Modelling Surf Break Wave Mechanics with SWASH – an application to Mangamaunu Point Break (Kaikōura, New Zealand)

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Modelling Surf Break Wave Mechanics with SWASH – an application to Mangamaunu Point Break (Kaikōura, New Zealand)

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Abstract

High-quality surf breaks are rare assets with high amenity value for the community. The value of these “precious” coastal regions is being increasingly recognized worldwide, notably through the creation of surfing reserves or specific protection schemes in coastal development policies. A prerequisite to ensuring appropriate protection is a robust understanding of the surf break wave mechanics, which provides the baseline to assess potential effects arising from future coastal modifications or environmental changes. This paper describes a numerical wave modelling framework used to characterise surf break wave mechanics of the Mangamaunu Point Break (Kaikōura, New Zealand). Mangamaunu is a high-quality surf break that was recognized as one of the 17 “nationally-significant” surf breaks under New Zealand Coastal Policy Statement. Following the November 2016 earthquake (7.8 Mw) that resulted in a dramatic uplift along the Kaikōura coastline, large-scale engineering works were required to repair the transport infrastructure. This included a new 17 km pedestrian and cycle path from Kaikoura township to the Mangamaunu Point, where sloping revetment structures would be needed to protect the path on the upper beach. To inform these works, a detailed characterisation of the existing surf break wave mechanics was undertaken using the non-hydrostatic wave-flow model SWASH. The dynamics of the pre-quake (i.e. pre-coastline uplift) and post-development configurations were modelled, allowing an evaluation of the potential impacts on surf quality to be assessed by examining the changes to breaker position and the incident and reflected wave energy gradients.

Keywords: surf break, wave modelling, SWASH, coastal structures, earthquake.

1. Introduction

The key objective of the paper is to show how a wave modelling framework can be used to characterise surf break wave mechanics and also assess the potential impacts of adjacent engineering works. The methodology is applied to the Mangamaunu surf break in the Kaikōura region on the east coast of the South Island of New Zealand (Figure 1). “Mangamaunu” is a high-quality right-handed point break which peels along a cobble and boulder seabed for 100-300 m, depending on the incident swell angle. Mangamamu Point has a lesser quality outer section that is highly exposed to southerly swells, and a high-quality inner section that can produce long, hollow rides during clean east to northeast swells. Mangamaunu has high amenity value to the local and wider community and was recognized as one of the 17 “nationally-significant” surf breaks under New Zealand Coastal Policy Statement [3].

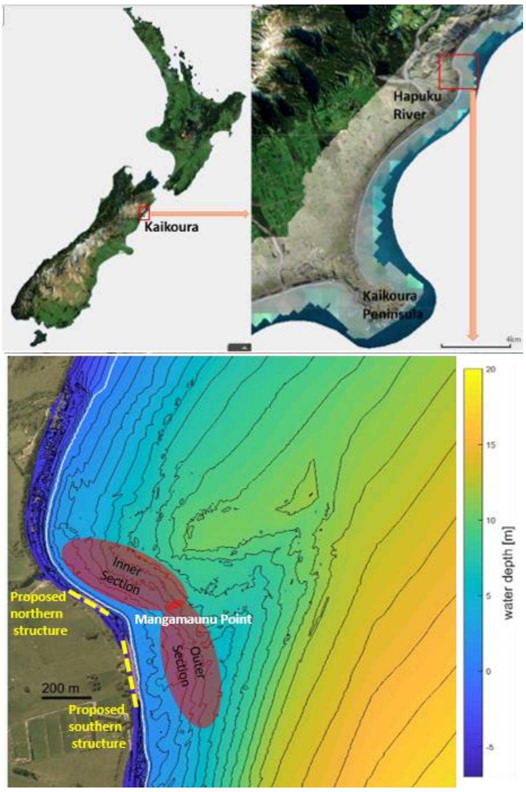

Figure 1. Location and bathymetry of Mangamaunu Point surf break including main features and proposed works.

The November 2016 earthquake had a magnitude of 7.8 Mw, with epicentre just 60 km south-west of the Kaikōura Township. The quake resulted in a significant coastline uplift and numerous landslips along the Kaikōura coastline, damaging roads and key transport infrastructure. The seabed and foreshore near Mangamaunu were elevated by ~0.8 m. Large scale engineering works were required to re-open roads and improve safety and amenities, including a new 17 km pedestrian and cycle path which would extend onto the Mangamaunu Point.

