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PROGRESSIVE COLLAPSE ON RCC MULTISTOREY BUILDING

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Abstract — *There are numbers of cases of building damaged or collapse due to blast, man-made disasters, internal gas explosions, Wind over pressure, extreme values of environmental loads, aircraft impact, vehicular collision, earthquake etc. On buildings is a serious matter that should be taken into consideration in the design process.*
When a member of reinforced concrete frame structure such as column is damaged by explosion, earthquake or manmade hazards, etc., it will cause failure of some part or whole structure is called as progressive collapse.
Progressive collapse analysis method and its criteria to be considered for analysis as given by the US General services administration (GSA).To avoid progressive collapse three methods are available like indirect method, specific local resistance method and alternate load path method.
A Symmetrical and unsymmetrical 5m x 5m bay frames with four storey building is studied for progressive collapse analysis with SMRF design without Infill masonry wall using alternate load path method. All the building frames are designed with dead load, imposed load and earthquake load with different zone and importance factor I = 1. Evaluation of progressive collapse potential for seismic loading is carried out using linear static analysis. Linear static analysis is performed in ETABS. The demand capacity ratios (DCR) found for flexure in beam at critical location using linear static analysis for all cases of column failure.

Keywords- *Progressive Collapse Analysis, U.S. General Service Administration (GSA) Guidelines, Removal of Columns, different zone and different column removal case, Demand Capacity Ratio (DCR), Linear Static Analysis, ETABS2015*

I. INTRODUCTION

Such word as progressive collapse was not appeared so a long time ago. For the first time engineers faced with this types of condition in 1968 when the Ronan Point apartment building was destroyed. The structure was a 23-storey building. A gas explosion in a corner on the 18th floor blew out the load bearing wall and causing the collapse of one entire corner of the building, but the entire building did not suffer. After that the term progressive collapse has been used to describe the propagate of an initial local failure in a manner like a chain reaction that causes to partial or total collapse of the structure.

When a building gets exposed to any natural hazards say Tsunami or Earthquake or due to manmade hazards such as fire, explosion of gases, impact of vehicles, etc., it affects the behavior of structure and causes collapse of a portion of structure or entire building. Progressive collapse implies a phenomenon of sequential failure of part of the structure or the complete structure initiated by sudden loss of vertical load carrying member (mostly column).
Some more popular examples of progressive collapse are Alfred P.Murrah Federal Building and world Trade center (WTC).

There were two building collapses in Asia Region:

- 1100+ killed in Building collapsed in Dhaka, Bangladesh on 23rdApril 2013.
- 74 killed in Building collapsed in Mumbai, India on 4th April 2013.

II. CONSIDERATION FOR PROGRESSIVE COLLAPSE AS PER THE U.S. GENERAL SERVICES ADMINISTRATION (GSA) GUIDELINES

The purpose of these Guidelines is to reduce the potential for progressive collapse in new and renovated Federal buildings. It is intended to bring a consistent level of protection in the application of progressive collapse design to Federal facilities and to bring alignment with the suite of security standards issued by the Interagency Security Committee (ISC) and the General Services Administration (GSA) in their philosophy, decision-making methodology and application.

2.1. Design Approaches for Progressive Collapse

A. Indirect Design

With Indirect Design, resistance to progressive collapse is considered implicitly "through the provision of minimum levels of strength, continuity and ductility".

B. Direct Design:

Direct Design approaches include "explicit consideration of resistance to progressive collapse during the design process…" These include:

- Specific Local Resistance
- Alternate Path Method (APM)

2.2. Considerations for Column Removal Location

The following analysis considerations shall be used in the assessment for progressive Collapse.

A. Exterior Consideration

a. Analyze for the loss of a column located at or near the middle of the short side of the building.
b. Analyze for the loss of a column located at or near the middle of the long side of the building.
c. Analyze for the loss of a column located at the corner of the building.

B. Interior Consideration

a. Analyze for the loss of a column that extends from the floor of the underground parking area or uncontrolled public ground floor area to the next floor.

2.3. Analysis Procedures for Progressive Collapse

When analyzing a structure, four different analytical procedures may be used to investigate the structures behavior:

a. Linear Static (LS)
b. Nonlinear Static (NLS)
c. Linear Dynamic (LD)
d. Nonlinear Dynamic (NLD)

a. Linear Static Analysis (LS)

In the linear static analysis column is removed from the different location being considered in building plan and analysis with the gravity load imposed on the structure has been carried out as per load combination given in GSA guideline, From the analysis results demand at critical locations of beam and column are obtained and from the original seismically designed section the capacity of the member is determined, then demand capacity ratio(DCR) is calculated as per guideline for affected member. If the DCR of a member exceeds the acceptance criteria, the member is considered as failed. The demand capacity ratio calculated from linear static procedure helps to determine the potential for progressive collapse of building.

