Tsunami Hazard Assessment for Port Hedland

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Abstract
This study assesses the tsunami hazard potential for Port Hedland, a critical maritime hub in Western Australia, with a focus on seismic activity originating from the Sunda Trench. The Sunda Arc's tectonic activity has produced major earthquakes, with recent seismic events including the 1977 Sumba Earthquake and the devastating 2004 Indian Ocean Earthquake. Although previous events have had a minor impact on Port Hedland, this assessment models the potential effects of larger seismic events on the port's operations and infrastructure.

Using NOAA's Method of Splitting Tsunamis (MOST) model, we conducted high-resolution numerical simulations for various earthquake scenarios, including Mw 7.7, Mw 8.5, and Mw 9.0 events. The study also analysed tidal conditions and their influence on tsunami wave heights and arrival times. Results indicate that while smaller events, such as the 2006 Java earthquake, produce minimal impacts (<5 cm wave height), larger events, especially Mw 9.0 earthquakes, could generate wave heights up to 2 meters at Port Hedland, posing significant risks to vessels and infrastructure. Additionally, currents exceeding 5 knots in the port area could cause serious operational disruptions.

The findings suggest that Port Hedland is particularly vulnerable to tsunamis originating from the eastern Indonesian region, which could lead to more severe impacts compared to events from the Sunda Trench. The study recommends improvements in early warning systems and disaster preparedness measures, especially for seismic events exceeding Mw 7.5, to mitigate the risk to port operations and the surrounding community.

Keywords: tsunami, ports, infrastructure, coastal structures, maritime, earthquakes, natural hazards

1. Introduction

Port Hedland, located on the northwest coast of Australia, is one of the country's most vital ports, with a throughput of over 573 million tonnes annually, making it a cornerstone of Australia's economy (https://www.pilbaraports.com.au/). The port's strategic importance, particularly in the export of iron ore, means that any disruption, especially from natural hazards like tsunamis, could have severe economic repercussions both locally and nationally. Its exposure to tsunamis is shaped by its geographic proximity to the Sunda Trench, a major subduction zone where the Indo-Australian Plate meets the Eurasian Plate. The potential consequences of a tsunami—such as vessel damage, infrastructure loss, and shipping delays—necessitate a robust hazard assessment.

This study investigates potential tsunami impacts at Port Hedland, quantifies their severity, and outlines implications for port operations. Scenarios are based on historic and plausible seismic events and evaluated through hydrodynamic modelling.

2. Tectonic Setting and Earthquake History

Port Hedland lies along the northwest coast of Australia, facing the Sunda Trench (Figure 1), a key part of the seismically active Sunda Arc. This subduction zone marks the boundary between the Indo-Australian Plate and the Eurasian Plate, resulting in frequent and significant seismic activity. The Sunda Trench, with fault movement rates of 33-75 mm/year (Hutchings and Mooney 2021 and Okal 2007), is comparable to other major seismic regions like Japan and Chile, making it a source of potential tsunamis that could impact Western Australia.

Figure 1 Global tectonic settings

2.1 Significant Earthquake Events and Tsunamis

- **1977 Sumba Earthquake (Mw 8.3)**: Minor sea level changes observed in northern Australia.

- **2004 Indian Ocean Earthquake (Mw 9.1):** Generated a trans-oceanic tsunami. Port Hedland saw measurable sea level disturbances.

- **2006 Java Earthquake (Mw 7.7):** Tsunami confined to Indonesia; negligible Australian impact.
- **2010 Mentawai Earthquake (Mw 7.7):** Severe impacts in Indonesia; no Australian consequences.

These events show that while Port Hedland is distant from epicentres, tsunami signals can still reach its coast depending on magnitude and directionality.

