Risk Management Strategies for High-Risk Construction Activities in Marine Bridge Projects

*Shubham Nandi *[1], Tarun Prasad Sonwani*[2], Gulab Chand Sahu*[3]*

[1]M.Tech. Student, Department of Health Safety and Environmental Engineering Shri Rawatpura Sarkar University, Raipur (C.G)

[2]Assistant Professor, Department of Mechanical Engineering, Shri Rawatpura Sarkar University, Raipur (C.G)

[3]Assistant Professor, Department of Mechanical Engineering, Shri Rawatpura Sarkar University, Raipur (C.G)

Abstract- The purpose of this study is to identify high-risk activities in maritime bridge-building projects and create risk reduction techniques. It examines pile driving, cofferdam building, underwater concreting, naval shipping, heavy lifting, and work at heights. The study contains a review of previous material, case studies, and risk management measures. The study evaluates the effectiveness of technologies, including permit-to-work systems, Hazard Identification Techniques (HAZID), Job Safety Analysis (JSA), and Risk Assessment Matrices, in mitigating hazards. Proactive planning, cutting-edge building technology, expert labor training, continuous safety monitoring, and emergency preparedness are also emphasized. Strong stakeholder collaboration, stringent safety practices, and statutory regulatory compliance are all stressed. The study finds that structured risk management strategies tailored to marine environment difficulties can improve safety performance in impending marine bridge building.

Keywords - ***High-risk activities, Maritime bridge building, Risk reduction techniques, Pile driving, Hazard Identification Techniques (HAZID), Job Safety Analysis (JSA), Risk Assessment Matrices, Emergency preparedness.***

INTRODUCTION

In order to link remote regions, foster regional ties, and advance socioeconomic development, marine bridges are essential. Urbanization and industrialization have increased demand for them, particularly in emerging countries like India. However, there are difficulties in constructing sea bridges, including intricate technical designs, harsh weather conditions, and safety requirements. One high-risk project that exemplifies sophisticated engineering and risk management strategies is the Mumbai Trans Harbour Link (MTHL). The MTHL serves as an example of how crucial project advancement and safety are in demanding settings. The intricacy and structural engineering difficulties of marine bridge projects, such as the Mumbai Trans Harbour Link (MTHL), present risks. Accidents are caused by inadequate protocols, subpar safety precautions, and employees' inexperience in dangerous environments. To address these risks, a thorough safety management plan that emphasizes meticulous planning, execution, and worker competency is required. The Mumbai Trans Harbour Link (MTHL) project is the primary focus of the study, which examines safety protocols and risk-reduction tactics in India's marine bridge construction projects. It draws attention to high-risk situations, activities, and monsoon weather. In order to raise the global standard for marine construction safety protocols, the study intends to create thorough safety measures for additional projects.

LITERATURE REVIEW

[1] Tata Projects Ltd. (2023). *MTHL Safety Management Manual*. The safety management framework for the Mumbai Trans Harbour Link project is described in the internal handbook of Tata Projects Ltd., with a focus on site-specific hazard control procedures, safety KPI conformance, and real-time monitoring. It offers information on best practices for large-scale marine infrastructure initiatives.

[2] Ministry of Road Transport and Highways (MoRTH). (2022).*Manual for Bridge Construction in Coastal and Marine Zones*. With its engineering guidelines, environmental considerations, safety recommendations, regulatory compliance, risk mitigation strategies, proactive planning, and integrated safety protocols, the government-issued handbook serves as a national reference for bridge construction in coastal and marine environments.

[3] L&T Construction.(2022). *Safety Guidelines for Intertidal Marine Works*. To save downtime and guarantee regulatory compliance, L&T Construction has published a safety handbook for intertidal marine works that covers danger zones, work scheduling, protective equipment requirements, underwater concreting, rope access, and emergency rescue.

[4] PWD Maharashtra.(2022).*MTHL–Environment & Safety Guidelines for Marine Construction*. In a circular on environmental and occupational safety in marine building projects, the Maharashtra Public Works Department highlights the significance of inter-agency cooperation, safety exercises, and permit-to-work mechanisms.

