MAE 1033 Structural Assessment & Repair
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The Collapse of Buildings & Duties of a Forensic Engineer

(Compiled from various internet-based sources)

1.0 INTRODUCTION

Buildings, like all structures, are designed to support certain loads without deforming excessively. The loads are the weights of people and objects, the weight of rain and snow and the pressure of wind--called *live loads*--and the *dead load* of the building itself. With buildings of a few floors, strength generally accompanies sufficient rigidity, and the design is mainly that of a roof that will keep the weather out while spanning large open spaces. With tall buildings of many floors, the roof is a minor matter, and the support of the weight of the building itself is the main consideration. Like long bridges, tall buildings are subject to catastrophic collapse.

2.0 CAUSES OF BUILDING COLLAPSES

The causes of building collapse can be classified under general headings to facilitate analysis. These headings are:

- Bad Design
- Faulty Construction
- Foundation Failure
- Extraordinary Loads
- Unexpected Failure Modes
- Combination of Causes

2.1 Bad Design or Design Error

Bad design does not mean only errors of computation, but a failure to take into account the loads the structure will be called upon to carry, erroneous theories, reliance on inaccurate data, ignorance of the effects of repeated or impulsive stresses, and improper choice of materials or misunderstanding of their properties. The engineer is responsible for these failures, which are created at the drawing board.

2.2 Faulty Construction

Faulty construction has been the most important cause of structural failure. The engineer is also at fault here, if inspection has been lax. This includes the use of salty sand to make concrete, the substitution of inferior steel for that specified, bad riveting or even improper tightening torque of nuts, excessive use of the drift pin to make holes line up, bad welds, and other practices well known to the construction worker.

2.3 Foundation Failure

Even an excellently designed and constructed structure will not stand on a bad foundation. Although the structure will carry its loads, the earth beneath it may not. The Leaning Tower of Pisa is a famous example of bad foundations, but there are many others. The displacements due to bad foundations may alter the stress distribution significantly. This was such a problem with railway bridges that statically-determinate trusses were greatly preferred, since they were not subject to this danger.

2.4 Extraordinary Loads

Extraordinary loads are often natural, such as repeated heavy snowfalls, or the shaking of an earthquake, or the winds of a hurricane. A building that is intended to stand for some years should be able to meet these challenges. A flimsy flexible structure may avoid destruction in an earthquake, while a solid masonry building would be destroyed. Earthquakes may cause foundation problems when moist filled land liquefies.

2.5 Unexpected Failure Modes

Unexpected failure modes are the most complex of the reasons for collapse, and we have recently had a good example. Any new type of structure is subject to unexpected failure, until its properties are well understood. Suspension bridges seemed the answer to bridging large gaps. Everything was supported by a strong cable in tension, a reliable and understood member. However, sad experience showed that the bridge deck was capable of galloping and twisting without restraint from the supporting cables. Ellet's bridge at Wheeling collapsed in the 1840's, and the Tacoma Narrows bridge in the 1940's, from this cause.

The conservative, strong statically-determinate trusses were designed with pin-connected eyebars to be as strong and safe as possible. Sad experience brought the realization of stress concentration at the holes pierced in the eyebars. From earliest times, it has been recognized that tension members have no surprises. They fail by pulling apart when the tension in them becomes too high. If you know the tension, then proportioning a member is easy. A compression member, a column, is different. If it is short and squat, it bears its load until it crushes. But if you try to support a load with a 12-foot column that will just support the load with a 1-foot column, you are in for a surprise. The column bends outward, or *buckles*, and the load crashes to earth.

Suppose you have a beam supported at the ends, with a load in the centre. You know the beam will bend, and if the load is too great, it may break apart at the bottom, or crush at the top, under the load. This you expect. However, the beam may fail by splitting into two beams longitudinally, or *shearing*, or by the top of the beam deflecting to one side or the other, also called buckling. In fact, a beam will usually fail by shearing or buckling before breaking.

A hollow tube makes a very efficient column or beam. If you think about it, it is the material on the surface that most resists buckling and bending. A column that is modified from a compact cross-section, like a cylinder, to an extended cross-section, like a pipe, can still support the same load per unit area, but with much greater resistance to buckling. As a beam, one side is in compression and the other in tension, while the pipe cannot buckle to one side or the other. When you do bend a pipe, notice that it crushes inward reducing the cross-section to a line, which bends easily. Tubes need to be supported against buckling. Such a tube has a very high ratio of strength to weight, and hence strength to cost.