2.4. Acceptance Criteria for Progressive Collapse

The GSA proposed the use of the demand–capacity ratio, the ratio of the member force and the member strength.

$$DCR = Q_{ud} / Q_{ce}$$

Where,

Q_{ud} = force acting on member, i.e. Demand (M)
Q_{ce}= expected ultimate capacity of the member, i.e. Capacity (M_u)

In the linear static analysis, the loading is applied to the RCC building subjected to column failure, and the demand-to-capacity ratio of flexural moment is calculated to assess the progressive collapse potential.

The allowable DCR values for Symmetrical and unsymmetrical structural elements are:

- DCR < 2.0 for Symmetrical structural building plan.
- DCR < 1.5 for Unsymmetrical structural building plan.

2.5. Scope

- The Main objective of this study is to understand the analysis and design of framed building structure to reduce the potential of progressive collapse.

- The objective of this study is to understand the analysis and design methodology of framed building structure using ETABS 2015.
- To analyze symmetrical and asymmetrical building considering four different case of column failure at ground storey using ETABS 2015.
- Identify performance of structure under progressive collapse considering different parameters like building height, Different column removal at different locations different zone consideration etc.

III. METHODOLOGY

GSA guideline has provided following stepwise procedure to carry out Progressive collapse analysis using linear static method.

Step1: First the building is analyzed with gravity load (Dead Load + Live Load) and also earthquake load and results for moment and shear are taken without removing any column.

Step2: Now by removing a vertical support (column) from the position under consideration and carry out a linear static analysis to the different structure model and Load this model with 2 {Dead Load + 0.25(Live Load)} load combination in ETABS.

Step3: The Static load combinations were entered into the ETABS 2015 program and a model of the structure was generated. An ETABS 2015 computer simulation was executed for each case of different Column removal location on the model and the results are reviewed.

Step4: Further from the analysis results obtained, DCR for different member is found out. if the DCR for any member end connection or along the span itself is exceeded the allowable limit based upon moment and shear force, the member is expected as a failed member.

Step5. If DCR value exceed its criteria then it will leads to progressive collapse.

IV. PROBLEM FORMULATION & ANALYSIS

For the analysis, symmetrical and Unsymmetrical frame model of plan as shown in Fig.1 & 2 taken for the study of progressive collapse analysis. Bay width in both the plan direction is taken as 5m

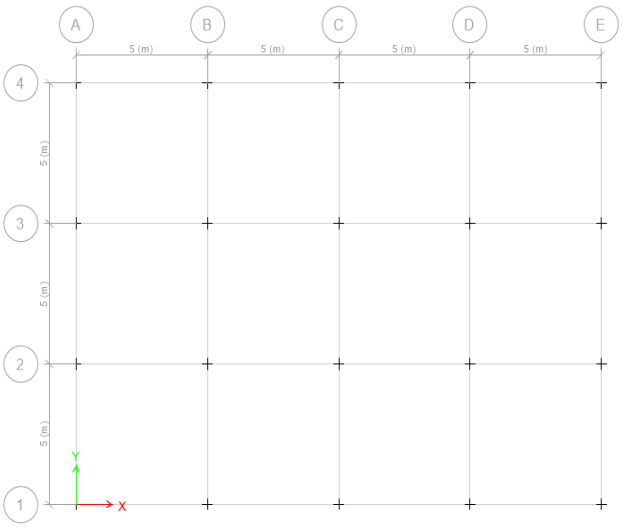


Figure 1.Symmetrical Building Plan

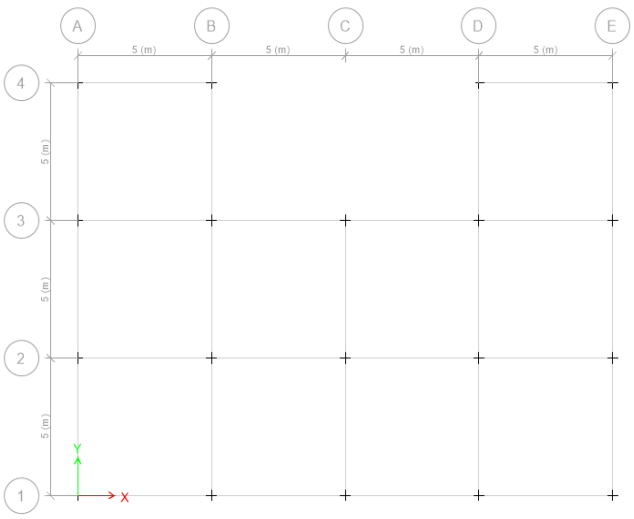


Figure 2.Unsymmetrical Building Plan

4.1. BUILDING DETAILES

Table 1 Element sizes

Storey	Beam(mm)	Column(mm)
1	300X400	350X450
2	300X400	350X450
3	300X350	350X450
4	300X350	350X450

