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Root Cause Analysis Of Accidents In Infrastructure Project

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ABSTRACT

This paper is focused on the identification of the underlying causes of large-scale infrastructure accidents in India based on a comparative analysis of Morbi Suspension Bridge collapse (2022), Delhi Metro bridge collapse (2009), and Silkyara Bend–Barkot Tunnel collapse (2023). Qualitative multiple case study design was used in the research, where secondary data taken from investigation reports, technical literature, academic researches and other publicly accessible sources were analyzed. The research techniques that were used included 5-Why technique and Fishbone Analysis for identification of the immediate causes, contributory factors and root causes of the studied events. Based on the obtained results, one can conclude that despite of the various technical triggers of the accidents – structure failure, temporary works failure, and geological instability – similar organizational problems were found among the cases. Risk assessment, safety planning, supervision, safety audit, regulation and emergency planning proved to be the major contributory factors. Management failure proved to be one of the major root causes, confirming that infrastructure accidents are not only due to technical issues.

Keywords: Infrastructure Safety; Root Cause Analysis; Construction Accidents; Safety Management; Risk Assessment; 5-Why Technique; Fishbone Analysis

1. INTRODUCTION

Projects related to the construction of bridges, metro railways, tunnels, roads, and other large-scale infrastructure facilities not only provide connectivity but also assist in the development of the economy. But with the growth in the complexity of infrastructure projects, there has been an increased level of safety concern. Safety hazards in infrastructure projects may lead to casualties, injuries, damages, monetary losses, delays in the project, and even loss of trust among the people. Infrastructure accidents not only involve technical defects, but their occurrence is dependent on several human, managerial, organizational, environmental, and regulatory factors.

Root Cause Analysis is a methodology which involves systematic investigation of accidents and finding out what allowed those accidents to happen. The methodologies used under Root Cause Analysis include 5-Why Analysis and Fishbone Analysis. With the help of these techniques, researchers are able to find out the relationships between the causes and the classification of the factors as human behavior, equipment, methods, materials, management, and environment. This methodology is very much applicable in the context of infrastructure projects as accidents are a consequence of multiple interrelated causes.

Several studies have stressed the significance of risk assessment, safety management, project complexity, and organizational control in preventing construction accidents. Recent research work has indicated the special importance of technical complexity, geology uncertainties, temporary works, supervisory problems, and interconnected project management in the case of tunnel and metro projects. But little amount of research has been done on root cause analysis in infrastructure projects in India.

1.1 Background of the Study

Infrastructural Development is one of the key drivers of economic and social development of any country. In the modern times, infrastructure development involves building bridges, highways, metro rail lines, tunnels, and airports. Such infrastructure development is particularly important in developing countries like India which have witnessed major construction due to national initiatives such as Smart City Mission, Bharatmala Pariyojana, Sagarmala, Metro Rail projects, and National Infrastructure Pipeline of NITI Aayog during the past two decades.

In spite of advancement in technology and engineering practices, infrastructure development still faces incidents leading to loss of lives, injuries, destruction of properties, delay in the completion of projects, and monetary losses. For instance, the incidents of bridge collapses, metro rail accidents, tunneling mishaps, and accidents due to use of cranes reflect that there are problems associated with safety management and risk management in such projects. The facts regarding past incidents of accidents in infrastructure developments indicate that such accidents are not only due to technical reasons; there are usually multiple reasons behind such accidents which include design issues, human error, management issues, poor communication, poor compliance of regulations, and poor safety management culture in organizations.

Root Cause Analysis (RCA) is a systematic technique for finding out root causes of accidents rather than symptoms of accidents. Through RCA, an accident can be traced back to its contributing causes and appropriate preventive measures can be developed.

1.2 Need for the Study

Despite the availability of sophisticated safety guidelines, codes, and management practices, accidents during infrastructure construction have been a recurring issue. In most cases, the analysis of such accidents has only paid attention to technical reasons for accidents without taking into account organizational and managerial factors that may contribute to the occurrence of accidents. The current Indian cases of infrastructure accidents have revealed that lack of adequate planning, supervision, risk assessments, management of temporary works, and regulatory control significantly enhance the probability of accidents.