[5] Yadav, K. (2022). *Deck Finishing Safety During Monsoons*. *Construction Risk Review*, 10(2), 29–35. In monsoon seasons, Yadav draws attention to the risks associated with building a maritime bridge deck, such as slick surfaces, strong winds, and poor vision. It advises using PPE, weather-adjusted work schedules, non-slip platforms, prolonged scaffolding inspections, and worker training.

[6] Patel, N., & Chatterjee, R. (2022). *Zero Harm Philosophy in Marine Infrastructure Projects*. *EHS Today India*, 6(1), 11–20. The article presents the "Zero Harm" concept, a safety culture in maritime infrastructure that emphasizes digital monitoring, behavioral safety, and leadership commitment. It promotes making zero damage an official performance standard.

[7] Deshpande, R. (2021). *Fire Hazards in Marine Infrastructure*. *Safety Engineering Journal*, 17(2), 92–100. Fuel storage, welding, and electrical installations are among the maritime infrastructure fire hazards that are examined in Deshpande's study. It offers insightful information on maritime and coastal infrastructure projects, identifies regulatory loopholes, and suggests emergency response strategies and drill-based training.

[8] Mangalore Port Trust. (2021). *Safety Manual for Port-Adjacent Construction*. The handbook published by the Mangalore Port Trust provides safety rules for building operations close to operating facilities. These guidelines include topics such as restricted zone access, ship-to-shore communication protocols, navigation, and construction schedule, encouraging coordinated action to reduce hazards.

[9] Bureau Veritas. (2021). *Marine Construction Inspection Guidelines*. The guideline from Bureau Veritas provides an objective framework for risk control and performance audits by outlining criteria for inspection and quality assurance in maritime construction. It focuses on structural and safety requirements, third-party protocols, and international safety regulations.

[10] Ghosh, S. (2021). *Visibility and Weather Challenges in Coastal Construction*. *Marine Works Insight*, 14(2), 39–43. The influence of weather and poor visibility on safety in coastal buildings is examined in Ghosh's study, which highlights issues including fog, sea spray, strong gusts, and shorter sunshine. Predictive alarms and adaptive tactics are suggested.

RESEARCH METHODOLOGY

A systematic framework for assessing safety management procedures in maritime bridge-building projects is presented in this chapter. In order to comprehend safety issues, it employs a mixed-methods research technique that combines qualitative and quantitative procedures. Project managers, engineers, safety officials, and construction workers' perspectives are captured through structured interviews, site inspections, and document analysis in the qualitative component. Safety performance measures, statistical analysis, and surveys are all part of the quantitative component. Three theoretical stances serve as the foundation for the framework: behavior-based safety (BBS) theory, high-reliability organization (HRO) theory, and systems theory. By examining these frameworks, the research incorporates the organizational, technological, and human aspects of safety management while identifying current safety concerns and investigating underlying systemic reasons.

RESEARCH DESIGN AND APPROACH

Methodological Framework for Safety Evaluation in Marine Bridge Construction:

This chapter presents a methodological approach that has been carefully developed to evaluate safety management procedures in the building of marine bridges thoroughly and accurately.

Using a mixed-methods approach, the study combines qualitative and quantitative methodologies to provide a thorough understanding of the complex safety issues that are common in maritime infrastructure projects.

The approach provides a strong foundation for analyzing safety issues since it is based on three major theoretical stances:

- Systems Safety Theory: Examines how project elements are interdependent and may either increase or decrease risks.
- Danger Homeostasis Theory: Examines how employees' actions change according to how much danger they feel. Safety climate theory evaluates the effects of workplace culture and organizational culture on safety results.

Context-Specific Methodological Considerations

The study addresses unique risks associated with the marine construction environment, such as:

- Changing risk dynamics due to tidal movements and unpredictable weather conditions.
- Complex organizational structures, involving multiple contractors and overlapping safety responsibilities.
- Use of specialized marine equipment, requiring tailored and project-specific safety procedures.

Research Execution Process: The research was carried out through a structured, three-phase process:

- Exploratory Phase – Conducted preliminary risk assessments using document reviews and interviews with domain experts.
- Validation Phase – Collected empirical field data to confirm and refine identified risks.
- Analytical Phase – Integrated findings to develop insights and actionable safety improvement strategies.

