The Impact of Changes or Un-inspected Works during the Construction Phase in Building Failures: The Structural Check-up

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Abstract

Over the past decade, numerous buildings have collapsed, resulting in catastrophic consequences, including the loss of hundreds of lives and substantial material costs. These collapses were often due to structural failures linked to problems arising during construction, such as uncontrolled design changes or inadequately inspected works. Despite numerous studies and reports aiming to identify solutions, the complexity of the involved systems and variations in international legislation have rendered a universal solution nearly impossible. This exploratory research identified four primary causes: (1) poor initial design, (2) miscommunication of design requirements, (3) poor construction practices and (4) failure in monitoring and controlling design changes. The solution identified outlines a proposal to critically examine the current practices of reinforced concrete structural inspections to evaluate their effectiveness in documenting construction processes and identifying potential risks associated with these practices. New technologies could be pivotal in developing a classification system for building structures to gauge their integrity levels. An initial set of tests is proposed, serving as a reference for future building 'structural check-ups' to assess the ongoing and future reliability of a building's framework. This is generally applicable across different countries and regulatory frameworks.

Keywords: *Structural Integrity, Construction Oversight, Building Failures, Inspection Technologies, Risk Assessment*.

1. INTRODUCTION

Over the past few decades, multiple catastrophic building collapses have resulted in significant loss of life and substantial financial damage worldwide. A recent study identified 281 buildings that collapsed between 1980 and 2021, with a peak in 2000 (Simons et al., 2022). Faulty design and deficient construction practices have been a primary factor in these disasters. Changes made during construction without proper consultation or oversight have significantly contributed to several cases. These changes are often driven by developer demands or the desire to improve constructability, leading to tragic consequences when structural integrity is compromised (Shoar and Chileshe, 2021). In some cases, contractors or developers made last-minute modifications to the building's design or construction process, ignoring the advice of the original design consultants.

Poor initial design is one of the most significant contributors to building failures and potential collapse. Insufficient attention to detail during the design phase can lead to structural weaknesses, inadequate load-bearing capacity, and incorrect material specifications. Often, incomplete analysis of engineering conditions or a poor understanding of site-specific factors, including soil and hydrogeological conditions, compromise a building's stability (Liao et al., 2023, Hadipriono, 1985). When designs fail to account for these factors, the resulting structural weaknesses may escalate, becoming especially dangerous in environments prone to natural disasters like earthquakes or hurricanes, where detailed designs are crucial to withstand extreme forces (Cao et al., 2022).

A critical issue arises when there is a misunderstanding or miscommunication of design requirements between contractors, subcontractors, and the design team. Frequently, contractors or subcontractors misinterpret design elements due to poor communication or inadequate technical understanding (Othman and Mydin, 2014). This leads to errors during construction, such as improper installation of structural components or the use of substandard materials. Such misunderstandings, compounded by a lack of proper coordination, often result in latent defects that become apparent only after the building is operational. Inadequate communication between contractors and design consultants further aggravates these issues, leading to costly remediation or catastrophic failures (Parfitt, 2008).

Poor construction practices, including the use of substandard materials, insufficient workmanship, and inadequate site inspections, are often a direct result of the issues mentioned above. Without proper site inspections, defects may go unnoticed, leading to errors that compromise the building's safety. Key issues such as improper welding, misaligned structures, and insufficient quality control during critical stages are frequently observed in projects with lax oversight (Suaris and Khan, 1995, Shinde and Meshram, 2020). Regular site inspections are essential to ensure that construction adheres to the design, and when ignored, these practices can lead to failures that could have otherwise been prevented through rigorous supervision.

Finally, design changes during construction or alterations throughout the building’s lifecycle without proper consultation from the original design team can lead to severe problems. Such unapproved modifications can weaken the building's integrity, introducing vulnerabilities that may not have been foreseen. Additionally, changes in the surroundings—such as new nearby construction, increased load demands, or environmental shifts—may impose stresses that the building was not originally designed to withstand (Vijayan et al., 2023). This becomes particularly critical in extreme weather conditions, where unassessed modifications can lead to damage or collapse. Proper consultation with the original design consultants during such changes is crucial to maintaining the building's structural integrity throughout its lifecycle (Alhamaydeh and Ghazal Aswad, 2022).

