

Forensic Engineering: Need for Structural Failure Investigation in India- A Review

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Abstract: Failures in buildings are frequent occurrences. Poor construction practices, coupled with inadequate material handling, can result in failures and defects within structures, such as building collapses, which may lead to significant losses in resources, time, and finances, as well as endanger lives. Therefore, to comprehend the factors contributing to building collapses, it is essential to examine forensic engineering and legal investigations related to structural failures, aiming to reduce such incidents. Forensic engineering involves the analysis of materials, products, structures, or components that fail or do not function as intended, resulting in damage to public safety and property. Currently, in foreign countries, forensic engineering is evolving into a specialized field for professional practitioners who can assess structural failures and identify responsible parties. In contrast, India is witnessing an increasing demand for forensic engineering, especially within the industrial sector, as the complexity of infrastructure projects and manufacturing processes requires precise analysis of accidents and failures. However, it still encounters challenges such as a lack of standardized practices, qualified professionals, and sufficient infrastructure to fully harness its potential. This study addresses this gap and outlines the necessary steps to enhance awareness of forensic engineering, reduce the likelihood of structural failures, and identify and punish the parties that are responsible.

Keywords: Forensic Engineering, Structural Failures, Building Collapse, Legal Investigation.

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I. INTRODUCTION

Failures in buildings are common phenomena. The poor construction along with improper material handling may lead to failures and defects in structure such as building collapses which can cause unnecessary loss of resources, time, money along with damage to life.^[1] Hence to understand the factors behind the building collapses we need to study forensic engineering and legal investigation in structure failures so that such failures could be minimised. Forensic engineering is the study of material, products, structure or components that fails or doesn't operate or function as designed, causing damage to public and property.^[2]

Forensic Engineering is a specialized branch of engineering that deals with the investigation of failures, accidents, and other performance problems related to engineered systems. It applies engineering principles, scientific methods, and analytical techniques to determine how and why a structure, material, machine, or component failed, especially when such failures lead to legal disputes, safety concerns, or loss of life and property.^[3]

Forensic engineers play a crucial role in the investigation of structural failures, including the collapse of buildings, bridges, flyovers, dams, and towers. Their work commences following a failure and centres on the scientific identification of the cause, mechanism, and accountability

related to the incident.^[4] Such investigations are imperative when failures lead to loss of life, injuries, property damage, or legal conflicts.

In present scenario in the foreign countries the forensic engineering has become is evolving into a designated field of professional practitioners so that they can determine the structural failures and identifying the parties responsible.

But In India, forensic engineering is currently experiencing a growing demand, particularly in the industrial sector, as more complex infrastructure projects and manufacturing processes necessitate accurate analysis of accidents and failures, but still faces challenges related to a lack of standardized practices, qualified professionals, and adequate infrastructure to fully utilize its potential.^[5] The present article deals with this gap and what are the steps to be taken to expand the awareness about forensic engineering, minimize chances of structure failures and identify and punish the parties responsible.

II. CASE STUDIES HIGHLIGHTS THE NEED FOR STRUCTURAL FAILURE INVESTIGATIONS

➤ *Morbi Suspension Bridge Collapse, Gujarat (2022)*

The Morbi suspension bridge spanning the Machchhu River unexpectedly collapsed, resulting in the deaths of more than 130 individuals. The bridge had recently been renovated and was reopened to the public without proper safety certification. Initial investigations indicated issues such as overloading, inadequate maintenance, and design deficiencies. Forensic engineering was crucial in assessing cable failures, load capacity, material quality, and renovation practices to ascertain accountability.

➤ *Kolkata Vivekananda Flyover Collapse (2016)*

The collapse of the Vivekananda Flyover in Kolkata on 31 March 2016 is regarded as one of the most devastating infrastructure failures in India, highlighting the urgent necessity for forensic engineering in the realms of construction, monitoring, and failure analysis. The flyover was designed as a 2.2 km long elevated roadway aimed at alleviating traffic congestion in North Kolkata. At the time of its collapse, the project was still under construction and had already encountered several delays. During the peak hours of the afternoon, a significant section of the flyover near Girish Park unexpectedly gave way, resulting in the crushing of vehicles and pedestrians below.

