REDESIGN OF TUTUKAKA MARINA FOR TSUNAMI RESILIENCE

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INTRODUCTION

Tutukaka Harbor is located on the east coast of New Zealand, approximately 140 km north of Auckland (Figure 1). At the head of the harbor is Tutukaka Marina which is a popular focal point for maritime recreation and an important economic driver for the area. Tutukaka Harbor is a well-known tsunami 'hot spot' as the irregularly shaped harbor is known to amplify incident tsunami energy due to resonance (Borrero and O'Neill, 2019).

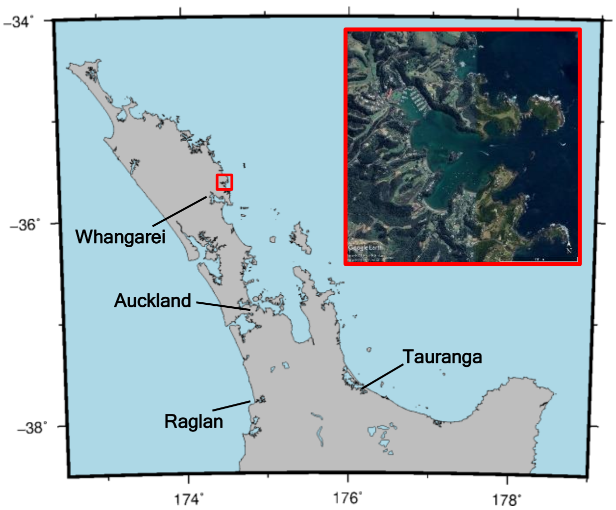

Figure 1 Location of Tutukaka (inset) Tutukaka Harbor.

Tutukaka has a long tsunami history with eyewitness accounts of tsunami effects from distant-source tsunami events, notably in 1877 (northern Chile), 1946 (Aleutian Islands), 1952 (Kamchatka) and 1960 (Southern Chile). The February 2010 Maule tsunami from central Chile and the 2011 Tohoku tsunami from Japan also caused strong, long-lasting surges that made navigation difficult while the former also caused damage to moored vessels as they were affected by the currents.

Tutukaka has also been strongly affected by regional and local source tsunami. In 1976 the marina suffered damage following a M 8.0 earthquake near Raoul Island along the Tonga-Kermadec subduction zone. More recently, the harbor was affected by surges following the M 7,7 Loyalty Islands earthquake (February 2021) and again one month later by waves cause by the March 5th, 2021 M 8,0 earthquake, which occurred in nearly the same location at the 1976 event.

Most recently, the eruption of the Hunga Tonga-Hunga Ha'apai volcano in Tonga generated a tsunami which caused unexpectedly large surges and strong currents at the entrance to the marina (Borrero et al., 2022). These caused severe damage to a fuel dock, broke boats from moorings causing multiple collisions and resulted in the sinking or loss of 5 vessels. Total damage was estimated at more than NZ$2 million.

MODIFICATIONS TO THE MARINA ENTRANCE

The objective of this study is to investigate a possible reconfiguration of the entrance to Tutukaka Marina to reduce the severity of tsunami induced currents. Over the years, breakwaters have been constructed narrowing the entrance to the marina. While the breakwaters are effective in blocking wind and swell wave energy, they have had the unintended consequence of enhancing tsunami induced currents forced through the narrow (60 m wide) gap (Figure 2).

