CHAPTER 1: INTRODUCTION

1.1. BACKGOUND

The development of Ibu Kota Nusantara (IKN) is a national strategic project aimed at transforming Indonesia's capital into a sustainable and modern city. One of the critical infrastructure components in this development is the Multi Utility Tunnel (MUT), which integrates various underground utilities such as electricity, telecommunications, water supply, and drainage systems. MUT offers several advantages, including optimized land use, reduced surface congestion, and improved maintenance access (Zhao et al., 2019). However, the complexity of MUT construction introduces significant safety risks, such as excavation-related accidents, structural failures, and hazards associated with confined spaces (Halim et al., 2021). Ensuring workplace safety in large-scale infrastructure projects is paramount to minimizing accidents and ensuring compliance with safety regulations (Machfudiyanto et al., 2022). With IKN set to become Indonesia's future capital, establishing a robust safety management system for MUT construction is crucial to preventing disruptions, minimizing fatalities, and enhancing worker protection (Siregar et al., 2024).

This study addresses the need for safer MUT construction methods by comparing the safety performance of two techniques: cast-in-place (in-situ) concrete construction and pre-cast segment construction. Cast-in-place methods offer on-site adaptability but involve extensive excavation and prolonged work duration, potentially heightening risks. Pre-cast methods reduce on-site work and speed up construction, but introduce hazards related to heavy lifting and transportation of tunnel segments. Comparative safety studies between these methods, especially for an ambitious project like IKN, remain limited. Geotechnical challenges in IKN (such as claystone soil prone to shrink-swell behavior) further exacerbate risks like tunnel collapse or water infiltration (Rahman et al., 2022). Therefore, a comprehensive safety engineering analysis is urgently needed to guide stakeholders in choosing and executing the safest construction approach for MUT in IKN.

Existing research lacks tailored geotechnical risk mitigation strategies for MUT construction in Indonesia. This study addresses the gap by developing a comparative risk assessment model to evaluate safety performance between pre-cast and cast-in-place methods, incorporating safety engineering analysis for geotechnical risk mitigation, structural risk mitigation, and also lifting risk mitigation. By identifying the risk factors associated with pre-

cast concrete and cast-in-place methods, this research will help mitigate potential hazards and optimize safety performance in IKN's infrastructure development. The urgency of this research is underscored by the high-risk nature of underground construction, where worker fatalities and injuries remain a global challenge (Shen et al., 2020). In Indonesia, construction-related accidents account for a significant proportion of occupational hazards (Pongtuluran et al., 2024), making it essential to explore proactive safety strategies tailored to MUT projects (Arman et al., 2025). Moreover, policy-makers and contractors require empirical evidence to select the safest and most efficient construction methodology for MUT.

Indonesia's limited experience with MUTs, compared to countries like Japan, Germany, and China, underscores the importance of learning from international best practices (Zhao et al., 2019). Japan emphasizes earthquake-resistant MUT designs; Germany employs modular precast tunnel systems; and China uses smart monitoring technologies for underground construction. Aligning IKN's MUT project with both global best practices and Indonesian regulations will enhance safety outcomes. This research contributes a structured methodology for risk identification, assessment, and mitigation in MUT construction, aligning with international safety standards (e.g. OSHA guidelines, ISO 45001). The ultimate goal is to provide empirical safety insights that help policymakers, engineers, and contractors implement safer and more efficient MUT construction in Indonesia's new capital.

1.2. OBJECTIVES AND BENEFITS

1.2.1. Objectives

This research aims to achieve the following objectives:

1. Identify and analyze the key safety risks associated with both precast and cast-in-place methods of Multi Utility Tunnel (MUT) construction in the Ibu Kota Nusantara (IKN) project, considering both general construction hazards and geotechnical-specific risks.
2. Compare the safety risk profiles of the precast concrete method and the cast-in-place method for MUT construction.
3. Develop a mitigation framework that integrates safety engineering analysis approaches, including geotechnical risk control strategies, structural safety measures, and lifting operation risk control, tailored for large-scale underground infrastructure projects.

1.2.2. Benefits

The expected benefits of this research include:

1. Strategic Decision Support: Providing empirical data, risk assessment models, and comparative safety metrics to assist policymakers and project stakeholders in selecting the safer and more effective MUT construction method for IKN. This helps ensure that decisions on construction approach are informed by safety considerations, not just cost or schedule.
2. Industry Best Practices: Contributing to the development of improved safety standards and risk mitigation strategies tailored to Indonesia's geotechnical context and regulatory framework. The findings draw from global best practices and can strengthen national construction safety regulations (e.g. enhancing Construction Safety Management System implementation as per Permen PUPR No. 10/2021).
3. Academic Contribution: Addressing research gaps in comparative risk assessment of underground construction methods, thereby providing a reference for future studies in infrastructure safety engineering. The methodological framework and results can be used by researchers and educators to further the knowledge on construction safety engineering, especially for emerging projects like smart city infrastructures.

1.3. RESEARCH LIMITATION

This final project focuses on specific aspects to maintain scope and depth. The key limitations are as follows:

1. The analysis is limited to two construction methods for MUT: pre-cast and cast-in-place. Other potential methods (e.g. full tunneling with Tunnel Boring Machine beyond the shallow depth applicable to IKN) are excluded from the comparison.
2. The study is focused strictly on safety risks. It identifies hazards via multi-hazard analysis and evaluates risk assessment; however, non-safety aspects such as cost, schedule implications, or environmental impact are beyond the scope of this research.
3. Engineering controls (technical measures) are the primary focus for risk mitigation. Behavioral (human) controls and administrative management controls are discussed only for context and are not evaluated in depth, since the study prioritizes engineering solutions to eliminate or control hazards at source.
4. The engineering control analysis is specific to high-risk activities identified in MUT construction. It includes technical evaluations such as excavation slope stability analysis,

concrete pressure for formwork stability analysis and a detailed lifting operation plan for heavy precast segments. Other engineering analyses (e.g. ventilation for confined spaces, fire safety systems) are not covered.

5. Building Information Modeling (BIM) is utilized in this project for 3D visualization of construction stages and safety planning, but it is not implemented as a real-time project management or monitoring tool. The BIM usage is limited to enhancing understanding of the construction sequence and identifying hazard interactions in a virtual model.

1.4. SYSTEMATIC WRITING

The systematic writing of this final project is as follows:

CHAPTER I : INTRODUCTION

The introduction has introduced the research background, problem statements, objectives, benefits, and scope/limitations.

CHAPTER II : LITERATURE REVIEW

Provides theoretical foundations and related research, including construction safety concepts, regulatory frameworks, risk assessment models, and specifics of MUT technology and construction methods.

CHAPTER III : RESEARCH METHODOLOGY

Explains the research design, data collection methods, hazard identification process, risk assessment approach, and the analysis techniques

CHAPTER IV : RESULTS AND DISCUSSION

Results and discussion presents the findings of the study : detailing identified hazards, comparative risk assessment results for cast-in-place vs. pre-cast methods, and discussions on the implementation of engineering controls.

CHAPTER V : CLOSING

Concludes the report by summarizing key findings, drawing conclusions regarding the safer construction method, and providing recommendations for practice and future research.