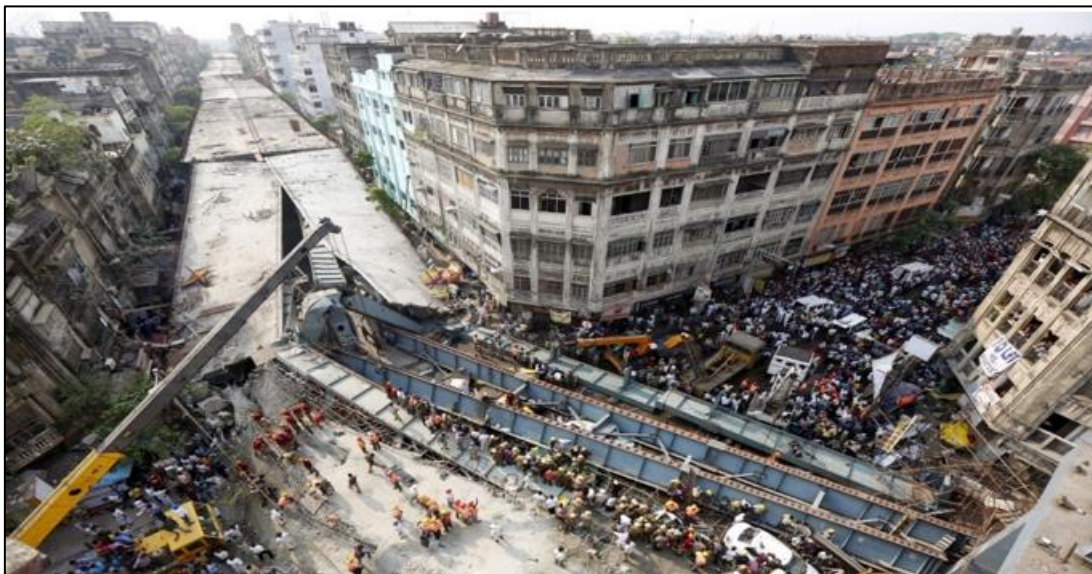


Fig 1 : Kolkata Vivekananda Flyover Collapsed

This tragic event led to the loss of 26 lives and left over 90 individuals injured, in addition to causing substantial property damage. The collapse not only resulted in a human tragedy but also severely disrupted traffic flow and economic activities in the city for a prolonged duration.

Investigations conducted after the accident revealed that the collapse was mainly attributed to deficiencies in structural design and failures during the construction phase. Reports indicated that cantilever spans were built without sufficient temporary supports, resulting in instability.

Additionally, the application of incorrect construction sequencing and potential deviations from the approved structural drawings further compromised the integrity of the structure.

➤ *Delhi Lalita Park Building Collapse (2010)*

The collapse of the Lalita Park building in East Delhi on 15 November 2010 stands as one of the most catastrophic residential structural failures in India. This incident starkly revealed significant deficiencies in design, construction, regulation, and safety oversight, highlighting the critical

necessity for forensic engineering in urban construction and investigations following failures. The structure that collapsed was a four-storey residential building situated in a densely populated region. The building fell unexpectedly during the early morning hours when the majority of

residents were present inside. This disaster led to the loss of over 60 lives and caused numerous injuries, in addition to extensive damage to property. Rescue efforts faced considerable challenges due to the narrow streets and the precarious state of nearby buildings.



Fig 2: Lalita Park Building Collapsed

Investigations have uncovered that the building was erected unlawfully, with several additional floors constructed without the necessary authorization from local government officials. The foundation and structural design were found to be insufficient to bear the heightened load. The use of substandard construction materials, fragile concrete, and lack of adequate reinforcement were recognized as significant contributing elements.

➤ *Chennai Moulivakkam Twin Tower Collapse (2014)*

The collapse of the Moulivakkam twin towers in Chennai, Tamil Nadu, on 28 June 2014, stands as one of the

most notable structural failures during the construction phase in India. This incident highlighted severe deficiencies in design approval, construction quality, supervision, and regulatory oversight, underscoring the urgent need for forensic engineering in high-rise construction projects. The project consisted of two 11-storey residential towers that were under construction. In the early hours of the morning, one of the towers unexpectedly collapsed, followed closely by the partial failure of the second tower. At the time of the incident, numerous construction workers were on-site. The tragedy resulted in the loss of 61 workers' lives and led to significant economic and material damages.



