Progressive Collapse of Structures-Analysis-Behaviour

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Abstract- *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 can be triggered by manmade, natural, intentional or unintentional causes like Fires, explosions, earthquakes, or anything else causing large amounts of stress and the failure of a structure's support elements can lead to a progressive collapse failure. The purpose of this study was to describe the process of progressive collapse and to find more methods and approaches to design the structure for preventing different kind of failure.*

Progressive collapse is a complicated dynamic process where the collapsing system redistributes the loads to prevent the loss of critical structural members. For this reason, beams, columns, and frame connections must be designed in a way to handle the potential redistribution of large loads.

This project involves the use of a computer program to perform analysis of a reinforced concrete structure. ETABS 2016 v2.1 is used to perform analysis and observe the stability of structure with local failure and its effect on the overall structure. Several column failure conditions are studied as per Indian standards and as per General Service Administration guidelines, where for these two conditions gravity load combinations are different. As load combinations are different, changes are found in collapse pattern, which indicates Indian standards gives more conservative design than General Service Administration guidelines.

Keywords- Progressive Collapse, General Service Administration guidelines, ETABS 2016

I. INTRODUCTION

Society expects that the structure of a building is to be sufficiently safe and durable. This safety should be the result of robust design, proper execution, and good material choice. A safe structure should be able to bear the loads acting on it and may not collapse completely when a structural element fails due to an accident or unforeseen action. Unfortunately, there are a number of instances where this was not the case. The one that is most referred to is the 22-story Ronan Point apartment tower in Newham, east London 1968. When an occupant on the 18th floor of the tower struck a match in her kitchen, which triggered a gas explosion because of gas leakage and that knocked out the load-bearing precast concrete panels near the corner of the building. The loss of the load bearing precast concrete panel at the 18th floor caused the floors above to collapse. The partial collapse of the 22 story Ronan Point apartment building in 1968 is a landmark of progressive collapses in recent history that triggered code changes. It was caused by a gas explosion on the 18th floor. For this building, the exterior cladding panels supported some edges of exterior slab panels. The explosion caused loss of cladding panels leading to the collapse of the slab when edge supports were lost. The weight of the debris from the 18th-22nd floor caused the collapse of the lower parts to the ground. This collapse brought changes to the British codes since the early 1970s and was referenced extensively in literature published in the United States. The impact of these collapsing floors set off a chain reaction of collapses all the way to the ground (see Figure 1). This phenomenon is known as a progressive collapse. Progressive collapse can be defined as a situation where the local failure of a primary structural component leads to the collapse of adjoining members, which in turn leads to additional collapse. In 1995, the Murrah Federal Office Building in Oklahoma City collapsed because of a terrorist bomb explosion at the ground floor. In 2001, the famous World Trade Center, New York, collapsed because of planes impacting the upper levels of the tower. The status of RC structures regarding their vulnerability to progressive collapse has become an important question.

In particular, the collapse of Ronan Point has served as an encouragement for the development of new regulations in the UK. The one which is most important is the Fifth Amendment from 1970. These regulations set additional requirements for the robustness of a structure. One of the main items of these additional requirements is that the removal of a single element of the structure may not lead to a disproportionate collapse. Technical institutes and building authorities in several countries developed design guidelines and criteria that would reduce or eliminate the susceptibility of buildings to progressive collapse. One of the standards that provide design guidelines with respect to progressive collapse is the Eurocode. With the introduction of the Eurocode in the Netherlands, it is ensured that there are more tools available to design a robust structure. However, the introduction of the Eurocode also leads to new discussions about and researches to progressive collapse. This study will continue the research to the progressive collapse of reinforced concrete structures. A remark should be made with respect to the research to progressive collapse. The phenomenon of progressive collapse is mainly studied for in- situ-cast buildings. However, precast structures are more vulnerable to progressive collapse than cast in situ buildings. This enhanced vulnerability to the progressive collapse of precast structures is mainly caused by a smaller degree of cohesion between the structural elements. The connections between precast elements are less rigid than the connections between in- situ cast elements, therefore a lower amount of cohesion can be achieved with precast structures. Due to a lack of time, it was not possible to investigate the complex behaviour of the connections within precast structures in the current study.