Figure 2. Mangamaunu surf break on the 10th May 2010. (Photo by Matt Moriarty).

Accordingly, the upper beach would require protection using a sloping rubble mound revetment at two locations.

To understand the impact of the proposed development on the surf break, a baseline characterization of the existing wave mechanics was undertaken first considering effects of bathymetry, incident wave conditions (height, period, direction) and water levels. The approach was reproduced for the pre-quake (i.e. pre-coastline uplift) and post-development surf break configurations to evaluate relative changes in incident and reflected wave energy and wave breaking positions and potential effects on the wave quality. Note this numerical wave modelling study fits within a wider surf break assessment framework described in a companion paper [12].

The following sections describes the general numerical wave modelling approach (Section 2), key results (Section 3) and main conclusions (Section 4). The complete numerical wave modelling investigation is described in further details within [8].

2. Numerical wave modelling framework

2.1 Wave climate hindcast

The regional and surf-specific wave climates were characterised using hindcast spectral wave conditions off the surf break. A modified version of the SWAN (Simulating WAves Nearshore) wave model was employed to dynamically downscale deep-water conditions from MetOcean Solutions' WAVEWATCH III (WW3) global wave model, providing a 39-year local hindcast at 100 m resolution.

Threshold wave conditions producing "surfable" and "optimal" surfing conditions were defined in consultation with the local surfing community and used to quantify the break surfability and select a set of representative surfing wave events to simulate dynamically [7]. The wave climate at Mangamaunu surf break is dominated by far-field generated swell approaching predominantly from the southeast quadrant. Locally generated wind seas can disturb the surf quality, mainly when winds blow from the NE, E, SE and S sectors (~23% of the time). The break is expected to be "surfable" about 50% of the time on an annual basis, with surfability increasing to around 65% during the months of July and August.

2.2 Nearshore wave propagation modelling

Detailed nearshore (<20 m depth) wave modelling of the surf break was undertaken with the non-linear, non-hydrostatic wave-flow model SWASH [13,14,17]. 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 [3,5,6,9]. 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 applied a domain of 1400 by 900 grid cells, with a spatial resolution of 2 m. The model was run in depth-averaged mode accounting for wave breaking using the hydrostatic front approximation [13]. The existing bathymetry was interpolated from merged bathymetric datasets, including high resolution LIDAR data and regional scale data (electronic charts and surveys). A pre-quake bathymetry was determined assuming a homogeneous rise of the seabed and sub-aerial beaches following the earthquake of 0.80 m throughout the entire model domain. The "proposed" bathymetry including the structures and revetments considered for the cycle path was defined based on a design bathymetric dataset. Proposed structures' reflectivity was implemented by means of porosity layers which use porous flow model [15] 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 [14].

2.3 Modelling approach

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. Monochromatic wave conditions

