

# ASSESSING THE EFFECT OF EARTHQUAKE-INDUCED UPLIFT AND ENGINEERING WORKS ON A SURF BREAK OF NATIONAL SIGNIFICANCE

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In November 2016 a Mw7.8 earthquake struck the northeast coast of the New Zealand South Island triggering numerous large landslips which severed key infrastructure and caused parts of the coastline to be uplifted by up to 3 m. This affected a notable surf break at Mangamaunu, north of Kaikōura. The uplift of the seabed at this location caused changes in the wave breaking characteristics and, at the same time, infrastructure recovery efforts proposed construction of engineering works along the site shoreline. The potential impacts of these works on the surf break caused significant local, national and international concern. An extensive study was initiated to better understand the characteristics of the surf break, the effects of the earthquake-induced seabed uplift and the potential effects of the engineering works. This included collection of topographic and bathymetric data using a combination of LiDAR, multibeam and an innovative UAV-based collection method within the surf zone. This provided a seamless terrain model which could be adjusted to pre-earthquake levels based on observed uplift rates. Two fixed camera stations were established with ground control information to collect data on wave breaking position and GPS-watches were deployed and utilized by the local surfing community to collect similar data. Image processing algorithms were developed to extract wave breaking on a wave-by-wave basis and aggregate to obtain breaking exceedance contours, an improvement from threshold analysis on time-averaged imagery. Both physical and numerical modelling was undertaken to better understand the effect of the earthquake and of the proposed works on wave characteristics, particularly wave reflection. The non-hydrostatic wave-flow model SWASH (Smit et al., 2013) was used to evaluate changes in the breaking position, the incident and reflected wave energy gradients, and surf zone hydrodynamics during a range of typical and optimal surfing conditions for present day and future water levels. An innovative wave breaking position post-processing routine was developed to allow assessment of the impact of reflected waves on the surfability of incoming wave forms on a wave-by-wave basis. Results found that the breaking mechanics of the surf break is controlled not only by nearshore bathymetry around break point but also offshore features which cause focusing of wave energy. The uplift has caused significant changes to the breaking characteristics, with increased wave focusing, breaking and dissipation. The proposed engineering works were found to potentially cause increased wave reflection at the outer part of the surf break during high water levels, however the spatial and temporal characteristics of this reflection mean that direct impacts on surfability are likely to be limited.

*Keywords: surf break, effects assessment, phase-resolve numerical modelling, physical modelling, image processing*

## BACKGROUND

### November 2016 Earthquake

On 14 November 2016, an earthquake comprising a complex sequence of ruptures lasting over 2 minutes and with a combined magnitude of 7.8 occurred approximately 60 km south-west of the Kaikōura Township, on the east coast of the South Island and lower North Island (Figure 1). Rupture reached the ground surface on more than 20 faults with maximum horizontal displacements of up to 12 m and vertical movement of up to 9m (NZCS, 2019). Thousands of landslides were recorded over the region with over 80 landslips occurring along coastal slopes and blocking rail and road corridors (Figure 2).

Coastal deformation occurred along 110 km with vertical displacement ranging from -2.5m to +6.5m, with around 1 m of uplift experienced at Mangamaunu Point. This uplift typically manifest as exposed intertidal and sub-tidal platforms.

In the Kaikōura and North Canterbury area, significant damage occurred to the Main North Line (MNL), State Highway 1 (SH1) and related infrastructure. The damage resulted in access being severed across large sections of both networks. In response, the New Zealand Government passed a suite of special legislation and formed the North Canterbury Transport Infrastructure Recovery Alliance (NCTIR) to enable the restoration and recovery of the area.

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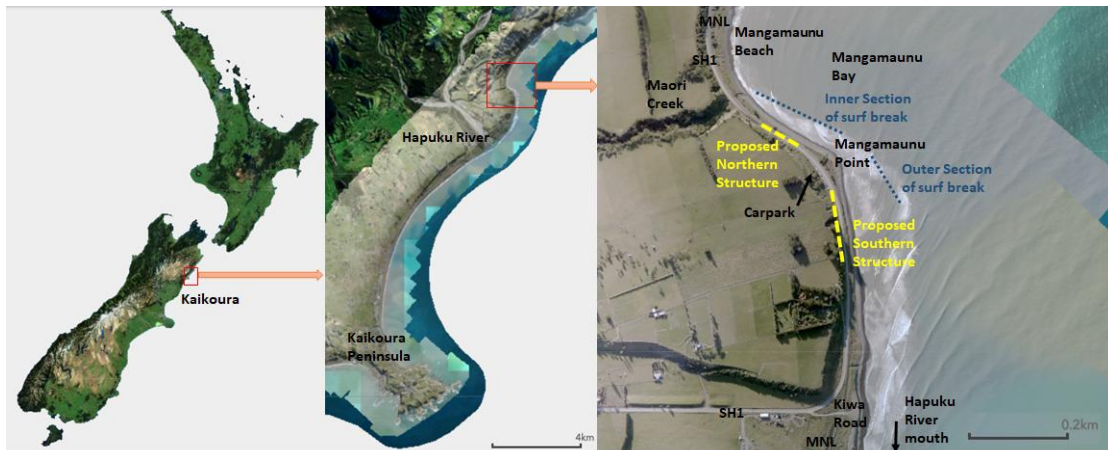


Figure 1. Location and features of Mangamaunu Point, surf break and proposed works