Fig 3: Chennai Moulivakkam Twin Towers Collapsed

Investigations uncovered several critical failures. The primary issue was inadequate soil investigation and insufficient foundation design, which rendered the structure incapable of safely transferring loads to the ground. Additionally, substandard construction materials, such as low-strength concrete and improper reinforcement detailing, were also identified.

➤ *Bihar Sultanganj–Aguwani Bridge Collapse (2023)*

The collapse of the Sultanganj–Aguwani Ghat Bridge in Bhagalpur district, Bihar, in June 2023, serves as a significant illustration of failures in public infrastructure, revealing critical shortcomings in design validation, construction quality, monitoring, and accountability. This

bridge was an ambitious endeavour spanning the Ganga River, aimed at enhancing regional connectivity and fostering economic development. Its failure led to substantial financial losses for the public treasury; however, it is fortunate that there were no casualties. The bridge was in the process of construction and was designed to extend over 3 km, making it one of the longest bridges in Bihar. Alarming, the structure had experienced a partial collapse in 2022 during its construction phase, prompting subsequent repair efforts. Despite these interventions, a significant section of the bridge collapsed again in 2023, raising grave concerns regarding the thoroughness of investigations and the effectiveness of corrective actions taken following the initial incident.



Fig 4: Bihar Bridge Collapsed

Initial investigations indicated that the collapse was likely due to flawed design assumptions, substandard construction practices, and insufficient quality control measures. The failure of piers and elements of the superstructure pointed to potential issues with foundation stability, river hydraulics, and load transfer mechanisms. Additionally, the incident highlighted concerns regarding improper sequencing of construction activities and a lack of adequate consideration for hydrodynamic forces during the monsoon season.

III. ROLES OF A FORENSIC ENGINEER IN STRUCTURAL FAILURE INVESTIGATION

➤ *Site Inspection and Documentation*

The engineer carefully examines the failure site to observe collapse patterns, crack propagation, deformation of structural members, and debris distribution. Photographs, videos, sketches, and measurements are taken to preserve the condition of the site.

➤ *Collection and Preservation of Physical Evidence*

Gather samples of concrete, steel reinforcement, bolts, beams, columns, and various other structural elements.

These samples are accurately labeled and preserved to ensure their evidentiary significance.

➤ *Review of Design and Construction Documents*

Assessed to confirm if the structure was constructed in accordance with the approved codes and standards. At this point, design errors, erroneous load assumptions, or deviations from the specified safety factors can be detected.

➤ *Material Testing and Analysis*

Laboratory tests are performed to assess the strength, quality, and durability of construction materials, including concrete and steel. These tests identify issues such as substandard concrete mixtures, insufficient curing, reinforcement corrosion, fatigue, or material degradation, thereby assisting in determining if material failure played a role in the collapse.

➤ *Failure Mechanism Analysis*

Determine whether the failure occurred due to bending, shear, buckling, fatigue, or progressive collapse. By reconstructing the sequence of events, they explain how a local failure may have triggered the collapse of the entire structure.

➤ *Load and Environmental Assessment*

Forensic engineers evaluate whether the actual loads acting on the structure exceeded its design capacity.

➤ *Identification of Human and Procedural Errors*

Forensic engineers evaluate the quality of workmanship, the supervision of construction, and the practices of maintenance. They identify unauthorized structural alterations, inadequate quality control, insufficient inspections, and non-adherence to building codes as human-related factors contributing to failure.

➤ *Use of Advanced Analytical Tools*

Structural modeling, finite element analysis, non-destructive testing, and computer simulations are utilized to confirm failure hypotheses. These instruments assist forensic engineers in delivering scientifically credible conclusions.

➤ *Preparation of Forensic Engineering Report*

The preparation of a forensic engineering report is an essential duty. This report encompasses observations, test results, calculations, photographs, and expert opinions articulated in a clear and impartial manner. It is crafted to be legally admissible and comprehensible to non-engineers, including judges and lawyers.