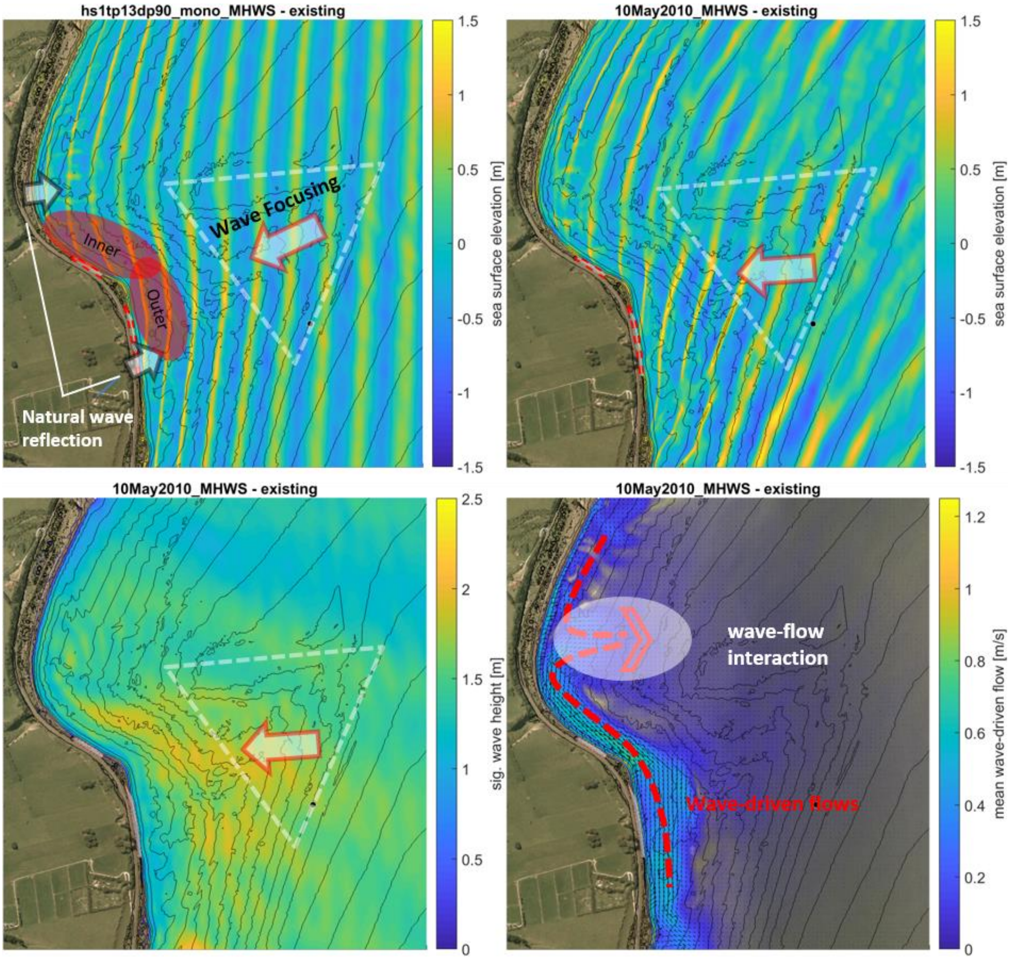

Figure 3. Examples of water level snapshots during optimal monochromatic (top left) and spectral (top right) surfing conditions. Bottom panels show significant wave height (left) and mean flow fields (right) during the 10th of May spectral wave conditions. Annotations locate the main functional features of the surf break.

expected to be close to ideal conditions for the surf break were simulated first as reference case i.e. Hs=1,0 m, Tp=13 s, Dir=90 degT at mean high water spring level, MHWS hereafter). Each parameter (water level, wave height, period and direction) was then modified individually while keeping others constant. Note that monochromatic wave events represent “pure” swell conditions where only a single wave height, period and direction are assumed. These events are useful to characterise key wave patterns affecting incoming waves as they propagate over the seabed, notably in a surfing context (“ideal” conditions) , but are not fully realistic when compared to true sea states composed of a multitude of superimposed waves with different heights, periods and directions (i.e. wave spectrum). Hindcast spectral wave events coinciding with recorded surfing events were also simulated to reproduce more realistic conditions notably these of the 10th May 2010 (Figure 2).

3. Results

3.1 Existing wave mechanics

Mangamaunu surf break is a “point-break” which means that the incoming wave energy is modified into high-quality surfable waves through refraction around a headland with appropriate bathymetry (i.e. relatively smooth contours). Such a configuration typically makes incoming waves “wrap” around the headland and eventually break with peel angles (angle between the wave crest and the path scribed by the moving break point) appropriate for surfing i.e. > 30 deg [16].

Indeed, snapshots of water levels during the reference monochromatic event and optimal spectral wave event (10th May 2010) show waves effectively wrapping around the headland (Figure 3) with wave crests and troughs locally larger off the Point relative to further north. Some reflection patterns, evidenced by the wave crest interference, are visible in the water level snapshots, notably off the northern beach area where there is a steep profile especially at high tide. Here the finer beach sediments are more reflective than the boulder lined foreshore of the headland. Some subtle reflection patterns can also be identified off the prominent east-facing stretch of coast of the headland (the region of proposed southern structure) with some small waves being radiated north-eastward. It is