Loading considered on the building for the study are as follows:

Dead load as per IS 875 (Part I):

- Self- weight of the structural element
- Floor finishes = 1.5kN/m^2
- Wall load on beams = 7kN/m(115mm)
- Wall load on beams = 14kN/m (230mm)

Live Load as per IS 875 (Part II):

- On roof 1.5kN/m^2 , and
- on floors 3kN/m^2

Slab thickness considered is 150mm.

F_{ck} is 25 N/mm^2
F_y is 415 N/mm^2

Seismic loading as per IS:-1893

- Soil type - II ,
- Importance factor – 1
- Type of soil- Medium
- Response reduction factor –5 (SMRF)

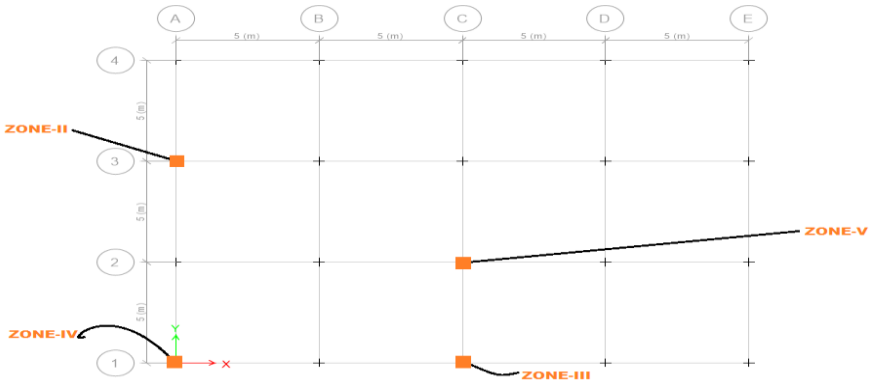
Building is analyzed for above loading and designed in the ETABS. Load combinations for seismic design are considered as per IS 1893: 2002 as:

1. 1.5 (DL+LL)
2. 1.2 (DL + LL ± EQX) And 1.2 (DL + LL ± EQY)
3. 1.5 (DL ± EQX) And 1.5 (DL ± EQY)
4. 0.9DL ± 1.5EQX And 0.9DL ±1.5EQ

After seismic design for reinforcement for both symmetrical and unsymmetrical building progressive collapse analysis is carried out by liner static analysis for following consideration.

Consideration for progressive collapse analysis for symmetrical and unsymmetrical buildings:

- Zone-II column removal case for column located at or near the middle of short side of building.
- Zone-III column located at or near the middle of the long side of building.
- Zone-IV column located at the corner of the building.
- Zone-V interior column at the middle of the building.



4.2. Calculation of Demand Capacity Ratio:

Capacity of the member at any section is calculated as per IS 456:2000 from the obtained reinforcement details after analysis and design. Capacity of member is found out by considering strength increasing factor. Member forces are obtained by analysis results carried out in ETABS. Demand capacity ratio after removal of column is found out considering the member force for the load combination as per GSA guidelines and ultimate capacity of member.