This paper aims to highlight the importance of inspections to identify building issues and prevent their failures. It starts by looking at the human error causes of the failures, initial design, misunderstandings in design, improper construction practices, changes during construction and after the building was in operation with renovations, ampliations, etc. In the second part of the paper, several inspection methodologies are presented to inspect reinforced concrete structures on bridges, and opportunities to transfer that knowledge to the building industry are analysed and discussed.

2. METHODOLOGY

This study uses an exploratory approach to investigate the causes of building failures and propose strategies to prevent potential structural collapses. A review of current cases identified fundamental causes, patterns, and trends over recent years, examining how regulatory frameworks and other factors contribute to failures. Lessons learned from case studies across different regions were highlighted.

The authors also incorporated their practical industry experience to enhance the analysis, combining theoretical insights with real-world applications for a balanced perspective and informed recommendations.

3. BUILDING FAILURES

Building failures and potential collapses can occur due to various factors; however, this paper focuses on identifying predictable causes and avoidable human errors. From the cases analysed, four leading causes emerged: poor initial structural design, errors resulting from contractors’ misinterpretation of the design, improper construction practices, and design changes during the construction phase without adequate consultation and supervision by the original design consultant team. Many design-related issues were driven by the owner’s insufficient initial investment in design consultants or last-minute modifications requested by builders or contractors to improve constructability, reduce costs, or save time. Unfortunately, these changes often overlooked their integration into the overall design and their potential consequences. Uninspected or poorly inspected design and construction phases were a significant factor in the collapse of several buildings, leading to catastrophic human and material losses.

3.1. Poor Detailed Initial Design

Poor design is a significant cause of building failures. Gross (1986) Studied various multi-story buildings with structural failures in the US and identified human error during the design phase, such as undersized components and inadequate load-bearing structures, which can go unnoticed until failure occurs. Moreover, confusion over design responsibilities and improper material selection are common issues leading to catastrophic results (Parfitt, 2008). Alaneme et al. (2021) further highlighted the role of poor-quality materials and under-reinforcement, a direct result of improper initial design, in many structural failures. Lang and Marshall (2011) demonstrated how Haiti's lack of initial design seismic considerations contributed to widespread building failures during earthquakes. Błaszczyński and Sielicki (2019) also noted that contractor errors and faulty design modifications were key contributors to the collapse of a tenement building, stressing that initial design flaws can lead to cumulative structural degradation if left unchecked. Jara et al. (2023) analysed how the collapse of soft-story buildings during the 2017 Mexico earthquake was due to improper design and insufficient attention to soil-structure interaction, resulting in increased collapse risk.

3.2. Misunderstanding of Design by Contractors

Miscommunication between contractors and design teams is another primary cause of building failures. Poor coordination during construction often leads to errors in executing the design, thus compromising structural integrity (Gross, 1986, Parfitt, 2008). Inadequate follow-up on design warnings, simultaneously with a lack of clarity in responsibilities between contractors and engineers, exacerbates the risks of misleading (Terwel, 2019). Terwel examined the collapse of several balconies in a large residential complex in Maastricht. The failure occurred due to insufficient reinforcement in the balcony slabs, which were not built according to the structural engineer’s specifications. The collapse highlighted serious miscommunication between contractors and engineers, resulting in multiple fatalities. Effective communication and collaboration between stakeholders are essential, especially when design changes are made during construction (Shoar and Chileshe, 2021). Alaneme et al. (2021) showed how improper communication between contractors and design teams leads to the use of low-quality concrete and inadequate reinforcement, further compounding the building's structural vulnerabilities. The lack of proper coordination often deviates from the original design intent, posing serious safety risks.