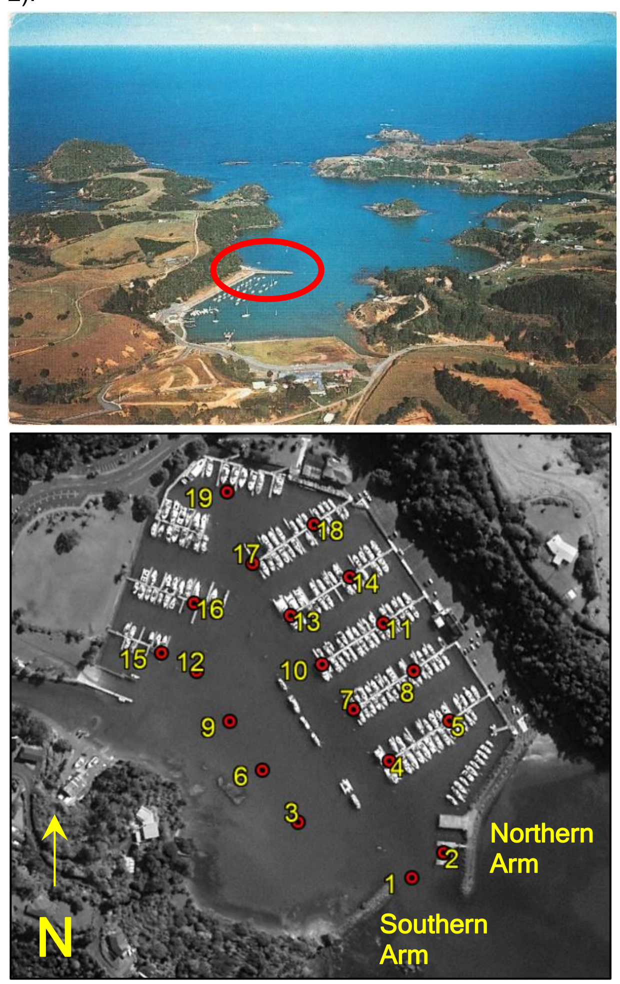

Figure 2 (top) Tutukaka in the 1970's with only the northern breakwater present and (bottom) today with the extended northern and southern breakwater. Numbered dots are locations where model output (speed, water level) was compared between scenarios.

HYDRODYNAMIC MODELLING

Numerical modelling was done with the Community Model Interface for Tsunamis (Titov et al., 2011) which uses the MOST hydrodynamic algorithm (Titov and Gonzalez, 1997). Model grids were constructed from the best available bathymetry and topography including LiDAR topography, nautical charts covering offshore bathymetry and two recent multibeam bathymetry surveys of Tutukaka Harbor and Marina.

MODELLING APPROACH

Due to the extremely high tsunami hazard that exists from local source tsunami along the north-eastern coast of New Zealand, it is recognized that there is an upper limit to what can be mitigated through design modification and strengthening of structural components within the marina itself. For this reason, we focus on what we consider to be 'survivable' far-field events as well as near source events.

Initially we use the source of the January 1976 tsunami – an M~8 earthquake near Raoul Island to investigate the effect of different marina configurations on tsunami currents in the marina. The 1976 event was chosen as it is a known near-source event that caused damage in the marina principally from the tsunami induced currents. The modelling was first done for the present-day configuration then through a series of modified entrance configurations (Table 1). After each run the output was visually inspected and compared to the baseline configuration.

Table 1 Marina breakwater configurations trialed at Tutukaka.

Scenario	Description
Existing	As it is today
Option 0	Remove all breakwaters, not feasible, just for comparison
Option 1	Southern breakwater out, northern unchanged
Option 2	Southern breakwater in, northern in
Option 3	Southern breakwater in and out, northern in
Option 4	Remove existing southern breakwater, add 130 m composite breakwater, SE orientation
Option 5	Remove existing southern breakwater, add 250 m breakwater, E-W orientation
Option 6	Detached breakwater 100 m
Option 7	Variation on Option 5, curved southern breakwater
Option 8	Same as Option 7, northern breakwater shortened

Modelled maximum tsunami current speeds for the 1976 source over a subset of the trial configurations is shown in Figure 4 (a-d). The existing configuration induces a jet of strong currents aimed towards the northwest directly into the piers and boat mooring areas. Option 2 changes the orientation of the northern breakwater but does not yield a significant improvement in that it produces a strong rotational eddy in the basin. Option 6, an offshore detached breakwater, does not significantly reduce current speeds. The most improvement is seen when the southern breakwater is completely removed and replaced with a larger structure protruding towards the E-SE. This was the approach trialed in Options 4 and 5 (not pictured).

