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Building Collapse: Factors and Resisting Mechanisms, a Review

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Abstract*— All through the ages in all human civilizations men have been engaged in construction activity, not only to build their dwellings and house their activities, but also roads, bridges to facilitate means of transport, and communication etc. The main concern in this activity was to ensure safety and reduce the collapse of the buildings and other structures. But even after taking all precautions it is impossible to guarantee the safety and collapse because of several unforeseen reasons like faulty constructions, design errors, overloading, soil liquefactions, gas explosion, material degradation, terrorist attacks and economic factors are also contributing to the collapse. It is also uneconomical to design the structure for unforeseen events unless they have reasonable chance of occurrence. In order to ensure the safety and prevent collapse, many guidelines have been framed by local bodies and government authorities in many countries like United States Department of Defence (DOD), United States General Service Administration (GSA) and Euro-Codes in European Nations. Some other practices are followed to incorporate redundancies in the structure like detailing, ductile designs, tying of elements at particular locations, provision of hinges and inter connections. It is also to be admitted that full proof safe design structure for accidental events cannot be prepared and implemented as it is uneconomical and the chances of such occurrences are less. This paper reviews past case studies of collapse of structures with an aim to develop an understanding of collapse mechanism. This study will definitely help to bring about a detailed improvement in the design to maximize the quality of the construction at a minimal cost.

Index Terms*— Collapse resisting mechanisms, column removal scenarios, progressive collapse, unforeseen factors.

I. INTRODUCTION

The famous writer Ralph W. Emerson says, "Bad times have a scientific value, these are occasions a good learner would not miss". Thus engineers in structural design have to focus on failures of their projects to evolve better designs as the Building Regulations Code 2010 states 'the building shall be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause'. One of the historical collapse event that took place is: the collapse of Campanile in Venice in 1902 where the triggering event was centuries – long stress redistribution due to creep and drying shrinkage. In later years, the collapses are due to terrorist attacks, aircraft impacts, vehicle collision, accidental fires, gas explosions, overload due to occupant misuse, storage of hazardous materials, bomb explosions and change of function other than the original purpose for which they were designed.

The partial collapse of Ronan Point Apartment, England, 1968 due to small gas explosion as well as attacks on the Alfred P. Murrah building, Oklahama, 1995 has made the engineering community to consider and understand the mechanism involved in such collapses. Now the focus is on achieving resilient buildings which can remain purposeful even after the occurrence of such events as they are occupied by several people and open to public visits.

II. CASE STUDIES

A. Collapse of Civic Tower of Pavia, Italy

The civic tower of Pavia built in 1060 collapsed in a matter a minutes in 1989. The investigations revealed several causes like the time dependent behavior of the rubble and mortar concrete caused creep over the years, this action resulted in lateral expansion of concrete leading to the bursting of the brick skin, weakening the structure to such an extent that it spontaneously collapsed, the industrial air pollution around accelerated the weakening of the compressive resistance of the lime concrete. Another cause was the belfry construction over increased the tower height and consequently the wind forces on it, it increased the dead load, dangerously increasing the compressive stresses in the weakened concrete [1]. Summarily the collapse of this tower can be attributed to degradation of material over the years or collapsed due to old age.

Fig 1: Tower of Pavia [2]

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B. Collapse of Ronan Point, England

Ronan Point- a 22 storey precast apartment tower building collapsed partly within three months of its service life. The collapse was shocking to the engineering fraternity as it was initiated by a small gas explosion. The blowing out of an outer panel resulted in the loss of a bearing wall on the 18th floor initiating the collapse of all the upper floors. The collapse was attributed to its lack of structural integrity, there was no alternative load path for redistribution of forces on the onset of loss of bearing wall [3]. Therefore it led to the second phase triggering the collapse of 17th floor and below. The dynamic loading imparted by the falling debris resulted in the collapse of the south east corner of the building up-to ground level.

Fig 2: Ronan Point apartment after collapse [4]

C. Alfred P. Murrah Building, Oklahama

This building was an office facility for the US government situated in Oklahama. It was a nine story building of reinforced concrete with ordinary moment resisting frame. This building was the target of a terrorist attack in which a truck bomb detonated in front of its north side. The explosion caused extensive structural damage which spread the entire width of the building. Three column which supported a transfer girder in the third floor were immediately destroyed by the blast triggering progressive collapse in the upper stories. The blast blew the granite panels of the infill walls from the 3rd to the 6th floor. The assessment team found that the removal of a column in the first would redirect additional loads to the laterally adjacent columns, exceeding their yield moment and shear capacity. The loss of these columns would leave the transfer girder only partially supported. The investigating team concluded that this ordinary moment frame could not sustain the level of ductility required to redistribute the loads with three columns missing in the first story [5]. The nearby buildings were too damaged due to the explosion.

Fig 3: Alfred P. Murrah Federal after bombing [6]

D. Royal Hotel Plaza, Thailand

It is a six storeyed building in Korat. It collapsed vertically with little lateral displacement and the floor slabs stacked nearly one above the other. The collapse was due to addition of three extra stories. The original margins of safety incorporated on ground floor columns exceeded leading to their collapse.

Fig 4: Royal Plaza Hotel collapse [7]

E. Sampoong Department store, Seoul

This building was initially designed for residential apartments which later converted to departmental store halfway through construction cutting away the number of support columns to install escalators. To maximise the floor space sizes of floor columns were reduced etc. In all this the personnel hired at different stages overlooked the ethical principles of engineering at the behest of the financer [8]. This structure collapsed in 1995, six years after its construction causing hundreds of deaths and injuring people.

