Predicting Hazardous Conditions on Coastal Rock Platforms

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Abstract

On average, eight people per year lose their lives during rock fishing incidents on the New South Wales Coast. The NSW coroner has identified rock fishing as having one of the highest fatality rates of any sport in the state. There is a pressing need to: understand the critical factors governing overtopping of rock shelves and characterise the risks to people exposed to such conditions; and, to relate these risks to prevailing water level and offshore wave conditions so that appropriate warnings can be incorporated within daily weather forecasts. While a high proportion of fatalities occur during larger than average wave conditions, fatalities have also occurred during smaller wave conditions indicating that even during relatively benign conditions, some hazard may exist. Other studies have shown that proportionally higher fatalities also occur during long wave period conditions and during incoming tides, with wave groupiness also found to contribute to dangerous overtopping events.

Based on field characterisations of the platforms at a number of popular or high-risk rock fishing locations along the Greater Sydney Coastline, a physical study has been undertaken to characterise the behaviour of wave groups impacting coastal rock platforms. The specific objective of the study has been to increase understanding of the resultant overtopping processes and to enable the prediction of potentially hazardous conditions. Hazard has been defined based on the anticipated maximum overtopping flow depth and velocity compared to existing guidelines for people exposed to flood flows.

This investigation has allowed evaluation of the critical wave and water level conditions that lead to significant and potentially hazardous overtopping of rock platforms and the development of hazard prediction schemes. This prediction scheme is presently being incorporated into site specific assessments and forecasts at specific sites using local platform geometry and defined environmental conditions. Water level has been found to play a key role, with small increases in level resulting in large increases in potential hazard. The study findings have significant implications for the increased overtopping anticipated as a result of climate change and predicted sea-level rise.

1 Introduction

A recent report (Jones, 2003) has carefully quantified the risks associated with rock fishing in New South Wales, where approximately eight people per year lose their lives engaging in the pursuit. The NSW coroner has identified rock fishing as having the highest fatality rate of any sport in our state. DPINSW has been active in promoting safety equipment and awareness campaigns to assist participants to reduce their personal risk.

Jones (2003) found that experienced rock fishers represented a significant proportion of fatalities and that the dominant factor causing people to enter the water was unanticipated wave impact (94% of fatalities). A recent paper investigating similar incidents of fishermen being washed of rocky shores and breakwaters in Taiwan (Tsai et al., 2004) identified wave groupiness as an often-common factor contributing to dangerous wave overtopping. It was recommended that methods of forecasting conditions hazardous for rock fishing be developed.

The Water Research Laboratory (WRL) was commissioned by the Department of Primary Industries NSW (DPINSW) to undertake a laboratory based study investigating the effect of hazardous waves, particularly those associated with wave groups, on the safety of rock fishing.

Figure 1. A fisherman at Flat Rock, Harbord on the NSW coast braces as a wave overtops a rock platform.
A full description of methodologies and results is presented within Shand et al (2009).

This investigation has been undertaken in three phases. These include:

- a field study characterising rock shelves in the Sydney Region;
- a physical model investigation using representative platform geometries determined during the field study and varying environmental conditions;
- analysis and reporting including derivation of formula for predicting hazardous conditions.

2 Field investigation

2.1 Methodology and locations

Coastal rock platforms along the NSW coast are generally of relatively flat, backed by steep coastal cliffs, and immediately drop off into several metres water depth. While it has been impractical to complete detailed hazard studies for every fishing site along the NSW coast, a set of representative characteristics for NSW rock shelves have been determined.

Rock platform geometries are determined by GPS, laser level and satellite and aerial photography images at 11 representative rock fishing sites on the Greater Sydney coastline. These sites were typically selected where fatalities and near-drownings have occurred. Available bathymetric information has been used to similarly characterise offshore conditions.

2.2 Results

Platform widths were typically in the order of 20 to 50 m, with some wider platforms occurring due to specific geological conditions. Backing cliffs range from near vertical to around 1(H):1(V) and from 5 to 50 m high. The platforms are typically near horizontal and range in elevation from 1.1 to 2.3 m AHD71 (0.62 to 1.82 m relative to MHWL). Whilst the toe depth and front face slope of the platforms could not be measured directly, the front face slope was inferred from the slope of adjacent cliffs. This makes the assumption that the cliffs were originally formed in an emerged environment, with the portion of slope now beneath sea level subjected to the same processes as the emergent cliff is today. The toe depth is found by extrapolating the offshore slope from the most landward contour shown on the bathymetric charts and the slope of the front platform face until an intersection is found. An average front face slope of 58° and toe depth of 3 m below AHD71 was found.

