STUDY ON THE EFFECTS OF PROGRESSIVE COLLAPSE AND LIQUEFACTION

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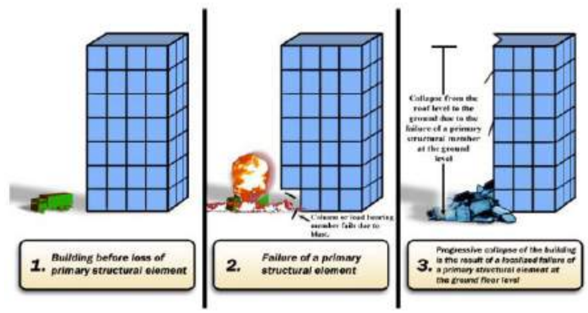
Abstract:Structural engineers are facing new challenges in designing safe structures due to the increase in terrorist actions carried out on landmark buildings which has the potential to cause great destruction, damage, and danger to people. As designers, Engineers are tasked with understanding all the possible loads that a building may encounter in its life and ensuring that the structural system will remain standing and ensure the safety of those inside. Abnormal loadings in the past were never considered during design, but an alarming string of events, mostly terrorist, have awakened the need for special considerations for potential targeted buildings. It is virtually impossible to predict what exact extreme load may be induced on a building, therefore when designing for structural integrity the most important consideration is progressive collapse.

Index Terms—linear static analysis, non linear static,linear dynamic,non linear dynamic,dynamic amplification facror,damping forces,lDynamic effect.

1. Introduction:

Structural engineers are facing new challenges in designing safe structures due to the increase in terrorist actions carried out on landmark buildings which has the potential to cause great destruction, damage, and danger to people. As designers, Engineers are tasked with understanding all the possible loads that a building may encounter in its life and ensuring that the structural system will remain standing and ensure the safety of those inside. Abnormal loadings in the past were never considered during design, but an alarming string of events, mostly terrorist, have awakened the need for special considerations for potential targeted buildings. It is virtually impossible to predict what exact extreme load may be induced on a building, therefore when designing for structural integrity the most important consideration is progressive collapse. Progressive collapse results when a localized failure spreads to a larger portion of the structure. Several examples will be given of progressive collapses that occurred in structures due to abnormal loading. Such a failure is catastrophic as collapse occurs in an instance, not allowing time for inhabitants to escape. There are certain details regarding design and retrofit of structures to resist progressive collapse that should be followed, especially for materials such as concrete and steel.

CROSS-SECTION OF REINFORCED CONCRETE BEAM



2. Objective:

To determine the optimum percentage of vermiculite that can be used in reinforced concrete beam. To determine the characteristic compression strength of the concrete. To determine the split tensile strength of the concrete. To study the flexural behavior of reinforced concrete beam with optimum percentage of replacement of vermiculite.

2. Scope:

To study the feasibility of using vermiculite aggregate in structural components. To reduce the usage of naturally available aggregate (river sand).To produce lightweight structures which is economical when compared with the conventional structures.

3. Nonlinear Static Procedure

:In a nonlinear static (NLS) procedure, geometric and material nonlinear behaviors are considered during the analysis. The NLS procedure is widely performed for a lateral load called pushover analysis. For progressive collapse analysis, a stepwise increase of vertical loads is applied until the maximum loads are reached or until the structure collapses, which is known as vertical pushover analysis. This procedure is a step above the linear static procedure because structural members are allowed to undergo nonlinear behavior during the NLS analysis. However, vertical push over analysis for the progressive collapse potential might lead to overly conservative results. Also, the NLS procedure still does not account for the dynamic effects, therefore it is ineffective to use for progressive collapse analysis. NLS analysis is not used in this research mainly because the structural members in the test buildings did not experience large deformations or nonlinear material response.

4. Linear Dynamic Procedure :

Progressive collapse is an inherently dynamic event. Dynamic effects may come from many sources during the collapse. After a structural member is failed, the structure transfers the load of that member and comes to rest in a new equilibrium position. During this dynamic load redistribution, internal dynamic forces affected by inertia and damping are produced and vibrations of building elements are involved. A sudden release in forces from any failed member can be another source of dynamic effects. Moreover, progressive collapse is generally initiated by dynamic event such as explosion, impact, and instantaneous failure of a structural member such as a connection. Therefore, dynamic effects for frame structures should be taken into consideration in progressive collapse analysis.

