CHAPTER 10

Analysis of Safety Practices in High-Rise Building Construction for Developing Effective Safety Management System

Amey Pimple[1], Swapnil Rajmane[1], Viraj Chavan[1],
Rahul Jadhav[1] and Abhijeet Sangapurkar[2]

ABSTRACT

The construction industry in India is a cornerstone of economic growth, with high-rise and super high-rise buildings symbolizing modern urban development. However, the vertical complexity of such projects amplifies the risks associated with construction activities, making it one of the most hazardous professions globally. This research focuses on analysing safety practices in high-rise building construction and designing an effective Safety Management System (SMS) to mitigate safety hazards and promote safe working conditions. Through a comprehensive methodology involving site interviews and a Likert-scale-based questionnaire survey, data were collected from safety personnel across multiple high-rise construction sites. Advanced statistical techniques, including SPSS-based factor analysis, were applied to identify critical factors influencing safety practices and challenges. These findings provided a robust foundation for understanding relationships among variables, simplifying data, and tailoring the SMS to address the root causes of safety issues. The proposed SMS integrates these insights to systematically tackle safety challenges, aiming to reduce workplace accidents, minimize costs associated with safety failures, and enhance overall health and safety for workers and staff. Furthermore, by promoting organization-wide adoption, this SMS is designed to standardize safety practices across the construction industry, fostering a culture of safety and resilience. This research not only highlights the importance of safety management in high-rise construction but also provides a practical, data-driven framework that can significantly enhance safety outcomes, ensuring a sustainable and accident-free future for the industry.

Keywords: Safety Management System; High Rise Construction; Factor Analysis; Safety Practices; Workplace Hazard Mitigation.

1.0 Introduction

High-rise construction poses significant safety risks due to height, complex logistics, and heavy machinery use.

[1]*School of Construction, NICMAR University, Pune, Maharashtra, India*
[2]*Corresponding author; School of Construction, NICMAR University, Pune, Maharashtra, India*
(E-mail: abhijeets@nicmar.ac.in)

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Despite safety advancements, accidents persist, often due to falls, struck-by incidents, and structural failures. A structured Safety Management System (SMS) is crucial for risk mitigation, compliance, and enhanced worker safety. This research evaluates current safety measures, identifies gaps, and proposes an improved SMS.

1.1 Motivation

The construction industry is inherently hazardous, with high-rise projects facing amplified risks such as increased fall hazards, adverse weather conditions, and complex coordination among multiple trades. Emergency response at elevated levels is another major challenge. Frequent safety lapses highlight the need for a structured SMS to improve regulatory compliance and safeguard workers.

1.2 Purpose and objectives

This study aims to develop an SMS tailored for high-rise construction by:

- Assessing current safety practices.
- Identifying deficiencies through surveys, case studies, and expert input.
- Proposing an SMS integrating risk mitigation, compliance, and emergency preparedness.
- Offering practical recommendations to improve safety performance.

1.3 Scope of the study

Focusing on high-rise construction by CTBUH and NBC standards, this study examines:

- Risk assessment and hazard identification.
- Safety planning, training, and supervision.
- Emergency preparedness and compliance monitoring. Findings may also inform broader construction safety management practices.

1.4 Limitations

This study has limitations, including a potentially non-generalizable sample size and response biases in self-reported data. Its focus on high-rise construction limits applicability to other sectors, and it does not account for future safety technology advancements or regulatory changes. Despite these constraints, the findings offer valuable insights into enhancing safety management in high-rise projects.

1.5 Organization of the paper

The paper is structured to ensure clarity and coherence. Section 1 introduces the study's motivation, objectives, scope, and limitations. Section 2 reviews literature on safety frameworks in high-rise construction. Section 3 details the methodology, including data collection and analysis procedures. Section 4 presents research findings and discussions, while Section 5 concludes with safety improvement recommendations.