The preferred Option 7 (Figure 4d.) is a hybrid of Options 4 and 5 in that it significantly opens the space between the breakwaters while the larger southern arm works with the existing rocky outcrop and features a more natural looking curved alignment. Overall, Option 7 produced the best results in terms of current speed reduction and constructability and this design was carried forward for more detailed scenario modelling and analysis.

We then ran several scenarios to compare the Present Day and the Option 7 modified bathymetry. Seven large historical Pacific Rim tsunami events were modelled plus two hypothetical events (Figure 3). The scenarios were chosen to provide good azimuthal coverage around the Pacific and are at the upper end of the plausible range for earthquake magnitude, representing near-worst case type scenario for distant source events. We also modelled two hypothetical large magnitude distant source events, a M 9 event in Central Mexico and an M 9 event in Central Peru. These cases were added to fill in gaps in the Pacific Rim from regions that have been shown in previous modelling to produce a strong tsunami response along the coast of New Zealand (see Borrero et al., 2014 and Borrero and O'Neill 2019). A third hypothetical event, a moderate (M8) earthquake, similar to the 1976 and 2021 events, but positioned directly east of Tutukaka on the Kermadec Trench was also considered.

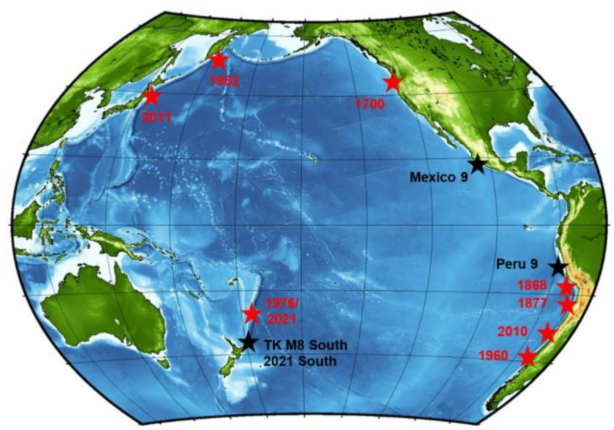

Figure 3 (red) Locations of large magnitude historical events used in the analysis. (black) Location of hypothetical sources based on historical events or output from other hazard studies.

Current speed and water level from the model output were compared at multiple locations in the marina (see Figure 2). At each point the percentage difference in the maximum water level and current speed was determined. The results show that changing the breakwater configuration results in an overall reduction in current speeds at vessels mooring locations. More than 75% of the output points showed a reduction in current speed and 95% of the output points showed a reduction in maximum water level. Maximum current speeds are compared for the 1877 northern Chile tsunami (M~8.9) in Figure 4 (e, f) clearly showing that the reconfigured marina entrance acts to redirect the tsunami currents towards the west and away from the floating docks while reducing the overall current speeds.

