Impact of Earthquakes on Ports and Associated Facilities

EARTHQUAKE FORUM

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Introduction

Introduction

- Earthquakes impact ports through immediate structural damage and cascading effects, which can halt trade and hinder humanitarian relief efforts.

- Earthquakes pose significant risks to ports, affecting infrastructure and disrupting global supply chains.

Earthquake Risks to Port Infrastructure

- Ports built on reclaimed or loose, saturated land are particularly vulnerable to ground failure, a primary cause of seismic damage.

- Understanding the impacts helps develop resilient systems for crucial maritime operations.

02

Impacts on Port

- Seismic Impacts
- Operational Impacts
- Environmental & Safety Impacts
- Cascading & Network Impacts

Earthquake Hazards for Ports

- **Ground shaking**
  → structural damage to cranes, warehouses, jetties
- **Soil liquefaction**
  → instability of quay walls & container yards
- **Tsunamis**
  → flooding of coastal facilities
- **Landslides** (in hilly coastal areas)
  → block access roads & pipelines

Ground shaking:

- Strong ground motion can directly cause structural damage to buildings, wharves, docks, and cranes.

- Observations from past earthquakes, revealed that traditional force-balance design approaches are often insufficient against severe shaking, leading to the development of modern, performance-based guidelines.

1995 Kobe Earthquake

Kobe Earthquake damage in Japan.

Historical Meriken Wharf destroyed by Great Hanshin Earthquake.

Soil liquefaction and lateral spreading:

- Seismic shaking can cause saturated, loose, granular soils to temporarily lose their strength and behave like a liquid.
- It is a major cause of port damage, can damage wharves, foundations, and seawalls.
- Liquefaction can also cause "lateral spreading," where gentle slopes move toward a water body, causing ground fissures and massive displacement of foundations and other structures.

Tsunamis:

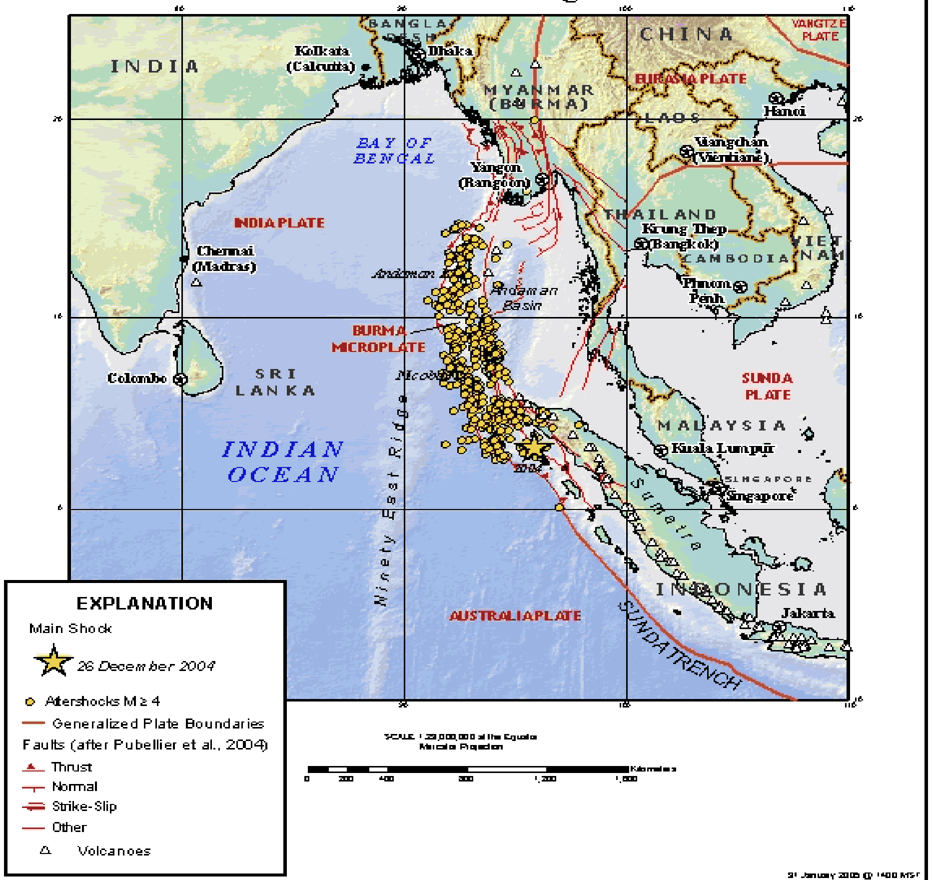
- Earthquakes can trigger tsunamis that destroy port infrastructure with strong waves and currents.
- Waterfronts can be crushed by returning waves and debris.
- Strong currents can snap mooring lines, causing moored vessels to collide with other ships or dock structures.

