ASSESSMENT OF PROGRESSIVE COLLAPSE IN ASYMMETRIC MULTISTORY BUILDING

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Abstract: The structures generally get collapse due to the failure of one or a few structural components which then progresses over the successive of other components. This process is referred as progressive collapse of the structure. Local damage that initiates progressive collapse is called initiating damage. In order to study the collapse in analytical way, loading pattern or boundary conditions are required to be changed so that other structural elements within the structure are loaded beyond their capacity. This leads to development of alternative load paths to initiate the redistribution of loads. A typical model of a 12 storey structure is made on ETABS Software and analysis of reinforced concrete framed structure under critical column removal has been carried using the linear static analysis methods as per the guidelines provided in GSA (2003) and FEMA: 356 guidelines respectively taking into consideration the provisions of IS1893:2002 codes to simulate dynamic collapse problems. The results are then compared for the parameters such as Demand capacity ratio PMM ratio and Robustness indicator were checked for the acceptance criteria provided in GSA 2003.Based on results and comparing DCR values of different beams and columns with acceptance criteria given in GSA 2013 and American Society of Civil Engineering (ASCE) 41 [10].

Index Terms - Progressive Collapse, GSA, Demand capacity ratio, Robustness indicator, ETABS, PMM ratio.

I. INTRODUCTION

The term "Progressive Collapse" can be simply defined as the ultimate failure or proportionately large failure of a portion of a structure due to the spread of a local failure from element to element throughout the structure.

Progressive collapse happens when relatively local structural damage, causes a chain reaction of structure elements failures, disproportionate to the initial damage, causing in partial or full collapse of the building. Local damage that initiates progressive collapse of building is called initiating damage. In general, progressive collapse occurs in a very short time in seconds. It is also possible that it can be characterized by the loss of load-carrying capacity of a relatively small portion of a building due to a typical load which, in turn, initiates a fall of failures affecting a main portion of the structure.

A progressive collapse is forceful event as it comprises of the vibrations of structural components and results in forceful internal forces. These internal forces could be such as inertia forces etc., whose intensity is not absorbed by the building structure. Progressive collapse is a natural non-linear event, in which structural components are stressed beyond their elastic limit to occur the failure.

Progressive collapse is the spread of local damage, from an initiating event, from element to element resulting, eventually, in the collapse of an entire structure or a disproportionately large part of it; also known as disproportionate collapse (*Bruce R. Ellingwood, 2007, p. 1*). As can be seen the different norms approach the progressive collapse in different ways, but they have in common some limits for the extent of the damage. Typically destruction in such a collapse would extend one structural part, 100 m2 of floor area, or two stories. That kind of crash can be initiated by many causes, including design and construction mistakes and load events that are over design dimensions or are not taken into account. Such events would include abnormal loads not usually considered in a project.

The potential abnormal loads that can cause the progressive collapse are categorized like that:

- a. Pressure Loads
- Internal gas explosions
- Blast
- Wind over pressure
- Extreme values of environmental loads

- b. Impact Loads
- Aircraft impact
- Vehicular collision
- Earthquake Overload due to occupant overuse Storage of hazardous materials



Figure 1: Process of Progressive Collapse

In the above figure the general process of progressive collapse in explained .let us assume a column of 18th floor in any 22 storey building is lost due fire or explosion of LPG cylinder in the kitchen (as shown in fig a.) the building is a multistory building may be of precast concrete panels. This failure may lead to the failure of building elements (beams and columns) near to this damaged column of 18th floor that will form a chain reaction of failure (shown in fig b.).

The similar phenomenon can be happen due to explosion of outer column in a terrorist attack on any high rise building (as done in WTC 9/11).

II. THE GSA (GENERAL SERVICE ADMINISTRATION)

The aim of General Service Administration (GSA) guidelines is to minimizing potential for the progressive collapse and provides help for evaluating the progressive collapse risk in new and existing buildings. The GSA (General Service Administration) provides a step-by- step guidance for the structure analysis which is subjected to a sudden removal of load carrying structural element. This guideline also provides provisions for removal of the columns including external and internal columns and load-bearing walls.

