards.

After the observing various progressive collapse in past collapsed structure, many codes and standard around the world, attempted to address the issue of progressive collapse by providing provisions in their relevant guidelines. They were based on either explicit design requirements or on general structural integrity requirements.

2. Modeling of RC structure using Etab 9.7.1

2.1 Introduction

The behavior R.C.C structure mainly depends on framing of the structure and how members perform interactively with each other. The column bases are assumed to be fixed. Thus the frame behavior can become very complex. In the thesis one twelve storey building is considered, to study effect of single column failure in the building. Symmetrical building configuration is chosen for better understanding of the behaviour. Evaluation of progressive collapse potential of building designed for seismic loading is carried out.

2.2 The basic outline for analysing a structural model with the Etab 9.7.1 structural analysis program.

General data:-

- Type of structure : R.C.C. Framed Structure
- Number of stories : G+12
- Live load : 4 kN/m^2 (Considered commercial use of building)
- Floor Finish load : 1.5 kN/m^2
- Floor to floor Height of each storey : 3 m
- Height of the building : 36 m
- Software used : Etab 9.7.1
- Earth quake zone : II
- Response reduction factor : 5
- Wind speed : 44 m/sec
- Lateral load (calculated as per IS 1983-2002)
- Yield stress (N/mm2) : Fe500
- Concrete grade : for column : M40

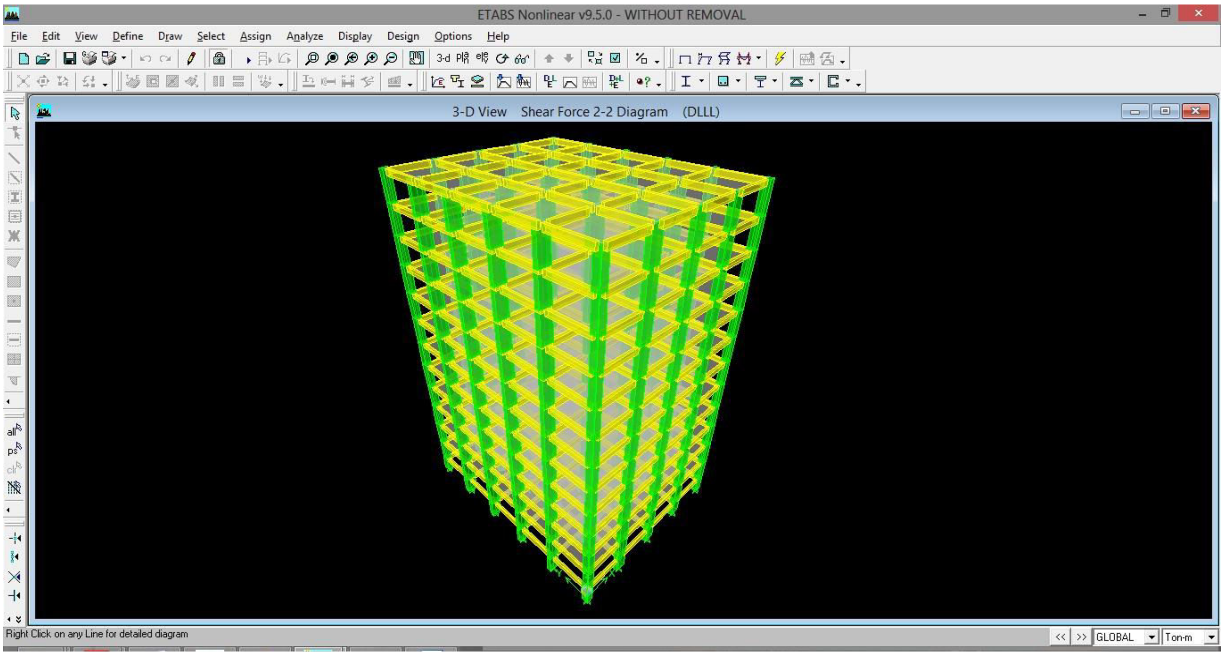
  For Beam: M30

  For slab: M25

There are four main parts –

1) Set up the Model
2) Analyze the Model
3) View the Analysis output
4) Print the output.

Etab model of building structure :



Model of building structure

2.3 Summary:

All beams remain safe in shear after removing any column but all are getting fail in bending moment and deflections. While removing the column, due to high rise structure axial load are increasing bending moment in beams Moreover, beams are getting fail in deflection due to same reason. Etab software don't consider the flange action of the beam in analysis and designing. If we consider flange action of beam, beams are safe in bending moment. Flange action of beam can control the deflection of the beam up to some extent.

Hence we can conclude that if we design a building according to Indian Standard code, Building don't collapse due to live load and dead load. It collapses only due to unexpected impact load. If impact load is not higher than structure try to stabilize the forces.

Moreover, if some structural element stands successfully after impaction than it can be use after repairing damages to structure.

