Why Do Structure Fail?

Ms. Sonam Subhash Shinde
Student
Department of Civil Engineering
Adarsh Institute of Technology, (Polytechnic), Sangli, India

Abstract— The design of structures should satisfy three fundamental requirements:

1) Stability: The structure should be stable under the action of loads.
2) Strength: The structure should resist safely stresses induced by the loads.
3) Serviceability: The structure should perform satisfactorily under service loads.

Defective construction that causes failure may be due to numerous reasons that may not be easy to predict before or during the construction. The major causes of structural failure are defective designs that have not determined the actual loading conditions on the structural elements. Inferior construction materials may also be the cause since the loads are calculated for materials of specific characteristics. Structure may fail even if the design is satisfactory, but the materials are not able to withstand the loads. Employment of unskilled labor on construction work is another reason for structural failures. Reducing failures of buildings and other structures requires competent design; clear communication of that design to the contractor by means of engineering drawings, etc.; careful and competent construction; and effective construction supervision. Therefore, it is important that the owners, designers, and builders are fully conscious of the reasons of failure, and undertake all preventive measures. Stability, strength and serviceability can only be achieved by following basic design principles. This paper presents some cases of different structural failures and the preventions, so other engineers can benefit from this knowledge.

Keywords: Structure Fail, Defective construction, Stability, strength and serviceability

I. INTRODUCTION

Structural integrity is the ability of a structure to withstand its intended loading without failing due to fracture, deformation, or fatigue. It is a concept often used in engineering to produce items that will serve their designed purposes and remain functional for a desired service life.

To construct an item with structural integrity, an engineer must first consider a material's mechanical properties, such as toughness, strength, weight, hardness, and elasticity, and then determine the size and shape necessary for the material to withstand the desired load for a long life. Since members can neither break nor bend excessively, they must be both stiff and tough. A very stiff material may resist bending, but unless it is sufficiently tough, it may have to be very large to support a load without breaking. On the other hand, a highly elastic material will bend under a load even if its high toughness prevents fracture.

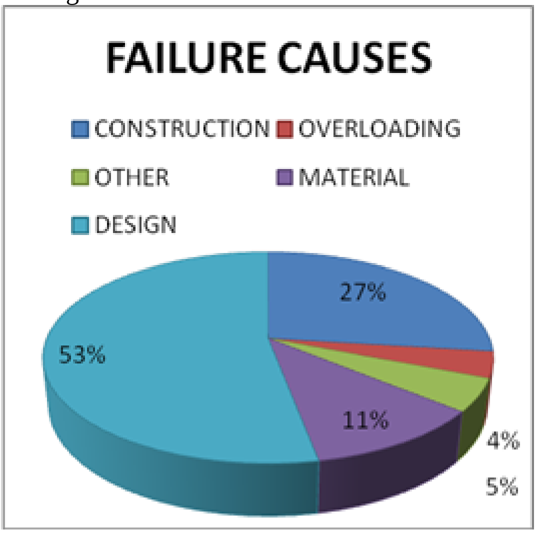
Structural failure refers to the loss of structural integrity, or the loss of load -carrying capacity in either a structural component, or the structure itself. Structural failure is initiated when a material is stressed beyond its strength limit, causing fracture or excessive deformations; one limit state that must be accounted for in structural design is ultimate failure strength. In a well- designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure.

Structural failure is defined as loss of the load-carrying capacity of a component or member within a structure or of the structure itself. Structural failure is initiated when the material in a structure is stressed to its strength limit, thus causing fracture or excessive deformations

II. STRUCTURAL FAILURE CAUSES

1) Poor communication between the various design professionals involved, e.g. engineers involved in conceptual design and those involved in the supervision of execution of works.
2) Poor communication between the fabricators and erectors.
3) Bad workmanship, which is often the result of failure to communicate the design decisions to the persons, involved in executing them.
4) Compromises in professional ethics and failure to appreciate the responsibility of the profession to the community at large could also result in catastrophic failures.
5) Lack of appropriate professional design and construction experience, especially when novel structures are needed.
6) Complexity of codes and specifications leading to misinterpretation and misapplication.
7) Unwarranted belief in calculations and in specified extreme loads and properties.

