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Comparative Assessments of Robustness Against Disproportionate Failure of RC Frame Structure And Flat Plate Structure

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ABSTRACT:* Building structures may face several natural and man-made loads in its life time. But it is not prudent and economical to design the structure for all types of actions. However, if the possibility is high enough to occur and the consequence of the occurrence is very severe and cataclysmic, it needs to be considered by the concerned personnel. If a local failure occurs, structureneedsrobustness to avoidadisproportionate failure that propagates either throughout or a portion of the structure disproportionately to the original local failure. Hence this study was made to assess the potential ability of frame structure and flat plate building structure against disproportionate failure using the General Services Administration (GSA) guide lines.An eight storiedRC framed and flat plate building structures were considered in this study to evaluate the Demand Capacity Ratio (DCR) as per GSA guidelines. The Linear static analysis was carried out using finite element software (ETABS) according to BNBC Standard codes. The main parameters studied were the axial load, flexure, and shear reinforcement required for the RC framed and flat plate buildings. Hence, robustness against disproportionate failure were evaluated and compared for the two types of buildings.In nearly all cases the columns in flat plate structure produces less DCR value than that of framed structure. It signifies that for similar building plan and loading model flat plate building generates less DCR value and hence, is less vulnerable to disproportionate failure.

***Keywords:* Robustness, Disproportionate failure, Frame structure, flat plate, Demand Capacity Ratio (DCR).**

1. INTRODUCTION

Modern technologies facilitate the analysis, design and construction of different structures with complex condition. But it may not be possible or

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economical to design a structure for all kinds of extreme events due to human error or excessive settlement [4]. These extreme level loads are considered to design the robust structures. Robustness of the structure is the capability of the structure to resist the extreme level loads without being damaged disproportionately to the original cause. Robust structure should not suffer from disproportionate failure under extreme level events [9]. It is an imperative to assess the robustness against disproportionate failure of the structures. A disproportionatefailure is identified as the initial local destruction of structural elements that paves to the failure of adjacent members first and then leading to the failure of a disproportionately large portion of a building [8].

There are several methods for analysis of disproportionate or progressive collapse of RC structures[11], [12] . Analysis methods include linear static, nonlinear static, linear dynamic and nonlinear dyna mic [6]. For the present study, linear static method in associated with GSA guide lines was used to assess the progressive collapse of a typical regular plan 8- storied framed building structure and flat plate building structure.In this method, one of the important vertical structural elements in the load transfer path (i.e. column, load bearing wall etc.) is eliminated to simulate the local damage consequence and the remaining structure is checked for other available alternate load path to withstand the load [3].In the alternate load path approach, due to removal of a column, the loads coming on the structure are considered to confirm that they are appropriately redistributed to the undamaged members.

2. SCOPE OF THE STUDY

In the present study, the difference between performances of two types of structural system against disproportionate failure was investigated and their robustness characteristics were assessed with GSA guide lines [2]. Regular plan eight- storied framed building and flat plate building were modeled in ETABS and designed as per ACI 318-11 specifications [1] to assess the performance of frame structure building and flat plate structure [7], to help the concerned personnel to recognize which structural system need to be considered to make the structure robust, depending on the basic characteristics of structural system and exposure to the extreme events.

3. GENERAL SERVICE ADMINISTRATION (GSA) GUIDE LINES CRITERIA

The GSA criteria for existing and newly developed structures which are not exempted from disproportionate failure, contains guide lines for analysis of typical and atypical structural system. In this study two typical structural systemshaving relatively simple layout with no unusual structural configurations, were considered.

To assess the potential of disproportionate failure for the typical structures, designers can carry out structural analyses in which the instantaneous loss of one of the following first floor columns at a time is assumed:

i. An exterior column near the middle of the long side of the building.
ii. An exterior column near the middle of the short side of the building.
iii. A column located at the corner of the building.
iv. A column interior to the perimeter column lines for facilities that have underground parking and/or uncontrolled public ground floor areas.

This analysis utilizes the alternate load path method to assess the potential of resisting disproportionate failure of the structure.In this work, only linear elastic static analysis is performed. For static analysis the following gravity load is applied to each structural member of the alternate path structure:

Load = 2(DL + 0.25LL)

Where,

DL = Dead load

LL = Floor Live load.