1.3 Problem Statement

Infrastructure construction is a multifaceted process that entails engineering systems, numerous stakeholders, dynamic construction sites, and hazards related to safety issues. Despite improvements in engineering systems and construction technologies, accidents on the scale of bridges, metros, and tunnels still take place. While nearly all accidents are associated

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with some technical trigger, recent studies show that there is an equal or even more important part played by organizational factors, including poor risk assessment, poor safety management, poor supervision, non-compliance with regulations, and lack of safety culture. There is no scientific literature analyzing accidents from the perspective of the same analytical framework for infrastructure construction sectors.

2. LITERATURE REVIEW

Medaa, Shirzadi Javid, and Malekitabar (2025) undertook a systematic literature review of the various risk analysis techniques used in construction disasters and the studies on construction accidents conducted from 2010 to 2025. In their research, they carried out a literature review of the development of risk analysis techniques and identified the various risk analysis techniques that have been used to study the hazards of construction projects. They established that construction accidents were caused by various interconnected factors such as technical, organizational, and human factors rather than single causes.

Sharma, Agarwal, and Dwivedi (2025) Conducted an analysis of major accidents that occurred in tunnels, with the aim of finding out the causes of such accidents, learning lessons, and recommending ways of ensuring tunnel safety. In their analysis, they considered various types of accidents and discussed the role of geological factors, poor safety practices, lack of monitoring, and risk management deficiencies. They recommended that for effective tunnel safety, there was need for hazard identification, proper support system, monitoring, and contingency plans. They concluded that lessons from past accidents could be very helpful in preventing future accidents.

Sruthilaya, Vilventhan, and Gopal (2024) studied complexity factors in metro rail projects and examined the relationship between those factors. This study highlighted various complexity factors and then explored the interaction between those factors during implementation of metro rail projects. It was found that factors such as technical, organizational, managerial, stakeholder, and environmental ones had impacted complexity. It has been proven through this study that factors related to a project can interact and cause uncertainties that impact project performance and safety. This study is significant for accident analysis in infrastructure because it has been established that an accident caused in metro projects cannot be blamed on a single technical factor.

3. RESEARCH METHODOLOGY

For the current study, the qualitative multiple case study methodology was chosen in order to analyze the basic reasons behind the accidents that occurred in the country's infrastructure. The secondary data collected from the investigation reports, technical journals, research papers, and other relevant sources was used for analysis. Three major cases of Morbi Suspension Bridge Collapse, Delhi Metro Bridge Collapse, and Silkyara Tunnel Collapse were considered in this context.

3.1 Research Design and Approach

The current research uses qualitative multiple case study methodology, chosen because of its ability to analyze accidents, reveal the mechanism of accident formation and facilitate comparisons between cases. Case study methodology allows more profound analysis of decisions and behavior of organizations, which are key elements of research focus in comparison with pure quantitative methodology. Research process included such stages as case study selection, secondary data collection and validation, construction of accident chronology, RCA methods implementation, root cause determination and comparison and prevention recommendations formulation.

3.2 Data Collection

This study is based on secondary information gathered from reliable sources such as government inquiry reports and SIT reports, industry journals and construction safety literature, academic journals and papers presented at conferences, and reliable newspaper and media reports. The use of different sources helped to cross-verify important facts.

3.3 Case Selection

These cases have been chosen on the basis of five characteristics, namely the seriousness of the accident in terms of life lost or injury sustained; relevance to bridges, metro or tunnels; adequate availability of investigatory and technical data; variety of accident types; and the significance at the national level. The three cases that meet the above characteristics include: The Morbi Suspension Bridge Collapse in Gujarat in 2022; The Zamrudpur Delhi Metro Bridge Collapse in 2009; and The Silkyara Bend – Barkot Tunnel Collapse in Uttarakhand in 2023.

3.4 Root Cause Analysis Framework

A systematic six-step approach to RCA was systematically utilized for each accident case:

Step 1 – Data Collection: Collection of factual data, chronology of events, and technical data associated with the accident.

Step 2 – Accident Narration: Writing of an accurate account of how the accident occurred.

Step 3 – Identification of Immediate Causes: Determination of the technical cause of the incident.

Step 4 – 5-Why Analysis: Asking of causes repeatedly until the cause-effect chain ends in the root cause.

Step 5 – Fishbone Analysis: Listing of the contributory factors in Man, Machine, Method, Material, Management, and Environment categories.