Fig. 1.1: The collapse of a part of the Ronan point apartment

Although it can be argued that the collapse of the World Trade Center on September 2001 does not necessarily fit the definition of progressive collapse in current codes and standards, the significant loss of lives in the incident introduces important questions. The first question is whether existing buildings have adequate capacity to resist progressive collapse and the second question is whether available design guidelines are sufficiently clear for engineers to design new buildings against progressive collapse.

Private sector building owners and government entities are increasingly interested in estimating the progressive collapse potential of existing buildings and in designing new buildings to resist this type of collapse. Although some technical literature addressing progressive collapse became available after the 1968 Ronan Point collapse in Britain, little research has been done in this area since the mid-1970s.

General overview

Progressive collapse occurs when relatively local structural damage causes a chain reaction of structural element failures, disproportionate to the initial damage, resulting in the partial or full collapse of the structure. Local damage that initiates progressive collapse is called initiating damage. Progressive collapse of building structures is initiated by the loss of one or more load-carrying members. It can be said that a collapse of a segment of a building generated by the failure of a certain section of the structure is a result of an abnormal event. As a result, the structure will seek alternate load paths to transfer the load to structural elements, which may or may not have been designed to resist the additional loads. Once a column is failed, the building's gravity load transfers to neighbouring members in the structure. If these members are not properly designed to resist and redistribute the additional load that part of the structure fails. Failure of overloaded structural elements will cause a further redistribution of loads, a process that may continue until stable equilibrium is reached. Equilibrium may be reached when a substantial part of the structure has already collapsed. The resulting overall damage may be disproportionate to the damage in the local region near the lost member. Loss of primary members and the ensuing progressive collapse are dynamic nonlinear processes.

The degree of progressivity in a collapse can find out by measuring the ratio of the collapsed area to the area destroyed by the triggering event. Structures that have failed previously such as the Ronan point had a ratio of the order of 20 and was clearly disproportionate as a small explosion in the structure that did not kill someone within a few meters managed to severely damage the structure. New and existing structures should be checked against progressive collapse, as harmful events are increasing nowadays. Worldwide, several design codes which include methods of reducing the possibility of progressive collapse are provided by the GSA, UFC and Eurocode 1. The UK and European codes of practice suggest the tying force method to mitigate progressive collapse but unfortunately, do not take into consideration explosions and terrorist attacks when designing a structure.

American design codes recommend two approaches to use, which are direct and indirect methods. When considering the direct methods, the Alternate Load Path, and the Enhanced Local Resistance method can be used. In the ALP method, the structure must be able to bridge over a removed structural component and ensure that the degree of damage is less than the maximum damage. Another method which can be used is the ELR method, as it increases the shear and flexural strength of the structural members by decreasing the possibility and extent of initial damage to member. Meanwhile, indirect approaches aim to increase the structural integrity of the building.

Progressive collapse is a dynamic event since it involves vibrations of building elements and results in dynamic internal forces, such as inertia forces, whose energy may or may not be absorbed by the structure. Progressive collapse is also an inherently nonlinear event in which structural elements are stressed beyond their elastic limit to failure. From an analytical point of view, progressive collapse occurs when a sudden local change in building geometry results in dynamic internal forces that exceed the bearing capacities of surrounding elements leading to their failures, which in turn results in transmission of additional internal dynamic forces until the remaining structure stabilizes and absorbs the energy of the vibrations collapses. In general, progressive collapse happens in a matter of seconds. The best way to mitigate the effects of progressive collapse is to prevent it altogether. However, total prevention. e., reducing the probability of occurrence to zero is not always feasible. Alternately, proper structural design can greatly reduce the probability of progressive collapse, through attention to structural details and material properties. Progressive collapse analysis is performed to evaluate the likelihood that the initiating damage would propagate throughout the structure causing major structural failure and the subsequent loss of life.

Some of the events that can initiate progressive collapse by causing the loss of one or more primary load-carrying members includes explosion, blast, foundation failure, vehicle impact, fire, and seismic forces. The loading rate of these events may be different. For example, while blasts apply pressure for a very short period of time, gas explosions cause slow pressure waves similar to static pressure. Each of the above events can cause localized damage that may trigger a cascade of collapses leading to substantial damage to the structure before an equilibrium state is reached. The design philosophy of structures subjected to abnormal loads is to prevent or to mitigate damage, not necessary to avoid the collapse initiation from a specific cause. Hence, the total collapse is disproportionate to the original cause.