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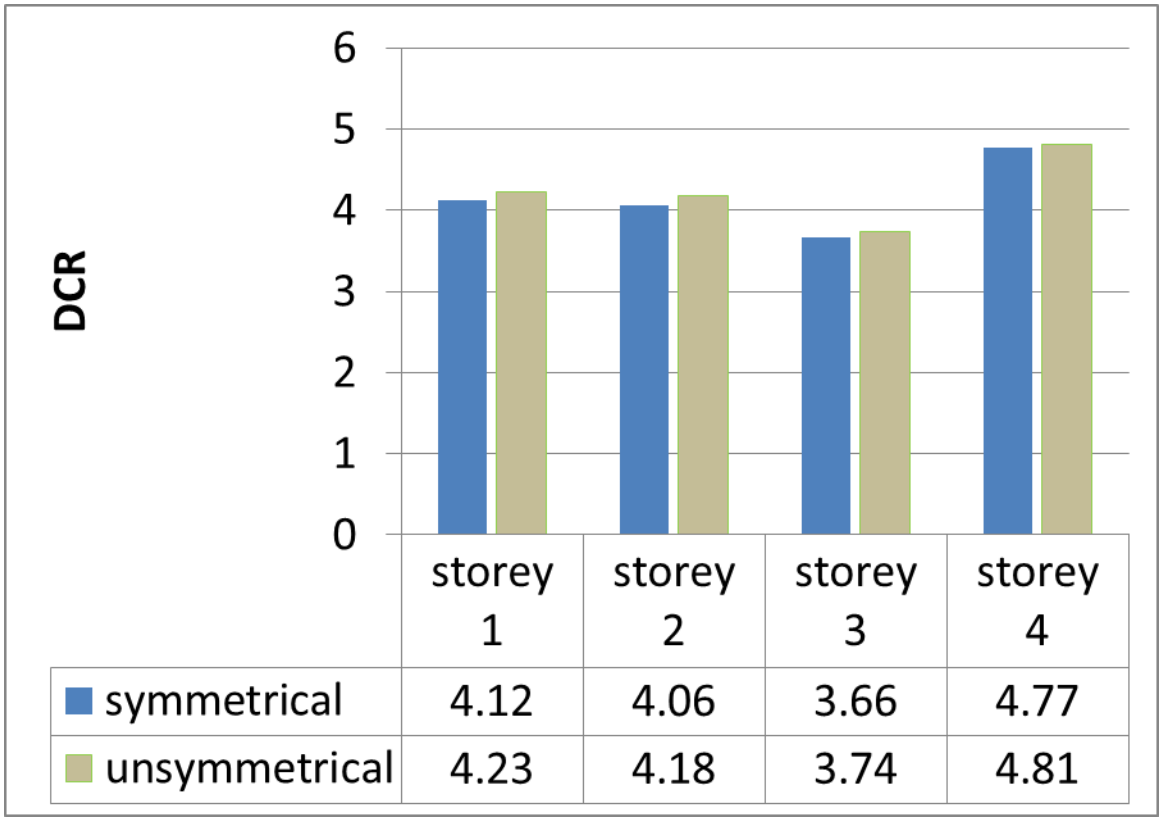
V. RESULTS AND DISCUSSION

The DCR values for the beam flexure in all the zone is found out for both symmetrical and unsymmetrical building plan as per GSA guideline. The DCR values exceed the acceptance criteria value suggested by GSA guidelines for most of the beam for different column removal case for this model and hence beams are not safe against progressive collapse. The DCR values of connected beams to failed column at different storey in all seismic zones are graphically represented for symmetrical and unsymmetrical building plan.

5.1. Graphical Representation of DCR

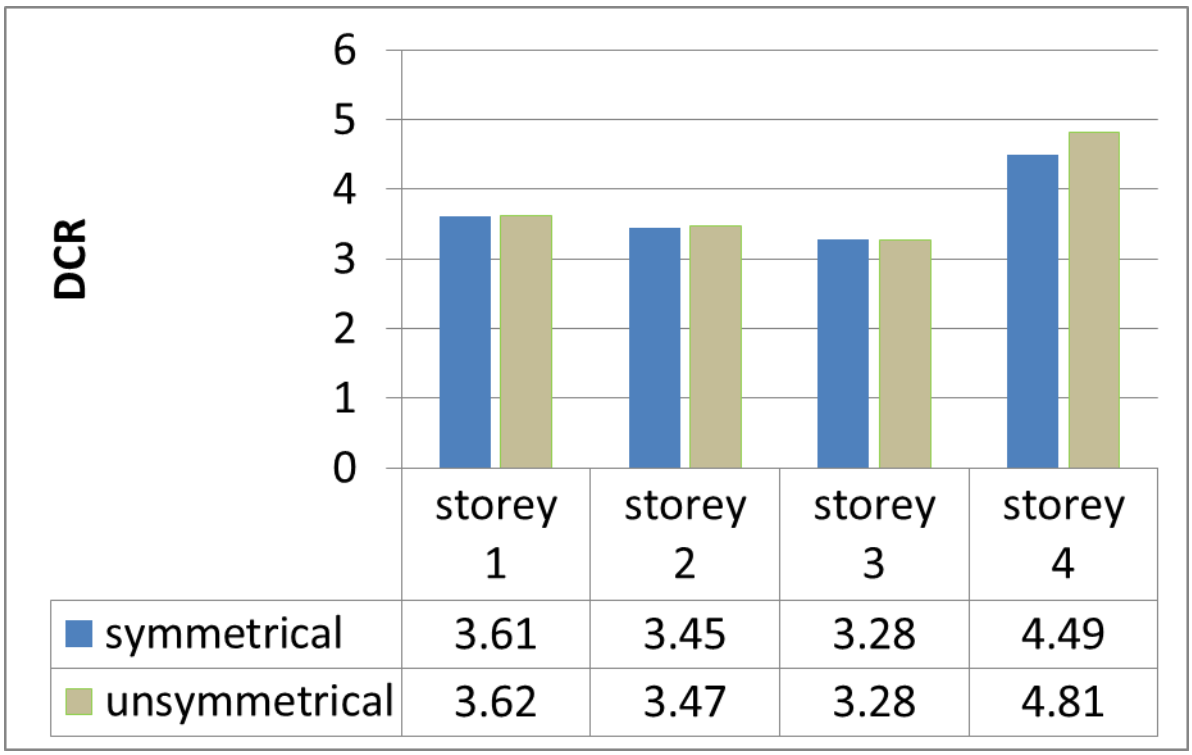
Comparative Study of DCR for Symmetrical building and Unsymmetrical building for all zones, graph is plotted DCR Vs. Storey.