2004 Indian Ocean tsunami

90-meter coal barge in Banda Aceh, Indonesia was deposited far inland.

USGS

Northeast Indian Ocean Region Tectonic Setting



Operational Impacts

- Port shutdowns → disruption of supply chains
- Loss of navigation aids, power, ICT & communication systems
- Delays in humanitarian relief & emergency imports
- Ripple effect on economy & trade

Operational Impacts

Port shutdowns

- lead to significant disruptions in supply chains, resulting in economic challenges and delays in essential services such as humanitarian relief and emergency imports.

- highlights the critical inter-connectedness of global trade and the economy, emphasizing the need for robust strategies to mitigate these impacts.

Impact of Port Shutdowns

Disruptions in Supply Chains

Halting goods movement, causing delivery delays.

Backlogs and Delays

Creating shipping delays and inventory management issues.

Increased Shipping Costs

Higher costs due to alternative transport methods.

Loss of Navigation Aids

Safety Hazards

The absence of navigation aids can lead to maritime navigation hazards, increasing the risk of accidents at sea and resulting in potential environmental disasters.

Impact on Trade Routes

With navigation aids compromised, major trade routes may become unsafe, further exacerbating delays and preventing efficient movement of goods across borders.

Reduced Shipping Efficiency

Ships may experience longer travel times and unexpected detours, leading to overall inefficiencies in maritime trade operations and increased costs.

Impact of Power and ICT Loss on Communication

Operational Disruptions

Loss of power and communication systems disrupts port operations, leading to delays in cargo handling and processing, which is critical for smooth logistics.

Inability to Track Shipments

Without effective communication systems, tracking shipments becomes challenging, causing confusion and uncertainties in supply chains and affecting customer trust.

Compromised Security

The loss of ICT systems may also lead to security vulnerabilities, increasing the risk of theft and fraud in ports which could deter future business.

Delays in humanitarian relief & emergency imports

Ineffective Aid Distribution

Port shutdowns can lead to significant delays in the distribution of humanitarian aid to regions in need, compromising efforts to assist vulnerable populations during crises

Health Risks

Prolonged delays in supplies such as medicine and food can lead to health risks and further complications in affected regions, undermining relief efforts.

International Response Challenges

Shutdowns may hinder international aid organizations' ability to respond effectively, leading to a panic in affected areas and heightening humanitarian crises.

Ripple Effect on Economy

Negative Economic Growth

Disruptions in trade and supply chains can result in reduced economic growth, as industries face difficulties in operations leading to potential job losses.

Inflationary Pressures

Increased shipping costs and supply shortages can contribute to inflation, affecting the overall purchasing power of consumers and raising living costs.

Global Trade Imbalances

Port shutdowns can lead to trade imbalances as countries struggle to export or import goods, affecting global economic stability and bilateral relations.

Environmental & Safety Impacts

- Earthquakes can profoundly disrupt port operations, leading to serious environmental and safety challenges.
- Key risks include oil spills, chemical leaks, fires, and navigational hazards, all of which threaten worker safety and the well-being of surrounding communities.
- Addressing these concerns is crucial for minimizing the impact of seismic events on port facilities.