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2.0 Literature Review

High-rise construction presents significant safety challenges due to complex designs and high-risk activities. A well-structured safety management system is essential to ensure worker safety. This review examines key studies on safety practices, risk management, and technological advancements in safety management.

2.1 Construction safety management and hazards

Yang *et al.*, (2015) identified hazardous zones in construction sites, particularly in high-wind-speed areas, using Computational Fluid Dynamics (CFD), Building Information Modeling (BIM), and Geographic Information Systems (GIS). Their study emphasizes the need for pre-construction, safety planning and risk management. Tetteh & Liang (2020) studied safety practices in Ghana's high-rise projects, revealing inadequate enforcement, frequent falls, and poor worker communication. They highlight the importance of stricter regulations, training, and awareness programs.

2.2 Critical safety factors

Yiu *et al.*, (2019) ranked major accident causes in Malaysian high-rise construction, emphasizing falls, lack of PPE, unsafe scaffolding, and environmental risks. Their findings stress the need for stricter enforcement and improved monitoring. Murali & Deraman (2021) found that voluntary safety measures, frequent hazard assessments, and leadership commitment reduce accidents. They highlight the role of safety culture and performance tracking in improving safety outcomes.

2.3 Technology in safety management

Limbasiya *et al.*, (2018) demonstrated BIM's role in fall prevention, real-time hazard monitoring, and better safety decision-making. AI-driven surveillance and predictive analytics further enhance risk identification and accident prevention.

2.4 Risk assessment and safety planning

Balkis *et al.*, (2018) analyzed risk assessment methods like Delphi and risk matrix modeling, identifying financial, operational, and legal risks. Their research highlights proactive risk management's role in improving safety and project efficiency. Khairuddin *et al.*, (2021) identified management support, structured inspections, and worker training as key factors for successful safety programs. They emphasize incentive-based programs and leadership involvement. These studies emphasize the importance of structured safety management, advanced risk assessment, and technology integration. Key recommendations include strict enforcement, comprehensive training, real-time hazard monitoring, and AI-driven predictive analysis. Future research should focus on cost-effective digital solutions to enhance safety in high-rise construction.

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3.0 Research Methodology

This study adopts a mixed-methods approach, combining quantitative and qualitative analysis to evaluate safety practices in high-rise construction. Data collection includes structured questionnaires for statistical insights, semi-structured interviews for expert perspectives, and on-site observations for validation, ensuring a comprehensive assessment for developing a Safety Management System (SMS). The questionnaire consists of four sections: (1) Site safety, covering PPE compliance, training, hazard assessments, equipment checks, incident reporting, and emergency preparedness; (2) Safety challenges, addressing equipment access, budget constraints, communication barriers, compliance issues, scheduling pressures, and technology adoption; (3) Incident management, analysing reporting frequency, investigation depth, corrective actions, and risk mitigation; and (4) Open-ended responses on best practices, challenges, and lessons learned. Responses are collected using a Likert scale and distributed digitally and in print to safety officers, project managers, and site engineers.

Semi-structured interviews with safety professionals and project managers complement the questionnaire, lasting 30–60 minutes and covering safety policies, enforcement challenges, incidents, mitigation measures, and cultural improvements. Conducted with participant consent, interviews are transcribed and analyzed. Ethical considerations ensure informed consent, anonymity, confidentiality, and secure data storage. Data collection includes online surveys for broad outreach, interviews for qualitative insights, and on-site observations for validation. SPSS is used for statistical analysis, while qualitative data undergoes thematic analysis and comparison with industry benchmarks. This methodology ensures academic rigor and supports the development of an effective Safety Management System (SMS) for high-rise construction.