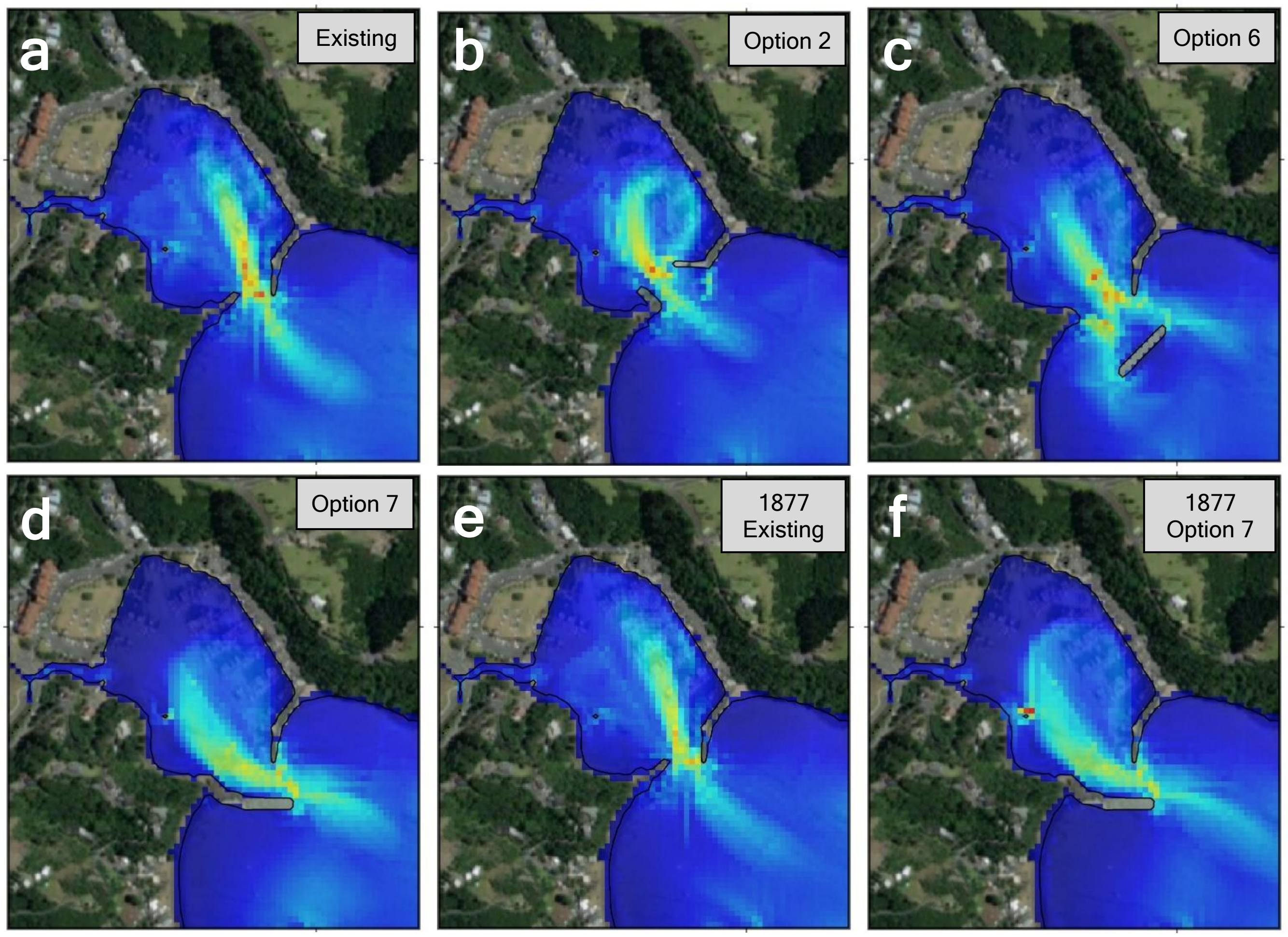

Figure 4 Comparison of model output. Panels a-d compare the 1976 scenario over 4 different configurations. Panels e and f compare the present-day configuration to Option 7 for the 1877 tsunami from northern Chile.

CONCLUSION AND RECOMMENDATIONS

Based on the modelling presented here we have shown that reconfiguring the entrance to Tutukaka marina can reduce the severity and intensity of tsunami currents under a range of tsunami scenarios including large magnitude far-field events and smaller, yet significant, earthquake sources located closer to New Zealand. The preferred configuration calls for the removal of the existing southern arm and replacing it with a larger structure extending approximately 150 m to the east (Figure 4d). The configuration also calls for the overall deepening of the entrance to the marina and the marina basin. The preferred breakwater configuration was also tested for wind waves and shown to be as effective in blocking wind and swell waves from entering the marina as the present-day configuration. As part of the remediation of Tutukaka Marina we also recommend that the layout and location of assets and services within the marina be re-evaluated in terms of tsunami currents, particularly regarding the location of the refueling area as its present location at the entrance to the marina makes it susceptible to strong currents. If a revised breakwater configuration is implemented, the construction of the new southern breakwater presents an excellent opportunity for the implementation of 'living shoreline' initiatives. Such initiatives can help to offset potential ecological damage or disruption that will occur because of the construction. Detailed design studies should also undertake a thorough analysis of the resonant periods of Tutukaka Harbor. While it is well known anecdotally that Tutukaka amplifies tsunami waves, this effect has never been quantified with data and confirmed with numerical models.

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