Oil Spills & Chemical Leaks

Damaged Tanks

Earthquakes can rupture storage tanks, leading to oil spills and chemical leaks.

Long-term Effects

The aftermath of spills can have lasting effects on the environment.

Regulatory Challenges

These incidents challenge regulatory frameworks and necessitate reviews of existing protocols.

Fires from Ruptured Pipelines

1

Pipeline Vulnerability

Earthquakes can compromise underground pipelines, leading to gas and oil leaks that may result in fires or explosions, posing immediate dangers to life and property.

2

Evacuation Protocols

In the event of a fire, effective evacuation protocols are crucial to ensure the safety of dock workers and surrounding communities, requiring clear communication and timely response measures.

3

Firefighting Challenges

Firefighters often face unique challenges during earthquakes, such as access issues and the potential for further aftershocks, complicating emergency response efforts.

Turkey’s İskenderun port on fire after powerful earthquake

Navigational Hazards

Debris Accumulation

Earthquake-induced debris in harbors poses significant navigational risks for vessels. Sunken or floating debris can cause collisions and accidents, disrupting shipping operations.

Harbor Assessments

Regular inspections and assessments post-earthquake are essential to identify and remove hazards quickly, ensuring navigational safety and resuming normal port activities.

Economic Impact

Disruptions to shipping routes and delays in cargo handling can have far-reaching economic consequences, impacting trade and revenue for port operations and related industries.

Risk to Workers & Communities

Worker Exposure

Dock workers face heightened risks during and after earthquakes, including accidents, exposure to hazardous materials, and psychological stress.

Community Safety

Nearby communities may also be at risk due to accidents, spills, or fires originating from port facilities.

Support Systems

Establishing support systems like counseling and training can enhance worker and community resilience.

Cascading and Network Impacts

Damage at one port can trigger far-reaching consequences across regional and global trade networks.

Logistics disruption: A single port shutdown can halt trade flows, disrupting shipping routes and impacting global supply chains.

Economic losses: Beyond the cost of physical damage, ports experience severe economic losses from disruptions to seaborne trade, highlighting the disparity between direct and indirect economic impacts.

Relief complications: Port incapacitation hampered the transport of crucial relief supplies for months.

03

Vulnerability of Port Facilities

Vulnerability of Port Structures

- Ports have complex structures like docks and cranes, which are highly vulnerable to seismic forces.
- Poor design or aging increases the risk of damage, affecting operational continuity.

Vulnerability of Port Facilities

Different types of port structures have varying levels of seismic resilience:

Quay walls: These structures are particularly vulnerable to lateral ground movement and liquefaction, and prone to collapse under seismic stress

[[In the 2016 Kumamoto earthquake, gravity quay walls experienced lateral spreading, while sheet pile walls showed no damage.]]

Vulnerability of Port Facilities

- ***Wharves and docks***: Pile-supported wharves often perform better during earthquakes than other wharf types, but the seismic performance of pile-to-wharf connections is critical. Without proper seismic isolation systems, connections can experience significant resistance and stiffness deterioration.

- ***Equipment:*** Cargo-handling equipment, like rail-mounted gantry cranes, can be damaged by ground shaking or foundation failure, causing significant downtime.

Vulnerability of Port Facilities

- ***Port buildings and warehouses***: While some studies suggest building damage may not significantly affect cargo movement, other events show steel-framed warehouses can be susceptible to seismic forces.

- ***Pipelines and utilities***: Damage to critical infrastructure like fire water lines and power substations can hamper emergency response and recovery.

04

Mitigation and Resilience

Mitigation and Resilience

Lessons from past seismic events have driven advancements in port design and disaster planning.

Performance-based design

Modern design approaches focus on performance requirements, allowing for some controlled damage during an earthquake while ensuring structural integrity and preventing collapse.

Seismic isolation systems

The use of isolation systems for wharves and piles can significantly enhance seismic performance by reducing the transfer of force to the piles and wharf deck.