Fig 2 : Materials used

5. Nonlinear Dynamic Procedure:

The nonlinear dynamic (NLD) procedure is the most detailed and thorough method of progressive collapse analysis. This method includes both dynamic nature and nonlinear behavior of the progressive collapse phenomenon. More accurate and realistic results can be obtained from the NLD method while it is very time-consuming to evaluate and validate analysis results. In this research, NLD analysis is performed by instantaneously removing a load-bearing member from the already loaded structure and analyzing time history of the structure response caused by the loss of that member. Both dynamic effects and geometric and material nonlinearity were considered in the NLD analysis conducted in this research.

5. Nonlinear Dynamic Effect :

The performance of any structure under abnormal loadings depends not only on its geometrical properties, but also on the properties of the materials used to construct the structure. Member stiffness ratio is derived to account for geometrical nonlinearity and member shear deformation. The effect of shear deformation is generally insignificant for the conventional framed structure, but it can be considerably important for heavy transverse loading. Geometric nonlinearity is commonly described in terms of “P-Delta Effect” in the model. Member axial compressive forces act through the displacement of one end of a member relative to the other amplify the lateral bending response of a beam column. Therefore, the P-Delta effect influences the transverse bending stiffness of an element. Most failure or collapse causing in typical structures are mainly due to the advent of nonlinear material behavior, referred to as post-elastic or plastic behavior. Therefore, material properties such as yield strength, ultimate strength, and ductility are important parameters to design buildings with safety.

DESIGN APPROACHES FOR PROGRESSIVE COLLAPSE

The American Society of Civil Engineers (ASCE) Standard defines two general design methods to minimize Progressive collapse potential, which are

Indirect design method and **direct design method**. Each of these approaches is described in the following section.

Indirect Design Approach :

The indirect design approach attempts to prevent progressive collapse through the provision of minimum levels of strength, continuity, and ductility. The examples of this approach are to improve joint connections by special detailing, to improve redundancy, and to provide more ductility to a structure. The indirect design approach is generally integrated into most building codes and standards since it can create a redundant structure that will perform under any conditions and improve overall structural response. However, this method is not recommended for progressive collapse design because of no special consideration of the removal of members or specific loads.

Direct Design Approach :

The direct design approach explicitly considers resistance of a structure to progressive collapse during the design process. There are two direct design methods: **the specific local resistance method** and **the alternate load path method.**

The specific local resistance method seeks to provide strength to resist progressive collapse.

The alternate load path method seeks to provide alternative load paths to adsorb localized damage and resist progressive collapse.

Specific Local Resistance Method :

The specific local resistance method requires that a critical structural element be able to resist an abnormal loading. Regardless of the magnitude of the loads, the structural element should remain intact because of its robustness. For this method, a sufficient strength and ductility of the element must be determined during design against progressive collapse. The critical element can be designed to have additional strength and toughness to resist the loading, simply by increasing the design load factors.

Alternative Path Method :

In the alternate path (AP) method, the design allows local failure to occur, but seeks to prevent major collapse by providing alternate load paths. Failure in a structural member dramatically changes load path by transferring loads to the members adjacent to the failed member. If the adjacent members have sufficient capacity and ductility, the structural system develops alternate load paths. Using this method, a building is analyzed for the potential of progressive collapse by instantly removing one or several load bearing elements from the building, and by evaluating the capability of the remaining structure to prevent subsequent damage. The advantage of this method is that it is independent of the initiating load, so that the solution may be valid for any type of the hazard causing member loss.

The alternate load path method is primarily recommended in the current building design codes and standards in the U.S., including General Services Administration (GSA, 2003) and the Department of Defense (DoD, 2005) guidelines. Thus, this research also focuses primarily on the AP method and used it for progressive collapse analysis.

Design guides to resist progressive collapse :

Progressive collapse is of an important concern because local damage may cause massive destruction and collapse of a structural system. The progressive collapse by terrorist attacks in recent years has further created an urgent need for all code-writing bodies and governmental agencies to provide design guidelines and criteria to prevent or minimize progressive collapse. There are a number of building codes, standards, and design guidelines for the prevention of progressive collapse, such as the General Services Administration (GSA, 2003) and the Department of Defense (DoD, 2005).