Demand Capacity Ratio (DCR)

The numerical index used in robustness assessment against disproportionate failure called Demand capacity Ratio (DCR), is defined as the ratio of the force (bending moment, axial force, shear force) resulting from elastic analysis of the structure for a design load in the structural member after the instantaneous removal of a column to the member capacity. The Demand Capacity Ratio (DCR) of each primary and secondary member of the alternate path structure is calculated from the following equation:

$$DCR = \frac{Q_{UD}}{Q_{CE}}$$

Where,

Q_{UD} = Acting force determined in the structural element.

Q_{CE} = Expected ultimate, un-factored capacity of the structural element.

In order to resist disproportionate failure of the alternate path structure, the allowable DCR values for each structural element must be as follows:

DCR < 2.0 for typical structural configuration

DCR < 1.5 for atypical structural configuration

Structural elements that yield DCR values beyond the above limits will not have additional ability to redistribute the loads effectively, are considered failed, and can, therefore, result in collapse of the whole structure.

4. MODELING FEATURES

Regular plan one eight storied framed building and one flat plate building were modeled in a finite element software ETABS [10]. The primary and secondary (after column removal) structures were analyzed using linear static analysis method. The preliminary data of the models and design of two structures are given in Table-1:

Table 1: Preliminary model data.

	Frame building	**Flat Plate building**
Plan size (length x width)	88 ' x 58 '	88 ' x 58 '
No. of storey	8	8
Bottom storey height	12'	12'
Typical storey height	10'	10'
Beam size	B-01 : 10" x 10" (exterior)	Not Applicable
	B-02 : 10" x 15" (interior long)	Not Applicable
	B-03 : 10" x 20" (interior short)	Not Applicable

Column size	C-01 : 12" x 12" (corner)	C-01 : 12" x 12" (corner)
	C-02 : 15" x 15" (periphery)	C-02 : 15" x 15" (periphery)
	C-03 : 18" x 18" (interior)	C-03 : 18" x 18" (interior)
	C-04 : 20" x 20" (plan middle)	C-04 : 20" x 20" (plan middle)
Slab Thickness	6"	9"
Support condition	Fixed	Fixed
Concrete strength	4 ksi	4 ksi
Steel yield strength	60 ksi	60 ksi
Gravity Loads(in addition to self weight)	live load: 40 psf, partition wall :25 psf, Floor Finish: 20 psf	live load: 40 psf, partition wall : 25 psf, Floor Finish: 20 psf
Lateral Loads	As per BNBC-2017 (zone-II)	As per BNBC-2017 (zone-II)

To estimate the DCR value, it is conducive to identify the beam and columns of the two models. The Figure.1 shows the beam and column layout and identifications of column removal point according to GSA guide lines.Figure.2 and Figure. 3 show the 3D- models of frame structure and flat plate structure respectively. For progressive collapse analysis according to GSA criteria three models for each building system have been modeled and analyzed by the finite element software. The case identification for column removal as per GSA guide line is given below in Table 2-

Table 2: GSA case identification Table.

Case identification	**Eliminated Column identification**	**GSA criteria**
Case -I	C-03	An exterior column near the middle of the long side of the building.
Case - II	C-11	An exterior column near the middle of the short side of the building.
Case - III	C-05	A column located at the corner of the building

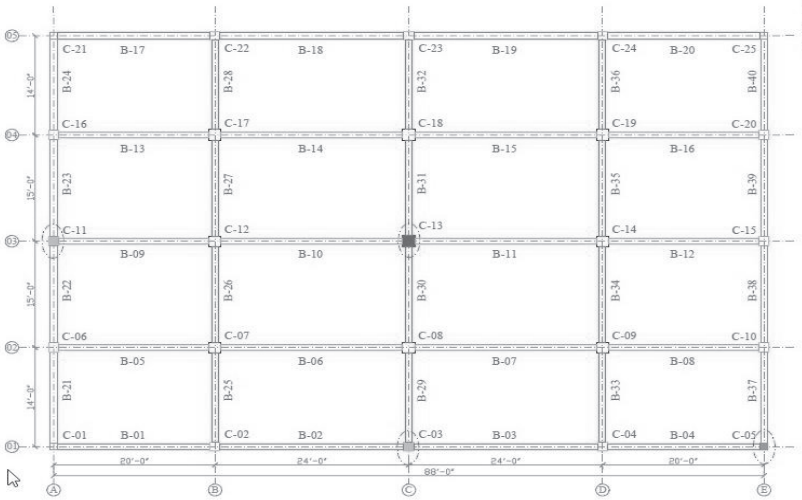

Figure 1: Column and beam layout and identification of column removal point of the framed and flat plate building structure.