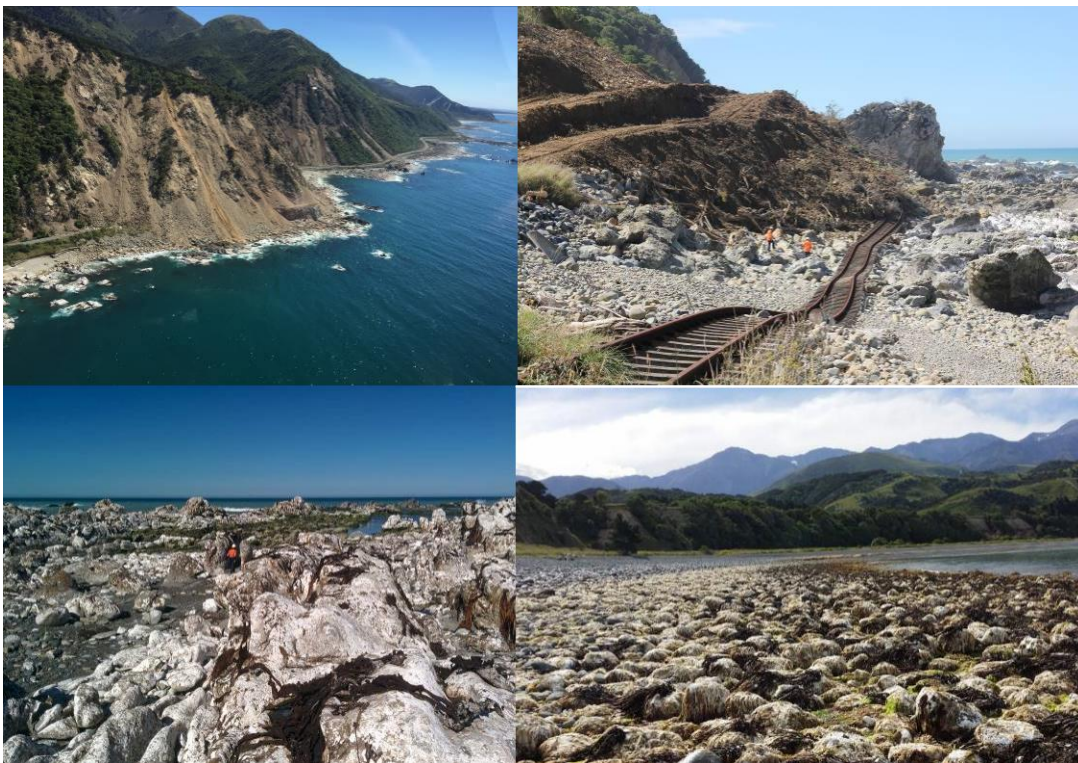


Figure 2. Effects of November 2016 Earthquake: Top Left - Ohau Pt, NCTIR; Top right - Kiwirail Main North Line, Stuff; Lower Left - Uplift at Waipapa Bay, T. Shand); Lower Right - Uplift at Mangamaunu, K. Shaw.

### Mangamaunu Surf Break

Mangamaunu Point is located on the northern edge of the Hapuku River Delta some 2.5 km north of the Hapuku River mouth and 12.5 km north of Kaikōura township (Figure 1). Mangamaunu is a right hand point break with waves peeling along a cobble and boulder seabed off Mangamaunu Point. The Point comprises an outer section which picks up more southerly swell but is of lesser quality and an inner section which works better on east to northeast swells (Figure 3). This results in waves with long walls and hollow sections peeling for up to 250 m.

The surf break was also impacted by the November 2016 earthquake with the seabed and foreshore being raised by around 0.8 m (Figure 2). Based on local surfer feedback, this resulted in changes to the apparent water level and observed wave breaking characteristics.

Mangamaunu is recognised as a surf break of national significance within the New Zealand Coastal Policy Statement (Dept. of Conservation, 2010) and is of high importance to local surfers, iwi and the wider community.



Figure 3. Inside section of Mangamaunu surf break (photo: Brent Proctor)

### Proposed Works

Large-scale engineering works were required to re-open the road and to improve its long-term resilience to storms and effects of climate change. As part of the improvement works, a shared pedestrian and cycle path along the seaward edge of the state highway was proposed extending 17 km from Okiwi Bay in the north to Mangamaunu in the south. At Mangamaunu Point (Figure 3), there is a narrow transport corridor where the state highway and main rail trunk line compete for space and the existing rail line is meters from the coastal edge in places. The close proximity of the rail to the coast would result in the shared path needing to extend onto the upper beach in two locations with some form of coastal protection being required to support and protect the path.

These proposed works would take the form of either a revetment or a piled structure and would intersect the underlying cobble/boulder substrate below the ephemeral gravels/sands. A landscape visualisation of options for the proposed southern works is shown in Figure 4. Consents granted for the coastal works required a baseline assessment characterising the surf break and the effects of the earthquake sequence, as well as an effects assessment to quantify and avoid adverse effects by the proposed works. The resulting assessment is described in detail in Shand and Reinen-Hamill (2018) and Shand et al., (2019).



Figure 4. Landscape visualisations of the engineering works proposed to support the shared path (source: NCTIR)

### FRAMEWORK FOR DETERMINING EFFECTS

In order to assess the potential effects of the proposed works on the surf break at Mangamaunu a framework was developed (Figure 5). The framework is described in detail in Shand et al., (2018, 2019) but first characterizes the existing environment and the way in which the surf break is used and enjoyed by the local community (Figure 6). The potential effects of proposed works on that usage could then be evaluated using appropriate methodologies (Table 1) with results used to inform a risk assessment that could be fed into decision-making or design optimisation.

While the physical features of a surf break may be generally described using field data and modelling tools, detailed characterisation of a surf break requires incorporation of local knowledge of the surf break mechanisms; how the wave breaks, what conditions it works in, how it has changed over time and what is involved in surfing it. Each surfer views the surf break slightly differently depending on the board they ride, the conditions they enjoy and the part of the wave they tend to surf. It is therefore important that local knowledge is sought from a wide cross-section of the user community.

For Mangamaunu, interviews were undertaken with a cross-section of local surfers. These surfers described the surf break, the conditions it works in, how the earthquake has affected the break and finally key concerns with the proposed works. This local knowledge could then be combined with field data such as topography, bathymetry, sediment data, long-term wind, wave and water level hindcasts and detailed numerical wave-flow modelling to develop a comprehensive description of the coastal processes and surf break mechanics.