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Fig 5: Sampoong Department Store collapse [9]

F. Lotus Riverside Compund, Shanghai

It is thirteen storey apartment building making up the Lotus riverside in Shanghai. It just fell flat on the ground in Jun, 2009 while it was still under construction. Fortunately all the workers escaped the site sensing its collapse. The reasons for the failure was that, the foundations were undermined by digging a pit of 4.6 m deep for underground car parking and dug out soil was piled 10 m high against one side of the building resulting in its collapse.

Fig 6: Lotus Riverside Compound Shanghai [10]

G. Dhaka garment factory collapse, Bangladesh

It is an 8 story commercial building called Rana Plaza. It collapsed leaving only the ground floor intact. The reasons for the collapse were its conversion from commercial to industrial use, it was built on a filled pond and three additional floors were added to the original plan.

Fig 7: Bangladesh Building Collapse [11]

H. Collapse of residential building, Canacona

A six storied building collapsed at the fourth floor in 2014 while the construction of fifth floor was going on. The reasons for the failure include design of footing inappropriate for the filled area, bad design of columns, and defective execution of work at the site.

Fig 8: Residential building collapse [12]

I. Noida Building collapse

This building collapsed in 2018, a year after its construction due to water seepage. The investigations revealed poor quality of construction materials used like high water cement ratio i.e. low cement content in rubble and mortar, low grade of concrete, smaller diameter bars etc.

Fig 9: Greater Noida Collapse [13]

III. FACTORS CAUSING COLLAPSE

Most of the collapses and failure of buildings around the world are attributed to manmade causes due to negligence in areas like geotechnical investigation, foundation works, ill planning and design of tall buildings for extra loads and stresses against wind loads, compromising quality of building materials, inadequate monitoring and poor quality of workmanship. Negligence in enforcing building codes and seeing their compliance at every stage till its completion by the relevant authorities, supervisors and industrial professionals also contribute to these disasters.

In the cases cited above most of the collapses are due to human irregularities. But it is also to be stated that nowadays due to constraints on the availability of land, construction industry is focusing on high rise/ slender structures and that too speedily and in all this everything is compromised to maximize profit at minimal cost.

IV. UNDERSTANDING COLLAPSE MECHANISMS

A collapse refers to the failure of structure to maintain its structural integrity. Any structural failure begins when a material/ element in it is stressed beyond its strength limits causing it to fracture or undergo excessive deformations. On application of system of loads to an elastic body, it deforms and shows a resistance against deformation. Collapse occurs when there is no more remaining stable element that can carry additional load. The large economic losses and extensive casualties suffered compelled the researchers to undertake studies to advance the understanding of behavior under sudden loss of load bearing elements like beams, columns, slabs, walls, etc.

Studies reveal that the collapse mechanism of RC frame structures is the crushing of joint concrete and the fracture of steel bar. The state of the beams in the vicinity of the removed column converts from arch action to cantilever action and the connection failure between horizontal and vertical components leads to the final collapse.

The stress time history curves of the beam end bottom bar suggests that increasing crushed failure of the compression zone concrete, the beam end bottom bar begins to bear tensile forces which means the stress state has now been converted to catenary action. And with further gradual increase in load, the bottom bar ruptures leading to the disconnection of horizontal components with the vertical ones causing the final collapse.

The collapse of structure begins as a local failure which sets in sequential reaction in neighboring parts causing failure of massive portion or even progressive collapse of the entire structure. Structural resistance can be improved against progressive collapse, by increasing redundancy and continuity in the structure [13]. Redundancy allows to redistribute the loads from that part which has lost structural integrity to an alternative load path with the remaining structural integrity. This is achieved through continuity and improved ductility. When one of the critical element say load bearing column fails, connecting spans deflect until rotational capacity provided by the adjacent slabs or beams is exhausted. Then catenary action of the beam enables it to carry vertical loads at large displacements.

Catenary action is considered as the last defence mechanism when the members in addition to tensile strength also possess ductility obtained from detailing of longitudinal reinforcement.

Stages of mechanisms:

a) Flexural action: initially all beams undergo flexural action i.e. sustain the loads they are designed for.
b) Compressive arch action: enhances the flexural strength at the most critical section in presence of axial compression provided by strong lateral restraints.

(Effective mechanism when horizontal displacement of the neighbouring columns is small)

c) Catenary Action: Catenary/ membrane behaviour of beams/ slabs bridging the damaged column (by means of large rotations and displacements).
d) Contribution of non-structural elements such as external walls and partitions.

V. CONCLUSION

The study of the cases cited above and others the world over suggests the failures and collapses of many buildings is due to several reasons: some related to human negligence and a case of unexpected explosion and some due to ageing or degradation of materials. The cases of human negligence is in areas like faulty geotechnical investigation in foundation works, faulty design and planning, selection of poor quality building materials, use of unqualified contractors and workmen, inadequate project monitoring and approval by relevant authorities, failure to ensure compliance of regulations by government agencies. All these irregularities are just to maximise profit with reduced cost.

Nowadays there is a need for greater awareness sand formulate regulations to contain many structural failures taking place due to combination several factors referred earlier. Though we cannot eliminate these failures totally we can at least reduce their chance of occurrence. Therefore this study aims to prevent progressive failures of structures irrespective of factors causing it. Here I suggest an example where in a column prone to collapse is removed and to see its effect on the remaining structure. Accordingly suggest some measures to avoid the progression and maintain structural integrity.

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