The influence of surfing wave parameters on manoeuvre type from field investigations at Raglan, New Zealand

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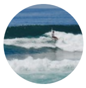

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THE APPLICATION OF SURVEYING TECHNIQUES TO ARTIFICIAL SURFING REEF STUDIES

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ABSTRACT

Interest in multi-purpose offshore reefs, or artificial surfing reefs (ASRs) is growing as more people are being informed about the benefits for surfing, erosion control and biological enhancement. Significant volumes of scientific literature have been published on the design, construction and effects on the coastal environment of human made surfing breaks. Surveying has become a key tool in research, construction and monitoring of ASRs. Spatial measurement of the seafloor shape, wave breaking locations and shoreline responses to reef is the realm of surveyors. This paper illustrates a novel application of surveying in the coastal environment.

A research methodology employed to study how surfing waves transform over complex reef bathymetry at Raglan, New Zealand is presented here. Experimental RTK-GPS was validated and utilised to measure a water level correction for depth soundings. This created one of the most precise charts of a surfing break to date. Small and large scale reef features are identified in the bathymetry that modify wave shoaling and breaking. These features create sections in the surfing ride that break with different character making for an interesting and changeable surfing wave. The breaking waves are tracked relative to the seafloor with measurements made using a modified a projective transformation of video image coordinates. The influence of the separate surfing reefs components can be seen by overlaying the wave path on the bathymetry and by wave refraction modelling.

The combination of state-of-the-art surveying and oceanographic methods used here has increased the understanding of how surfing waves transform. In particular, the research has shown how surfing manoeuvres are controlled by wave parameters such as height, peel angle, section length and breaking intensity. This has enabled a design criterion to be developed that incorporates a surfer's manoeuvre type into the sections of a ASR.

INTRODUCTION

Surveying techniques are utilised in many different industries and research fields. They are not limited to traditional uses such as cadastral surveying and hydrographic surveying for navigation. Here a novel application of seabed mapping and videogrammetry is presented to show how surveying can be used in non-conventional ways. A four month field study of the Manu Bay (Plate 1) surfing break in Raglan, New Zealand was undertaken by Scarfe (2002a) to develop design criteria for artificial surfing reefs (Scarfe, *et al.*, 2002). High-resolution bathymetry allows for detailed investigations of seabed changes and is the most vital factor for high-quality numerical modelling of wave and sedimentary processes.

Interest in multi-purpose offshore reefs, or Artificial Surfing Reefs (ASRs) (Barilotti, 1998; Black, 2001a and 2001b; Black *et al*., 1998; Black and Mead, 2001; Ranasignhe *et al*., 2001; Evans and Ranasignhe, 2001; Hutt, 1997; Mead, 2001; Scarfe, 1999 and 2002a; Scarfe, *et al.*, 2002) is growing as more people are being informed about the benefits in amalgamating amenity (e.g. surfing, sheltered swimming, diving, snorkelling, windsurfing etc.), erosion control and ecological enhancement. Significant volumes of scientific literature have been published on the design, construction and effects on the coastal environment of human made surfing breaks. Surveying has become a key tool in research, construction and monitoring of ASRs. After all, spatial measurement of the seafloor shape, wave breaking locations and shoreline responses to reef is the realm of surveyors.

Plate 1. Manu Bay, Raglan, New Zealand – Easter 2001 (photo source – A . Stringer).

ARTIFICIAL SURFING REEFS

COASTAL PROTECTION

Most coastal protection methods defend coastal development from ocean forces at the expensive of recreational and/or aesthetic values. Many solutions, such as seawall and groins, are applied routinely without seeking alternative options. Often little is understood of the coastal processes that are causing the erosion. Black (2001a and 2001b) and Mead (2001) have given credibility to the use of artificial surfing reefs to rotate and dissipate wave energy, modifying wave climate and current patterns to stabilise the shoreline in the lee of the submerged reef.

SURFING ENHANCEMENT

Offshore and near shore bathymetry controls how often a surfing break will have surfable waves. The seafloor can be modified to maximise the number of surfable days at a surf spot. The use of human made reefs cannot generate swell but can optimise the number of good waves by rotating wave directions, controlling shoaling as well as by creating stable contours for waves to break on.

The four most important wave parameters for surfing are height, peel angle (α), breaking intensity and section length. Peel angle is defined as the angle between the trail of the broken white water and the crest of the unbroken wave as it propagates shoreward (Plate 2; Walker, 1974; Hutt, 1997; Hutt, *et al.*, 2001; Mead, 2001b). Peel angles range between 0° and 90° with low angles creating fast surfing waves and high angles slow waves. An angle of 0° is described as a close out (Mead and Black, 2001b).