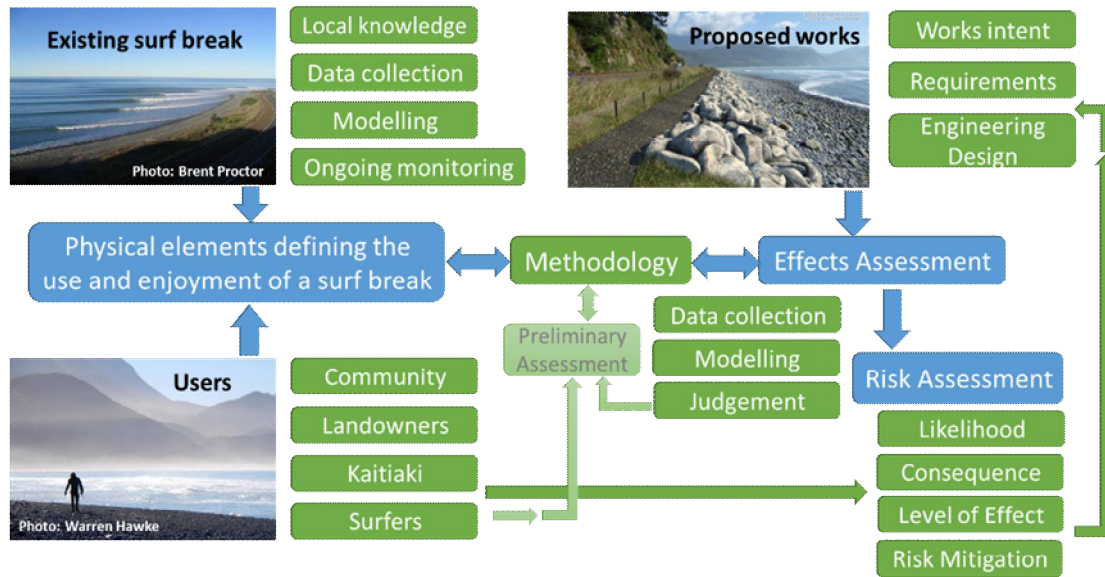


Figure 5. Framework utilised to characterise the surf break, and to assess effects and risk from proposed works (source: Shand et al., 2019)

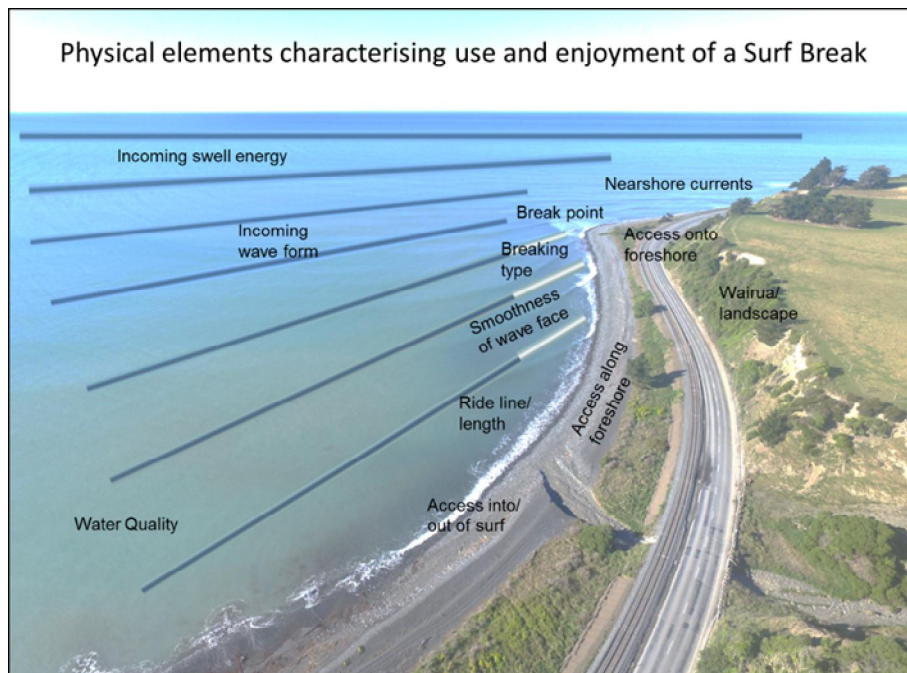


Figure 6. Physical elements affecting the use and enjoyment of a surf break (source: Shand and Reinen-Hamill, 2018)

## DATA COLLECTION

### Topography and bathymetry

Topography has been collected by a combination of LiDAR (Nov 2016, Nov 2017, May 2017, June 2018) and unmanned aerial vehicle (UAV) photogrammetry (January 2018, September 2019). Bathymetry was collected using multi-beam survey offshore (November 2017) and an innovative UAV dipping method (July 2018) in the nearshore. This method, developed during the NCTIR project and described in detail by Perwick (2018), utilizes a Trimble E8 GNSS receiver on a DJI Matrice 600 UAV for accurate positioning with a dipping line and spring mechanism to identify the point at which the seabed is reached a known distance below the UAV (Figure 7). This approach is slower than water-bourne survey but removes or reduces barriers associated with weather, shallow water, other users and obstacles. Combining these various survey, a complete terrain model of the relevant topography and bathymetry has been generated (Figure 8).

<b>Table 1 Proposed methodology for assessing potential physical effects on the Mangamaunu surf break</b>		
<b>Physical elements affecting the use and enjoyment of a surf break</b>	<b>Description and ways by which the surf break may be affected</b>	<b>Assessment methodology for Mangamaunu surf break</b>
Incoming swell energy	Controlled by swell corridor affecting energy reaching break. Can be affected by an offshore obstacle or change in seabed.	Wave hindcasting to determine dominant incoming wave directions. Wave modelling of pre-earthquake and existing conditions and with proposed works to determine difference in wave height reaching break.
Incoming wave form	Controlled by offshore and nearshore bathymetry prior to breaking. Can be affected by change in seabed.	Wave modelling using phase-resolving model to confirm incoming wave characteristics under a range of conditions for existing, pre-quake and proposed bathymetries.
Breaking point/type	Dependent on seabed morphology at breakpoint and offshore pre-conditioning (incoming wave form).	Assess potential for increased reflection due to proposed works during storm conditions to move seabed materials (cobbles/boulders) using 1D physical model.
Smoothness of face	Affected by reflected waves, prior breaking inducing decomposition, irregularity in seabed.	Assess potential for wave reflection under existing situation and with proposed works using 1D physical model <sup>1</sup> and in 2D using numerical model.
Ride line/length	Affected by structures or other objects in the ride line or change in bathymetry along ride line.	Use 1D physical model to identify potential for reflection and changes in seabed offshore of structure and 2D numerical model to identify changes in currents causing seabed changes and changes in break point.
Currents	Can be affected by surf zone circulation, modification of tidal flows.	Use 2D numerical model to identify changes in currents for pre-earthquake and existing conditions and with proposed works.
Access onto foreshore	Interruption of access between backshore (or arrival) and the foreshore (of surf access).	Identify post-works access locations compared to existing.
Access along foreshore	Interruption of safe access along the foreshore.	Assess structure geometry/location compared to depth of overlying sands/gravel beach and wave run up levels as % of total time.
Access into/out of surf	Interruption of safe access into/out of water.	Identify post-works entry/exit points compared to existing.
Water quality	Can be affected by discharges into the Coastal Marine Area.	Identify potential sources of contamination input.
Landscape (Wairua)	Factors affecting the look and feel of a surf break.	Assess using landscape visualisations and consultations (Korero)