Step 6 – Root Cause and CAPA Identification.

4. CASE STUDY AND ANALYSIS

In this part of the report, we conduct an analysis of major infrastructure accidents in India, namely, the Morbi suspension bridge collapse, the Delhi Metro bridge collapse, and the Silkyara Bend – Barkot tunnel collapse. Each of these accidents is analyzed on the basis of Root Cause Analysis in order to determine the causes and factors leading to the accident.

4.1 Case Study 1 — Morbi Suspension Bridge Collapse (2022)

On October 30, 2022, a tragic collapse of the Morbi Suspension Bridge in Gujarat led to 141 fatalities and 180 injuries. The bridge had been renovated recently but had not been issued a formal fitness certificate for structural strength. Over 500 people were using the bridge at one

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time, although its capacity was only around 125 people. The investigation revealed that the bridge suffered from poor maintenance, rusting of cables supporting loads, lack of testing of new parts, and lack of proper visitors' regulation.

Table 1: Root Cause Analysis of Morbi Suspension Bridge Collapse

RCA Dimension	Identified Finding
Immediate Cause	Structural failure of the suspension system
Technical Factors	Corroded suspension cables, inadequate testing, excessive loading
Human Factors	Poor crowd management and inadequate supervision
Method Factors	Absence of adequate load testing before reopening
Management Factors	Ineffective operational safety management and maintenance oversight
Regulatory Factors	Reopening without formal fitness certification
Environmental Factors	Peak festival-season crowding
Root Cause	Failure of management and inadequate regulatory oversight

From Table 4.1, the Morbi Bridge disaster is a result of the combination of technical, human, management, and regulatory failures. Though the immediate cause for the failure is the collapse of the structure caused by the suspension system, the underlying factors include corrosion of the cables, overcrowding of people on the bridge, lack of testing, and ineffective crowd management. The lack of a fitness certificate prior to opening the bridge again clearly shows that there was a regulatory failure.

4.2 Case Study 2 — Delhi Metro Bridge Collapse (2009)

A launching girder along with its temporary structures collapsed on July 12, 2009 at Zamrudpur site while constructing Delhi Metro Central Secretariat-Badarpur Corridor. This incident caused the death of six people and many more got injured. This failure was due to the flaws in the design, checking, reviewing, and monitoring of temporary structures.

Table 2: Root Cause Analysis of Delhi Metro Bridge Collapse

RCA Dimension	Identified Finding
Immediate Cause	Failure of the temporary support system
Technical Factors	Structural inadequacy and overloading of temporary support
Human Factors	Insufficient site supervision
Method Factors	Deficiencies in erection and construction procedures
Management Factors	Weak inspection, review, and safety management
Regulatory/Engineering Oversight	Inadequate design review and monitoring
Environmental Factors	Constrained construction-site conditions
Root Cause	Inefficient management of temporary works and engineering oversight

As per Table 4.2, the failure was mainly due to problems associated with temporary work management. While structural overloading was one of the reasons for the collapse, it was basically the failure of the support system that led to the collapse. It was due to poor site management and safety control measures that the problems were not resolved. Therefore, it can be said that the technical problem was the immediate cause, whereas the engineering problems were the deep-rooted causes.

4.3 Case Study 3 — Silkyara Bend–Barkot Tunnel Collapse (2023)

The Silkyara Bend-Barkot tunnel in Uttarkashi of Uttarakhand collapsed on 12 November 2023, and 41 people working there were trapped in it. This tunnel had been built in weak and fissured geological conditions without any escape shaft for the workers in case of an emergency.

Table 3: Root Cause Analysis of Silkyara Bend–Barkot Tunnel Collapse

RCA Dimension	Identified Finding
Immediate Cause	Failure of the tunnel roof
Technical Factors	Weak and fractured rock formation
Human Factors	Limited on-site geotechnical expertise
Method Factors	Inadequate excavation and ground-support planning
Management Factors	Inadequate risk management and emergency planning
Monitoring Factors	Absence of real-time monitoring system
Environmental Factors	Active geological fault zone
Root Cause	Inadequate geotechnical risk management

Table 4.3 shows that geology instability served as the trigger; however, the impact level of the event was affected by poor risk management in the geotechnical aspect. The poor condition of the rock strata demanded the provision of support systems; however, problems with geotechnical risk analysis, excavation process, and emergency response were found out. Lack of the emergency escape hole made the situation more hazardous for the miners. Consequently, the main reason of the failure was poor risk management and analysis in the geotechnical aspect.