DoD Guideline :

The U.S. Department of Defense published a document, “Design of buildings to resist progressive collapse”, in the frame work of the Unified Facilities Criteria (UFC) (DoD, 2005). This document was prepared for the new DoD construction such as military buildings and major renovations. Especially, all DoD buildings with three or more storeys are required to consider progressive collapse. TheDoD guideline can be applied to reinforced concrete, steel structures masonry; wood and cold-formed steel structural components. The DoD guideline describes how to analyze and design the building structures to resist progressive collapse. A combination of direct and indirect design approaches was used, which depends on the required level of protection for the facility: indirect design for very low and low levels of protection, and both indirect and direct design (Alternate Path) for medium and high levels of protection. An appropriate level of protection can be provided to lessen the risk of mass casualties for all DoD personnel at a reasonable cost.

GSA Guidelines

The U.S. General Services Administration (GSA) guideline, entitled "Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects", was specifically prepared to ensure that the potential for progressive collapse is addressed in the design, planning, and construction of new federal office buildings and major modernization projects (GSA, 2003). The intent of the guidelines is to prevent widespread collapse after a local failure has occurred. Based on the GSA guidelines, progressive collapse analysis is accomplished by the implementation of the alternate path method of design. The primary method of analysis in this design guideline is the linear elastic and static approach. Linear procedures are used for low- to medium- rise structures, with ten or less storey's and typical structural configurations. The GSA guideline recommends that the use of nonlinear procedures should be considered for the buildings with more than ten storeys. This document describes detailed procedures for the analysis of progressive collapse, the loads for use in the analysis, and the acceptance criteria for progressive collapse. The issues related to the prevention of progressive collapse are discussed for reinforced concrete and steel building structures.

EFFECTS OF LOSING AN EXTERNAL COLUMN IN A RC STRUCTURE:

The below figure (b) illustrates that the conventionally designed system gets totally collapsed when the structure is subjected to an External blast loading. The main reason is that gravity-load designed systems are not adequately detailed to develop alternative load paths after removal of a primary vertical support. Buildings designed for seismic & wind loads can have the ability to resist the lateral loads and to create the alternate load paths after the column loss. Hence, the special moment resisting frames (SMRF) cannot be collapsed on external blast loading as shown in the Figure (c).

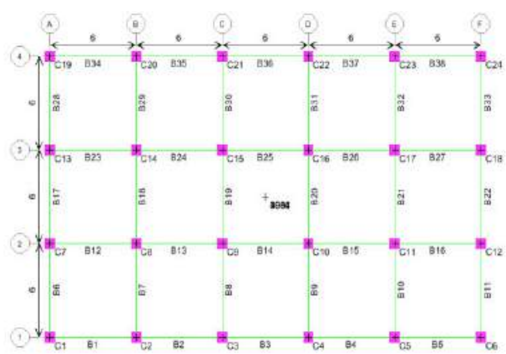
(a) Conventional design: Progressive collapse

(b) Alternate load path design: No progressive collapse

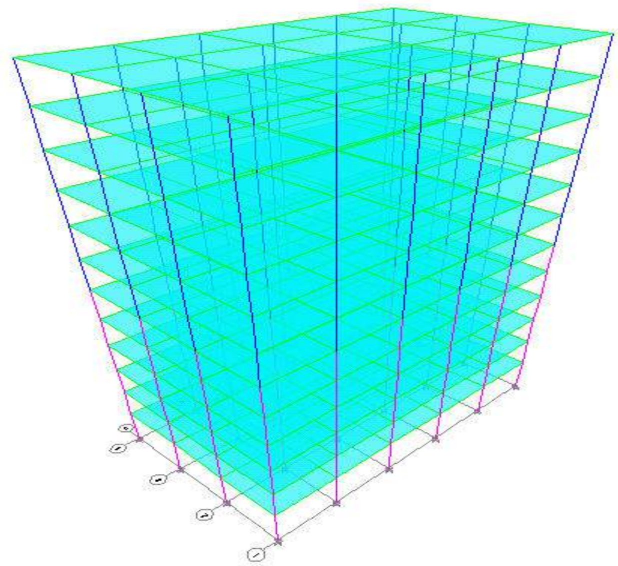
STRUCTURAL ANALYSIS AND DESIGN :