Figure 7. Topography and bathymetry of Mangamaunu Point (m NZVD2016)

**Sediments**

The main sediment source for Mangamaunu Beach is from sediments transported down the Hapuku River and from sediments eroded from the delta. These sediment sources may historically have been supplemented by coarse sediments from small streams and landslides from the adjacent cliffs, but since the transport corridor has been in place, these locations are not anticipated to provide any significant quantities of sediment.

A description and size analysis of the beach surface was been undertaken at four cross-sections along Mangamaunu Beach. The lower foreshore tends to be comprised of cobbles and boulders (200-600 mm) often embedded in a matrix of finer materials (sands and gravels). Above and overlying this

boulder and cobble substrate is an ephemeral beach comprised predominantly of gravels with some coarse sand size material. This beach level fluctuates depending on wave and sediment supply (Figure 9).

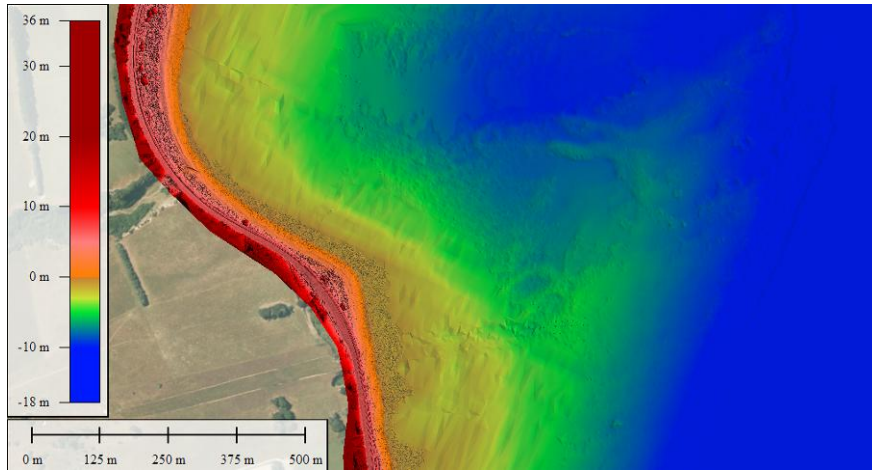


Figure 8. Topography and bathymetry of Mangamaunu Point (m NZVD2016)



Figure 9. Example of beach sediments in Jan 2018 (top), July 2018 (middle) and Sept. 2018 (lower) south of Mangamaunu Point with a high tide gravel and coarse sand beach evident in the later photographs

#### Wave conditions

A 39 year (1979-2017) wave hindcast was undertaken by Metocean Solutions Ltd. Conditions occurring during several optimal days reported during discussions with local surfers or as evidenced in photographs provided (Figure 10) have been assessed with results showing most optimal days have had waves with significant wave heights between 1 and 2 m and periods between 10 and 14 s with waves arriving from 80 to 112°. Winds have generally been very light or from the south west quarter.

The hindcast was used to derive the number of ‘surfable’ and ‘optimal’ conditions based on conditions reported by local surfers. This indicates that the wave is generally surfable 50% of the time, with higher proportions during autumn and winter and lower during spring. The wave is ‘optimal’ for short and bodyboards some 4.2% of the time, again higher during winter and during spring, and is optimal for longboarding and stand up paddle boarding 3.4% of the time, typically higher during autumn and winter. These values are likely to be subjective with some people surfing during a wider range of conditions and some during a lesser range.



Figure 10. Optimal conditions occurring along the Mangamaunu inside section on 10 May 2010 (left, M. Moriarty) and 22 March 2018 (right, H. Melville)

### Fixed cameras

Two solar-powered cameras were installed on the cliff top overlooking the Mangamaunu Surf Break (Figure 11). The southern camera (1) looks over the outer section and the top of the inner section, and the northern camera (3) looks up the point including both the inner and outer sections. The cameras are M26 Mobotix MX-M26A-6D with a L32/B061 (35mm) lens on camera 1 and a L65/B119 (65mm) lens on camera 3. Images are being captured at 1920 x 1080 pixels at 1 frame/second for the first 20 mins of every hour with images transmitted to a control station and stored for processing. These cameras recorded imagery from 13 September 2018 to 12 November 2019.

Ground Control Points were surveyed on land (permanent GCPs), on the foreshore (temporary land GCPs) and in the nearshore (temporary marine GCPs). The land-based GCPs were surveyed using RTK-GPS and the marine GCPs using a Trimble E8 GNSS receiver on a DJI Matrice 600 UAV with a sphere suspended a known distance below. These GCPs are used to relate real world coordinates (Northing, Easting, Elevation) to pixel location (m,n) for each camera. This process allows images to be corrected for perspective distortion and geo-referenced for further analysis. This rectification was carried out using the *g\_rect* software package (Bourgault et al., 2020).



Figure 11. Location, field of view and rectified view of two remote camera systems installed at Mangamaunu

### GPS surf watch

A GPS watch (Rip Curl Search GPS) has been deployed with local surfers recording information on their rides (Figure 12). Horizontal accuracy is not stated but is expected in the order of 5m. These records are then extracted into a GIS for comparison with camera imagery and wave model break points/ride line during similar conditions to provide further validation.