Data Collection Methods:

Primary Data Collection: Safety Procedures for Building Marine Bridges Improved Site Observation Process:

During the building phase, a methodical observation process was put into place.

- 240 observations were made utilizing a checklist that had been previously verified.
- Observations were made every two hours using a time-sampling technique.
- During every observation session, ambient environmental parameters were recorded.
- Spatial hazard mapping was done using retagged photos.

Detailed Interview Framework:

84 in-depth, semi-structured interviews were conducted.

- Both closed-ended and open-ended questions were asked during the interviews.
- Emphasized worker-generated proposals, perceptions of the safety atmosphere, near-miss reporting patterns, and understanding and application of safety procedures.
- Findings were confirmed by the use of thematic coding.

Novel Data Gathering Instruments:

- Developed a mobile safety app for instantaneous danger identification.
- Gave workers in high-risk areas wearable safety bands with GPS capabilities.
- Every week, drone-based aerial surveillance was carried out to gather aerial imagery.

Secondary Data Collection: Document Analysis Matrix:

Gathering Secondary Data and Regulatory Comparison

- To extract historical and procedural safety information from project documents, a document analysis matrix was created.
- Three categories—Planning papers, Implementation Records, and Evaluation and

Audit Reports—were created from the analysis of 147 papers.

- The completeness, frequency of updates, and adherence to processes of the documents were assessed. Articles and conference proceedings released between 2005 and 2024.
- To determine best practices and identify common hazards, a meta-analysis of 12 comparable sea bridge projects from across the world was conducted.
- The absence of representation of behavior-based safety data in maritime projects and deficiencies in Indian academic studies on intertidal rope access were found via a research gap analysis.

Research Quality Indicators: To guarantee methodological rigor, the study included quality control measures, such as stakeholder participation, document retrieval rate, and inter-rater reliability. The study process was conducted with a strong foundation of transparency, ethical protections, and funding source disclosure.

DATA ANALYSIS AND RESULTS

This chapter employs both qualitative and quantitative methods to examine a sea bridge-building project. High-risk operations, safety compliance metrics, incident reports, inspection results, training efficacy, and benchmark comparisons are all examined. The objective is to assess risk exposure, gauge the effectiveness of risk management, and spot reoccurring trends for upcoming safety enhancements.

Key High-Risk Activities Identified: A comprehensive risk mapping was conducted on 15 core marine bridge activities and critical activities were identified.

