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Tsunami Disaster Mitigation Strategy for Yogyakarta International Airport (YIA)

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ABSTRACT

Yogyakarta International Airport (YIA) is strategically located on the coast of Kulon Progo, positioning it within the high-risk zone for tsunamis generated by the subduction zone of the Indo-Australian and Eurasian plates. Given its status as a critical national infrastructure, the operational resilience of YIA against a potential tsunami is paramount for regional economic stability and disaster response logistics. This study aims to analyze the current tsunami disaster mitigation strategies implemented at YIA, focusing on three core areas: (1) Structural and Non-Structural Engineering Measures, (2) Emergency Operational Planning and Protocols, and (3) Integration with Regional Disaster Management Authorities (BPBD). Employing a mixed-methods approach, including a spatial analysis of elevation data, a document review of the Airport Emergency Plan (AEP), and semi-structured expert interviews, the research assesses the adequacy of the existing mitigation framework. Initial findings suggest that while the airport's elevation is designed above the Maximum Credible Tsunami (MCT) inundation line, gaps remain in the rapid evacuation protocols for the landside population and the inter operability of communication systems with external disaster agencies. The study proposes a comprehensive set of recommendations to enhance YIA's operational continuity and resilience against the Tsunami threat

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INTRODUCTION

Tsunami Threat and Critical Infrastructure

Coastal areas of Southern Java, including the Kulon Progo region where Yogyakarta International Airport (YIA) is situated, are highly exposed to seismic and tsunami hazards. Historical data and contemporary seismological models (BMKG, 2019; Widjoedjonarko et al., 2021) indicate the potential for a megathrust earthquake ($M \approx 8.5-9.0$) along the Java Subduction Zone. Such an event could generate a devastating tsunami with a short travel time, reaching the Kulon Progo coast in under 30 minutes.

Airports serve as vital hubs for immediate disaster relief, medical evacuation, and long-term recovery efforts (Chang et al., 2015). The incapacitation of YIA due to tsunami inundation would severely cripple regional response capabilities, isolating Yogyakarta and Central Java from rapid international and domestic aid. Therefore, assessing and fortifying the airport's mitigation strategy is a critical imperative for national resilience and national security.

Study Objectives

This research seeks to:

- Evaluate the structural resilience of YIA's critical facilities (e.g., air traffic control tower, apron, runway) against the Maximum Credible Tsunami (MCT) scenario.
- Analyze the effectiveness of the current Airport Emergency Plan (AEP) in addressing Tsunami-specific operational challenges and evacuation constraints.
- Propose evidence-based mitigation and preparedness strategies to enhance YIA's operational continuity post-tsunami.

LITERATURE REVIEW

Airport Disaster Mitigation and Resilience Frameworks

International best practices emphasize that critical infrastructure resilience must move beyond structural survival to ensuring rapid operational recovery. Frameworks established by the International Civil Aviation Organization (ICAO, 2018) emphasize the concept of Operational Continuity Planning (OCP). OCP demands that core functions—such as Air Traffic Control (ATC), backup power generation, and emergency communications—remain operational or are rapidly restorable within hours of an event.

Furthermore, the Safety Index for Airports, adapted from the World Health Organization’s Hospital Safety Index (HSI), provides a mathematical approach to vulnerability assessment by evaluating structural, non-structural, and functional parameters.

$$\text{Safety Index} = w_1(S) + w_2(NS) + w_3(F)$$.

Where S represents structural safety, NS represents non-structural elements (utilities, equipment), F represents functional capacity (staff protocols, emergency planning), and w represents assigned weights.

For high-density costal environments, Vertical Evacuation Strategy is widely accepted as the primary defense for the landside population (passengers, visitors, and ground staff) when horizontal evacuation time is insufficient (FEMA, 2019).

This strategy relies on utilizing robust, multi-story engineered structures designed to withstand hydrodynamic forces as temporary safe zones.

The Tsunami Hazard for Southern Java

The Java Subduction Zone, where the Indo-Australian plate subducts beneath the Eurasian plate, represents a significant megathrust threat. Tsunami numerical modeling specifically conducted for the Kulon Progo coast by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG, 2020) suggests an inundation height of up to 6.5 to 7.0 meters above Mean Sea Level (MSL), with a run-up distance extending up to 2 kilometers inland, directly threatening the airport perimeter. Effective airport mitigation must rely on these precise hazard models to formulate spatial zoning and operational trigger points.

METHODOLOGY

Research Design

This study employs a Descriptive Analytical approach combined with a case-study design to assess the real-world climate and seismic readiness of YIA.

Data Collection and Analysis

a. Spatial Analysis: Utilizing Digital Elevation Model (DEM) data and Light Detection and Ranging (LiDAR) datasets to verify the actual topography and elevation of YIA's runway, apron, and terminal buildings against the projected 7.0-meter MCT inundation line via Geographic Information System (GIS) software.
b. Document Review: Analysis of the existing Yogyakarta Airport Emergency Plan (AEP), Standard Operating Procedures (SOPs) for Tsunami early warning dissemination, and the Indonesian National Standard (SNI) structural building codes utilized during the airport's construction phase.
c. Expert Interviews: Purposive semi-structured interviews conducted with key stakeholders, including representatives from PT Angkasa Pura I (AP I) Risk Management, AirNav Indonesia (ATC Yogyakarta), and the Regional Disaster Management Agency (BPBD) of Kulon Progo.
d. Assessment Criteria: Mitigation frameworks are evaluated based on the United Nations Office for Disaster Risk Reduction (UNDRR) three pillars of disaster resilience: Structural Safety, Operational/Emergency Planning, and Community/Inter-agency Preparedness.