5. COMPARATIVE ANALYSIS AND DISCUSSION

Comparison of the Infrastructure accidents has been carried out in three instances namely Morbi Bridge, Delhi Metro and Silkyara Tunnel to find out the common underlying causes of the accidents. While each of these accidents was triggered by a unique technical cause, it is clear that each of them lacked in terms of management, risk assessment, supervision and audit of safety measures.

5.1 Comparative RCA Findings

Cross-sector causes for the occurrence of infrastructure accidents are reflected in Table 5.1. Technical malfunction and human element have occurred in all three types of cases, whereas managerial failure is rated High in all instances. Risk assessment and safety audit failures are also common to the bridge, metro and tunnel cases.

Table 4: Comparative Root Cause Analysis of the Three Infrastructure Accidents

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Parameter	Morbi Bridge	Delhi Metro	Silkyara Tunnel
Technical Failure	Present	Present	Present
Human Error/Factor	Present	Present	Present
Management Failure	High	High	High
Regulatory Deficiency	High	Moderate	Moderate
Safety Audit Inefficiency	Present	Present	Present
Risk Assessment Inefficiency	Present	Present	Present
Emergency Preparedness Deficiency	Moderate	Moderate	High
Dominant Root Cause	Management & regulatory failure	Temporary-works management & engineering oversight	Geotechnical risk management

In the Morbi incident, regulatory inadequacy was highly prevalent, while emergency preparedness was notably lacking in the Silkyara Tunnel incident. Though the technical causes were different, the comparative study showed that there were common underlying causes such as lack of planning, supervision, risk management, etc.

5.2 Technical Factors

The above three cases illustrate different technical failures that occurred because of different factors. For instance, the case of Morbi had failure due to structural decay, cable corrosion, and overloading, while the accident at Delhi Metro was due to instability of temporary works. Finally, the failure at Silkyara was due to poor geological conditions and insufficient support to the soil. Nevertheless, these technical aspects alone do not constitute a cause.

5.3 Human Factors

Human factors were involved in all three accidents in terms of poor supervision, lack of competency, poor communication, improper decision-making, and underestimating hazards. The human factors combined with the organizational deficiencies, and affected the implementation of safety procedures.

5.4 Management Factors

Management failure was common to all three incidents. Poor safety planning, poor risk assessment, poor supervision, tardy corrective measures, and the lack of independent audits provided an environment in which any predictable hazard was left unchecked. These results thus justify the position that management failures can create conditions through which technical and human failures culminate in disasters.

5.5 Regulatory and Governance Factors

The weak regulatory system is also revealed, especially with regard to inspections, enforcement, safety certification, taking corrective measures, and accountability. The Morbi accident case is the best evidence here since the bridge was reopened despite the lack of necessary safety certification after renovation.

6. CONCLUSIONS

The study aimed at identifying the main causes of major Indian infrastructure accidents by means of root cause analysis and drawing practical safety recommendations based on the results. In fact, the empirical evidence shows that major infrastructure accidents are never caused by one factor; on the contrary, they occur due to a gradual degradation of several safety barriers over time, which is in line with modern theories of accident causation like the Swiss Cheese Model and Bird's Loss Causation Model. Technical defects could easily be identified in the aftermath of the accidents, but organizational and management failures turned out to be even more important factors contributing to accident causation in all three accidents analyzed. The Morbi Bridge case demonstrates the importance of poor safety governance since the bridge was re-opened without proper safety certification and without any occupation restrictions and control over the activities of the repair company. The Delhi Metro accident demonstrates the risks associated with low safety priority attached to the temporary facilities under construction.

7. FUTURE SCOPE

- Future studies can analyze a larger number of infrastructure accident cases.
- Research can cover bridges, tunnels, metro projects, and highways.
- Advanced technologies such as artificial intelligence and real-time monitoring can be explored for early risk detection.
- Comparative studies of safety regulations can help improve accident prevention.
- Future research can focus on strengthening safety management and regulatory oversight.

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