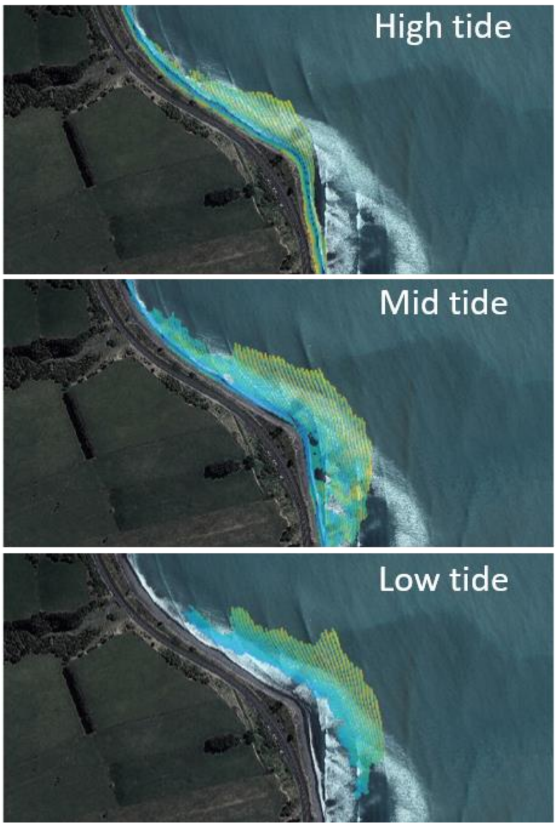

Figure 4 Wave breaking footprints predicted during reference monochromatic conditions (H=1.0m, T=13 sec., Dir = 90degT) at low, mid and high tides.

noted that the monochromatic conditions will typically create the worst-case reflection effects given the single wave period and non-stop wave trains (i.e. equivalent to non-stop sets during pure swell conditions), but they are useful to more easily show underlying patterns.

The significant wave height field shows an area of increased wave heights off the Point and towards the inner section which is due to wave focusing developing over a large submerged wedge off the Mangamaunu Headland (dashed triangular shape, with a relative shadow zone just north of it). Mean wave-driven flow indicates north-directed flows originating from the southern coast that become relatively variable and turbulent along the east-facing stretch of headland and then re-organize into northwest-directed flows down the Point. This northwest-directed flow eventually meets with southward flows from northern beaches and veers offshore into a (topographic) rip current.

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 (MHWS, MSL, LAT respectively) are shown in Figure 4. To provide a degree of (qualitative) validation to model predictions, these are presented on geo-referenced aerial image with some wave breaking. Although wave conditions were different than those modelled, the general agreement between the observed and predicted wave breaking footprints is good and predicted wave crest peel angles are consistent with the images. In agreement with local surfing community observations, wave breaking footprint patterns suggest that mid to high tides produce better surf conditions with longer, more contiguous rides. In contrast, on the lower tides some waves tend to break 'wide' on the outer section, with shorter and likely softer waves (see spurs along the breaking envelope on bottom image of Figure 4).

The range of modelled scenarios allows a functional characterisation of how the important surfing wave parameters modulate with respect to water level, incident wave height, direction, and period [8]. In general, increasing wave heights shift the wave breaking footprints offshore which can eventually make waves to break 'wide' even on the highest tides. For a given offshore height and period, wave direction directly modulates exposure of the break's outer and inner sections to the incident wave energy i.e. smaller for southerly swells, larger for easterly swells. The wave period, and so wavelength, has a direct influence on the water depth at which shallow water wave transformations occur. As a result, increasing wave period (for given height and direction) tends to enhance the wave energy reaching the surfing breaker zone. Longer wave periods (e.g >12 s) act to bring more wave energy towards the break during southerly swells. In general, the optimal conditions occur when the offshore wave focusing that develops over the submerged wedge off the Point aligns with the higher-quality inner break section on a mid to high tide i.e. medium-sized, clean easterly and north-easterly swells.