3. Case study

3.1 Introduction

Saptashringi building located at tarwala nagar on dindori road Nasik. Among frontal shops middle shop was using for storage of chemical of fire crackers. Others are cyber café, general and jewelry shops. Building was in regular use. People was residing in flat which located above the shops. There is no permission to store fire cracker in normal residing area. Shop which was using for storing fire cracker

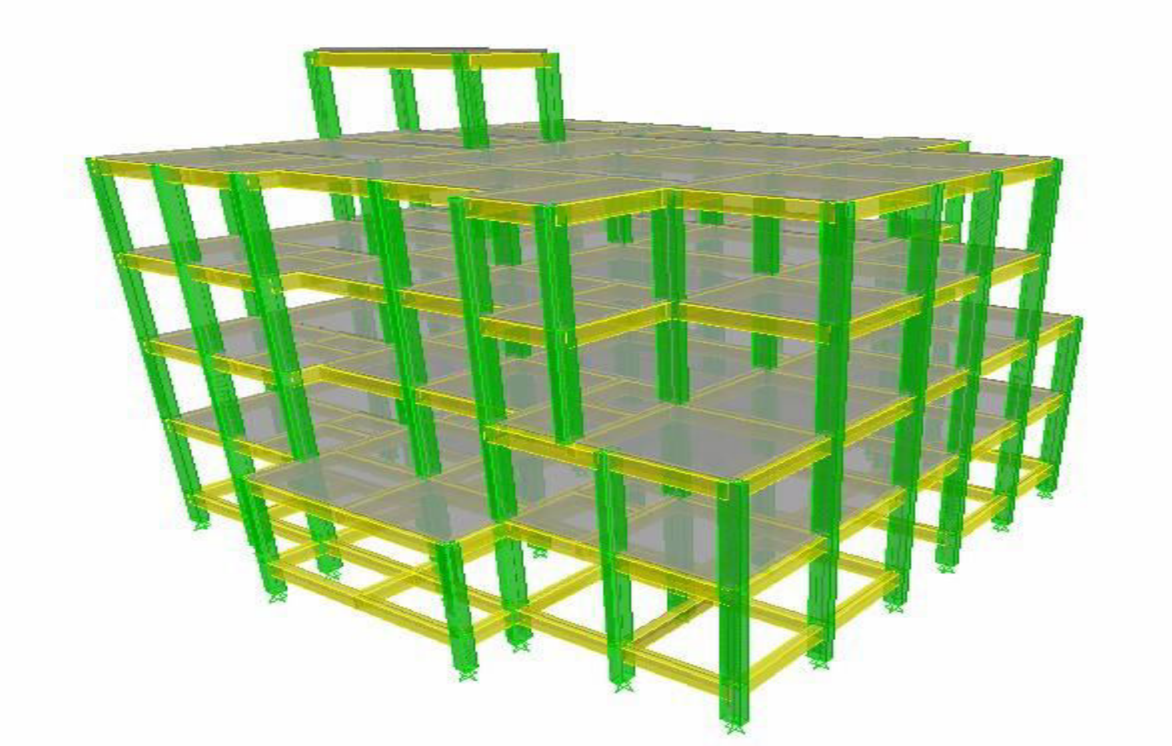
was rented just before 10 month of mishap and nobody had prediction of mishap which happens due to this regardless thing.
On June 8 2011 blast took place in that shop because of miss handling explosive chemical. The blast was so powerful that it blew off the slab of this shop, completely brought down the adjacent cyber cafe, threw shutters to pieces. The impact also blew away vehicles parked in the compound. The balcony on top of shop also came down crumbling. In this blast 4 people were killed and 12 others seriously injured.

The building was residential as well as commercial. Therefore, Mishap due to commercial activity makes suffer to residing people. The blast was so powerful that it blew off the surrounding wall and column. Although, it blew of the column and upper slab, structure wasn't collapse.
Design a building with in limitation of Indian standard code gives much more stability to building.

