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*Research Article*

# Quality Analysis on Leaning Tower of PISA

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***Abstract***

*When it comes to Construction industry, Quality is quite important. It matters a lot to the Construction Project. The quality of a product, which relates to the perception of the degree to which the goods or services matches the customer's expectations. There are several approaches for improving the quality of construction projects. Some of the modern tools include Fish Bone Diagram, Deming Cycle, Histogram, Flowchart, Decision Matrix etc. In this Case study on the leaning tower of Pisa, the quality element of the construction is described utilising inventive and flexible tools and techniques. The Fish Bone Diagram, Deming Cycle, and Flowchart were used to analyse tower of Pisa case study. When compared to other methods of analysis, all of the approaches used yielded similar results, and the process was likewise straightforward. The cost and time it took to complete the structure would have been decreased if these tools had been approved at the time of construction.*

***Keywords:*** *Leaning tower of Pisa; Quality Analysis; Quality tools; Fish bone diagram; Deming's cycle; Flow chart.*

## Introduction

Quality management in construction is the policies, processes and procedures put in place to improve an organization's capacity to deliver quality to its customers. Construction quality refers to a project's achievement within the scope of work's established parameters. The quality document acts as a set of guidelines for the project based on the owner's expectations, and it explains how to carry out the project in accordance with these guidelines.

The quality tools adopted for analysing and detecting the defects of quality are Fish borne diagram, Deming's cycle and Flow chart. Fish borne diagram, Deming's cycle and Flow chart are the quality tools used to analyse and detect quality issues. The fish borne diagram can aid with brainstorming and sorting ideas into relevant groups, as well as identifying possible causes of an issue.

In Deming's cycle the Deming wheel of continuous improvement spiral and a logical sequence of four recurring phases for continuous improvement and learning: Plan, Do, Check and Act.

## Factors Affecting Quality in Construction

### Pre construction

- Storage facilities
- Carriage or transport facility
- Improper Planning
- Improper Designing
- Contract Management
- Site Management
- Decision Making
- Construction Methods
- Failure to document changes and practices
- Lack of project management system
- Prepare Estimation and budgets
- Building Permits
- Acquire land and site clearance

### Procurement

- Skill set and experience of labor
- Availability of needed raw materials
- Quality of available equipment and raw materials
- Site management
- Supplier and vendor failures
- Accessibility to the site (lead time)

### Construction Phase

- Escalation of material prices
- Site management
- Complexity of design and project
- Unanticipated Site condition
- The perspective of site workers towards work
- The condition of Weather
- Construction mistakes & defective labour work
- Subcontractor mishandling and delay
- Last minute Changes

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- Scope Creep
- Ignored testing
- Safety and risk management
- Adherence to milestone
- Labour stress in Productivity

### Commissioning and O &M

- Finance and payment of completed work
- Ignored audits
- Constructing mistakes and defective work
- Building Warranty period

In addition to these factors, there are also few more factors which affect the quality of construction throughout the stages. They are listed below:

- Improper communication
- Major disputes and negotiation
- Contract duration
- Employee satisfaction

### Basic analysis

Experts disagree over whether the lean was intentional by the architects or caused by structural issues with the soil at the tower's base.

Tests undertaken in the twentieth century, on the other hand, have convincingly proven that the inclination began after the building.

The subsoil was studied, and underground rivers had washed away an inter-layered clay-type material. The foundation for the Tower of Pisa, made mostly of marble and lime, was laid in 1173; the tower was built in a five-foot-deep circular trench over clay, fine sand, and shells.

An interaction between the clay, fine sand, and shells used to build the tower causes the lean. The south side of the soil mix is more compressible, but the Tower of Pisa stopped sinking and began to rotate as the tilt rose, causing the north side to ascend toward the surface.

### Analysis using Quality Tools

### Fishbone Diagram

The Ishikawa diagram, often identified as the fishbone diagram, is a cause-and-effect diagram that helps managers figure out where flaws, variances, problems, and failures come from. The graphic looks like a skeleton of a fish, with the problems at the top and the causes of the problem running down the spine.