8) Inadequate preparation and review of contract and shop drawings.



III. SIGNS OF DAMAGE

1) Cracked, corroded, delaminated or flaked metal.
2) Holes, thinned or missing sections of beams or columns.
3) Bent, buckled or crushed beams or columns; missing or damaged struts or braces.
4) Damage from equipment impact.
5) Missing, loose or corroded bolts.
6) Cracked, broken or inadequate welds.
7) Bulging or deformed bin sides or tops; gapped joints.
8) Damaged building siding.
9) Cracked, broken, spalled or undermined concrete.
10) Delaminated plywood or water-weakened wooden structures.

IV. REASONS OF STRUCTURES FAIL

A. *Design Deliberations*

Construction imperfection in design and manufacturing can be extremely expensive to settle. Architectural design and construction defects cause a structure to be improper for its proposed intent. Correct structural design is significant for all buildings, but exceptionally essential for tall buildings. Therefore, civil engineers are required to be exceptionally careful and methodical in ensuring an appropriate building design that can sustain the applied loads. All failure modes need to be examined by using modern software on the subject. However, a designer and a builder cannot be wholly confident about the design.

B. *Defects Due to Inferior Workmanship*

Defects due to inferior workmanship can lead to structural damage and failure. Poor workmanship is often the origin of construction defects. Even superior quality materials, if used imperfectly, may not successfully serve the planned function, or be as durable as designed. Poor workmanship is the actual cause of most construction defects. General defects due to poor workmanship are leaking roofs, cracked floor tiles, shedding paint, and other numerous problems. Proper procedures have been created for almost every construction operation, and only implementation is required. A superior quality paint that is applied to an unclean surface is likely to fail, not because the material was substandard, but because it was used with a poor quality of work.

C. *Foundation Failure*

Many building foundations are not properly designed and constructed for the existing site soil conditions. Since suitable land is often not available, buildings are constructed on soil that has inadequate bearing capacity to support the weight of the structure. Furthermore, the near surface soils may consist of expansive clays that shrink or enlarge as the moisture content is changed. Movement of foundation may occur if the clay moistening and drying is not uniform. Vegetation, inadequate drainage, plumbing leakage, and evaporation, may cause soil variation. The top soil layers provide the bearing capacity to hold the structure, and ensure stability of the foundation. If the bearing soil is inadequately compacted preceding construction, the foundation may be affected by settlement.

V. TYPES OF FAILURE

1) The first is that the structure is not strong and tough enough to support the load, due to its size, shape, or choice of material. If the structure or component is not strong enough, catastrophic failure can occur when the structure is stressed beyond its critical stress level.
2) The second type of failure is from fatigue or corrosion, caused by instability in the structure's geometry, design or material properties. These failures usually begin when cracks form at stress points, such as squared corners or bolt holes too close to the material's edge. These cracks grow as the material is repeatedly stressed and unloaded (cyclic loading), eventually reaching a critical length and causing the structure to suddenly fail under normal loading conditions.
3) The third type of failure is caused by manufacturing errors, including improper selection of materials, incorrect sizing, improper heat treating, failing to adhere to the design, or shoddy workmanship. This type of failure can occur at any time and is usually unpredictable.
4) The fourth type of failure is from the use of defective materials. This type of failure is also unpredictable, since the material may have been improperly manufactured or damaged from prior use.
5) The fifth cause of failure is from lack of consideration of unexpected problems. This type of failure can be caused by events such as vandalism, sabotage, or natural disasters. It can also occur if those who use and maintain the construction are not properly trained and overstress the structure.

VI. CAUSES OF BAD DESIGN AND DESIGN FAILURE

A. *Internal factors/Human Errors*

The internal factors for 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 structural engineer is responsible for these failures, which are created at the drawing board. Sometimes the failure occurred due to obvious negligence, a gross human error.