Figure 12. Example of wave ride lines recorded for two session using the GPS surf watch

## MODELLING AND ANALYSIS

### Physical modelling

Physical model testing was undertaken at Manly Hydraulics Laboratory to validate and allow value engineering of the revetment structure, and to test the effect of the structure on wave reflection. Wave reflection was assessed for the existing boulder foreshore without a gravel beach, the foreshore with a gravel beach, 2 T and 500 kg rock armour revetments and a piled structure (Figure 13). Tests were undertaken for the upper limit of surfable conditions ( $H_s = 2$  m) with period of 13 s and a range of high tide and high tide + sea level rise conditions as well as 20 and 100 year ARI events. Testing was undertaken on two representative profiles for the southern (M1) and northern (M2) revetments. Reflection is computed using a three probe array in deep water using the methods of Mansard and Funke (1980) to separate incident from reflected wave spectra. A series of three tests were undertaken for the existing foreshore under identical wave and water level conditions. These showed reflection within 0.1% validating the repeatability of tests.



Figure 13. Physical modelling testing of the existing boulder beach (top left), a 2T rock armour revetment (top right) with optimization of the rock revetment (lower left) and testing of a piled structure (lower right)

The existing beach exhibited reflection of 17.5% at the southern profile and 12.5% at the northern profile during surfable conditions at MHSW and including +0.3 m sea level rise (SLR) With a gravel beach present, reflection values are slightly (+1 to 1.5%) higher. Results generally indicated that the



revetments do not have substantial effect on reflection with changes to absolute reflection in the order of  $\pm 1\%$  under surfable conditions and  $\pm 3\%$  under storm conditions. It is acknowledged that these reflections are measured offshore in 10m water depth and higher reflections may occur in shallower water before the reflected waves deshoal.

### Numerical Modelling

Detailed nearshore (<20 m depth) wave modelling of the surf break was undertaken with the non-linear, non-hydrostatic wave-flow model SWASH (Smit et al., 2013). SWASH is a phase-resolving model that simulates individual non-linear waves as they propagate over the nearshore bathymetry and break, forcing wave-driven currents which may in turn interact with the incoming wave field. These processes are particularly relevant in a surf break assessment context. Resolving individual waves allows reproducing the details of wave crest patterns as waves propagate towards the coast and identify possible wave focusing and crest bifurcation processes which are often conducive to high-quality surfing waves. Predictions of surf zone dynamics including wave breaking patterns and wave-driven current allow defining general wave breaking footprints, wave sections as well as key features of the surf break circulation.

The SWASH simulations were applied over a domain of 1400 by 900 grid cells, with a spatial resolution of 2 m (Figure 14). The model was run in depth-averaged mode accounting for wave breaking using the hydrostatic front approximation (Smit et al., 2013). Full detail of the analysis is provided in Shand and Reinen-Hamill (2018) and Weppe et al. (2019).

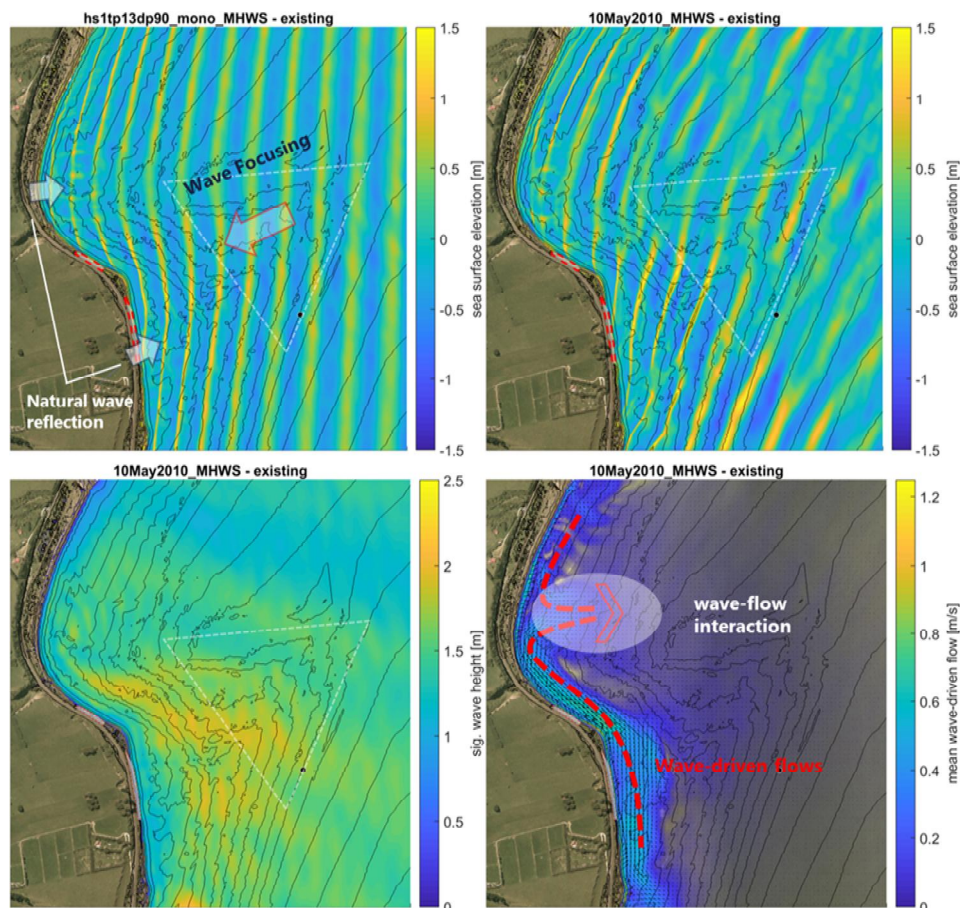
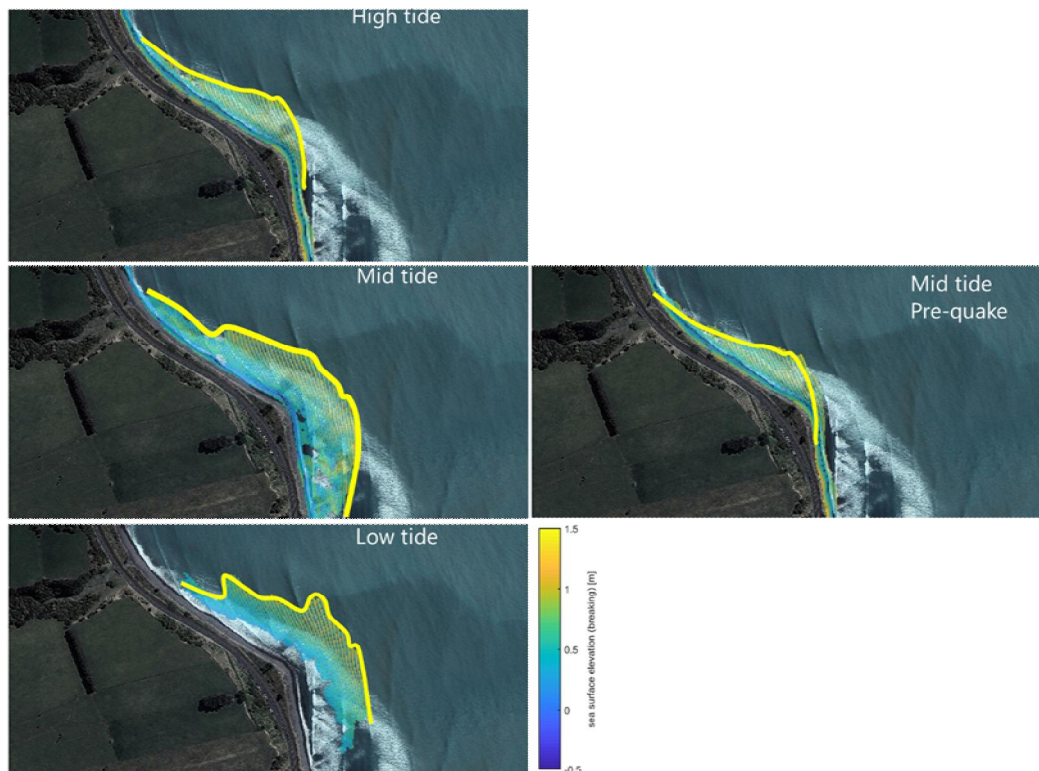