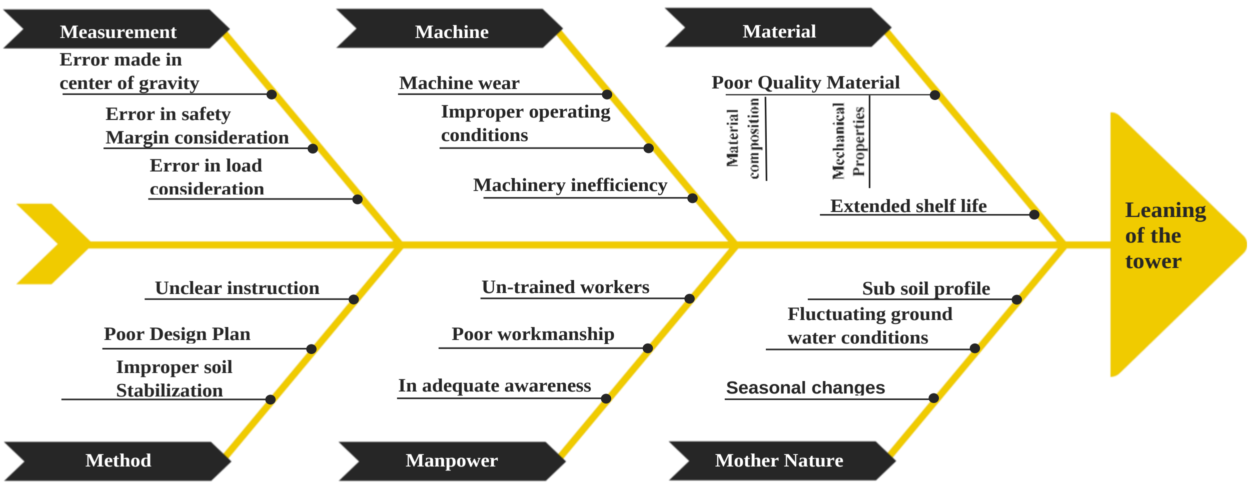


**Figure 1:** Fishbone Diagram

Once all of the sources of the problem have been recognised, managers can begin looking for remedies. This will prevent the problem from recurring. As a result, the fishbone diagram is a great tool for spotting and avoiding quality problems before they happen.
In this case study, we have considered 6M's which are used to label the different branches on the diagram as below:

- Man is someone who is a part of the construction and contributes to the outcome
- Methods in which the process is carried out and the specific requirements for carrying it out, such as policies, procedures, rules, and common practises.
- Machines includes the equipment and tools required to complete the work
- Materials include all of the raw materials, parts, papers, packing, and consumables needed to complete the construction.
- Measurements includes the information used to assess the project's performance
- Mother Nature(or Environment) is the project's operating conditions, including location, time, temperature, and culture

Based on 6M's fish borne diagram cause and effect of the case study is found out as below.

It is highly clear from figure 1 the various sources and means through which the leaning of the tower would have took place. Although the effect was due to faults from all branches, it is evident that the major cause is due to the soil nature, method of construction and Measurements. The soil profile by nature was weak and composed of soft soil. On addition to this, there was a regular fluctuation in ground water level.

As a subsequent measure, proper and intense care should have been taken during the foundation phase. The load considerations such as wind load, seismic loads and the normal load of the building with respect to the soil type should have been done with intense care and accuracy. Also, special Soil stabilization techniques, regular monitoring and proper communication with the labours would have led to smooth functioning of the tower.

These categories were finalised as the causes as they were able to satisfy the 5 WHY technique.

Why Leaning of the Tower? - Poor Soil Stabilization
Why Poor Soil Stabilization? - Poor Workmanship
Why Poor Workmanship? - Improper Instruction
Why Improper Instruction? - Improper Design
Why Improper Design ? -Poor load and soil Consideration

From fish bone diagram and 5 WHY technique, it is inferred that poor soil condition and improper load considerations are main reasons for the leaning of the tower.