B. The External Factors

These are often natural, such as extraordinary loads, heavy rains, or the shaking of an earthquake, or the winds of a hurricane and a defective site with very unusual ground conditions like sinking holes, swampy land etc. A building that is intended to stand for some years should be able to meet all those challenges and required to be incorporated in the building design.

C. Inadequate Awareness

Many structural failures have been the consequence of poor technical research and knowledge. As technical awareness gets better, errors are becoming by far the major cause of known structural collapses, mainly in technologically advanced countries. An error in this situation is a gross error or mistake, not a negligible computation error or construction divergence.

VII. Causes of Construction Failure

A. Inappropriate construction techniques

Contractor's failure to build in accordance with drawings and specifications can also add to failure of structures. Use of inferior or sub-standard building materials is another probable reason of building failures. Overloading during the life span of building can critically weaken the structural reliability of the building. Extra loads due to unauthorized change of use or additions and alterations to the structure can intensify an under- designed building and can contribute to its eventual failure.

B. Performance failures

Performance failure can be described as an intolerable difference between anticipated and existing design and construction. The engineer's design interpretation and aim must go during the construction stage in order that the structure is effectively constructed.

C. Failure may occur due to consultants' and contractors' inadequate supervision and control of site operations and quality control. Such errors ultimately lead to a situation, which may involve such failures, which are related to excavation and equipment, inappropriate sequencing, not enough temporary support; unnecessary structure weight; untimely taking away of shoring or formwork; and non-conformance to design objectives.

VIII. Causes of Materials Failure

Most of the structural failures are associated with materials and are the consequence of human blunder involving a lack of know how about materials or the combination of contrary materials. There are structural failures that can be endorsed to irregularity in materials. Although too much reliance is given on modern structural materials yet the manufacturing or production faults may exist even in the most dependable structural materials, such as standard structural steel or centrally blended concrete. Stone frontage sheets or glass curtain walls may have hidden serious faults.

IX. Cases of Structural Failure

A. Building Collapse

Part of a building in Vijayawada collapsed one early morning killing a person. On inspection, it was found that the collapsed part was constructed adjacent to the main building with 25mm expansion joint. The collapsed building was constructed on two columns. Each column has 6-16mm main steel. Load from each column is transferred to a single under reamed pile which has 6-10mm bars.
It appears that the collapse is due to three causes:

1) The overlap length of steel rods at the junction of pile & column is inadequate.
2) Structure is unstable due to number of columns used (two only)
3) Unsymmetrical wall load on the structure.

The collapse of the building could have been prevented by structurally connecting it to main building there by providing stability.

B. Collapse of a Foot–Bridge

A Footbridge in Vijayawada collapsed one day before opening & fell into the canal below killing two painters. The footbridge has a span of 40m. It consisted of two welded trusses, cross girders & precast RCC slabs. On inspection, it was found that the welding is defective.

1) Prevention

Following the provisions in IS code for structural steel fabrication would have prevented this failure.

C. Collapse of a Residential Building

One evening, a three story residential building collapsed a day before occupancy killing watchman & his family.
On inspection, it was found that one of the building columns was constructed on filled up well. The old well is filled with sand and an Isolated footing was constructed on the well. As the construction progressed, load on column increased. The foundation has settled, leading to the failure of the building.

1) Prevention

Isolated footing is a wrong choice for the foundation on the old well. For that column a well foundation should have been a better choice.

D. Vibration of Slab

Owner of a college building complained that a floor slab in one of the rooms is vibrating, when students were walking or jumping on the slab. On inspection, no structural cracks were found in the slab. The size of the slab is 8m X 9m and it is supported on four sides by beams. It is continuous on three sides. The thickness of slab was 150mm. It appears that deflection check was not done in the slab design.

1) Prevention

Generally, slab thickness is calculated based on deflection criteria. A proper design of slab may have given a safe design. The slab had failed in deflection check; however it is safe in flexure.

E. Structural Cracks in the Slab

A dining hall of size 18m X 48m was constructed with two bays in east west direction and six bays in north south direction. Size of each slab is 8m X 9m and the slabs were designed as two way slabs. 1mm wide cracks developed in the slab at the location of maximum negative bending moment.