A small group of researchers from New Zealand have been investigating in recent years how surfing parameters relate to artificial surfing reefs. Hutt (1997) and Hutt *et al.* (1998 and 2001) have investigated relationships between wave peel angles, wave height and surfer skill levels. They conceived a classification scheme that links surfer skill to wave height and wave character. The scheme can be used directly to determine design criteria for an artificial surfing reef. An empirically derived formula for wave breaking intensity has been found by Mead and Black (2001c). The formula, based on the orthogonal seabed gradient, is used to estimate the wave vortex ratio, or how hollow a wave will break, on an artificial surfing reef. Moores

(2001) has quantified the size of a wave section that can successfully surfed by surfers of different abilities under the Hutt (1997) skill level scheme.

The type of manoeuvres that surfers can perform is largely controlled by the wave parameters. Wave height, peel angle, breaking intensity and section length for different parts of an ASR need to be designed to allow certain manoeuvre types. The first investigations into how different types of waves dictate manoeuvres was undertaken by Scarfe (2002a) and Scarfe *at al.* (2002).

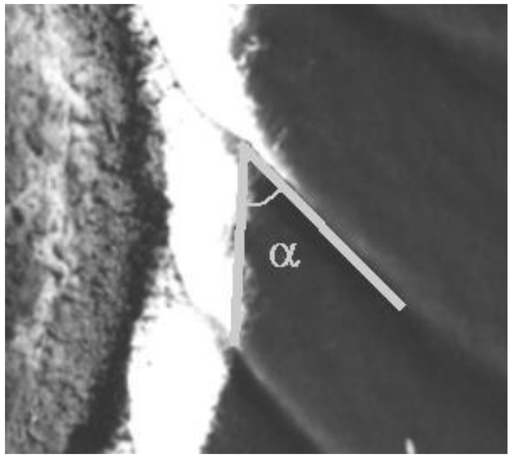

Plate 2. The peel angle, α, is defined as the angle between the trail of the broken white water and the crest of the unbroken part of the wave as it propagates shoreward (after Mead, 2001).

BIOLOGICAL ENHANCEMENT

Since it is likely that many organisms are habitat limited (Pickering and Whitmarsh, 1996), aartificial reefs provide substrate for a variety of marine organisms (Pratt, 1994). Biological enhancement is a beneficial artefact of providing stable substrate in the nearshore zone in the form of offshore reefs, but can also be improved by the provision of specific habitat within the structure. While constructing a structure on the seabed will smother and kill almost everything that is residing there at the time, a new structure is likely to provide better habitat and consequently a community with higher species abundance and bio-diversity than previously existed at the site. There has been a large amount of work on ecological enhancement using artificial reefs throughout the world (e.g. Bulletin of Marine Science, 1994). From these studies it is evident that, as a general rule, species abundance and diversity are greater when the habitat is more stable (in comparison to mobile substrates – e.g. Mead *et al*., 1998), topographically more complex (a higher number of different niches are available) and when the reef is larger (Pratt, 1994). Construction of artificial reefs also provides the opportunity to create specific habitat and 'seed' specific species that may be of commercial or cultural value (e.g. Saito, 1992). Therefore, the biological enhancement due to the construction of a multi-purpose reef may include, increased environmental value (increases in bio-diversity and abundance), increased amenity in the form of a diving and snorkelling venue and enhanced fisheries by the incorporation of specific habitat.

Sandy sediments are normally present in the shallow sub-tidal zone at the majority of sites where coastal protection is required. While an area may be ecologically healthy in terms of a mobile sand habitat, such environments typically have low biodiversity in comparison to solid substrates, such as reefs (e.g. Morton and Miller, 1968), which is due to the mobile and abrasive nature of sand. Construction of a multi-purpose reef provides a more complex and stable habitat and will therefore increase the biodiversity. The reef itself provides a substrate for larval organisms in the water column to settle on and become established. Indeed, after only two weeks in place, the geotextile containers used to construct the multi-purpose reef on the Gold Coast were already well covered by juvenile seaweeds. Once primary producers become established, these organisms, and the reef itself, provide shelter and a food source for fish and other marine life and act as a fish aggregating device (FAD) (Bohnsack and Sutherland, 1985). In addition, a reef may also subtly alter the local hydrodynamics in a way that could increase settlement in the lee of the reef (e.g. Black and Gay, 1987).

STUDY SITE AND RESEARCH METHODOLOGY

Much of the key research on surfing waves in recent years has been done at Raglan, New Zealand just south of Auckland on the West Coast of the North Island (Andrews, 1997; Hutt, 1997; Moores, 2001; Sayce, 1997; Scarfe 2002a). The Raglan headland has a series of consistent surfing breaks that are popular for many surfers in the region (Plate 3). The breaks are made up of complex reef and boulder formations in the shallow water where waves break. In the deeper water, dynamic and changeable sand bars (Phillips *et al.*, 1999 and 2001; Scarfe, 2002a) precondition waves as they approach the surfing area.