The purpose of these Guidelines is to:

- Assist in the reduction of the potential for progressive collapse in new Buildings.
- Assist in the assessment of the potential for progressive collapse in existing Buildings.
- Assist in the development of potential upgrades to facilities if required.

The GSA (2003) Guidelines Recommended Missing Column Scenario:

The potential for progressive collapse is evaluating using linear static analysis and nonlinear static analysis in four damage analysis cases. These four damaged column cases are shown in the fig. below:



The loss of an exterior column located near the middle of the short side (case C1).

The loss of an exterior column located near the middle of the long side (case C2).

The loss of a corner column (case C3).

The loss of an interior column (case C4).

III. SOME TERMINOLOGIES USED IN THIE STUDY

• Robustness Indicator:

Robustness indicator (R) is defined as the ability of building to survive the local failure to withstand the loading and does not cause any disproportionate damage.

 $\mathbf{R} = \mathbf{V}\mathbf{d} / \mathbf{V}\mathbf{i}$

Where,

Vd is the Base shear of damaged building,

Vi is the Base shear of intact building.

The value of Robustness indicator must be equal to 1, then the structure is able to provide an alternative load path.

• Demand-Capacity Ratio:

The magnitudes and distribution of potential demands on both the primary and secondary structural elements have been identified through linear elastic analysis to quantify the potential collapse areas. These magnitude and distribution of demands are being indicated by Demand-Capacity Ratios (DCR).

Acceptance criteria for the primary and secondary structural components is determined as:



Where,

QUD = Demand force (acting) such as bending moment, axial force, shear force

QCE = Expected ultimate, un-factored capacity of the component and/or connection/joint (moment, axial force, shear and possible combined forces)

The load bearing structural elements are considered to be severely damaged or collapsed if their DCR values through linear elastic approach, exceeds the allowable values. These, the allowable values of DCR are:

DCR < 2.0 for typical structural configurations (GSA 2003 Section 4.1.2.3.2) **DCR < 1.5** for atypical structural configurations (GSA 2003 Section 4.1.2.3.2)

• Compression-bending Ratio (PMM ratio):

The Compression-bending Ratio (PMM ratio) is the sum of axial force demand /capacity ratio and the maximum bending moment demand /capacity ratio. The PMM ratio for any member is the compression-bending ratio considering Euler and Lateral-torsional buckling based on the interaction equations.

PMM ratio = P ratio + M ratio

Where,

P ratio = Axial force demand / capacity ratio

M ratio = Bending moment demand capacity ratio

Acceptance criteria for the primary and secondary structural components is given as PMM ratio = P ratio + M ratio < 1.5

IV. OBJECTIVES OF THE STUDY

The main objective of this work is to do the Progressive Collapse Assessment of an asymmetric G+11 HOTEL BUILDING situated in zone II and of India. The same structure is modeled and analyzed by ETABS software

Following are the objectives of this work-

- 1) To identify the critical columns for the progressive collapse analysis of a multi-storey building.
- To determine the DCR (demand capacity ratio) for beams neighboring to removed columns in both shear and flexure criteria.
- 3) To determine the PMM Value (Column forces) for columns neighbouring to removed columns and determine the percentage increment in the forces as compared to the intact conditions.
- 4) To plot the maximum displacement curve for all the structures.

V. METHODOLOGY

In this work, the analysis based on linear static method is used to investigate **Progressive Collapse Assessment of High rise** Asymmetric building under Accident loading and its Modelling Using Etabs Software as per IS-standards. In order to study the effect seismic force on Progressive Collapse Assessment zone II of India is considered.

Software used	Configuration of Building	Model Dimensions	Storey	Remarks
ETABS	Asymmetrical (L Shaped)	30 m X 40 m	12	Seismic forces of Zone II as per IS: 1893:2002.