3.2 Pre-quake wave mechanics

The November 2016 Earthquake caused an uplift of the seabed and foreshore zone estimated to be around 0.8 m at Mangamaunu and environs (no pre-quake bathymetry was available for more accurate evaluation). The "pre-quake" bathymetry was therefore assumed to be 0.8 m deeper than "existing". The tidal range being ~ 1.3 m, this means that high tide on the "existing" configuration is comparable to mid-tide on the pre-quake configuration. Accordingly, the pre-quake configuration did not affect the underlying mechanics of the break but rather reproduced variations that were also observed on the "existing" configuration at higher water levels. This includes wave breaking closer to shore (see Figure 4) and relatively increased (natural) wave reflection from

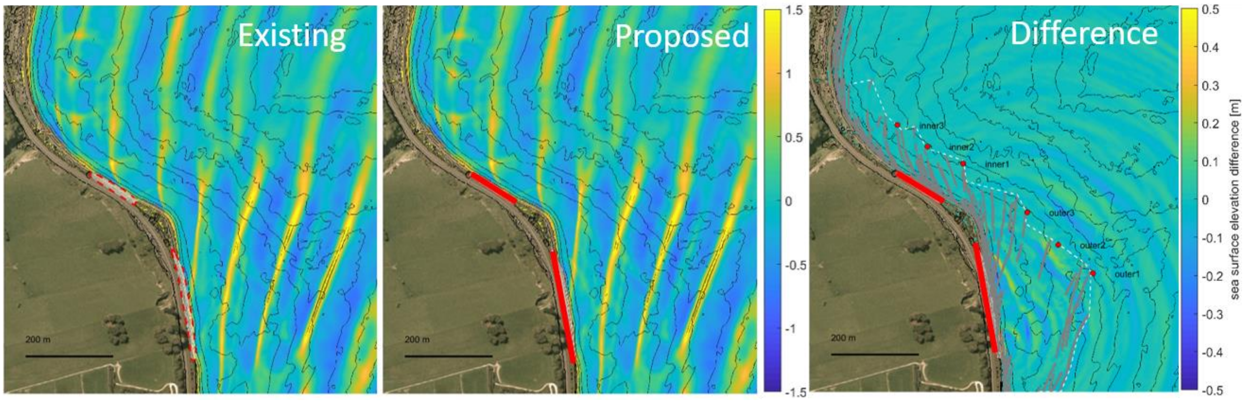

Figure 5 Water level snapshots on existing (left) and proposed (middle) bathymetries and differences (right) during optimal surfing conditions (10th May 2010 at mean high spring tide). The proposed structures are shown in red. Stations used for spectral wave analysis are shown as red dots on the right image; grey lines locate wave breaking positions.

the Point and beach shorelines. Further, it is likely that the deeper "pre-quake" bathymetry allowed relatively delaying the threshold conditions at which waves started to "break wide" as identified for larger incident wave height or lower water levels and therefore provided longer good surfing windows for some wave conditions.

Note this should be contrasted by the consensus within the local surfing community suggesting that under previously ideal conditions the wave can now be split in two but the break is now perceived to be surfable more often in a wider range of conditions. These features are difficult to assess given the likely imperfect picture of the "pre-quake" surf break configuration for which no baseline data is available.

3.3 Post-development wave mechanics

Proposed development includes building two structures along the east and northeast-facing stretches of the Mangamaunu headland coastlines, located between +2 and +3m above mean sea level (see Figure 1). The main risk associated with such structure is to modify the natural swash dynamics and increase the amount of wave energy reflected seaward, which can adversely impact surfing conditions. The proposed structures were included the SWASH domain bathymetry (using porosity layers, see [14,15]) and simulations of optimal surfing conditions were reproduced for comparison with the existing state. The tested conditions included low, mid tide, and high tide (LAT, MSL, MHWS) as well as a higher water level at 0.3m above MHWS to account for potential sea level rise and/or storm surge.

Comparative analysis showed no modifications of the predicted wave height field and very limited modifications of mean wave-driven flow fields between the "existing" and "proposed" bathymetric configurations at low and mid tides. However more evident changes become visible for high tide (MHWS) and MHWS+0.3m water levels for which the southern structure was found to radiate some wave energy back through the surf break. This is illustrated in Figure 5 (right image) that shows the difference between "existing" and "proposed" surface elevations at a given time and thus captures the change in reflected waves. Associated wave height change patterns (Figure 6) are relatively stripy due to interference patterns present in water level time series but they suggest a net height increase in front of the structure progressively reducing seaward. The magnitude of changes is relatively limited (up to ~± 0.1m, ±10 %) and breaking footprint envelopes are essentially conserved (see black and green lines in Figure 6). In contrast, the model results suggest a much more limited influence of the northern structure, with some localized changes only in the immediate vicinity. This can be attributed to its position further down the headland making less exposed to residual wave energy due to general wave sheltering effect as well as a more progressive and efficient wave energy dissipation as waves peel and break around the headland.