**Deming Cycle**

Deming Cycle is an iterative four-step management method used in Construction projects for the managing and continuous improvement of processes.

With the use of a case study, we've demonstrated the various phases of Deming Cycle. We would aware of the aspects that might be impacted, such as time, money, and so on. Because of the repetitious process, for example, here, modifications must be planned over a longer period of time, and as a result of these changes, a significant amount of money must be spent.

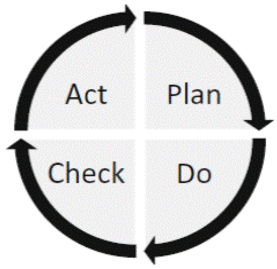


**Figure 2:** Deming Cycle

**Deming Cycle Analysis**

| | Cycle 1 | Cycle 2 | Cycle 3 |
|---|---|---|---|
| PLAN | Aim: Stabilizing the leaning Tower of Pisa<br>Cause: The cause of the lean is due to a reaction of the composite of clay, fine sand, and shells that the tower is built on. | | |
| DO | Solution:<br>Install a 660-ton counterweight on the north side of the tower base to stop the rotation. | Solution:<br>Inserting Frozen steel cables and the subsoil. | Solution: The soil is mainly obtained from two layers of earth: the upper layer of sandy soil and the second from sea clay. When the sandy soil is removed, the soil compresses and the clay hardens, creating a stronger base.<br>The drills 21 centimeters in diameter, extract soil from inside a drill casing without disturbing anything outside it. The cavity shuts very softly when the drill is retracted. The ground then settles, forming a cradle that cushions the tower as it shifts slightly to the north. |
| CHECK | Performance: It failed. | Performance: This increased the lean of the structure. | Performance: Using this method engineers have reduced the lean back toward the center by 50 centimeters, where it was in 1838. The top of the tower now slopes a little more than 4 meters off-center. |
| ACT | Lesson: The problem did not resolve as the solution did not target the core root cause of the problem. The counter weight construction created additional cost and had a adverse effect on the leaning of the structure. | Lesson: The problem lie below the ground level and the action below the ground on the north side would solve the problem faced.<br>Temporary solution: As a part of temporary solution the counter weight increased to 960 tons from 660 tons on the north side of the tower | Lesson: the process of soil extraction could be repeated.The tower straightened itself by 38cm after the work was done and has continued to straighten. |

**Flow chart**

Flowchart is a pictorial representation of Sequence of Activities to obtain a solution for a given problem.

It aids in the visualisation of what is happening and what will be processed, allowing users to grasp the process more readily. Using flowcharts as basic quality tools brings to mind symmetrical diagrams that show a systematic approach to ensuring quality.

We can use the flow chart provided to the engineers in the given case study to gain a better grasp of the restoration process.

The first step is to conduct error-free survey and gather data. If the information gathered is insufficient, more research will be conducted. The reasons for the structure's deformation, as well as the fixes for the defects, are sketched out. A strategy for putting the offered ideas into action is devised.

Keen inspection during the execution phase is conducted so to ensure that the entire structure does not fail. If successful, the results are analysed and reported. Further research is also done to keep track of the structural stability. The flow chart proposed for this case study is represented in Fig 3.