Table 1: Cases Considered for the Study

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	Specifications				Data					
	Typical Storey Height					3 m				
	Base Storey Height				3.0 m					
	No. of Bays along X-Direction					4				
	No. of Bays along Y-Direction							5		
	Bay Length along X-Direction					7.5	5 m			
	Bay	Length alo	ng Y-Dire	ction			8.0) m		
		Concret	te Grade				М	-30		
		Density	of R.C.C.				25 K	N/m ³		
		Density of	f Masonry				20 K	N/m^3		
		Columns ((perimeter)			600 mm x 600 mm				
		Columns	(interior)			600) mm	x 600 m	m	
		Bea	ims			25	50 mm	x 550 mn	1	
Ļ		Slab Th	hickness				150	mm		
	Bot	ttom Supp	ort Conditi	ons			Fi	xed		
		Live .	Load-				1 V	N/m^2		
		Rest of the	e structure				2 K	N/m^2		
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-	Importance Factor						1			
_		Zone	Factor			As per IS	1893-2	- 2002 (Pa	rt 1) for	
					different_Seismic_Zones					
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 Table 2: Description of the Structure

Figure 2: Plan view of the structure





Cases considered for analysis

The following cases has been considered for the analysis of work. Modeling has been carried out using ETAB 16.2.1.

CASE (1) ASYMMETRICAL BUILDING SUBJECTED TO SEISMIC FORCES IN GENERAL CONDITION

Case (2) Column is lost due to Gas explosion – In this Interior column will be lost.

VI. RESULTS

(1) DETERMINATION OF DCR (DEMAND CAPACITY RATIO) VALUES FOR THE BEAMS NEIGHBORING TO

REMOVED COLUMNS:

In this case we consider that interior column C 10 of ground floor is suddenly removed. The effect of that on the neighbouring elements is explained in the form of parameters discussed below.



Figure 4: DCR values for flexure



Figure 4: DCR values for Shear

(2) DETERMINATION OF PMM (COLUMN FORCES) VALUES FOR THE COLUMNS NEIGHBORING TO REMOVED COLUMNS

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Building parameters related to C-9	Value in Damaged condition	Value in Intact condition	Increment in Percentage
Axial load (kN)	6220.20	4120.77	50.94%
Bending moment (kN-m)	288.98	185.54	55.75%
Shear force (kN)	112.47	54.22	107.43%

Table 4: Column forces (in C-8) for the case of removal of critical column C-10

Building parameters related to C-8	Value in Damaged condition	Value in Intact condition	Increment in Percentage
Axial load (kN)	6234.20	4137.23	50.68%
Bending moment (kN-m)	258.98	184.69	40.46%
Shear force (kN)	106.47	54.39	95.78%

(3) determination OF Maximum Base shear representation for all the structures

Fig 6 Deformed shape of Structure When No column is lost

Fig 7: Deformed shape of Structure When Interior column C-10 is lost

VII. CONCLUSIONS

Linear static analysis for progressive collapse resistance of a 12 storey Asymmetric RC building has been done for column removal cases namely interior as per General Service Administration (GSA) 2013 guidelines. It can be concluded that **Sudden removal of Interior column** leads to the generation of progressive collapse in Asymmetrical building subjected to seismic forces. The Demand Capacity ratios (DCR) for all the beams in flexure is very high (maximum 4.5 to minimum 3.5) that is approximately double of the limiting value 2.0 given by GSA 2013. Hence flexure in beam is the critical criteria for ground floor column removal case in progressive collapse process of building. The Demand Capacity ratios (DCR) for all the beams in Shear are just more than 2 (not exceeded by 2.6). Hence Shear in beam is not critical for ground floor column removal case) is increased by 61.44 % in X direction and 58.59 % in Y direction after the sudden removal of interior column. Redesigning of beams in flexure is required to prevent the progressive collapse of building.

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