From these surveys and existing literature on general NSW shore platform morphology together with existing bathymetric data, an idealised planform for model testing was designed and constructed.

3 Laboratory investigation

3.1 Facilities

Laboratory experimentation was carried out in the 0.6m wave flume located at the University of New South Wales Water Research Laboratory (WRL) in Manly Vale, Sydney. The wave flume used has maximum dimensions of 30 m in length by 0.6 m in width and 0.9 m in height. The flume has a solid bed, glass sidewalls and an open top and incorporates a synthetic absorption beach comprised of a perforated sloping bed and horsehair beach (refer Figure 2).

A piston-type paddle is used to generate waves within the flume. The paddle is fronted by a synthetic damping mat to reduce high frequency secondary waves and is driven by a servo-controlled actuator. This setup minimises secondary wave generation and allows wave group structures to be generated with excellent short and long-term stability.

Figure 2. Laboratory facilities including wave tank, piston-type wave maker, model bathymetry and platform and instrumentation.
Initial model scaling was based on geometric similarity with an undistorted scale of 1:40 used. The scaling relationship between length and time was determined by Froudian similitude. To minimise reflection from the steep front face of the structure and subsequent secondary reflection off the wave paddle, the platform has been constructed to an across-flume width of 150 mm (of an available 600 mm width). Perspex walls are used adjacent the model platform to channel the incoming wave and allowing the correct incident-reflected wave processes to occur offshore of the platform and the correct overtopping flows to occur on the platform.

Offshore wave data is collected using capacitance type wave probes. The experimental setup incorporated an array of six probes, configured in two in-line sets of three probes per line. These probes were mounted on a trolley, movable in the along-flume direction. The water surface position was recorded at a frequency of 125 Hz with testing of probes in static water yielded accuracies of ±0.3 mm and a standard deviation of 0.06 mm.

The characteristics of overtopping waveforms on the platform surface are evaluated using an array of Microsonic mic+ acoustic sensors. Sensor resolution is given by manufacturers at 0.18 mm and accuracy at 2%. Probes were spaced at 120 mm intervals at 5 locations from the platform edge. A sampling rate of 125 Hz ensured the sharp fronts of the overtopping waves were captured.

An example of raw waveform and overtopping data is presented in Figure 3. A wave group is first detected by a wave probe offshore from the modelled platform, then by 6 acoustic sensors extending across the platform. The largest overtopping flow is by the second wave in the group with flow depth decreasing with distance across the platform.

Prototype maximum wave heights of between 1.0 and 3.5 m have been tested with periods of between 5 and 14 s. While significantly larger waves occur frequently off the Sydney coastline, rock fishermen are unlikely to be present on platforms during these larger conditions and the transition between safe and hazardous conditions is likely to occur within the testing band. Six differing water levels between lowest and highest astronomical tide were similarly tested.

4 Results and discussion

4.1 Offshore wave distribution

The wave groups employed yield a reasonable approximation of a Rayleigh distribution of wave heights. However, the maximum wave observed corresponds to a probability of exceedance between 6 and 12% for a Rayleigh distribution. In later sections of this report, the likelihood of levels of hazard occurring on rock shelves will be defined. To enable a consistent level of likelihood to be defined for different conditions, we assign a probability of exceedance of 8% to the maximum waves for all test cases on the basis of a best-fit of deepwater wave height to a Rayleigh distribution.

4.2 Overtopping flow results

Data was processed using a peak detection algorithm. This enabled the evaluation of individual overtopping waveforms including the time of overtopping waveform arrival, time of the waveform peak and the elevation of the waveform peak. The use of an array of sensors allowed changes in the waveform including flow depth and velocity with distance from the platform edge.
to be assessed. Overtopping flow depth * velocity \((D^*V)\) values for each wave in an example test group is presented within Figure 4.

![Figure 4. An example of overtopping flow depth * velocity \((D^*V)\) values as a function of across-platform distance for each wave within a group.](image)

### 4.3 Derivation of hazard conditions formula

Pioneering work by Foster and Cox (1973) investigated the stability persons when exposed to flows within a controlled laboratory environment. Since this early report, a number of additional stability studies have been carried out both in Australia and overseas. These are summarised and additional test results presented within Cox et al., (2004). Cox et al. find that the safety of healthy adults is near assured at depth * velocity \(D^*V\) values less than 0.6 m\(^2\)/s and that many can withstand flow conditions up to 1.0 m\(^2\)/s. Other studies such as Ramsbottom et al., (2004), investigating flood risks during relatively steady flows, reported greater velocity-depth limits before safety is compromised suggesting that \(D^*V\) values of up to 0.6 m\(^2\)/s for all, 0.6 m\(^2\)/s to 1.25 m\(^2\)/s for most and 1 m\(^2\)/s to 2.5 m\(^2\)/s for some, including experienced and well equipped persons. While these limits were not established for pulsating flows, as occur during wave overtopping, they suggest that in some situations, higher tolerance limits may apply.