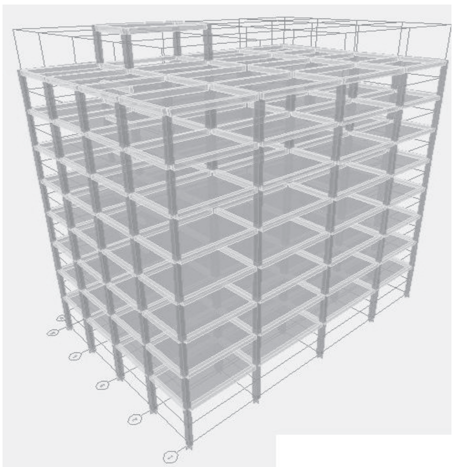

Figure 2: 3-D model of eight-storied RC framed building.

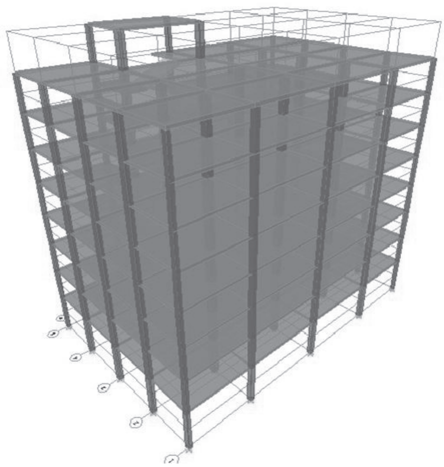

Figure 3: 3-D model of 8-storied flat plate building.

5. RESULTS AND DISCUSSION

To assess the robustness againstdisproportionate failure of the eight storey symmetrical reinforced concrete framed building and eight storey flat plate building using the linear static analysis, three column removal conditions are considered. Initiallythe two buildings are designed in

ETABS for the BNBC load combinations. Then,for two building systems, separate linear static analysis is performed for each case of column removal. Demand capacity ratio(DCR) values forall columns at ground floor are calculated for all three cases of column failure. Ground floor columns are considered for their critically loaded condition. Capacities of the columns at ground floor are calculated as per ACI 318-11 from the obtained reinforcement details after analysis and design. Demand capacity ratio (DCR) values for all three cases are estimated considering the member force for the load combination as per GSA guidelines. Member forces are found fromthe results of analysis carried out in ETABS.

The DCR values shown in Fig. 4,Fig. 5 and Fig. 6 for the columns in both building structures for all three cases do not exceed the allowable value suggested by GSA guidelines and hence columns are safe against disproportionate failure in both structural systems. But from Fig. 7, Fig. 8 and Fig. 9 it is observed that for a removed column DCR values of adjacent beams in framed buildinggo beyond the acceptance criteria value suggested by GSA guidelines.

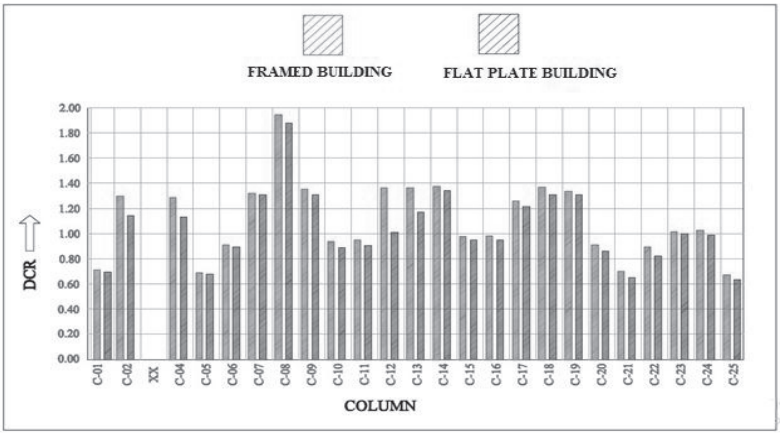

Figure 4: DCR values of columns of framed building system and flat plate building system for Case-1.

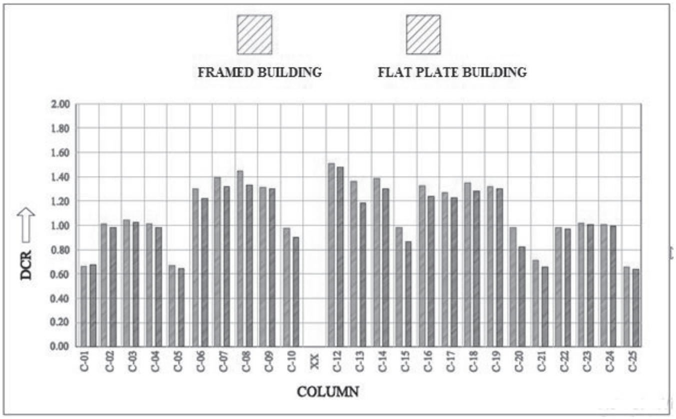

Figure 5: DCR values of columns of framed building system and flat plate building system for Case-II.