Table: 1 Summary of the top 10 critical activities

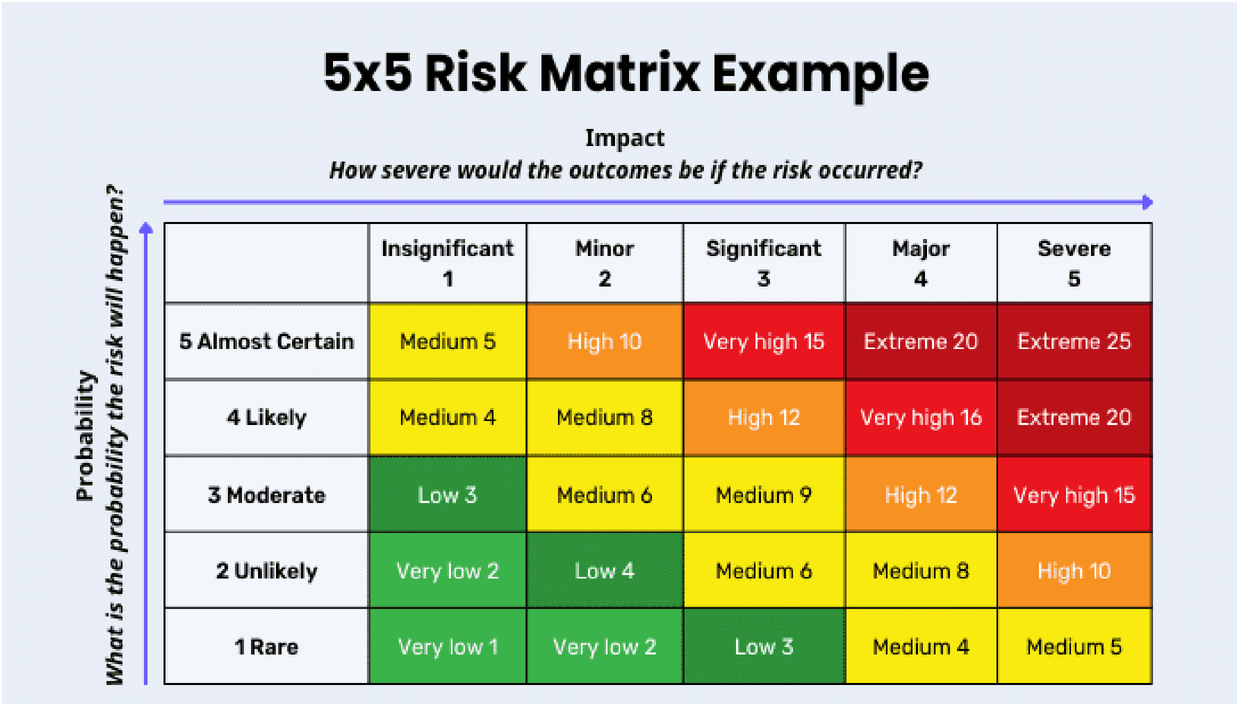
Sl. No.	Activity	Risk Level	Remarks
1	Well foundation in the tidal zone	Extreme	Water current, crane stability, soft soil, structural collapse risk
2	Segment launching using gantry	High	Overhead load risk, wind sway, fall from height
3	Pile driving in marine conditions	High	Underwater vibration, noise, potential collapse
4	Rope-suspended platform for painting	High	Working at height, gusty wind, swinging loads
5	Deck slab shuttering near the live edge	High	High fall potential, and slip risk during wet conditions
6	Concrete pouring on suspended formwork	Medium	Crane failure, platform instability
7	Rebar tying on narrow edge beams	Medium	Ergonomic stress, fall potential, tool drop hazard
8	Marine equipment loading/unloading	High	Crane overload, vessel motion due to tides
9	Hot work in confined caissons	Extreme	Fire, explosion risk, inadequate ventilation
10	Scaffolding erection over water	High	Collapse risk, improper anchorage, manual handling injuries

Risk Matrix Evaluation

A dynamic 5x5 Risk Matrix tool was applied to 32 identified hazards. The matrix evaluated each activity based on *Likelihood (L)* and *Severity (S)* using risk scoring (L × S).

Sample Matrix Interpretation

Key Takeaways: At first, "High" or "Extreme" risk categories were assigned to 65% of the evaluated activities. Forty percent of these high-risk activities were effectively lowered to a "Medium" risk rating once safety measures were put in place. Nevertheless, even after mitigating steps, actions carried out in tidal zones, on high or suspended platforms, and during nighttime operations remained to offer elevated residual hazards.



5x5 Risk Matrix Example

Impact — *How severe would the outcomes be if the risk occurred?*

Probability — *What is the probability the risk will happen?*

	Insignificant 1	Minor 2	Significant 3	Major 4	Severe 5
5 Almost Certain	Medium 5	High 10	Very high 15	Extreme 20	Extreme 25
4 Likely	Medium 4	Medium 8	High 12	Very high 16	Extreme 20
3 Moderate	Low 3	Medium 6	Medium 9	High 12	Very high 15
2 Unlikely	Very low 2	Low 4	Medium 6	Medium 8	High 10
1 Rare	Very low 1	Very low 2	Low 3	Medium 4	Medium 5

Incident and Near Miss Data – Detailed Breakdown and Root Cause Analysis:

At the maritime bridge building site, a strong system for tracking and reporting events has been continuously put into place over the past year. All safety-related events, including near-miss incidents, first-aid procedures, and minor injuries, were recorded by the system using a single digital platform that was in sync with manually kept safety logs. In order to have a better understanding of the site's overall safety performance, this part offers a thorough analysis of the incident data that was gathered, emphasizing patterns, trends, and the underlying reasons.