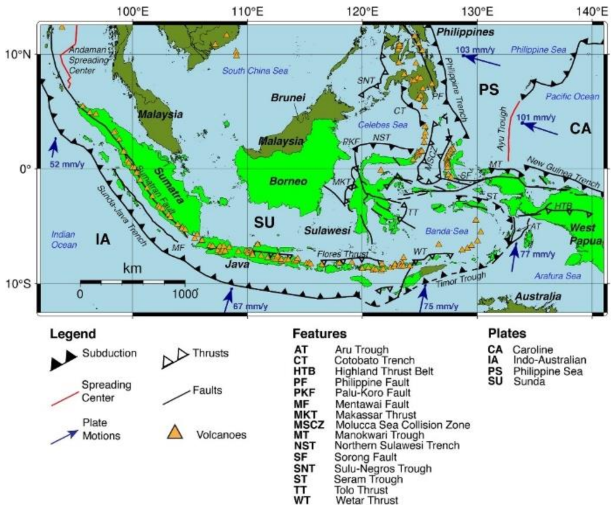

Figure 2 Tectonic settings in Indonesia (Hutchings and Mooney 2021).

3. Methodology

This study used NOAA's MOST (Method of Splitting Tsunamis) model, a non-linear shallow water wave model validated globally. This model is used for tsunami propagation, inundation studies, and early warning systems. It is particularly useful in real-time scenarios where rapid and accurate predictions are needed. It allows for the detailed simulation of tsunami generation, propagation, and inundation, using high-resolution bathymetric data to capture the complex interactions between seismic events and coastal geography.

The MOST model uses a nested grid approach with resolutions as fine as 3 seconds (90 metres), allowing for highly detailed simulations from the source area (e.g., Java) to the target location (e.g., Port Hedland). This is critical for accurately predicting the impact of tsunamis on specific locations, considering local bathymetry and topography (see Figure 3).

MOST is used for tsunami hazard assessments in regions such as Guam, the Northern Mariana Islands, the Port of Los Angeles, and Long Beach. Past studies (Uslu, Eble, Arcas and Titov 2013; Uslu, Titov, Eble and Chamberlin 2010; Uslu, Eble, Titov and Bernard 2010) provide a detailed look into the impact of tsunamis on coastal infrastructure and communities, which can be analogously applied to Port Hedland. These reports discuss the importance of accurate bathymetric data (down to 3-second resolution) and the use of nested grids to simulate the impact of tsunamis from nearby fault lines.

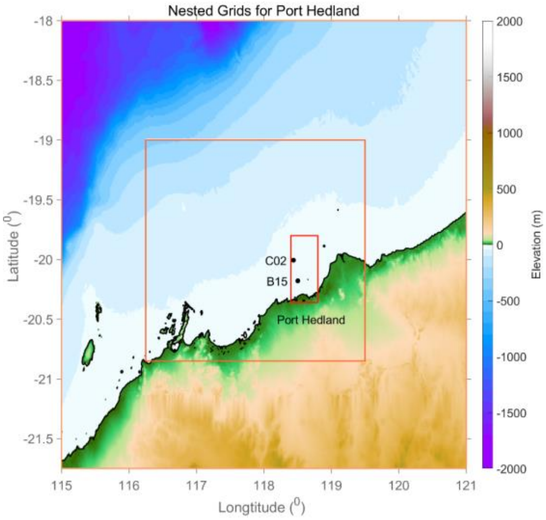

Figure 3 Nested grids for modelling Port Hedland

3.1 Scenarios modelled

To assess the potential impact of tsunamis on Port Hedland, the following earthquake scenarios were modelled:

- **Scenario 1: 2006 Java Earthquake (Mw 7.7)**: This scenario replicates the seismic event that occurred in 2006, allowing us to analyse the potential impact of a similar earthquake on Port Hedland.
- **Scenario 2: Large Earthquake (Mw 9.0) in the Sunda Trench**: This **1 in 500-year scenario** is based on the 2004 Indian Ocean earthquake, simulating a high-magnitude event to understand its potential impact on the port.
- **Scenario 3: Mw 8.5 Earthquake in Java**: A moderate-sized **1 in 150-year** event in the Java region, testing the port's vulnerability to earthquakes of this magnitude.
- **Scenario 4: Mw 8.5 Earthquake in Tenggara**: A similar magnitude event (**1 in 150-year)**, but originating from East Indonesia, to evaluate how the direction of the tsunami affects its impact on Port Hedland.
- **Tidal Variations**: Each of the above scenarios was also modelled under low tide conditions to assess how tidal stages

influence tsunami arrival times and amplitudes.