On inspection, it was found that the structural design was correct. Non-destructive tests revealed that concrete had required compressive strength. Thickness of slab was adequate from consideration of flexure & deflection. On further investigation, it was found that the top reinforcement has a clear cover of 130mm instead of 20mm. since the top steel is placed close to neutral axis, it became ineffective in carrying negative bending moment and hence the slab cracked at all the supports.

It is apparent that the rod bender fabricated the steel for 150mm thick slab and the site engineer did not understand the importance of top steel bars.

The slab became two way simply supported slabs instead of two way continuous slab. The dining hall is still functional. But before another floor is added the slab should be checked.

1) Prevention

Inspection of steel by structural engineering before placing concrete would have prevented this failure.

F. Cracks in Walls

In one of the college buildings, diagonal cracks were observed in many walls. The cracks pattern did not fit the standard cause of wall cracks. Structural analysis of the building was performed using STAAD pro software. From the analysis results, it was apparent that the frame did not meet the deflection criteria even though the beam has satisfied the deflection criteria.

Due to Architectural reasons, the columns were oriented in the frame along minimum moment of Inertia. The excess deflection of beam & column has caused the cracks in brick walls.

1) Prevention

Deflection of frame should be checked for safe design

G. Due to high wind pressure the structure collapse

COLLAPSED BARN AT HORSNE, SWEDEN

H. In the areas of heavy snowfall, the weight of the snow is on the structure. This may cause failure of structure.

Causes of failure are:

1) Insufficient or lacking lateral bracing.
2) Trapezoidal sheet steel roof plates with insufficient capacity or wit incorrect joints/ fastenings.

BUILDING COLLAPSE DUE TO SNOW WEIGHT

SVEN THELANDERSSON, SWEDEN

Accidents and many failures caused in these types various structural failures that have reached limit state of collapse & serviceability are the failures presented here:

1) Limit state of collapse due to stability
2) Limit state of collapse due to welding
3) Limit state of collapse due to unsatisfactory filling of old well
4) Limit state of serviceability due to excess deflections
5) Limit state of serviceability due to incorrect fabrication of steel
6) Limit state of serviceability due to orientation of columns

X. PREVENTIVE MEASURES

Supervisors can take measures to help prevent these potentially catastrophic incidents.

A. Good Housekeeping

Structural damage can go undetected due to poor housekeeping; accumulations of wet material can cause corrosion. Remove spillage from around the base of structures, columns and off the flanges of horizontal beams. Prevent further spillage and damage by front-end and skid-steer loaders and forklifts.

B. Inspections

Safety and supervisory personnel should inspect structures during audits, and miners should be trained to notice and report potential structural problems. Periodically, a structural engineer should perform a formal assessment of structural integrity. Examine steel, concrete, wood, masonry, aluminum and fiber reinforced polymer. Take all appropriate personal safety precautions while performing inspections, such as using fall protection at height and following safe confined space entry procedures.

C. Report and Repair

Occupants should report suspected damage and should take all reports seriously, determine the validity of each concern and take appropriate action. A qualified engineer should be consulted when there is any doubt. Barricade and post warning signs at affected areas and prevent entry pending repairs or rehabilitation.

D. New or Modified Construction

A registered professional engineer should design or review new or modified structures and equipment. New construction, and modifications to or demolition of existing facilities, should be performed by competent persons using accepted safe procedures and equipment and tools appropriate for the work.

XI. CONCLUSION

Structural integrity can be taken for granted, but failures can be sudden and unforgiving. Slight probability of failure is not acceptable since the results can be disastrous for human life and property. Care should be taken during construction and after construction.

Identification of the characteristics of particular site conditions by the engineers/consultants, through suitable geo-technical studies, can guide decisions about site selection and site progress that reduce the risk of failure.

Appropriate factor of safety is incorporated on the design calculations. Quality of material used should be checked. The workers should be skilled and supervisor must take care that the work is completed following the basic rules.

Structural failures are sudden and cannot be avoided but proper preventive measures can be taken to avoid them. Good supervision and proper construction can help avoid sudden failure of structures and accidents damaging live of people and property.

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