Multi-hazard risk assessment

Ports are increasingly adopting comprehensive risk frameworks that account for multiple, cascading hazards, including ground shaking, liquefaction, and tsunamis.

Emergency planning

It is essential for port authorities, operators, and shipping companies to minimize the impact of disruptions and prepare for a swift recovery.

Design and Engineering Challenges

- Designing ports to withstand earthquakes requires advanced engineering that considers ground motion, soil liquefaction, and infrastructure interdependencies.
- Enhancing resilience demands integrating seismic codes and innovative materials to reduce risks

Structural Reinforcement and Retrofitting

Retrofitting existing port facilities with seismic-resistant technologies, such as base isolators and dampers, strengthens structures and maintains operational integrity after earthquakes.

- Seismic-resistant design for quay walls & cranes
- Liquefaction countermeasures (soil improvement, deep foundations)
- Tsunami barriers & elevated storage areas
- Emergency response & continuity planning

Importance of Resilience Planning

Need for Resilience Planning

Businesses and governments must invest in resilience planning to mitigate operational challenges.

Collaborative Solutions

Global collaboration is necessary to enhance infrastructure and communication systems.

Long-term Strategy Development

Strategies focusing on supply chain diversity and technology investment are essential.

Emergency Preparedness and Response Plans

Effective emergency plans include evacuation protocols, staff training, and coordination with local authorities to ensure rapid recovery and minimize damage during seismic events.

Technological Innovations in Monitoring and Early Warning

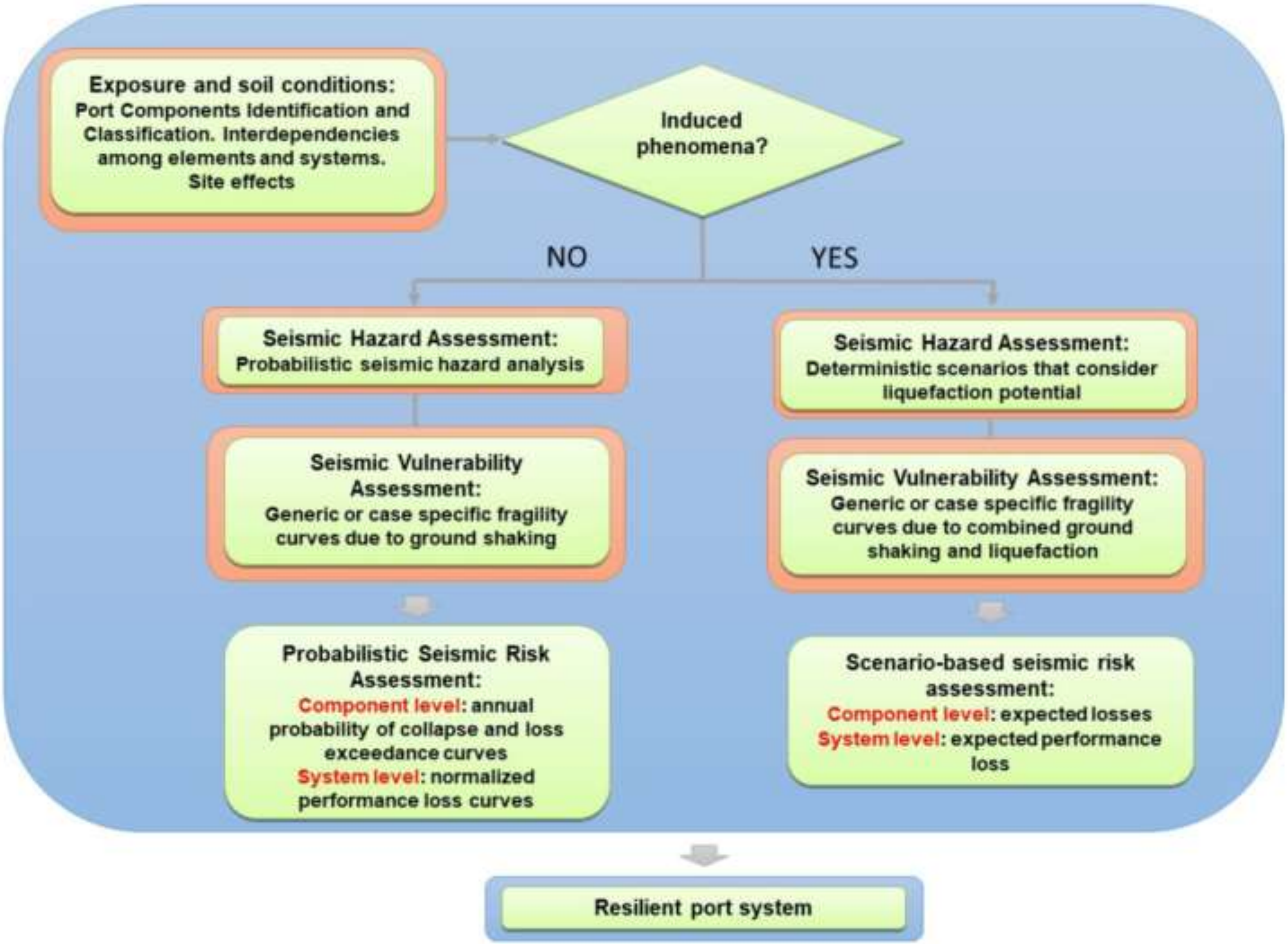
Advanced monitoring systems use seismic sensors and real-time data analytics to provide early warnings, enabling proactive measures and reducing disaster impacts on port operations.