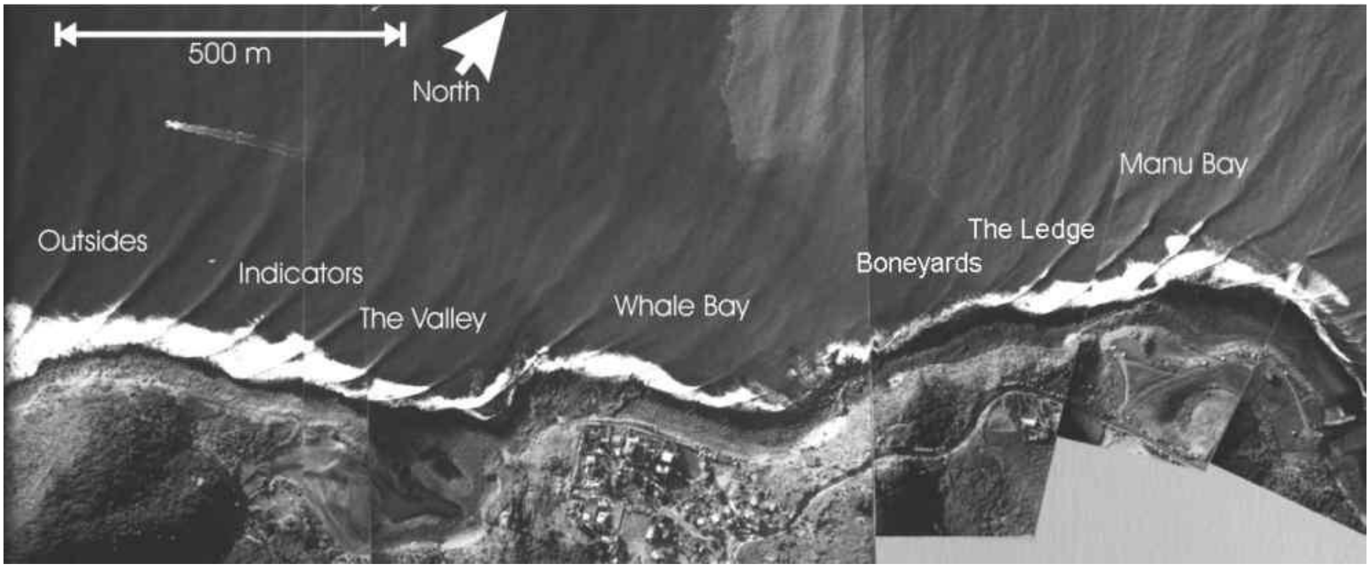

Plate 3. Aerial view of the Raglan surfing breaks (after Hutt, *et al.* 2001).

The research methods presented here are hydrographic and photogrammetric in origin. The Manu Bay seafloor was charted with experimental RTK-GPS hydrographic techniques validated by Scarfe (2002b). Side scan imaging of the seafloor by Phillips *et al.* (2001) showed the reef-sand boundaries and the presence of various scale morphological bars and ripples. Periodic surveys of sections of Manu Bay and neighbouring Indicators surf breaks quantified the scale of erosion and accretion of sediment near the reefs. Video images were used to track breaking waves and surfing rides relative to the surveyed bathymetry using a modified non-metric videogrammetry technique. Combined analysis of the wave paths with numerical modelling of the waves showed how the different components of the surf break modify wave refraction and breaking. This data allowed design criteria for different surfing wave parameters to be investigated.

HYDROGRAPHIC SURVEYING OF THE SURF BREAK

A lot of information about a surfing break can be seen simply from the bathymetry since it controls wave refractions and breaking. The configuration of different reef components (Mead and Black, 2001a and 2001b) dictates the preconditioning of waves and where the waves will break. Accurate charting is essential to understanding a surfing break and running successful numerical wave refraction model scenarios. Correcting depth sounding for tide and vessel motion must be made to produce accurate charts of the coastal zone.

Raglan has a large wave climate with a significant wave height of 2-2.5 m (Scarfe, 2002a). Although surveying is done during periods of low swell there is always a small underlying swell present. Accurate tidal corrections are difficult to obtain since no permanent tide station exists nearby. Equipment must be specifically deployed and calibrated to a local datum for the survey. These issues are not exclusive to Raglan and are applicable to many coastal areas. Additionally, many tide gauges are located in harbours and port embayment where the tide phase and amplitude can be significantly different to the open coast.