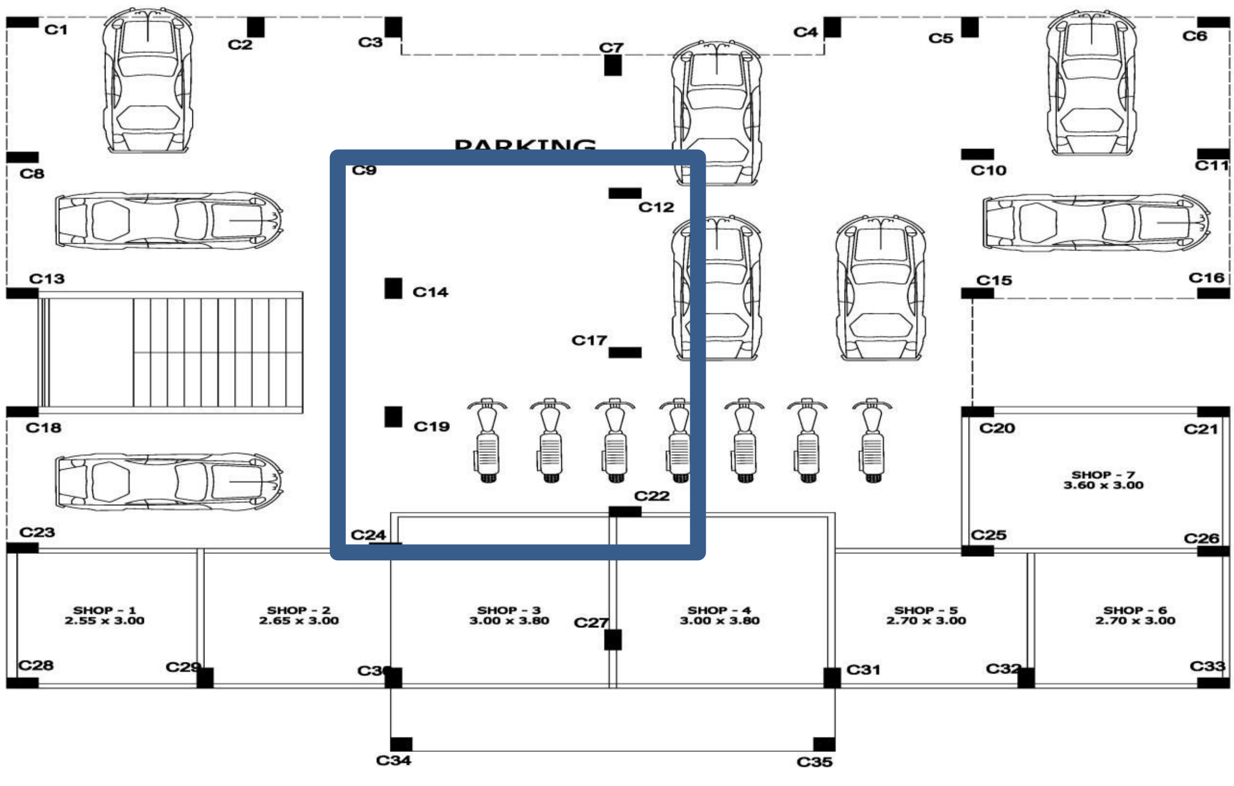
3.2 Analysis of Saptashrugi apartment using Etabs software:

- **Type of building**: Residential + Commercial building.
- **Storey of building** : G+3
- **Grade of concrete** : M20

- **Grade of steel** : Fe500



Etab model of Saptashringi Apartment



Critical area of the structure

4.3 Summary of analysis

As can be seen from the above results that removal column at outer side of the building does not causes any failure in shear , bending and deflection, but internal structural member does influence the deflection of the beam because it carry load from all four side of the point. Figure above showing critical area of the structure from which structure will collapse progressively. It was observed that as the outer column removal, structure can sustain excess load but as toward middle of the structure it's getting critical. In above geometry, removal of C17 cause progressive collapse of structure.

4.4 Review on actual condition of the structure:

In saptashringi building, surrounding structural element were bear and pass the excessive load safely except we do not disturb the C17. But if increase the section of beam which are transferring the load on C17 than structure becomes progressive collapse resistant structure. This kind of design of building is safe for progressive collapse. Progressive collapse resisting structure can save the life of residing people.

Saptashringi Apartment was safe after blast as it blew the outer column of the building. As per analysis of the structure, structure remain safe after removing after any column of the structure. It has enough rigidity to make path for excess load and It is visible practically in figure below.

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Fig.4.9 Saptashringi building at Tarwala Nagar, Nashik, June 8, 2011

Due to lack of analysis and study of progressive collapse of structure, this structure is considered as a failed structure and it has been demolished. It could be reused if it was go through proper study and analysis.

As per above analysis, If Designed structure is capable to carry impact load up to certain limit and it can develop the load path itself to make structure stabilize.

5. RESULTS & DISCUSSIONS

The primary objective of this study was to understand the behavior of the building structure when members were removed one by one & to investigate load redistribution to the remaining members. The secondary objective was to find the critical region of the building structure which would cause failure of the entire building & cause damage to its adjacent span.

The research conducted included the analytical model of typical G+12 building structure and Saptashringi apartment, Tarwala Nagar, Nashik by using Etab9.7. From the no. of iterations of the removal of the members, it was found that the critical members were the middle members of the structure. Removal of outer member make path successively to transfer the excess load.

These critical members should be given much safety.

5.1 Future Research

This study was limited in the fact that only analysis is done on the basis of present design criteria. By giving safety to critical member and increasing strength of critical member up to certain limit, we can design progressive collapse proof structure by considering economy of the structure. These investigations might be give economical progressive collapse resisting structure.

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