Using results from 57 tested scenarios, relationships between offshore wave conditions and platform freeboard and the resulting flow depths, velocities and \((D^*V)_{8\%}\) values were assessed using a statistical correlation analysis.

A resultant expression was derived (Eq 1) to determine the offshore significant wave height at which hazardous conditions are initiated on a platform as a function of wave period and platform freeboard. Hazardous conditions are defined by a limiting \((D^*V)_{8\%}\) value.

\[
H_{\text{sig}} = R_{c} \left( \frac{(D^*V)_{8\%}}{0.227 \sqrt{gL_{o}R_{c} \gamma_{x}}} + 0.722 \right)^{1.47}
\]

Where \(H_{\text{sig}} = \) significant wave height; \((D^*V)_{8\%}\)\(_{\text{Limit}} = \) limiting \((D^*V)_{8\%}\) value before conditions are deemed hazardous; \(L_{o}\) = deepwater wavelength; \(\gamma_{x} = \) adjustment with distance from platform edge and \(R_{c} = \) freeboard \((R_{c} >= 0.5)\).

Comparing the observed \((D^*V)_{8\%}\) values with those predicted using Eq. 1 (Figure 5) give a mean residual difference of 0.0006 and a std dev of 0.010. This shows the mean prediction using Eq. 1 to be in good agreement with observed values. Figure 5 shows with a trend for larger DV values to be either slightly over-predicted by Eq. 1 and thus conservative or under-predicted within 15%.

![Figure 5. Differences between observed and predicted \((D^*V)_{8\%}\) values based on Eq. 1.](image)

### 4.3.1 Distance from platform edge

Flow is observed to change with distance from the platform edge with differences noted dependent on the type of overtopping flow. Pullen et al., 2007) divides the overtopping regime at vertical and near vertical seawalls into non-impulsive (green water) or impulsive (white water) conditions, determined according to Eq. 2.

\[
h^* = \frac{h_{s}}{H_{m0}} \frac{2\pi h_{s}}{gT_{m1.0}^{2}}
\]

Where \(h^*\) is an impulsiveness parameter, \(h_{s}\) is the toe depth and \(H_{m0}\) and \(T_{m1.0}\) are spectral measures of significant wave height and period. This expression was found to provide reasonable differentiation of overtopping type for the steep-faced rock platform (Figure 6) with \(h^* > 0.06\) corresponding to white water (impulsive) overtopping and \(h^* <= 0.06\) to green water (non-impulsive) conditions.

For green water type overtopping, flow D*V values were found to decrease near linearly landward of the platform crest to around 30% of the value at the platform edge within 0.1 wavelength (Lo) and remaining at this value across the platform (Figure 7). For white water overtopping however, a substantial increase in D*V value was observed immediately onshore of the platform crest as a result of wave impact and the upward trajectory of the jet. This value then decreases exponentially, reducing to a similar 30% of the value at the platform edge at 0.1Lo.

Adjustment factors may be assumed as follows:

**Greenwater type overtopping (h* > 0.06)**
- For x/Lo = 0 to 0.1
  \[ \gamma_x = 1 - 7x/Lo \]
- For x/Lo > 0.1
  \[ \gamma_x = 0.3 \]

**Whitewater type overtopping (h* <= 0.06)**
- For x/Lo = 0 to 0.015
  \[ \gamma_x = 1 + 350x/Lo \]
- For x/Lo = 0.015 to 0.1
  \[ \gamma_x = 11e^{-38(x/Lo)} \]
- For x/Lo > 0.1
  \[ \gamma_x = 0.3 \]

Where x is the distance landward of the platform edge. An adjustment factor \( \gamma_x \) may thus be incorporated as a function of distance, as depicted within Figure 7, into the hazardous wave height equation.

**Figure 8. Envelope of maximum overtopping flow (DV)\% for varying spatial phasing of group evolution.**

Based on these results, ranges in overtopping (DV)\% values of up to +/-35% could be expected during highly non-linear wave group convergence events. Consequently, changes in the threshold wave height before hazard is initiated of 10 to 30% could be expected dependent on freeboard, wave period and limiting (DV)\% value. However, for simplicity, a reduction in the threshold wave height before hazard is initiated of 30% is recommended when highly grouped events are likely. While research into the prediction of groupiness in wave trains continues, spectral parameters such as spectral shape and the Benjamin-Feir index may, in the future, be of use.