Figure 14. Examples of water level snapshots during optimal monochromatic (top left) and spectral (top right) surfing conditions. Bottom panels show significant wave height (left) and mean flow fields (right) during the 10th of May spectral wave conditions.

The general surf break wave mechanics were assessed from simulations of representative wave events that included both idealized monochromatic and spectral events during optimal surfing conditions (Figure 14). Based on surfer interviews, examination of field data and nearshore wave modelling, it was found that the seabed to the south of the point gently slopes towards the southeast, acting as a 'ramp' (Mead and Black, 2001) which results in waves shoaling and becoming aligned to

the east-southeast contours, but relatively little three-dimensional change in the wave form. The outer section of the point acts as a wedge, with waves breaking and peeling towards the north. However, a submarine spit extends into Mangamaunu Bay as the shoreline moves away towards the northwest and the bay opens up. This relatively shallower feature acts as a focus, with waves refracting around the northern end of the shallow feature and moving more rapidly within the deeper water of the bay. This results in waves arriving at the inner section of Mangamaunu from a more northeast direction (Figure 14) as described by local surfers. These waves are more aligned or ‘square’ on to the contours and the seabed slopes more steeply from this direction. This results in a faster and harder breaking wave than would otherwise occur with waves peeling down the point.

Wave breaking “footprints” can be estimated by overlaying all successive segments of wave crests flagged as “breaking” in the SWASH model over the duration of the simulation (after a spinup period) and these are useful metrics to compare wave breaking patterns for different wave conditions. Wave breaking footprints predicted for the reference monochromatic event at high, mid, and low tides are presented in Figure 15. The effects of the uplift caused by the November 2016 Earthquake were modelled by lowering the bathymetry by 0.8m. Results showed that breaking characteristics at high tide are now similar to those that would have occurred at mid-tide previously. Give the higher quality inner section was reported better during high tide conditions this likely explains the reported decrease in quality. Following this, breaking occurring at mid tide would occur as low tide had previously and breaking occurring at low tide would not have occurred pre-earthquake. There have reportedly been improvements in outer sections of the wave during lower tides.



**Figure 15. Wave breaking edge for existing (left) and pre-quake (right) conditions. It is evident that high tide now breaks similar to mid-tide before the earthquake**

The proposed structures’ were added by modifying the bathymetry at the structure locations based on engineering design. Reflectivity was implemented by means of porosity layers which use porous flow model to predicts amount of wave/flow transmitted through and reflected by an obstacle. A porosity value of 0.4 was applied (as recommended for rubble mound van Gent (1995). Examination of the spectra during an optimal condition (Figure 16) show that some reflection occurs during higher water levels under the existing case with the addition of structures slightly increasing reflection in the outer section, by up to 5% but had negligible impact on the inner section. No changes in the breaking wave height or breaking position wave noted any negligible changes in surf zone hydrodynamics during surfable conditions. Further examination of the reflected wave-forms on a wave-by-wave basis (Figure 17) found that the reflections generally occurred off the southern revetment and reflected into the outer section of wave rather than the higher quality inner section.