Table 1: Total Variance Explained

Factor	Initial Eigenvalues	% of Variance	Cumulative %	Rotation Sums of Squared Loadings (% of Variance)
1	8.375	26.171	26.171	16.381
2	5.027	15.709	41.880	12.671
3	2.630	8.219	50.099	9.864
4	2.093	6.541	56.640	7.199
5	1.792	5.601	62.241	6.396
6	1.595	4.983	67.225	5.114
7	1.202	3.755	70.980	4.429
8	1.041	3.255	74.234	4.048

4.0 Data Analysis and Findings

Factor analysis using Principal Axis Factoring (PAF) with Varimax rotation identified eight key safety factors in high-rise construction. The Kaiser-Meyer-Olkin (KMO) test and

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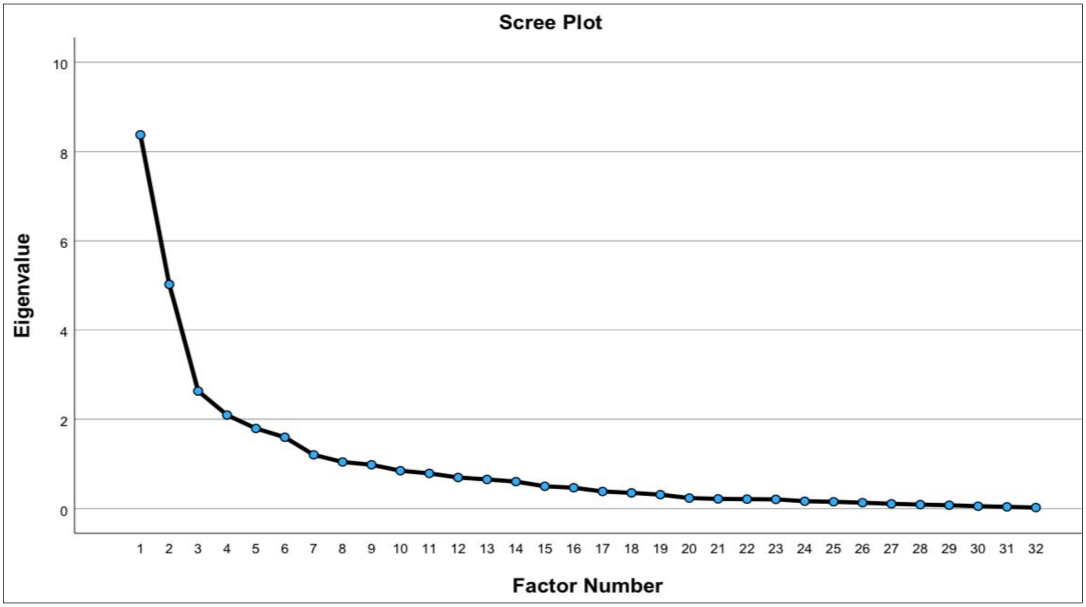
Bartlett's test confirmed dataset suitability. The extracted factors form the foundation of a Safety Management System (SMS) integrating planning, supervision, technology, compliance, and risk mitigation. The Total Variance Explained table clearly identifies factors which have eigenvalues above 1 and explain more than 66% of total variance. The scree plot also flattens after the 8th factor on the graph shown below:

Figure 1: Scree Plot



The variables are identified and grouped based on their loadings in each factor from Rotated Factor Matrix Table 2.

The study identifies key factors influencing safety management in high-rise construction, categorized as follows:

- *Safety Planning & Budgeting:* Adequate budget allocation and integration of safety measures within project planning are crucial for hazard prevention. Management commitment and leadership support play a vital role in ensuring effective implementation.
- *Incident Reporting & Investigation:* A structured system for incident documentation, corrective actions, and near-miss analysis strengthens workplace safety. Proper investigation of safety violations helps identify recurring risks and improve protocols.
- *Technology & Safety Infrastructure:* The use of AI-driven safety monitoring, IoT-enabled wearables, and real-time hazard detection enhances accident prevention. Well-maintained safety equipment and digital tracking systems contribute to a secure construction environment.