A. DCR for zone-II:



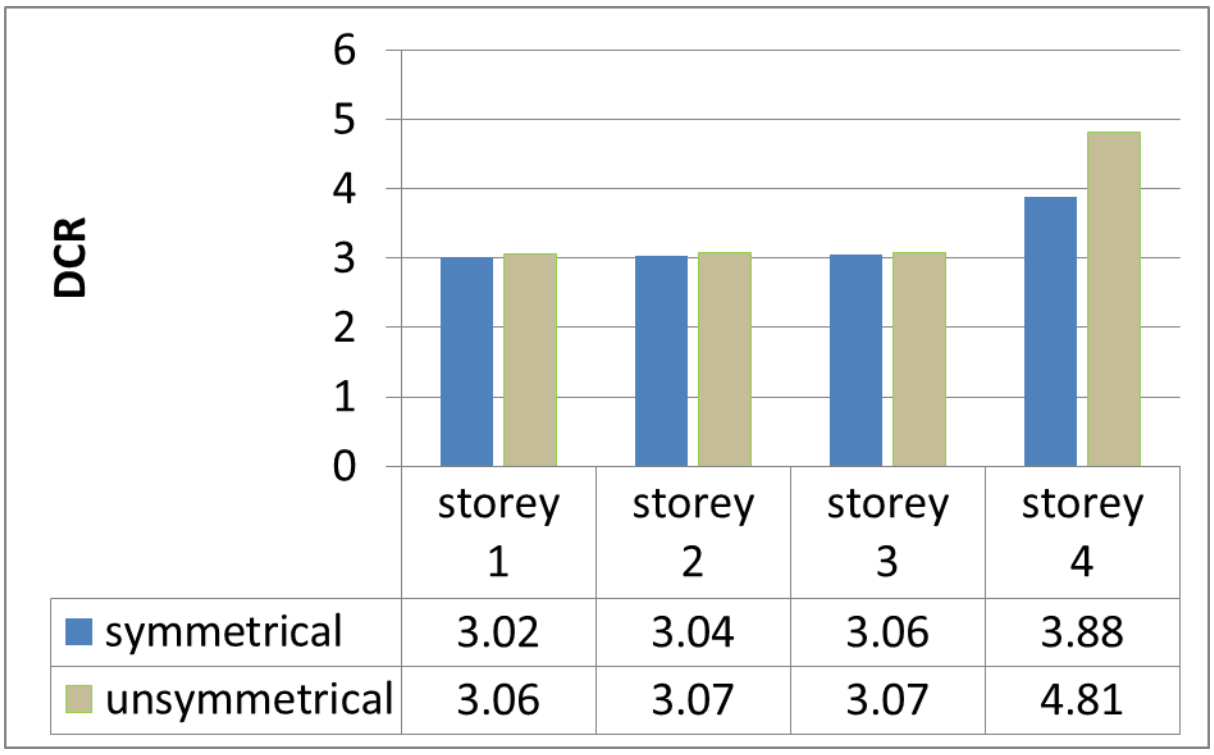
	storey 1	storey 2	storey 3	storey 4
symmetrical	4.12	4.06	3.66	4.77
unsymmetrical	4.23	4.18	3.74	4.81