The increasing influence of the structures on the wave dynamics for increasing water levels is not surprising. Indeed, higher water levels expose higher zones of beach foreshore to swash oscillations, which includes zones where proposed structures are to be located. The structure slopes that are steeper and hence more reflective than the surrounding the beach face locally increase wave reflection. This wave reflection "gradient" will expectedly disappear as soon as swash oscillations do not reach the structures any longer during lower water levels (i.e. mid to low tides), or that swash oscillations are sufficiently dissipated before they reach the structure (i.e. low energy).

In order to quantify the "existing" and "proposed" (i.e. post-development) reflection processes, directional wave spectra were estimated at a range of control points on the breaking line predicted along

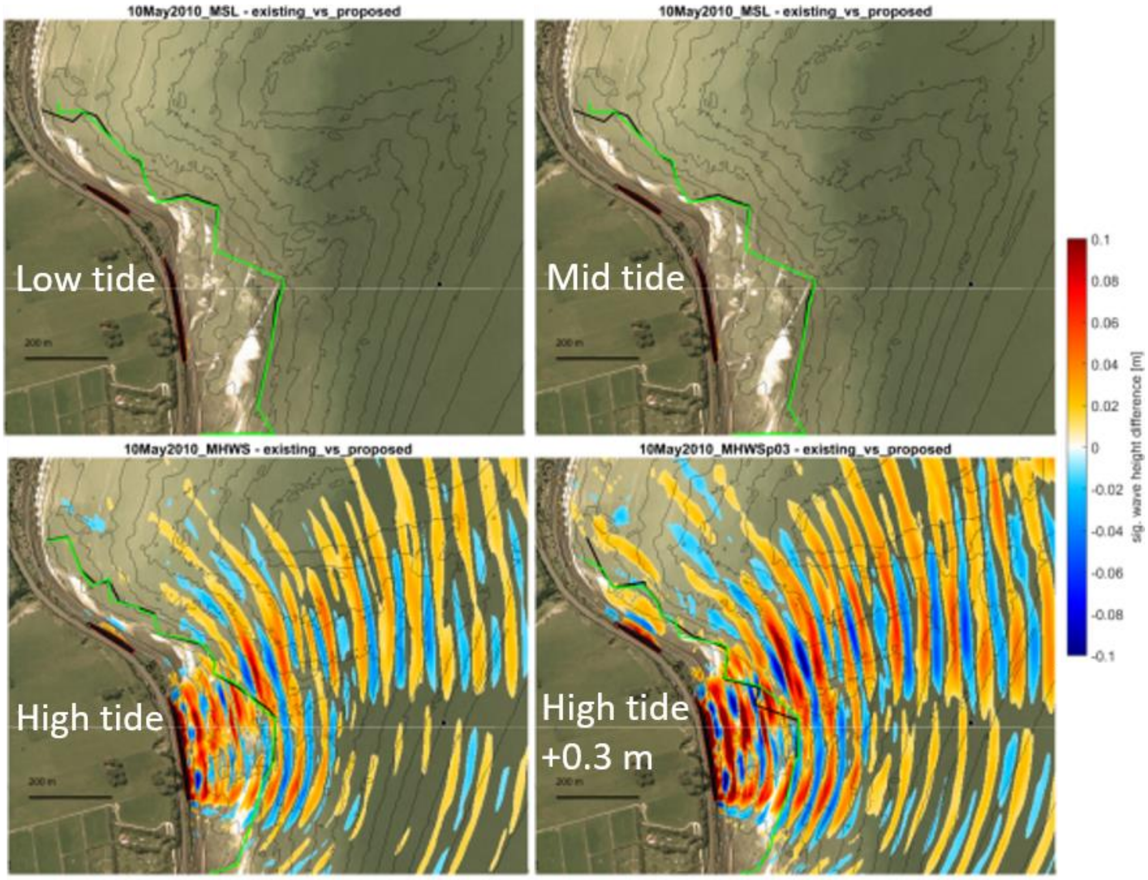

Figure 6. Predicted wave height difference, in meters, during an optimal surfing event (10th May 2010) at low, mid, high and high +0.3m tides. Existing and post-development wave breaking envelopes are shown as black and green lines respectively. Proposed structures are shown in black.