3.3. Improper Construction Practices and Lack of Site Inspection

Improper construction practices and bad use of materials, compounded by a lack of inspections, frequently result in building collapses. Halvoník et al. (2021) identified that improper handling of slab-column connections contributed to the progressive failure in a collapsed parking garage. A lack of lessons learned from a similar situation occurred in 1973, when a Skyline Plaza apartment building in Bailey’s Crossroads, Virginia, collapsed during construction due to the premature removal of shores (Schellhammer et al., 2013). Buitrago et al. (2020), also pointed out how overloading shoring systems during construction can lead to progressive collapse, suggesting that structural fuses could be implemented to limit damage to permanent structures.

The Sampoong Department Store in Korea collapsed in 1995, six years after it was opened to the public in 1989. Several construction deficiencies were found concrete used with a lower strength (18 MPa rather than 21 MPa), areas with reduced slab depth (360 mm rather than 410), and smaller column diameters (600 mm rather than 800 mm) (Gardner et al., 2002).

3.4. Uncontrolled Design Changes and Improper Surveillance

Without proper consultation or surveillance, uncontrolled design changes present significant risks to a building’s stability. Gross (1986) explained how unsanctioned changes lead to structural vulnerabilities exacerbated by human error. The Champlain Towers is an exemplary example of how uncontrolled postconstruction changes, such as the addition of heavy concrete elements or an additional level, contributed to the building’s structural failure. Originally designed as an office building, the Sampoong Department Store's purpose was changed mid-construction to a department store, significantly increasing the building's load. This unauthorised change was made without adjusting the structural design to account for the new load requirements. Improper surveillance and lack of oversight allowed these changes to go unchecked, leading to the building's collapse (Gardner et al., 2002).

After construction, several floors were illegally added to Rana Plaza, and heavy industrial equipment was installed without consulting structural engineers. These unauthorised design changes significantly compromised the building’s integrity. Improper surveillance and the lack of enforcement of building regulations led to the building's collapse (Holland, 2023). Uncontrolled modifications, especially when retrofitting older buildings, pose serious risks, mainly if carried out without consulting the original design team (Shoar and Chileshe, 2021). Buitrago et al. (2020) also recommended implementing real-time structural health monitoring systems to detect potential failures early and mitigate risks before they become catastrophic.

4. CURRENT INSPECTIONS SYSTEMS

No proper standard building inspection guidelines are available worldwide. This paper revisited different inspection methodologies currently used in bridges and evaluated the opportunity to use them in buildings to assess the structural health of buildings.

The bridge inspection requirements used by road authorities are summarised here. These requirements are developed so that the conditions of all structures are systematically monitored to ensure the structural integrity and safety of all road users. Data is also provided to develop maintenance programs and assess load capacity. They also assist in providing feedback for future designs and developing guidelines for strategically managing road assets.

In Australia, the Bridge Inspection Manual (BIM), also known as VicRoads’ Road Structures Inspection Manual (RSIM), was first published in 1995. It was followed by the release of the Bridge Maintenance Repair and Strengthening Guidelines.

As described by Muruganandam et al. (2012), bridge condition inspections are carried out at three levels to assess the condition of each structure and its principal components. Level 1 (L1) inspections are routine maintenance inspections carried out in conjunction with pavement maintenance on a six-monthly frequency. This is to check the general serviceability of the structure. L2 inspections are carried out to assess the condition state of each structure and its principal components. The frequency of inspection varies between two to five years. The bridge component condition state is described on a scale of 1 to 4, where 1 stands for ‘excellent condition’ and 4 stands for ‘serious deterioration’. Level 3 (L3) inspections are detailed engineering inspections conducted on a needs basis to assess the structural condition and capacity of structures that have been identified as potential candidates for rehabilitation, strengthening, widening or replacement. These structures are assessed for their load-carrying capacity at the same time. A Level 3 inspection of a bridge must be a structural inspection of the complete bridge and is usually carried out using non-destructive testing methods (NDT). The Bridge Inventory and Inspection Policy document of the Dept of Transport NSW is similar to the VicRoads document except for the addition of an important Level 4 for Load capacity assessment. Normally, a 2-year time interval for Steel and Concrete Bridges and an annual inspection of timber bridges is recommended for Level 2 assessment. In the mid-1990s, the University of Melbourne team had the unique opportunity to test the 59-year-old Barr Creek Bridge, a flat slab bridge of four short continuous spans over column piers until failure for VicRoads to develop Level 4 type of guidelines for existing cast-in-place reinforced concrete flat slab bridges (Haritos et al., 2000).