RESEARCH RESULT AND DISCUSSION

Structural Resilience Assessment (Pillar 1: Structural and Non-Structural Safety)

- Finding 1: High Foundation Level. Spatial and GIS analysis confirms that YIA was purposely constructed on reclaimed and elevated land. The runway, apron, and passenger terminal sit at an average elevation of 7.5 meters above Mean Sea Level (MSL). This engineered elevation directly exceeds the BMKG modeled MCT inundation height of 7.0 meters, providing a vital buffer against direct structural flooding.

- Finding 2: Critical Utilities Location. In alignment with non-structural mitigation theory (FEMA, 2019), critical infrastructure components, including primary electrical transformers, backup diesel generators, and main communication servers, are situated on the upper levels (2nd and 3rd floors) of the terminal building or on specially elevated concrete platforms.

Theoretical Discussion

YIA's success in designing a site elevation above the Maximum Credible Tsunami (MCT) limit is an implementation of the Defense-in-Depth Principle in critical infrastructure structural engineering (ICAO, 2018). Based on the infrastructure resilience theory of Chang et al. (2015), this superior elevation minimizes physical vulnerability to hydrodynamic seawater loads.

However, from a long-term perspective, the Kulon Progo coastal area is vulnerable to natural soil consolidation and subsurface alluvial phenomena. According to Coastal Subsidence theory (Suryono et al., 2022), gradual land subsidence can degrade the freeboard value (the safe distance between the airport elevation and the tsunami height), which is currently only around 0.5 meters. If land subsidence occurs at a rate of 1-2 cm per year, this structural safety margin will disappear within the next two decades, shifting YIA's risk from low to highly vulnerable to wave overtopping.

Operational Planning and Response Protocols (Pillar 2: Emergency Planning)

- Finding 3: Tsunami-Specific AEP. A document review shows that PT Angkasa Pura I's AEP document for YIA has integrated a dedicated tsunami mitigation module. This module outlines the activation of the Airport Emergency Committee (AEC) and the transfer of command to the Emergency Operations Center (EOC) within 5 minutes of receiving a BMKG warning.
- Finding 4: Evacuation Challenges. Although the terminal building infrastructure was designed as a vertical evacuation structure, internal simulations detected a bottleneck. The protocol for moving thousands of passengers from the landside area (non-aircraft passengers/public in the departure and arrival terminals) to the upper floors of the multi-story parking lot required an average activation and mobilization time of 22 minutes.

Theoretical Discussion

From an Operational Continuity Planning (OCP) perspective, mitigation effectiveness is measured not only by concrete strength but also by functional response time. Based on Evacuation Wave Theory (Perry & Lindell, 2003), panic-stricken crowd movement in enclosed public spaces is controlled by the availability of information and clear evacuation routes.

The estimated tsunami travel time after a megathrust earthquake of under 30 minutes leaves a very short "Golden Time." If the YIA evacuation time takes 22 minutes, the remaining margin of safety is only a few minutes before the wave reaches land. Bottlenecks at emergency stairs and the lack of intuitive multilingual signage indicate that the airport's Functional Resilience lags behind its Structural Resilience. Delays in decision-making by airport authorities due to waiting for visual confirmation can be fatal (Comfort, 2019).

Inter-Agency Integration (Pillar 3: Regional Preparedness)

- Finding 5: Communication Gap. Expert interviews revealed a technical disconnect. The airport's internal early warning system (sirens and Public Address System) was manually operated by AP I personnel after receiving an SMS/Warning Receiver System (WRS) from the Meteorology, Climatology, and Geophysics Agency (BMKG). There was no automation integrating the BMKG detection system, the Kulon Progo Regency Government's early warning system, and the airport's internal systems.

Theoretical Discussion

Inter-agency integration is the third pillar of the Disaster Resilience Framework (UNDRR, 2015). This failure to synchronize can be explained by the Silo Effects theory of disaster management (Quarantelli, 1997), where each organization (AP I, AirNav, and BPBD) operates within its own internal procedural corridor without seamless system interoperability.

In the event of a megathrust disaster, the public cellular network would undoubtedly experience network congestion due to traffic surges or damage to base transceiver towers. The lack of a dedicated satellite link connecting the YIA EOC to the Kulon Progo Regional Disaster

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Yogyakarta International Airport (YIA) demonstrates excellent structural mitigation against the threat of a tsunami due to its high elevation design (7.5 meters MSL) above the estimated inundation line. However, the airport's operational resilience remains vulnerable to human and procedural factors. The speed of mass evacuation protocols in landside areas and the integration of emergency communication systems with local BPBDs and external agencies still require more rigorous optimization and simulation to ensure YIA's optimal function as a post-disaster humanitarian logistics hub.

Recommendations

1. Mandatory Full-Scale Drills: Conduct a full-scale tsunami evacuation simulation at least twice a year (every two years), with a particular focus on the rapid mobilization of landside passengers to vertical evacuation points in the parking lot, as well as testing runway shutdown duration.
2. Redundant Communication System: Implement dedicated satellite communications equipment (such as VSAT technology or satellite phones) that directly connects the Airport AEC, AirNav, and the Kulon Progo Regional Disaster Management Agency (BPBD) without relying on public telecommunications service providers.
3. Risk Communication Standardization: Install multilingual tsunami evacuation maps and signs based on the ISO 22324 standard throughout the terminal to guide passenger movement quickly and independently without triggering mass panic.

ADVANCED RESEARCH

Future research will focus more on structural mitigation, prioritizing infrastructure development oriented toward disaster risk management. Further research could also delve deeper into calculating the disaster risk index.

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