Technological & Policy Measures

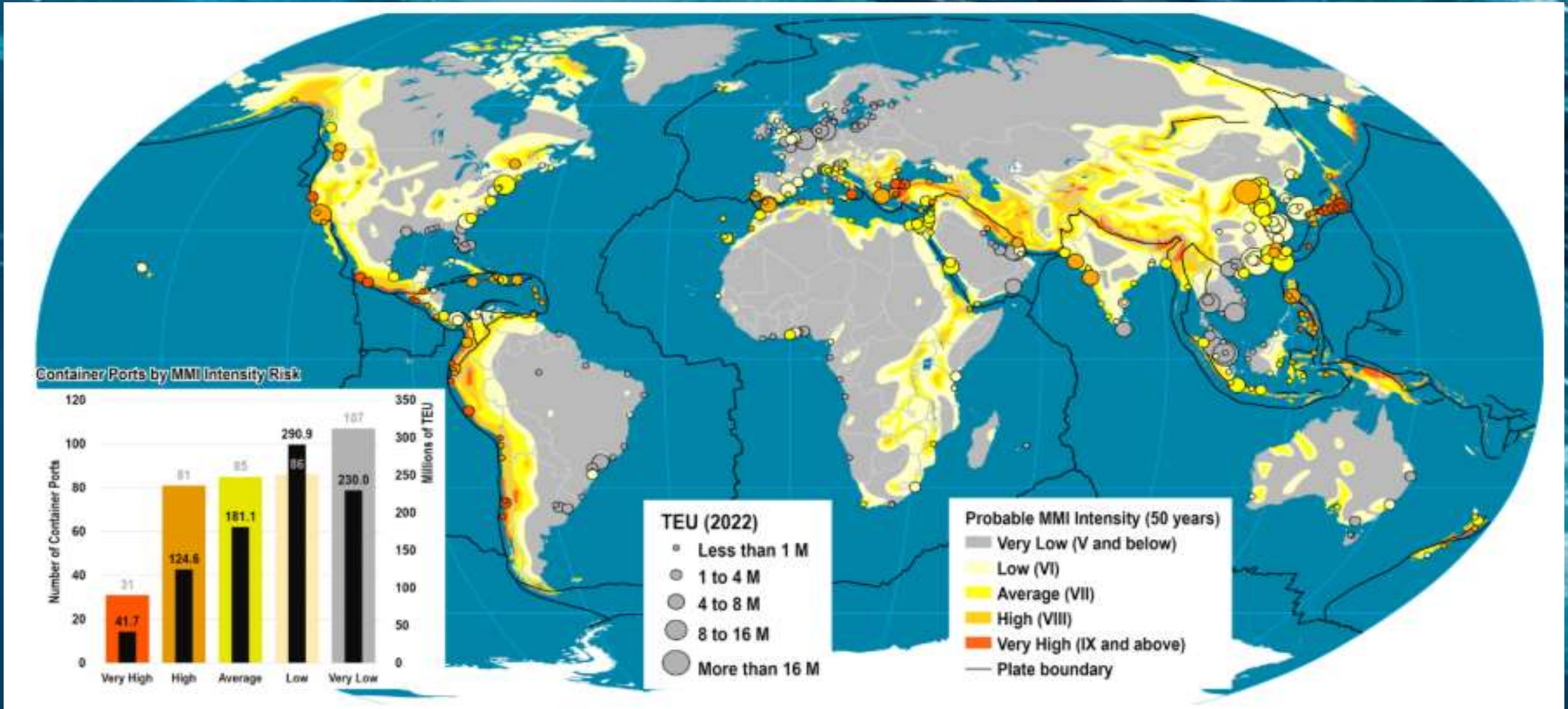
- Real-time seismic monitoring & early warning systems
- Remote sensing & drones for rapid damage assessment
- Port risk assessments in national disaster strategies
- International cooperation for resilient maritime trade