the outer and inner wave sections (Figure 5, right image). It is noted that the wave model was not validated and quantitative results should therefore be interpreted carefully and in a relative sense. Directional wave spectra were estimated using elevation and current time series extracted from the optimal surfing event simulation (10th May 2010) using the open-source toolbox DIWASP [1] (see Figure 7). Directional wave spectra provide valuable information as they can capture incident and reflected wave components on both the existing and proposed states. Incident and reflected wave heights were obtained by integrating the spectral densities over the incident and reflected directional windows, respectively [0-180 degT] and [180-360 degT], to define associated root-mean-square wave heights (i.e. $H_{rms} = \sqrt{8.m0}$). First, it is interesting to note that some reflected wave energy is present in the "existing" break state. Reflected wave heights generally increase for increasing water levels and are slightly larger along the outer break section that has a steeper foreshore and is more normal to incident waves. Inclusion of proposed structures results in a small increase of reflected wave heights along the break outer section at high tide (see Figure 7). There we see an increase from 0.29-0.38m to 0.3-0.42m (+10-15% relative to "existing" reflected wave heights) with negligible effects along the inner section (of order 1cm or less). The increased wave reflection during higher water levels could potentially impact the smoothness of wave face throughout the outer break section. Reflected wave height difference are otherwise negligible along both break's sections for mid and low tides which is consistent with previous observations in Figure 6.

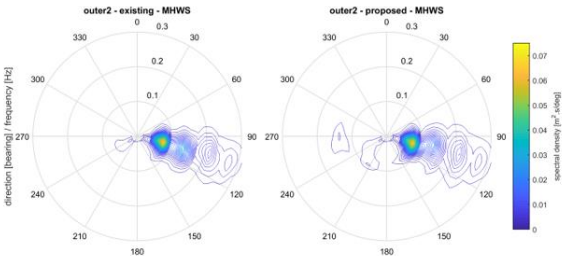

Figure 7. 2D wave spectra at site outer2 on existing (left) and proposed (right) configurations for the 10th May 2010 at high tide MHWS.

4. Summary

The paper describes a simple numerical framework to characterise the surfing wave mechanics of Mangamaunu Point break. The methodology includes a surf-specific wave climate assessment and numerical wave modelling of surfing wave conditions using SWASH to determine the key functional features of the existing surf break. Once established, the baseline information is used to assess potential impacts of proposed engineering works (foreshore revetment) and earthquake-related seabed uplift.

The wave modelling indicates significant wave focusing developing over a submerged bathymetric wedge off the surfbreak (10-15m water depth) which allows locally increasing the wave energy reaching the Mangamaunu Point break, particularly towards its higher-quality inner section. The Mangamaunu Point morphology then allows progressive refraction of the incident waves which wrap around the point and eventually break and peel for over long distances with angles appropriate for surfing. Comparative wave modelling of the post-development configuration indicates that the proposed southern structure increases the wave reflection from the east-facing shoreline outer section of the Point, at higher tides. Additional wave energy is radiated back in an east-northeast direction relative to the existing state and could locally impact the wave face smoothness along the outer section of the surf break. Based on this outcome and results of a wider surf break assessment [12], a decision was made by the Transport Agency not to progress the shared use path under the current consents.

The SWASH wave model proved to be a useful tool to understand key features of the nearshore wave propagation, wave breaking, and circulation in a surf break assessment context. The methodology presented here could readily be applied to other surf breaks for baseline characterization and impact assessment of inshore or offshore engineering developments. Ideally, this should include quantitative validation of the wave model through wave measurements, video imaging and comparison with surfer's GNSS tracks. Specific wave mechanics assessment should fit within a wider assessment framework also considering socio-economic aspects (e.g. [1,11,12]) to capture a complete picture of a surf break as a coastal zone asset.

5. Acknowledgements

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