4.1. Advances and New Technologies

Advances in sensors and the development of new materials and devices are allowing the way for new Non-Destructive Methods (NDT). NDT of concrete is increasingly gaining acceptance as a means of evaluating material and structural integrity (Mendis, 2015). State-of-the-Art Portable Facility for Non-

Destructive Testing of Concrete Infrastructure (N-Detect) was developed at the University of Melbourne by Mendis (2015). NDT gives a reliable method to provide an accurate assessment of the condition of a structure. These guidelines developed for Bridges summarised in this section, can be used as a first step for the regular assessment of buildings and in preventing failures. It is important that these guidelines are covered by legislation, making them mandatory.

These advances and new technologies can help in paving the way for a classification system for addressing these shortcomings in building structures. i.e. to gauge their integrity levels. It is proposed that an initial set of tests be made mandatory. This serves as a benchmark or reference point for continuing building structural assessment to monitor the health and reliability of a building's framework.

5. DISCUSSION AND CONCLUSIONS

Building failures and collapses have been a worldwide concern, with hundreds of thousands of human fatalities and enormous material and financial losses. The analysis of multiple case studies reveals that four interconnected factors, including (1) poor initial design, (2) miscommunication between contractors and design teams, (3) improper construction practices, and (4) uncontrolled design changes, often cause building collapses.

These issues are exacerbated by inadequate regulations, a lack of qualified inspections, and a failure to adhere to internationally established construction standards. A few examples were presented that government and local building authorities waited until serious catastrophes occurred to act and implement new regulations. Political factors such as the need to build quicker due to housing needs or political agendas have revealed catastrophic, allowing developers and builders to cut corners to build more and faster with potentially tragic consequences. The structural collapse of a building rarely occurs with a warning, sometimes, it is the structure itself that starts giving indications/alerts of problems, and at other times it is the consultants who give these alerts to the authorities or the building's authorities.,

In the case of Turkey, the country updated the building codes after a devastating earthquake in 1999. Several years later, in 2018, they implemented the 'Turkey Earthquake Building Regulations'. However, several experts alerted the government that construction had progressed without enforcing regulations and several buildings had already been built illegally. These non-compliant buildings were apparently built with the consent of the government due to the pressure to build more houses. The consequences were catastrophic (Inanc, 2023). In the Maimi case, the local government implemented a 40-year recertification requirement after the 1974 collapse of the Drug Enforcement Agency (DEA) building. This requirement mandates that all buildings over 40 years old must undergo structural and electrical recertification to ensure they meet current safety standards. The collapse of the Champlain Towers occurred after one of these 40 years when the engineering reports indicated serious structural problems that were almost ignored by the building owners. After this incident, the authorities are considering reducing this period to 30 years due to the fact that concrete for buildings regulations are, in general, only for 50 years, and Miami is a coastal area with increased severity.

In these scenarios, developing a proper health assessment of the existing buildings' structure is critical to understand how they were built and ensure the final buyers' and users' confidence in what was built. Implementing new technologies, such as real-time structural health monitoring systems, offers promising solutions to mitigate these risks. By integrating these technologies and ensuring strict oversight at every phase of construction, future building collapses can be prevented, and better assessment can be done at the moment to decide if a building must be demolished or retrofitted. Adopting a new classification system that incorporates advanced technologies for structural health assessments will further ensure the reliability and safety of both new and existing structures, protecting lives and minimising financial losses.

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