Seismic Hazard Assessment

- Accurate seismic hazard assessment involves geological studies and risk modeling.
- It is essential for planning and designing earthquake-resistant port facilities to minimize losses.



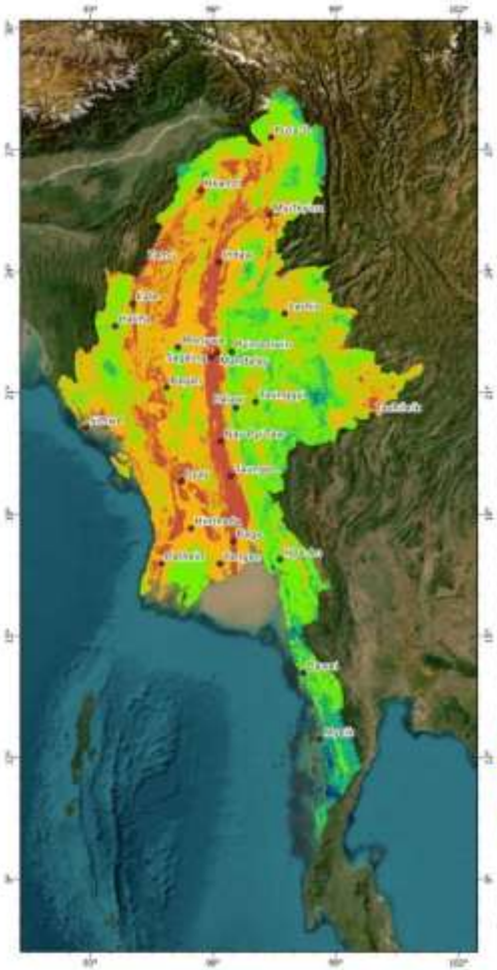
Exposure and soil conditions:
Port Components Identification and Classification. Interdependencies among elements and systems.
Site effects
Induced phenomena?
NO
YES
Seismic Hazard Assessment:
Probabilistic seismic hazard analysis
Seismic Hazard Assessment:
Deterministic scenarios that consider liquefaction potential
Seismic Vulnerability Assessment:
Generic or case specific fragility curves due to ground shaking
Seismic Vulnerability Assessment:
Generic or case specific fragility curves due to combined ground shaking and liquefaction
Probabilistic Seismic Risk Assessment:
Component level: annual probability of collapse and loss exceedance curves
System level: normalized performance loss curves
Scenario-based seismic risk assessment:
Component level: expected losses
System level: expected performance loss
Resilient port system



Risk of Earthquake for Global Container Ports

(Source: Earthquake risk from "The World Map of Natural Hazards", Munchener Ruckversicherungs-Gesellschaft (Munchener Re), Koniginstrasse 107, D-8000 Munchen 40, Germany.")