Progressive collapse analysis is a process to determine the potential of hazard to buildings. Progressive collapse analysis is a threat independent analysis, which is carried out as independent from the cause of the event. Some of the events that will cause the progressive collapse are abnormal loading, internal gas explosion, external blast, vehicular collisions, earthquake, foundation settlement, design, and constructional errors or other man-made or natural hazards. It is very important to mitigate the susceptibility of progressive collapse of the building if it is having a high potential for progressive collapse. Mitigation is also referred to as structural robustness. Structural robustness is an ability of the structure to absorb the effect of an accidental event without suffering damage disproportionate to the event that caused it. In the current situation, it is very necessary for engineers to consider progressive collapse mitigation as a basic design criterion.

The probability of progressive collapse as a result of an abnormal event can be broken down into three parts as 1. Probability of occurrence of an abnormal event. The 2. conditional probability of initial damage state of local damage as a result of the abnormal event. 3. conditional probability of the collapse of the structure as a result of damage state. Thus, the different strategies to limit the probability of a progressive collapse are identified, which aims to reduce the values of the partial probabilities, are 1. Prevent the occurrence of abnormal events, 2. Prevent the occurrence of local significant structural failure in consequence to the occurrence of abnormal events, 3. Prevent the collapse of the structural system in the case of local significant structural failure.

Resistance to progressive collapse is primarily an issue of gravity load. carrying capacity, the design of structural elements also depends on demands from other activities such as wind or seismic action. It means that, if beams, columns or joints have a larger load-bearing capacity due to more severe seismic actions considered in the design, these elements would have a higher capacity to confine the damage to the initially affected zone, and consequently to prevent progressive collapse. In fact, in order to mitigate the risk of progressive collapse due to abnormal loading event, structure must accommodate the initial local damage and develop an alternative load path to sustain the redistributed loads.

Researchers may need to develop new and innovative robust structural systems that are economical and do not interfere significantly with the functionality of the building. The success of the structural system is gauged by its capability of minimizing loss of life.

Objectives

The aim of this dissertation is to study a 10-story structure using a 3D model on ETABS and examine its structural response after removing a vertical load-bearing element under different column removal scenarios. The Alternate Load Path method adopted from the UFC and GSA guidelines shall be used and two approaches will be carried out for the analysis. A linear static approach will be used. The objectives thus can be summarized as: -

1. To understand progressive collapse of building by linear static and response spectrum analysis.
2. To study change in intensity of progressive collapse due to change in location of triggering incident.
3. Comparison of DCR values for RC SW structures by GSA guidelines and as per Indian standards.
4. To study behaviour of beams and columns during the progressive collapse.
5. To study resistance to progressive collapse of RC SW structure designed and Detailed with IS codes for seismic loads.
6. To suggest the best possible analysis for progressive collapse.

II. CONCLUSIONS

1. In plan as we move vertically downward for column removal case threat o progressive collapse will increase. Also, as we move towards center of building in plan for column removal case destruction will be more due to progressive collapse.
2. In both models, adjacent columns and beams are fails in D/C as per Indian standards.
3. But according to GSA guidelines none of columns fail in D/C. Whereas, adjacent beams are failing in D/C.
4. In the event of progressive collapse beams will provide arch action and catenary action. Columns situated above to removed column goes in tension to transfer the loads.
5. If RC SW building is designed and detailed according to the IS codes, it will prevent progressive collapse. A local collapse will happen, but progressive collapse will not start.
6. Indian Standards give higher load combination than GSA that's why failure will be more. That's showing Indian method for progressive collapse analysis is much more conservative.

Future Scope

The following point can be considered for future scope: -

1. The models are designed for without column removal condition with seismic zone III. It can extend for different seismic zones like II, IV and V.
2. One can study Wall removal scenario in RC SW structure and Wall structure.
3. Here linear Static and Dynamic analysis has been performed, Push-over or Time- history analysis can be done for same structure.
4. The present work is associated with ETABS 2016, other software like STAAD
   Pro, SAP 2000 can be used.
5. In this study DCR values found out for symmetric structure, Unsymmetrical structure can be studied.

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