B. DCR for zone-III:



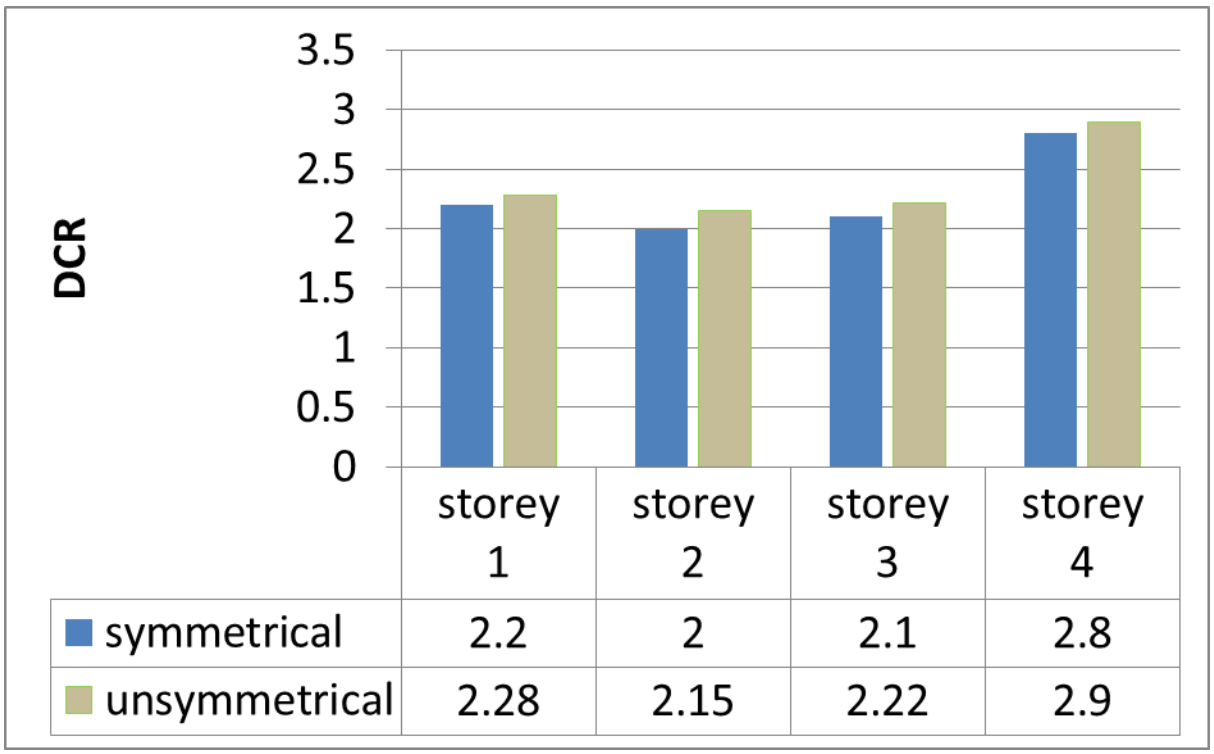
	storey 1	storey 2	storey 3	storey 4
symmetrical	3.61	3.45	3.28	4.49
unsymmetrical	3.62	3.47	3.28	4.81