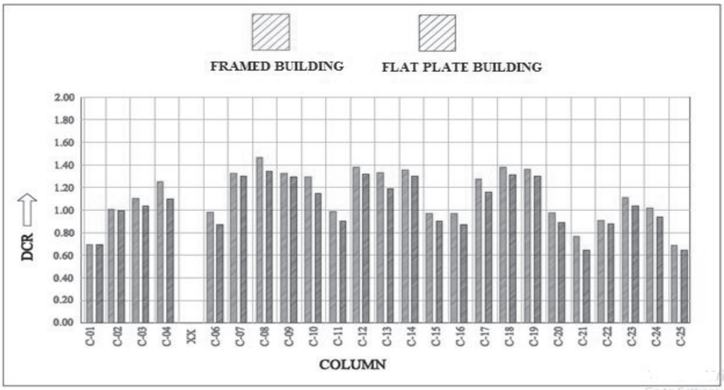

Figure 6: DCR values of columns of framed building system and flat plate building system for Case - III.

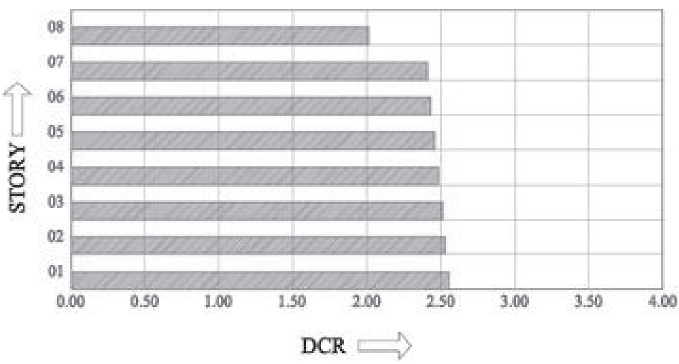

Figure 7: DCR values of beam B-29 (adjacent to column removal) of framed building for Case-I.

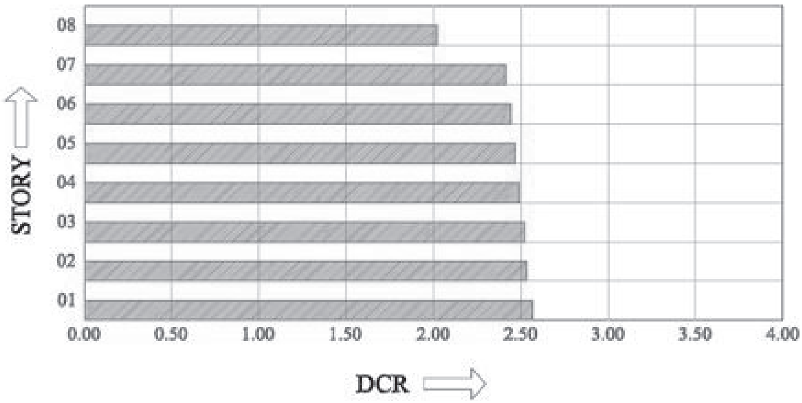

Figure 8: DCR values of beam B-09 (adjacent to column removal) of framed building for Case-II.

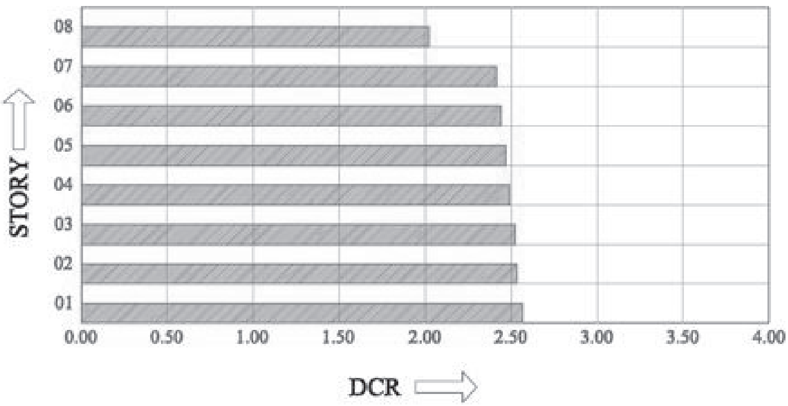

Figure 9: DCR values of beam B-04 (adjacent to column removal) of framed building for Case-III.