➤ *Expert testimony and Legal Support*

They explain their findings in courts, inquiry commissions, and technical committees. Based on the investigation, they recommend corrective measures, improved design practices, and stricter enforcement of building codes to prevent similar failures in the future.^[6-7]

IV. DISCUSSION

In India, there is a rising demand for forensic engineering, driven by the increase in industrial accidents and intricate litigation cases.^[8] However, this field encounters several challenges, including a shortage of qualified professionals, insufficient infrastructure, and the necessity for standardized practices to maximize its effectiveness in investigations concerning structural failures, product liability, and accident reconstruction.

Hence, the India is still in the developing phase, the comparison below highlights the major limitations and gaps in Indian scenario when compared with foreign countries.

➤ *Institutional Framework*

In nations such as the USA, UK, Canada, and Australia, forensic engineering is acknowledged as a distinct specialty. Professional organizations like the National Academy of Forensic Engineers (NAFE) and the Institution of Civil Engineers (ICE) promote standardized practices and ethical guidelines.

Conversely, India does not have a national authority specifically for forensic engineering. Investigations are primarily carried out by government agencies, academic committees, or consultants, lacking a cohesive framework, which results in varying standards of investigation.

➤ *Education and Training*

In numerous foreign nations, forensic engineering is provided as a specialized postgraduate program or as a form of professional certification. Engineers are trained in areas such as failure analysis, evidence management, legal protocols, and expert testimony.

In India, forensic engineering is infrequently incorporated into engineering curricula. The availability of formal training programs is limited, leading to a considerable skills gap and reliance on general engineers who possess minimal forensic knowledge.

➤ *Professional Accreditation and Certification*

Developed countries have established clear systems for the accreditation and licensing of forensic engineers. Expert witnesses are certified and acknowledged by the courts, which enhances their credibility.

In contrast, India lacks a standardized system for the accreditation or licensing of forensic engineers. As a result, courts often struggle to evaluate the qualifications of experts, which diminishes the legal significance of forensic findings.

➤ *Infrastructure and Technology*

Foreign nations boast advanced forensic laboratories, non-destructive testing facilities, structural health monitoring systems, and digital modeling tools. Sites of failure are preserved in a systematic manner.

In India, the forensic infrastructure is limited and unevenly distributed. Numerous investigations are hindered by the absence of advanced testing, inadequate site preservation, and digital reconstruction, primarily due to resource limitations.

➤ *Legal and Judicial Support*

In developed nations, forensic engineering is deeply integrated into the legal framework. Courts, insurance firms, and regulatory bodies routinely rely on forensic reports. There are established processes for timely investigations and clear liability frameworks.

Conversely, in India, legal proceedings are often sluggish, the technical understanding within courts is restricted, and expert opinions may be contested due to a lack of legal clarity and extended litigation.

➤ *Public Awareness and Safety Culture*

In foreign countries, public awareness about structural safety and accountability is high, encouraging reporting of defects and compliance.

In India, limited public awareness and tolerance of safety violations weaken the demand for forensic investigations.

The discussion highlights a considerable disparity between India and other countries regarding forensic engineering practices. In contrast to foreign nations that

possess well-established systems supported by robust institutions, cutting-edge technology, proficient professionals, and legal acknowledgment, India encounters obstacles including insufficient awareness, a shortage of skills, inadequate infrastructure, and fragile legal structures. To close these gaps, it is essential to implement policy reforms, enhance specialized education, develop infrastructure, establish professional accreditation, and incorporate forensic engineering into India's safety and legal frameworks.

V. CONCLUSION

The increasing incidence of structural failures in India underscores the critical necessity to enhance forensic engineering practices. To address the current deficiencies, it is imperative for the government to officially acknowledge forensic engineering as a distinct discipline and to create independent investigative bodies endowed with explicit legal authority. It is vital to fortify the legal framework, standardize the accreditation of experts, and enhance the judiciary's comprehension of technical evidence to ensure effective accountability.

Moreover, investing in infrastructure, laboratories, and advanced forensic technologies is equally crucial, alongside the integration of forensic engineering into regular structural audits and safety regulations. Educational and research institutions should implement specialized courses and training programs to bridge the skill gap, while professional organizations ought to establish certification and ethical standards.

A collaborative initiative involving the government, educational institutions, and regulatory bodies can elevate forensic engineering from a reactive measure to a proactive and well-recognized discipline, thereby guaranteeing safer infrastructure, safeguarding lives and property, and promoting sustainable development in India.

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