These scenarios were chosen to reflect a range of potential seismic events that could generate tsunamis impacting Port Hedland, helping to identify the most significant threats based on magnitude, location, and oceanographic conditions. Each scenario was modelled at low tide to evaluate worst-case conditions.

4. Results

In this study, we modelled the potential impact of tsunamis on Port Hedland, focusing on scenarios generated by significant seismic events in the Sunda Trench, including a repeat of the 2006 Java earthquake (Mw 7.7), an Mw 9.0 earthquake similar to the 2004 Indian Ocean event, and additional scenarios with varying magnitudes and tidal conditions, see Figure 4.

Key findings from the simulations focus on wave amplitudes and arrival times:
- Scenario 1: <5 cm wave; negligible impact.
- Scenario 2: Up to 2 m wave; ~3 hour arrival time.
- Scenario 3: ~20 cm wave; minor risk.
- Scenario 4: ~50 cm wave; moderate risk.

Tsunami-induced currents reached over 5 knots in extreme scenarios which are hazardous to moored vessels and port structures.

The arrival time of tsunamis varied based on the location of the earthquake, with an arrival time of ~3 hours from the eastern Sunda Trench, up to ~4 hours from Java. The tide height at Port Hedland slightly influenced the arrival time of tsunamis, where tsunamis near high water reached Port Hedland approximately 10 minutes sooner than tsunamis arriving near low water. The tide height did not greatly impact the wave heights or current speeds from the arriving tsunamis, see Figure 5.

Scenarios originating in East Indonesia (Tenggara) showed higher wave amplitudes at Port Hedland due to direct wave alignment.

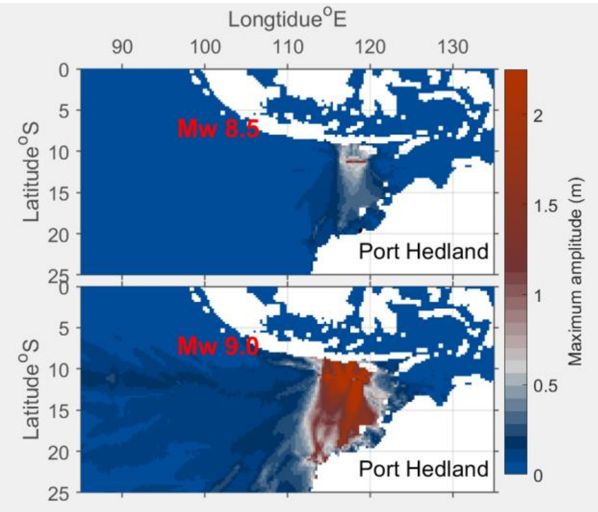

Figure 4 Comparing two large tsunami scenarios.

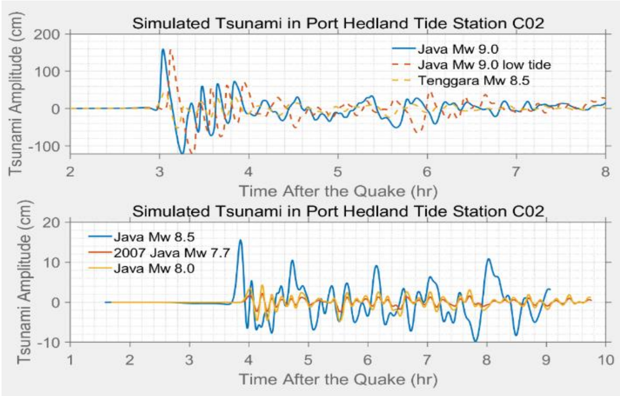

Figure 5 Wave amplitudes from different model scenarios

4.1 Impact on Port Operations

Modelled scenarios have the following quantitative impact on port operations:

- **Scenario 1: 2006 Java Earthquake (Mw 7.7)**: This **1 in 65-year** scenario results in a tsunami at Port Hedland less than 5cm. This would have minimal impact on the port and port operations. Vessels may surge/sway 1-2m so loading should stop, however line breakage is unlikely assuming lines are appropriate tended. There would be no impact on port assets and insignificant siltation into the channels.
- **Scenario 2: Large Earthquake (Mw 9.0) in the Sunda Trench**: This **1 in 500-year** results in a tsunami at Port Hedland of up to 2m (see Figures 4 and 5). This would be catastrophic. All vessels (including tugs and pilot boats) within the harbour should be cleared to deep water. Any remaining vessels would likely break free from the berths. Wharfs and navigation aids/metocean instruments are likely to be destroyed and would need major capital repairs/replacement before becoming once again operational. Siltation within the harbour and channels would be extensive with depths reduced by metres. Vessels at anchorage would also be impacted and are unlikely to be able to hold their anchors: time permitting, they should be sent out to deep water. In deep water there would be no impact on the vessels, the tsunami would be of a safe magnitude for these vessels who could ride the wave as it passes under them.
- **Scenario 3: Mw 8.5 Earthquake in Java**: A moderate-sized **1 in 150-year** event in the Java region resulting in a ***20 cm wave.*** Similar to Scenario 1, impact would be minor however there is a reasonable

chance that line breakage for moored vessels would occur, so it is recommended tugs be mobilised to assist any remaining vessels within the harbour to reduce the risk and impacts of line breakage.

- **Scenario 4: Mw 8.5 Earthquake in Tenggara**: A similar magnitude event **(1 in 150-year)** but from East Indonesia resulting in a ***50 cm wave.*** It is likely that any vessel remaining at berth (bulk or pilot/tug) would break free from the moorings so ideally all vessels should be cleared. Vessels at anchorage should be ok. Wharfs and navigation aids should be ok, metocean instruments may be damaged or lost and its likely there would be reasonable siltation in the harbour/channels up to 0.5m, so a safety allowance for this should be implemented and a bathymetry survey should be conducted at the earliest opportunity.

5. Conclusion

The results of this assessment indicate that while Port Hedland may not experience catastrophic impacts from smaller tsunamis generated by seismic activity in the Sunda Trench, the potential for significant damage from larger events, such as those similar to the 2004 Indian Ocean earthquake, cannot be overlooked. The port's proximity to this highly active seismic zone makes it vulnerable to tsunamis, particularly those resulting from extreme high-magnitude events.

Given the port's critical role in Australia's economy, it is essential to maintain and enhance early warning systems, ensure robust disaster preparedness plans, and consider infrastructure improvements to mitigate the impact of potential tsunamis. This study underscores the need for continued monitoring of seismic activity in the region and the importance of preparedness measures to protect Port Hedland from future tsunami events.

Trans-oceanic tsunamis are usually triggered by Mw 9 tsunamigenic earthquakes which rupture slowly and are harder to determine their mechanism. 2004 Banda Aceh and 2011 Tohoku earthquake magnitudes were initially predicted as 7.5 and later found out to be a 9.1. This delay can take precious time for Port Hedland and note that the Northwest Shelf is significantly more sensitive to Tenggara region (East Indonesia).

While only extreme earthquakes such as the 1 in 500-year earthquake modelled in this study will cause significant tsunami wave heights at Port Hedland, it must be noted that it can take hours to determine the magnitude of an earthquake after it occurs, and therefore an accurate estimate of the resulting tsunami will not be available immediately. Port Hedland need to be aware that if a large magnitude earthquake occurs (such as Mw greater than 6) then it is prudent to take precautions, as there is only a 3-hour lead time between earthquakes in the Sunda Trench and tsunami arrival at Port Hedland.

Worst case scenarios for Port Hedland originate from Tenggara region that could trigger waves that reach the port in 3 hours and both the significant wave heights and strong currents would impact the port. Currents of 5 knots are observed in Indian Ocean, Crescent City California and Japan.

Based on the short arrival time and delay in confirming exact magnitudes, we recommend that for any earthquake in the Sunda Trench registering Mw 7.5 or above, processes should immediately commence to clear the port and anchorages noting that there is a timeframe of 3-4 hours before the resulting tsunami arrives.

6. References

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Relevant UN SDGs: 9 (Infrastructure) and 11 (Sustainability)