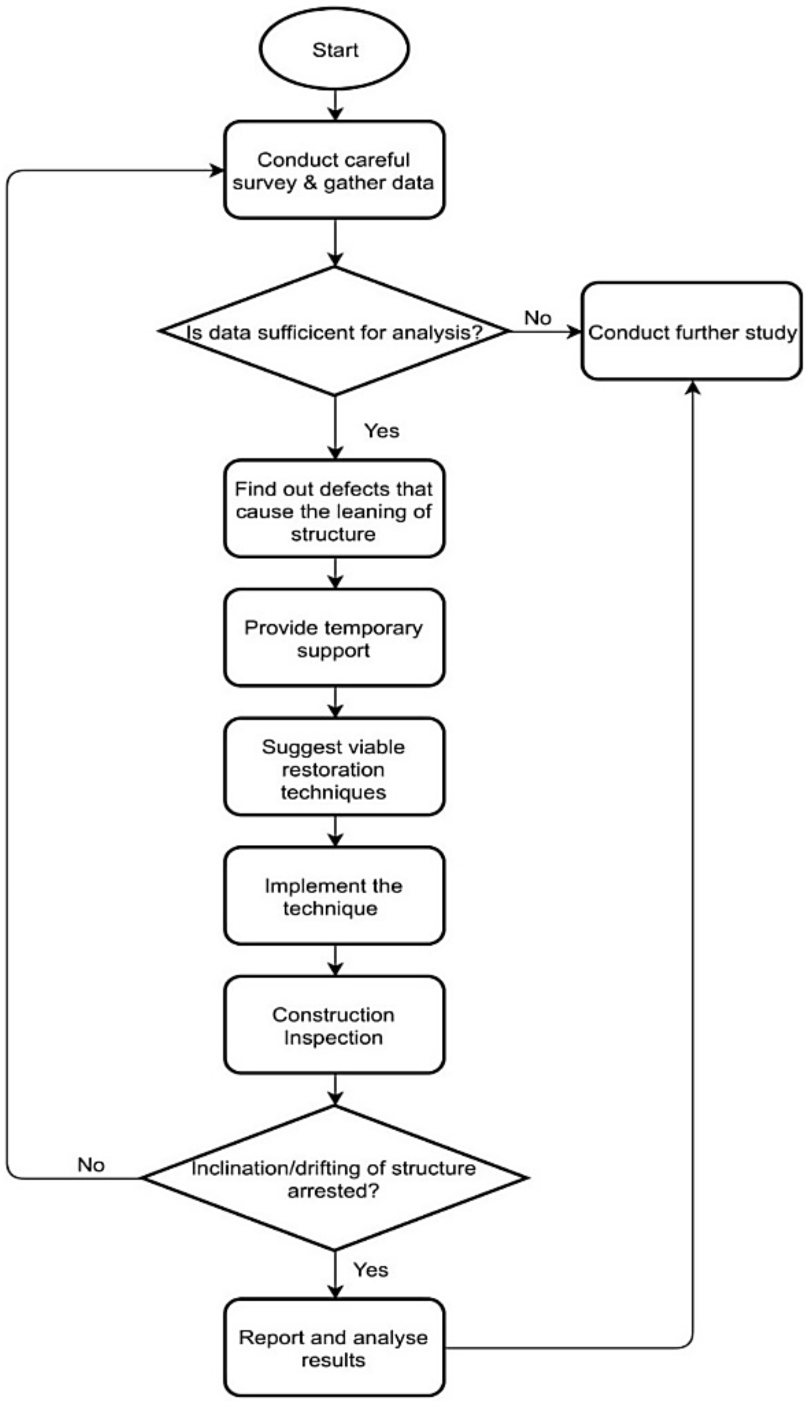


**Figure 3:** Flow Chart

## Conclusion

The Architects initially planned the Leaning Tower of Pisa as a Bell Tower, but it is now recognised as a World Heritage Site. The explanation for this is that the structure has been tilting for ages. It is undeniable that numerous serious errors were made before to and during construction, causing the structure to lean.

In this case study, thorough analysis was made on quality aspects using modern techniques and tools. The following observations were made.

The Fish Bone diagram reveals that improper soil stabilization and poor load considerations were the basic cause for the structure to lean.

The 5 WHY Technique also shows that poor soil and load considerations are the reason for the existing condition.

The PDCA cycle, on a constant analysis shows that through continuous stabilization of the soil and proper design of the foundation, the leaning of the structure has come to a halt.

The Flow Chart reveals the analysis process in a clear and distinct manner. When compared to other methods of analysis all of the approaches used yielded similar results, and the process was likewise straightforward. The cost and time it took to complete the structure would have been decreased if these tools had been approved at the time of construction.

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