EARTHQUAKE HAZARD MAP OF MYANMAR



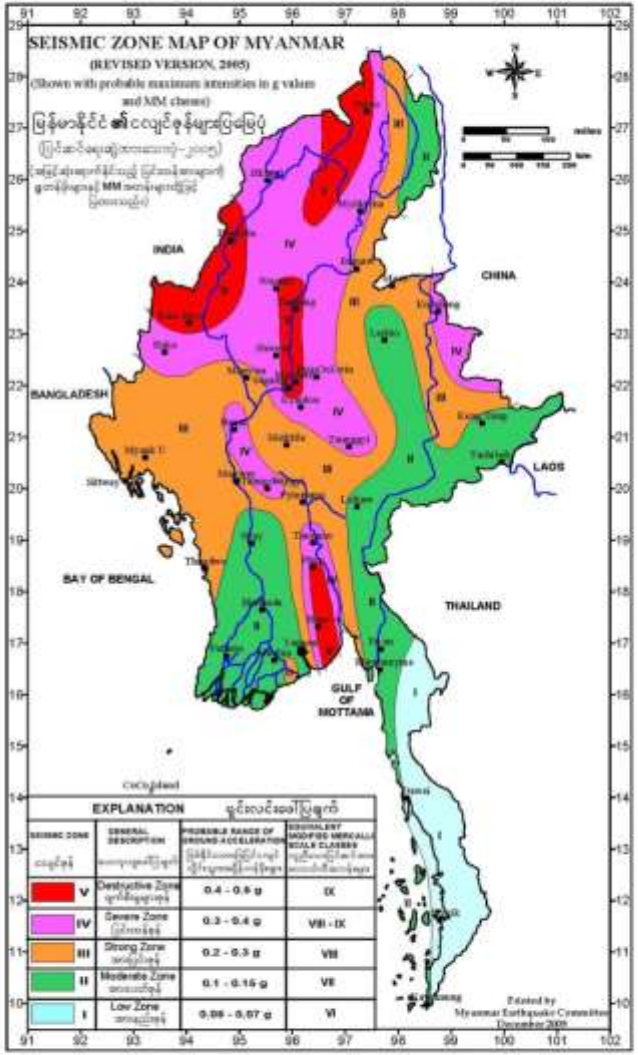
The earthquake hazard map provides a comprehensive spatial assessment of seismic hazard in Myanmar by integrating multiple geospatial and seismological factors. These include Peak Ground Acceleration (PGA), Vs30, distance to active faults, magnitude density, distance to epicenters, epicenter density, active fault density, slope, elevation, and newly mapped surface rupture data derived from recent field surveys. By combining these parameters through a geospatial multi-criteria approach, the map highlights areas that are most susceptible to strong ground shaking, fault displacement, and related earthquake impacts. This integrated analysis offers critical insights for identifying vulnerable regions, supporting disaster preparedness, land-use planning, and earthquake risk mitigation strategies.