C. DCR for zone-IV:



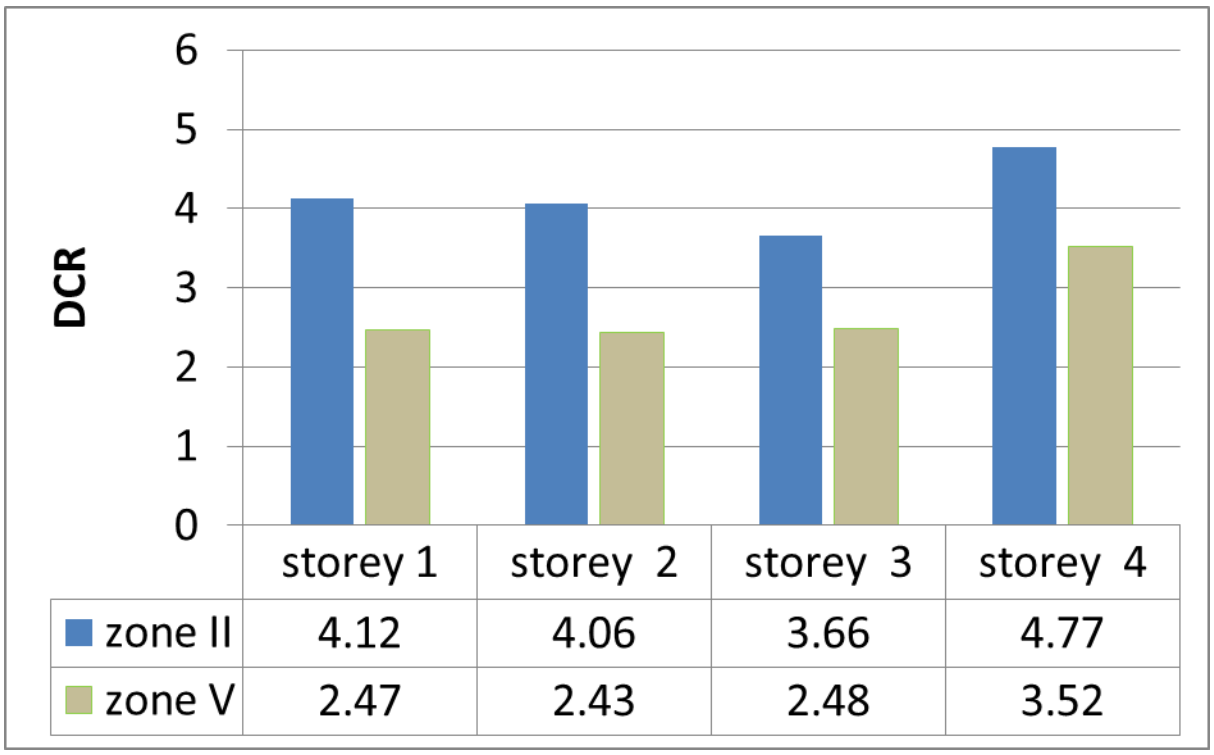
	storey 1	storey 2	storey 3	storey 4
symmetrical	3.02	3.04	3.06	3.88
unsymmetrical	3.06	3.07	3.07	4.81

D. DCR for zone-V:



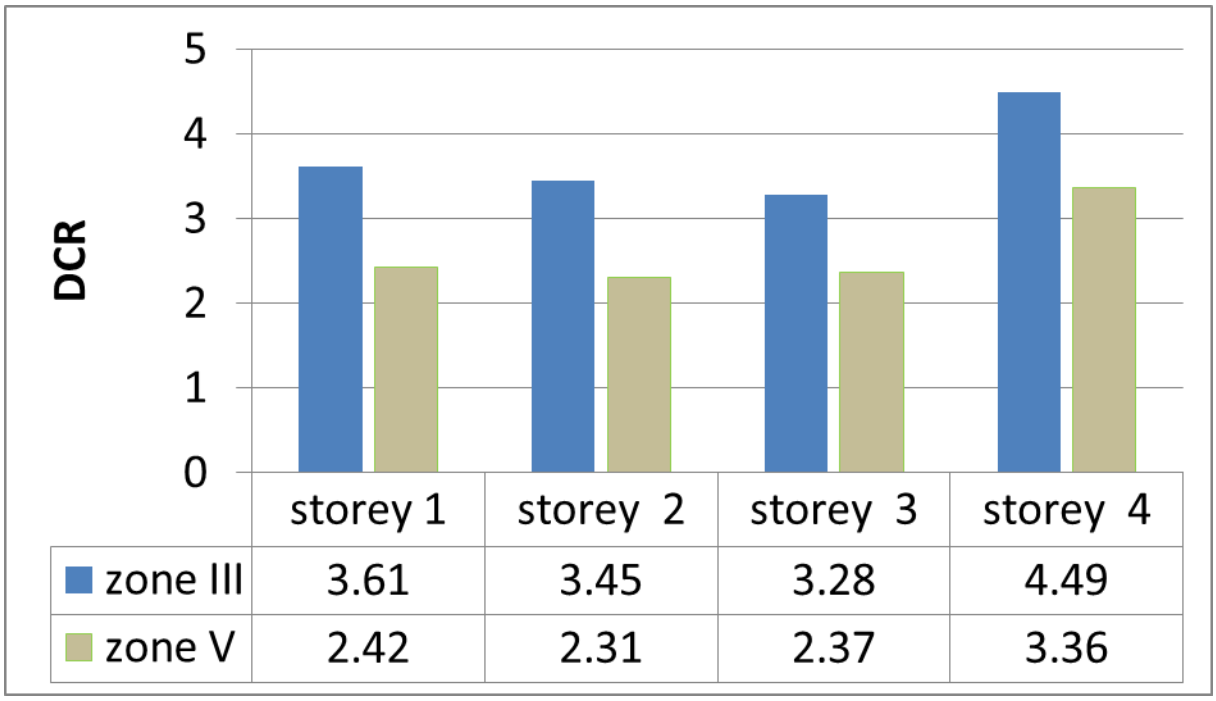
	storey 1	storey 2	storey 3	storey 4
symmetrical	2.2	2	2.1	2.8
unsymmetrical	2.28	2.15	2.22	2.9