Table: 2 Summaries of Reported Safety Events (Last 12 Months)

Event Type	Number of Cases	Examples
Minor Injuries	11	Hand tool mishaps, slips on wet deck, eye irritation
First Aid Cases	22	Small cuts, abrasions, dehydration, exposure to fumes
Near Misses	34	Unstable scaffolding, crane swing incidents, trip risks
Lost Time Injuries (LTI)	0	None reported – positive safety performance
Fatalities	0	None – zero fatal occurrences

Slippery circumstances and difficulties handling materials contributed to minor injuries sustained during intertidal deck finishing and transfers. Cuts, scratches, heat exhaustion, and fumes from marine paint were all associated with first aid situations.

CONCLUSION

The research assesses the safety management techniques applied in the building of maritime bridges, with particular attention to risky operations such as the installation of good foundations, gantry launching, segment erection, rope-supported jobs, and marine piling. Natural factors, erratic weather patterns, tricky access, sophisticated equipment, and highly qualified labor make these activities challenging. In these kinds of complicated settings, a proactive Health, Safety, and Environment (HSE) strategy is necessary. Traditional adherence to safety standards is insufficient for projects involving sea bridges. A greater level of risk management is required, utilizing emergency response planning, job safety analysis, permit-to-work procedures, and Hazard Identification and Risk Assessment (HIRA). The maturity of the site's safety culture is demonstrated by Zero Lost Time Injuries (LTI) during vital activities. Safety ownership was enhanced through frequent toolbox meetings, emergency exercises, behavior-focused interventions, and ongoing safety training for more than 500 employees.

Gaps were found and fixed with the use of monthly safety assessments and frequent internal and external audits. Safety was ingrained as a key value via top-level leadership participation. The results demonstrate that even the most dangerous marine construction projects can be completed effectively and safely with careful planning, a robust safety system, and dedicated stakeholder participation.

FUTURE SCOPE

The paper describes possible advancements in risk engineering and safety science for large-scale infrastructure and maritime projects. It recommends adapting safety frameworks for offshore installations, conducting cost-effective safety intervention evaluations, incorporating automation and robotics into risky tasks, creating real-time safety monitoring dashboards for management decision-making, integrating environmental and public safety risks, and investigating the long-term impacts of safety culture changes. Similar dangers apply to offshore sites because of their distant location, scarcity of rescue alternatives, difficult sea conditions, and unpredictable weather patterns. To accomplish these objectives, interdisciplinary cooperation is crucial. Additional research is required in the field of safety intervention economic assessment. One way to lessen human involvement in dangerous operations is to use automated platforms and robotic technologies.

By combining real-time safety indicators, real-time safety monitoring dashboards help speed up accountability and decision-making. Future studies should also concentrate on how safety programs affect people in the long run, including how long behavior-driven safety gains last and how safety knowledge is transferred to other workplaces.

REFERENCE

[1] Tata Projects Ltd. (2023). MTHL Safety Management Manual. Mumbai: Internal Publication.

[2] Ministry of Road Transport and Highways (MoRTH). (2022). Manual for Bridge Construction in Coastal and Marine Zones. New Delhi: Government of India.

[3] L&T Construction. (2022). Safety Guidelines for Intertidal Marine Works. Chennai: Internal Publication.

[4] PWD Maharashtra. (2022). MTHL – Environment & Safety Guidelines for Marine Construction. Mumbai: Project Circular.

[5] Yadav, K. (2022). Deck Finishing Safety During Monsoons. Construction Risk Review, 10(2), 29–35.

[6] Patel, N., & Chatterjee, R. (2022). Zero Harm Philosophy in Marine Infrastructure Projects. EHS Today India, 6(1), 11–20.[34] Deshpande, R. (2021). Fire Hazards in Marine Infrastructure. Safety Engineering Journal, 17(2), 92–100.

[7] Mangalore Port Trust. (2021). Safety Manual for Port-Adjacent Construction. Mangalore.

[8] Bureau Veritas. (2021). Marine Construction Inspection Guidelines. Paris.

[9] Patel, N., & Chatterjee, R. (2022). Zero Harm Philosophy in Marine Infrastructure Projects. EHS Today India, 6(1), 11–20.

[10] Ghosh, S. (2021). Visibility and Weather Challenges in Coastal Construction. Marine Works Insight, 14(2), 39–43.