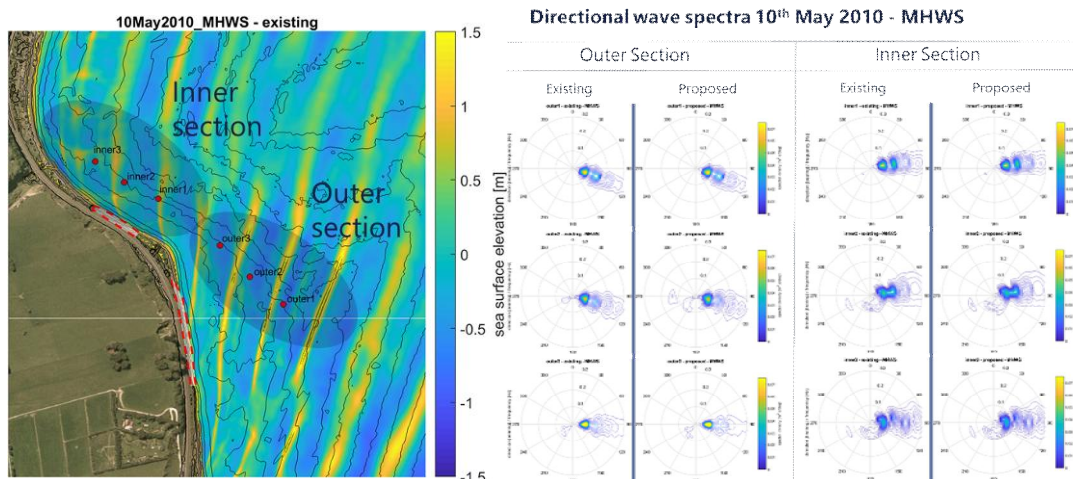


Figure 16. Effect of structures on directional wave spectra at MHWS

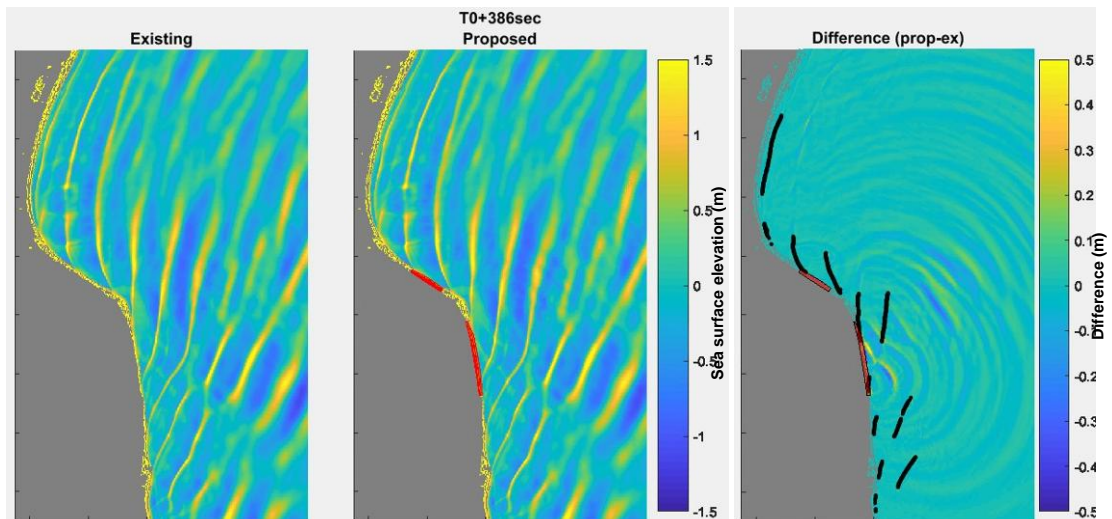


Figure 17. Snap shot of sea surface elevation during the 10th May 2010 event at MHWS water level for existing (left), with the proposed structure (middle) and the difference (right) with breaking waves overlaid in black

**Image processing**

After image rectification, images were processed using the matlab toolbox *SurfZoneFun* (Shand, in preparation). A function within this toolbox identifies the individual wave breaking position for each frame and sums the breaking position as a cumulative breaking portion during the observation period (Figure 18). The threshold for defining breaking is a variable and was optimized through sensitivity analysis yet provides more control and definition than more traditional time-averaged techniques applied since Lippman and Holman (1989). A breaking exceedance value can then be extracted from the cumulative breaking portion. Figure 19 shows the 10% exceedance breaking position overlying the time-averaged image.

Finally, the breaking exceedance position is overlaid with the GPS ‘ride lines’ extracted from the Surf watch for the same time period and the SWASH model outputs for the same conditions (Figure 20). Results show general agreement in these positions indicating that the 10% exceedance position is a reasonable measure the waves that tend to be surfed and that the SWASH model is also reasonably defining the breaking position. It is noted that only a limited number of cases were available with all three measures but over 1 year of image data is available for future processing.

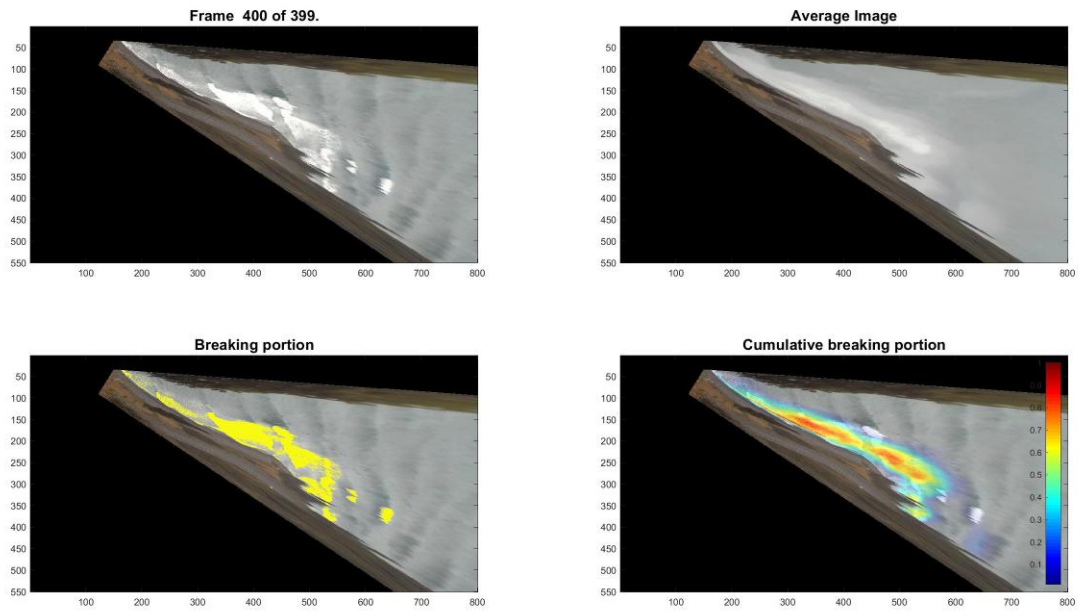


Figure 18. Example of image processing method used to identify the broken wave area in each image (lower left) and the cumulative breaking portion over the observation period (lower right)