E. DCR for zone-II & zone-V:

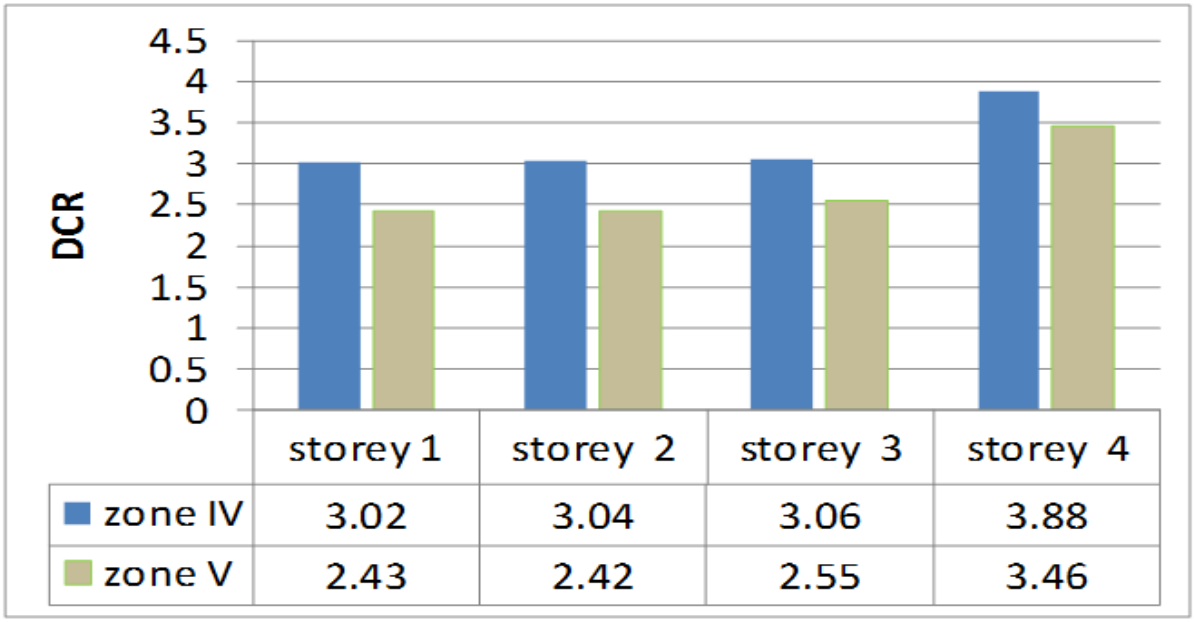


	storey 1	storey 2	storey 3	storey 4
zone II	4.12	4.06	3.66	4.77
zone V	2.47	2.43	2.48	3.52

F. DCR for zone-III & zone-V:



G. DCR for zone-IV & zone-V:



CONCLUSIONS

Based on the limited study of progressive collapse on symmetrical and Unsymmetrical reinforced framed building the following conclusions can be made.

- In both symmetrical and unsymmetrical 4- storey SMRF building without masonry Infill wall, demand capacity ratio at various stories at critical locations are found. DCR for flexure is much larger for both symmetrical and unsymmetrical structure plan.
- DCR for unsymmetrical structure beams are more than the DCR for symmetrical structure beams.
- DCR for zone II, zone III and zone IV are much more than DCR of beam in zone V.
- The beams whose DCR values are more than acceptance criteria value suggested by GSA for progressive collapse guidelines are unsafe. That beams are in connection with removal column.
- From this study it is observed that to avoid the progressive failure of beams and columns, after failure of particular column due to extreme loading, adequate reinforcement is required to limit the DCR within the acceptance criteria.

FUTURE SCOPE OF WORK

- Steel building can also be studied for evaluation of progressive collapse.
- Measures to reduced progressive collapse like providing bracing system at lower storey.
- Higher storey buildings can be studied with non-linear dynamic analysis for progressive collapse analysis.
- Investigating failure of columns located in floors other than the ground floor, for example in the middle level storey and just beneath the roof.
- Building can be analyzed for blast load by time history analysis method to know behavior of the structure.

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