Earthquake Hazard

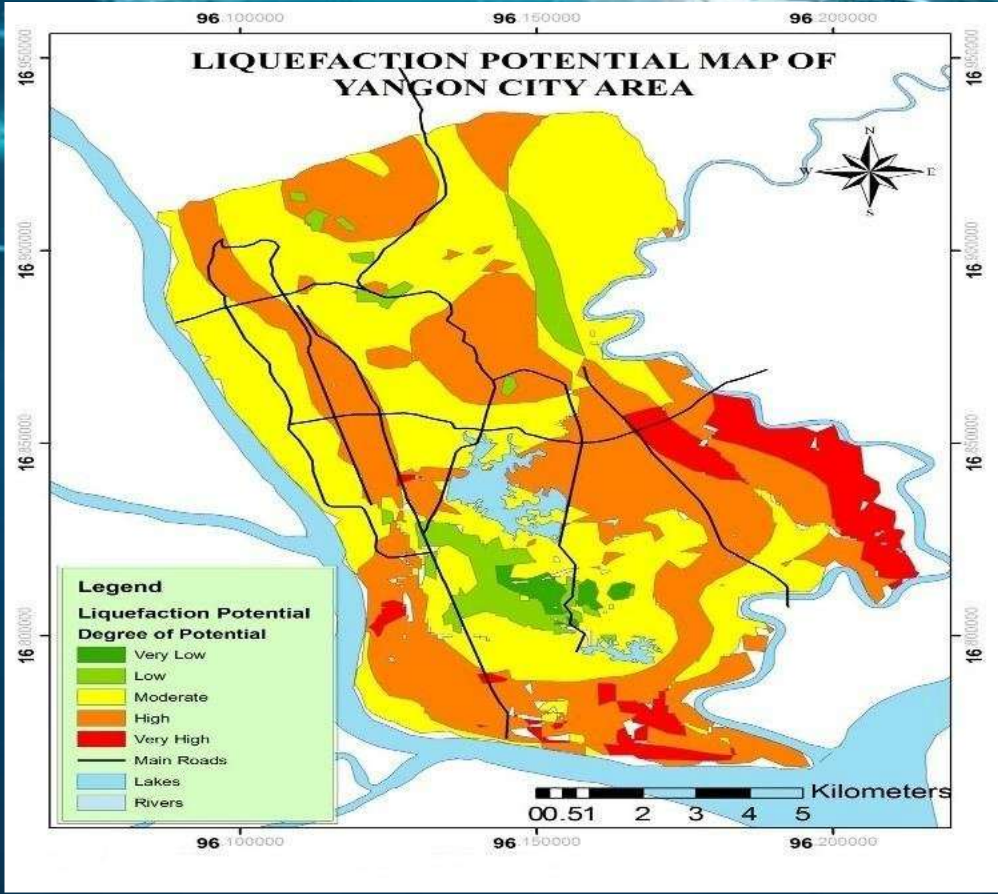
- Very High
- High
- Moderate
- Low
- Very Low

Map ID: EQ-Hazard-MM-2025
Map prepared by: Kaung Si Thu

0 50100 200 300 400 km



Revised by Dr. Maung Thein, U Tint Lwin Swe and Dr. Sone Han (December 2005)


LIQUEFACTION POTENTIAL MAP OF
YANGON CITY AREA
Legend
Liquefaction Potential
Degree of Potential
Very Low
Low
Moderate
High
Very High
Main Roads
Lakes
Rivers
Kilometers
0 0.5 1 2 3 4 5
N
S
W
E
96.100000
96.150000
96.200000
16.950000
16.900000
16.850000
16.800000

05

Conclusion

Conclusion

- Earthquake preparedness in ports is critical for safeguarding infrastructure and supply chains.
- Combining robust design, emergency planning, and cutting-edge technology enhances resilience and ensures continued functionality after seismic events.

Conclusion

- This presentation investigates various impacts on Port due to earthquake and vulnerability of Port Facilities.
- It also highlights the Design and Engineering Challenges, Important of Emergency Preparedness and Response Plans, Technological Innovations in Monitoring and Early Warning, and Seismic Hazard Assessment.
- By examining these elements, we aim to identify effective solutions that will enhance the efficiency and sustainability of port operations, ultimately supporting economic growth and community development in the region.

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- Chapter 10.4 – Port Resilience Authors: Dr. Jean-Paul Rodrigue, Dr. Theo Notteboom and Dr. Athanasios Pallis


Thank You !