DESCRIPTION OF BUILDING

The building used in the study is a twelve-storey cast-in-place reinforced concrete special moment resisting frame structure situated in Zone III. The detailed description of the Building is as follows:



Plan of the Building



Isometric view of the building

The choice of a regular and relatively simple structure as a first design example was mainly dictated by the need to identify any problems that may arise in applying the proposed procedure, other than those of the complexity of the structure, and obtain a first idea of the relative performance of the procedure in the case of regular frame buildings.

PROGRESSIVE COLLAPSE ANALYSIS AND RESULTS :

Following the design of the building for Gravity, Wind, and Seismic loads, first storey columns were removed at each of the four locations of the buildings as specified by the GSA criteria. The specified GSA load combination was applied and the demand forces were calculated for each member again using the ETABS program.

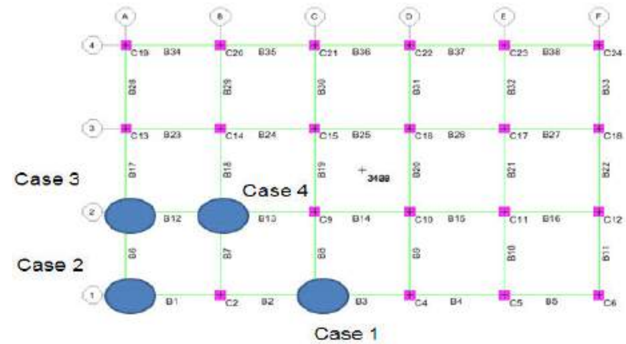


Figure 6.1-The location of removal of columns as per GSA criteria

In order to calculate the demand capacity ratio for each member, the section ultimate capacity was recalculated considering the actual area of steel provided in the design. Also, the material strength is increased by 0.25%, as specified by the GSA provisions, and the ultimate capacity of the structural member at any section is calculated as per **IS 456-2000**. For each beam, the demand capacity ratio was calculated for top and bottom reinforcement for each section along the beam in addition to the demand capacity ratio for the shear. Spreadsheets were developed to analyze the results from the computer program ETABS. For each beam the maximum DCR was determined. For each column the demand capacity ratio was calculated directly using the results from ETABS.

The demand capacity ratios (DCR) for the first storey columns for building are summarized in Table 6.1. The table shows that the demand capacity ratios for the remaining columns (un-removed) are below the GSA limit of DCR = 2 for the special moment resisting frame buildings. The following is a discussion of the analysis results for flexural and shear demand capacity ratio calculations and progressive collapse potential for the buildings subject to removal of first floor columns.

Summary of DCR's for first storey columns

		Case 1 - Long Side Column Eliminited	Case 2 - Short Side Column Eliminited	Case 3 - Corner Column Eliminited	Case 4 - Interior Column Eliminited
Grid Line	Column				
LINE 1	C1	0.63	0.71	X	0.51
	C2	1.11	0.68	0.95	0.98
	C3	X	0.53	0.92	0.78
	C4	1.12	0.47	0.73	0.72
	C5	0.84	0.53	0.71	0.74
	C6	0.55	0.33	0.46	0.49
LINE 2	C7	0.78	X	0.96	0.96
	C8	0.81	1.01	0.91	X
	C9	0.88	0.56	0.89	1.1
	C10	0.79	0.63	0.92	0.92
	C11	0.79	0.64	0.89	0.85
	C12	0.65	0.54	0.65	0.72
LINE 3	C13	0.77	0.92	0.91	0.73
	C14	0.79	0.97	0.89	1.08
	C15	0.76	0.56	0.89	0.92
	C16	0.78	0.63	0.92	0.93
	C17	0.77	0.64	0.90	0.85
	C18	0.66	0.54	0.65	0.72
LINE 4	C19	0.50	O.47	0.56	0.48
	C20	0.75	0.52	0.62	0.72
	C21	0.65	0.47	0.71	0.72
	C22	0.62	0.53	0.88	0.73
	C23	0.66	0.55	0.88	0.72
	C24	0.38	0.39	0.42	0.48

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