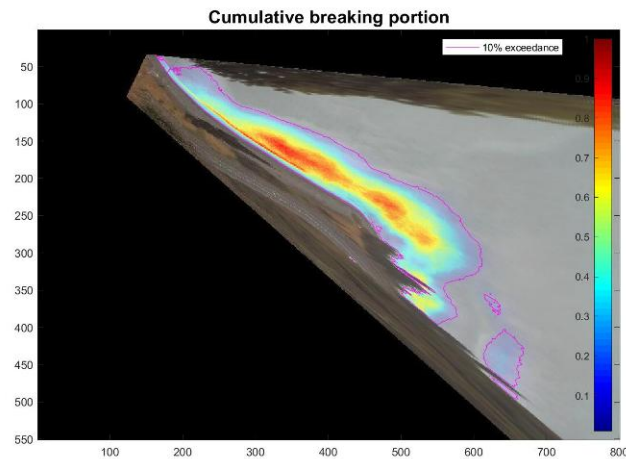


Figure 19. Example of the cumulative breaking portion after the observation period overlaid on the averaged image and with the 10% exceedance contour plotted

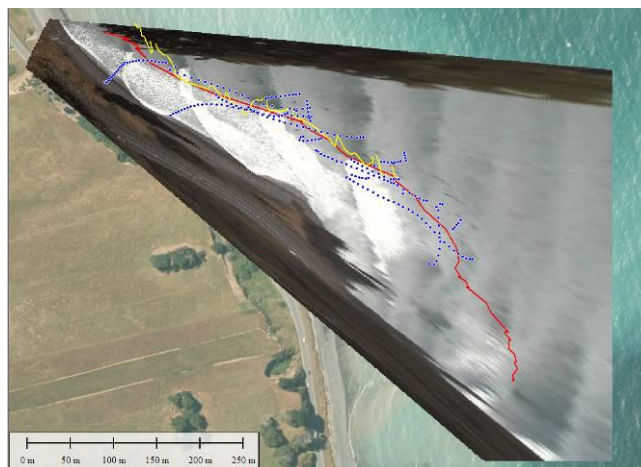


Figure 20. Comparison of the 10% exceedance breaking position from image analysis (red) with the SWASH breaking position for the same wave characteristics and water level (yellow) and GPS ride lines during the same period (blue) for 13 February 2019 at 11am.

**EFFECTS ASSESSMENT**

A risk assessment criteria was developed based on the NZTA coastal effects assessment guideline (NZTA, 2017) and modified to include effect level based on standard RMA terms (Quality Planning, 2018). A similar method is proposed by Atkin et al (2018) for assessing effects on surf breaks. Criteria for likelihood, consequence and level of effect are set out in Tables 2, 3 and 4. While the level of effect is a function of likelihood and risk, it should be determined by a combination of local and expert judgement rather than matrix based rules.

<i>None</i>	<i>Unlikely</i>	<i>Likely</i>	<i>Very likely</i>
No reasonable likelihood of effect occurring	Effect could occur in the future or may only occur in rare conditions at present	Effect likely to occur in the future or occasionally at present (i.e. during particular conditions only)	Effect expected to occur frequently (i.e. during most surfable conditions)

<i>None</i>	<i>Low</i>	<i>Medium</i>	<i>High</i>
No effect	Effect does not affect use of surf break or has minor effect on lower quality surf break	Effect has a minor adverse effect on the use of a high quality surf break or moderate effect on lower quality surf break	Effect has a moderate adverse effect on the use of a high quality surf break or significant adverse effect on the use of a lower quality surf break

<i>Level of Effect</i>	<i>Description</i>
No effect	No effects on the surf break at all
Less than minor adverse effects	Effects on the surf break that are discernible day-to-day, but too small to adversely affect surf break value
Minor adverse effects	Adverse effects on the surf break that are noticeable but that will not cause any significant adverse impacts
More than minor adverse effects	Adverse effects on the surf break that are noticeable that may cause an adverse impact but could be potentially mitigated or remedied
Significant adverse effects that could be remedied or mitigated	An effect that is noticeable and will have a serious adverse impact on the surf break but could potentially be mitigated or remedied
Unacceptable adverse effects	Extensive adverse effects on the surf break that cannot be avoided, remedied or mitigated

Table 5 sets out a risk assessment for Mangamaunu surf break based on the potential physical effects identified previously. Results found no change in incoming wave energy (the swell corridor), incoming wave form, the location of breaking waves, ride length or line. Some potential effect on wave smoothness in the outer section of the break was found with an increase in wave reflection from the southern revetment possible. The changes during surfable conditions were found to be negligible in the physical modelling ( $\pm 1\%$  change compared to existing reflection) but more notable changes (up to 6%) were identified in numerical modelling. Effects on the wave smoothness within the inner section of the surf zone was found to be negligible compared to existing in both the physical and numerical modelling.

<i>Description of effect</i>	<i>Risk assessment</i>			<i>Risk mitigation /comment</i>	
	<i>Likelihood</i>	<i>Consequence</i>	<i>Level of effect</i>		
Incoming swell energy	None	None	No effect	None	
Incoming wave form	None	None	No effect	None	
Breaking point/type	None	None	No effect	None	
Wave face	Outer section	Likely to Very likely (dependent on beach level)	Low	To be determined in consultation with affected users	
	Inner section	Unlikely at present sea levels	Medium at future sea levels		
Ride length/line	Unlikely	Low			
Surf zone currents	Likely	Low			
Access to/from foreshore	Unlikely – situation has not changed from existing	Low			
Access along foreshore	Likely – dependent on future beach levels	Low – Medium depending on beach levels			
Access into/out of surf	Unlikely – situation has not changed from existing	Low			
					To be determined in consultation with affected users

## CONCLUSIONS AND FURTHER WORK

This study provided an opportunity to investigate in detail the changes to a notable surf break due to earthquake-induced uplift and to develop methods to assess potential effects from engineering works. SWASH wave model outputs, validated with a new method for deriving breaking position from nearshore imagery, has proved to be a useful tool to understand key features of the nearshore wave propagation, wave breaking, and circulation and testing effects of changes in seabed level and the presence of engineering structures. Over one year of imagery data had been collected and, together with a detailed and high resolution bathymetry and water level and wave hindcast data, provides scope for further refinement of analysis methods.

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