6. CONCLUSIONS

In recent time, failure of some building structure such as the 1994 Northridge earthquake, 1995 Kobe earthquake, bombing of Murrah Federal building in 1995 and the 2001 attack on the World Trade Center have led to the collapse of structures, indicates that the design of structures with the current code of practice cannot make the structure robust enough to resist the extreme load events imposed unexpectedly on the structures [5]. In this work, the robustness of two 8-storied building structures with two different structural systems designed in compliance with the current code (ACI 318-11), was investigated for disproportionate failure. Based on the above analysis results found herein, the following conclusions can be drawn:

- The DCR values of all columns in both framed and flat plate buildings are less than 2; it suggests that columns are robust as per GSA guidelines for disproportionate failure analysis.
- In almost all cases the columns in flat plate structure yields less DCR value than that of framed structure. It indicates that for same building plan and loading pattern flat plate building produces less DCR value and is less susceptible to disproportionate failure.
- In framed building, the beams,adjacent to the removed column in respective cases, whose DCR values are more than the allowable value suggested by GSA for disproportionate failure guidelines are unsafe.

7. RECOMMENDATIONS

As per the considerations taken and conclusions drawn before, the followings are suggested as possible further work on the alleged topic.

- In this study, concrete structure buildings were considered to evaluatethedisproportionate failure. Researching into the potential of disproportionate failurein other structural systems like steel-frame structure may be the further attempt on this study.
- In this study, eight story typical concrete structure buildings were considered to assessthedisproportionate failure. Higher than eight story may be assumed to the next level analysis.
- As explained before, there are four types of analysis methods were used to evaluate the disproportionate failure. In this study, only linear static method was used for assessing the potential for disproportionate failure. Therefore, it would be more levelheaded to examine the robustness of structure by using nonlinear static analysis, linear dynamic analysis, and nonlinear dynamic analysis methods.

REFERENCES

[1] American Concrete Institute (ACI), (2011). Building code requirements for structural concrete and commentary (ACI 318m-11), Detroit, Michigan.

[2] IzzuddinB.A.,Vlassis A.G., ElghazouliA.Y., NethercotD.A. (2008) - Progressive collapse of multi-storey buildings due to sudden column loss Part I: Simplified assessment framework. Engineering Structures 30, 1308−1318.

[3] General Services Administration (GSA). (2003). Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects, GSA.

[4] HongyuW.,YoupoS.,QingshenZ. (2011), Design methods of Reinforced concrete frame structure to resistprogressivecollapse in civil engineering, Systems Engineering Procedia, , 48-54.

[5] Jose M. Adam, FulvioP., Juan SagasetaX. (2018), Research and practice on progressive collapse and robustness of building structures in the 21st centuryEng. Struct., 173 (October), pp. 122-149.

[6] MenchellK.,MassartT. J., Rammer Y., and BouillardP. (2009). Comparison and Study of Different Progressive Collapse Simulation Techniques for RC Structures. Journal of Structural Engineering-ASCE, 135(6):685−697.

[7] QianK. andLi B. (2012). Slab Effects on Response of Reinforced Concrete Substructures afterLoss of Corner Column. ACI Structural Journal, 109(6):845−855.

[8] KapilK.,Sherif E. - Pushdown resistance as a measure of robustness in progressive collapse analysis. Engineering Structures 33 (2011) 2653−2661.

[9] Kai QianM., ASCE, Bing L., Jia-Xing M. (2015), Load carrying mechanism to resist progressive collapse of RC buildings, J. Struct. Eng., 141 (2).

[10] Osama M., "Assessment of Progressive Collapse Potential in Corner Floor Panels of Reinforced Concrete Buildings", Engineering Structures, Elsevier, Vd. 31: 749-757, 2009.

[11] MarjanishviliS. andAgnew E. (2006). Comparison of various procedures for progressivecollapse analysis. Journal of Performance of Constructed Facilities, 20(4):365−374.

[12] Yi L.., Xinzheng L., Hong G., PeiqiR. (2016), Numerical investigation of progressive collapse resistance of reinforced concrete frames subject to column removals from different stories, Adv. Struct. Eng. J., 19 (2), pp. 314-326.