Tall buildings have generally been made with a rigid steel skeleton, sheathed in the lightest materials to keep out the weather. Alternatively, reinforced concrete, where the compression-resisting and protecting concrete surrounds the tough, tension-resisting steel, integrated into a single body, has been used. Such structures have never failed (when properly built on good foundations), and stoutly resist demolition. When the lower supports of a steel skeleton are destroyed, the weight of the building seems to crush the lower parts and the upper parts descend slowly into the pile of debris. Monolithic reinforced-concrete buildings are difficult to demolish in any fashion.

3.0 DUTIES OF A FORENSIC ENGINEER

Forensic engineers are engineers responsible for determining how accidents occurred or how a particular device failed. A kind of detective, forensic engineers will often inspect evidence drawn from the site of the failure to piece together the sequence of events that led up to it. The duties of forensic engineers vary, with some concentrating in specific fields, such as automobiles or civil engineering, but there are a number of tasks common to most positions within the profession.

3.1 Identify Failure

The first task of a forensic engineer summoned to the scene of a failure with be to identify the precise nature of the failure. In some cases, this will be obvious. For instance, in the case of a plane crash, the failure is the plane's crashing. But in other cases, such as a forensic engineer called to inspect a defective building, the damage may be more subtle.

3.2 Collect Evidence

Once the failure has been identified, the forensic engineer must then collect all relevant evidence to determine its precise cause. This can include physical evidence from the scene as well as witness testimony regarding the events leading up to the failure.

3.3 Develop Hypotheses

Once the engineer has collected the physical evidence, he will then use the evidence to form various preliminary hypotheses as to the failure's cause. These guesses will be refined, modified and eliminated as the engineer's research continues.

3.4 Perform Tests

The forensic engineer will often subject much of the physical evidence to a variety of tests to gain a better understanding of the incident. This can include tests to examine the composition of material found at the scene or to examine the mechanical health of a machine. For example, a forensic engineer examining the collapse of a building may test physical evidence for explosive residue or test steel in the building's structure to identify stresses it underwent during the incident.

3.5 Offer Conclusion

Once the forensic engineer has gathered all his evidence and performed all necessary tests, she will then analyze the results and offer a conclusion as to the likely cause of the failure. The conclusion may not always be definite, but will often include the probability of various scenarios. The conclusions will usually be laid out in a report in which the findings are described in both technical and lay terms.

3.6 Offer Testimony

In certain cases, the forensic engineer will also provide testimony in a courtroom as to the likely cause of the failure. This can be particularly important in court cases in which parties disagree over who is responsible for the failure, a determination that generally hinges on the cause of the failure.

4.0 FAILURE ANALYSIS PROCEDURE

The principal task of a failure analyst during a physical-cause investigation is to identify the sequence of events involved in the failure. Like the basic process of the scientific method, failure analysis is an iterative process of narrowing down the possible explanations for failure by eliminating those explanations that do not fit the observations. The basic steps are:

1. Collect data
2. Identify damage modes present
3. Identify possible damage mechanisms
4. Test to identify actual mechanisms that occurred
5. Identify which mechanism is primary and which is/are secondary
6. Identify possible root causes
7. Test to determine actual root cause
8. Evaluate and implement corrective actions

Generally, a failure analyst will start with a broad range of possible explanations but, over time, will narrow and refine the existing possibilities. The failure analyst must repeatedly ask the following questions as an investigation develops possible explanation(s) for actual events:

- What characteristics are present in the failed/damaged component?
- What characteristics are present or expected in an undamaged component?
- What are the possible explanations that would account for the differences between damaged and undamaged components?
- What test(s) can be performed to confirm or eliminate possible explanations and refine knowledge about the observed damage?

The investigator must understand the potential ways a component could be damaged, the clues that would differentiate between these various scenarios, and the physical meaning each of these clues would have. Comparison of observations with characteristics of expected damage and mechanisms will enable the analyst to narrow down the possible failure explanations and understand the meaning of the observations made.

5.0 ACCIDENT RECONSTRUCTION

The term *accident reconstruction* has traditionally been used to describe the investigation and analysis of motor vehicle and aircraft accidents. However, the term is also being used more often to describe the investigation and analysis of any unexpected event that causes loss or injury. Accident reconstruction is rarely a simple endeavour, and accident reconstruction requires personnel with proper training and experience in performing investigations/reconstruction. Reconstruction also often requires the assistance of other personnel with specialized expertise to address certain aspects of the investigation. The investigation and analysis of accidents and failures must be thorough to ensure that all information pertaining to the incident has been scrutinized and that accurate conclusions have been drawn.