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Table 2: Rotated Factor Matrix

Factor	1	2	3	4	5	6	7	8
Budget constraints	0.802							
Safety in project planning	0.780							
Management support	0.776							
Communication barrier	0.651							
Safety infrastructure	0.638							
New technology implementation		0.627						
Work schedules		0.607						
Qualified safety personnel		0.541						
Equipment access		0.486						
Weather condition		0.373						
Incident investigation effectiveness			0.811					
Timeliness of incident response			0.795					
Safety technology integration			0.776					
Near-miss reporting			0.701					
Documentation of risk management				0.633				
Corrective actions post-incident				0.511				
Incident reporting frequency				0.768				
Risk management training					0.692			
Site inspection					0.682			
Equipment checks					0.593			
Safety signage					0.508			
Safety supervision					0.428			
First aid preparedness						0.774		
Safety equipment access						0.640		
Safety training						0.625		
Height safety measures							0.845	
Age of respondent							0.738	
Experience of respondent							0.793	
Emergency preparedness								0.456
Use of incident data								0.673
PPE usage								0.744
Incident reporting								0.526

- *Training & Safety Supervision:* Regular training, clear safety signage, and dedicated safety officers are essential for regulatory compliance. Continuous learning and on-site monitoring help mitigate risks and improve worker awareness.

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- *Emergency Preparedness:* Ensuring first aid accessibility, firefighting equipment availability, and structured emergency response plans enhances accident management. Conducting regular drills strengthens site readiness for emergencies.
- *Work Environment & Conditions:* Factors such as extreme weather, work schedules, and the availability of safety personnel impact worker well-being. Managing environmental risks and optimizing work shifts help prevent fatigue-related incidents.
- *Construction-Specific Safety Practices:* Compliance with Personal Protective Equipment (PPE) standards, routine site inspections, and height safety measures minimize site-specific hazards, including falls and equipment-related injuries.
- *Incident Data Utilization & Risk Analysis:* Safety data analytics, predictive modeling, and audits aid in identifying high-risk areas. Analysing past incidents enables targeted interventions to enhance workplace safety.

These findings highlight the critical components necessary for improving safety outcomes in high-rise construction projects.

5.0 Conclusion, Limitations and Recommendations

5.1 Conclusion

This study identifies eight critical factors shaping safety management in high-rise construction, forming the foundation for an effective Safety Management System (SMS). These factors include safety planning and budgeting, incident reporting and investigation, technology and safety infrastructure, training and supervision, emergency preparedness, work environment conditions, construction-specific safety practices, and incident data utilization. Integrating these elements enables proactive risk mitigation, strengthens regulatory compliance, and supports data-driven decision-making. The findings underscore the importance of structured safety planning, technological advancements, continuous training, and emergency preparedness in fostering a safer construction environment. Implementing this SMS can significantly reduce workplace hazards, improve adherence to safety regulations, and promote a strong safety culture within high-rise projects.

5.2 Limitations

Despite its contributions, this study has certain limitations. Its focus on high-rise construction may limit the applicability of findings to other sectors, such as road infrastructure or industrial projects. The reliance on self-reported survey data introduces the possibility of response bias due to subjective perceptions of safety. Additionally, the factor analysis assumes independence among variables (Varimax rotation), whereas, in practice, some safety factors may be interrelated. The study also does not account for future technological advancements or regulatory changes that may impact the long-term effectiveness of the proposed SMS.

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5.3 Recommendations

Future research should broaden the industry scope and sample size to enhance the generalizability of findings across different construction sectors. A longitudinal study assessing safety improvements over time could provide deeper insights into the real-world impact of the SMS. Exploring alternative factor analysis methods, such as Oblique rotation, could help identify interdependencies among safety factors. Further investigation into emerging technologies, including AI-based hazard detection and IoT-enabled safety systems, could refine safety management strategies. Additionally, piloting the proposed SMS in active construction projects would help validate its effectiveness and allow for practical refinement based on real-world implementation challenges.

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