**4.4 Site-specific assessment**

Site-specific assessment may be carried out using the platform elevation and toe depth relevant to specific locations. For example, this has been undertaken for the popular fishing location of Flat Rock, Harbord on Sydney’s northern beaches (shown in Figure 1). Using site-specific platform geometry, Eq. 1 may be used to show the limiting wave height before hazard is initiated as a function of tide and hazard limit for selected wave periods (Figure 9).

Based on the example plot and Eq. (1), it may be noted that very rapid changes in overtopping flow may occur as a function of platform freeboard. This means that on rising tide levels, overtopping rapidly increases to a point at which hazardous conditions are reached.
Specifically, significant changes occur with only a change of 0.25 m in tide level. Under rising spring tide conditions, a change in 0.25 m tide level can occur in less than 30 minutes on the Sydney coastline and more rapidly on coasts subject to larger tidal ranges. Large wave groups occur intermittently. Consequently, in the presence of rapid changes in tide level, group intermittency can mask significant shifts in hazard that may be occurring.

### 4.5 Development of a prediction tool

A prediction tool has been developed to facilitate the use of the above schemes in determining hazardous conditions at specific sites using local platform geometry and defined environmental conditions (Figure 9). This tool enables specific hazard level based on wave and water level conditions to be assessed and for the change in hazard with tidal conditions, to be visualised.

This tool may be used by educational agencies as a learning tool or by members of the public undertaking personal safety checks prior to engaging in rock fishing. Discussions regarding the incorporation of the findings in wave measurement and weather forecasts are presently underway.

### 5 Conclusions

Prediction schemes for the 8% instability hazard as a function of platform freeboard, wave height, period and distance from the edge of the platform are developed. The 8% instability hazard is the level of hazard that would be anticipated to be exceeded (on average) by one in every 12 waves. Note that hazardous waves tend to occur collectively within groups interspersed by periods of relatively benign conditions. A predictive scheme has been developed to enable utilization of these results for site-specific locations.

Significant increases in hazard can be observed as a function of increasing wave period for the same wave height. This supports recent fatality analysis indicating higher relative risk for long period waves.

Overtopping and related hazard are critically related to platform freeboard and tide. Specifically, significant changes can occur with only a change of 0.25 m in tide level. Thus under rising spring tide conditions, a change in 0.25 m tide level leading to the initiation of hazardous conditions can occur in less than 30 minutes on the Sydney coastline and more rapidly on coasts subject to larger tidal ranges. Due to large wave groups and thus overtopping events occurring...
Intermittently, significant shifts in hazard may be masked to the general observer. Longer-term sea level rise may likewise lead to hazardous conditions being encountered more frequently.

Hazard rapidly changes with distance from the platform edge dependent on whether overtopping occurs in a white water or green water-type manner. A method for determining the type of overtopping expected and guidance for the decline in hazard within distance from the platform edge for each have been quantified during this study.

Variation in maximum overtopping flow values of up to +/-35% could be expected due to the spatial changes that occur within wave groups for the same sea state conditions. For design, a reduction in the threshold wave height of 30% for a specified level of hazard is recommended.

Research into the prediction of groupiness in wave trains is continuing with spectral parameters such as spectral shape and the Benjamin-Feir index offering possible improvements in the prediction of dangerous wave conditions.

During this study we have not incorporated reflections from a cliff-face behind the platform. We note that reflections may double the inundation depths on top of the platform, particularly during green water overtopping conditions. Large depths are likely to destabilise people on the platforms. Once destabilised, previous work on flood stability has shown that it is difficult for people to regain their footing.

6 Recommendations and future work
This investigation has allowed evaluation of the critical wave and water level conditions that lead to significant, and potentially hazardous overtopping of rock platforms. To further our understanding of these processes and to improve the accuracy and reliability of predictions, a number of future investigations are recommended. These include field verification of overtopping flow depth and velocity predictions of this study, and assessment of the influence of pulsating and aerated (white water) flows on tolerable overtopping flows. While very high overtopping values were noted for violent, whitewater-type overtopping events, little guidance is provided within existing literature on the tolerable overtopping flows in the presence of pulsating or highly aerated flows. Due to the low density of these aerated flows, higher threshold flows may be tolerable.

Similarly, the stability of fishermen wearing specialised equipment such as shoe cleats does not appear to have been measured. By refinement of these parameters, more accurate predictors of hazard can be achieved.

Quantification of platform levels and offshore toe depth at more sites in the Sydney and NSW region would enable better site-specific hazard predictions. Platforms could be grouped according to geometry and hazard ranked according to wave and water level conditions. Furthermore, this study has not incorporated the effects of wave direction or wave convergence due to bathymetric effects. Studies specific to a number of sites would allow hazards to be better characterised.

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8 References

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