A new theory to overcome problems with measuring separate heave and tide correction has been proposed. Scarfe (2002b) identified problems with measuring a separate heave and tide correction because the two are combined to correct a sounding for the water level at any one instant. What is required is a water level correction (WLC) that reduces a sounding to the local datum. Measuring the water level where a sounding is made removes errors caused by tidal corrections from remote locations.

To measure a WLC requires high update low latency RTK GPS. The GPS must calculate 3D positions at a high enough rate (> 5 Hz) to model the waves. The timing of the position must be matched precisely (< 50 ms) to the sounding. Most receivers output a positions around two-seconds after it is true because of the time taken to transmit carrier phase observations from the reference GPS to the rover. This latency can be corrected using techniques presented by Scarfe (2002b) but ideally the GPS should have negligible latency. Trimble's MS750 RTK GPS has a low latency (20 ms) mode that predicts the reference GPS's carrier phase observations a few seconds in advance. This is possible, as the reference GPS observations do not change significantly over a short time. There is a small loss in accuracy from ±2-3 cm (horizontal) to ±3-5 cm but this is acceptable within the error budget of a hydrographic survey. The 5 Hz Leica SR530 RTK GPS has been successfully used by the authors in synchronised mode. Some degradation in accuracy is expected but was not tested specifically.

Final Chart

The final chart of Manu Bay can be seen in Figure 1. The survey used a Knudsen 320MP echosounder, Trimble MS750 RTK GPS operating in low latency mode at 10hz and Trimble HydroPro Navigation software. Significantly more detail can be seen in the chart than from the previous survey in 1996.

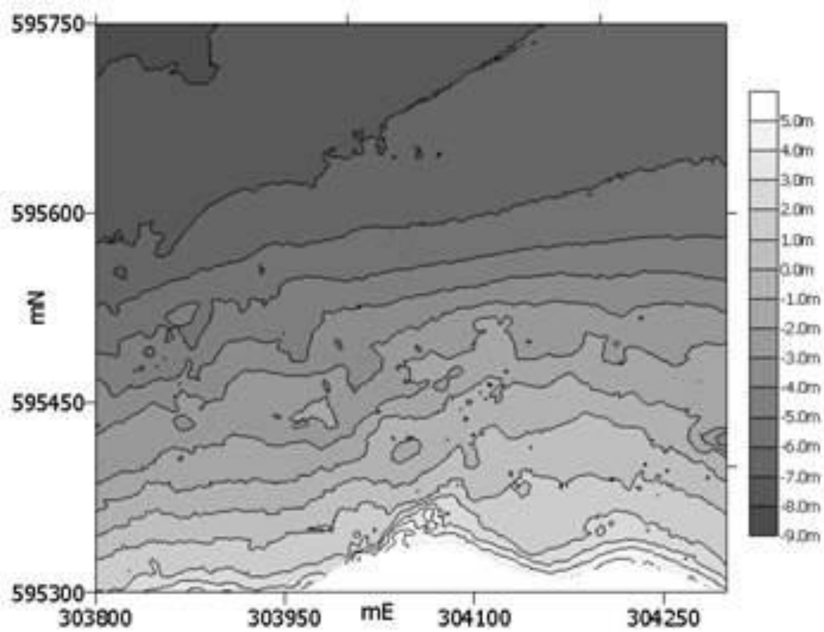

Figure 1. Manu Bay surfing break, Raglan, New Zealand. Depths relative to chart datum which is approximately lowest astronomical tide (after Scarfe, 2002a).

Scarfe *et al.* (2002) categorised Manu Bay as a macro-scale wedge in the deep water, with a meso-scale wedge in the shallower (Figure 2). A meso-scale ridge is superimposed on the meso wedge creating a section called The Ledge. A wedge (Figure 3) is a sloping seabed that initiates wave breaking and refracts incoming waves away from the favoured othorgonal direction (Mead and Black, 2001a). The favoured othogonal direction is the optimum waves direction for good surfing waves. A ridge (Figure 3) is a seabed ridge on a wedge or ledge aligned so that the offshore isobaths are at a greater angle to the favoured orthogonal direction than the preceding isobaths of the wedge or ledge (Mead and Black, 2001a). A ridge causes a local increase in seabed gradient and leads to a wave section with a steeper face and lower peel angles (Mead and Black, 2001a).

Further, micro-scale focusing (Figure 3) and ridge components were also observed on the wedge. The focuses converge wave energy creating a peak in wave height with a lower seabed gradient (Mead and Black, 2001a). These micro-scale features create sections along the surfing wave making the surfing ride more interesting than if the waves peeled at a continuous rate. It was seen that the micro-scale ridge features also act as focuses and vice versa depending on the tide level and swell amplitude (i.e. where and whether or not the waves break). This highlights how complex surfing reefs are, particularly when tidal ranges are meso or macro-tidal.

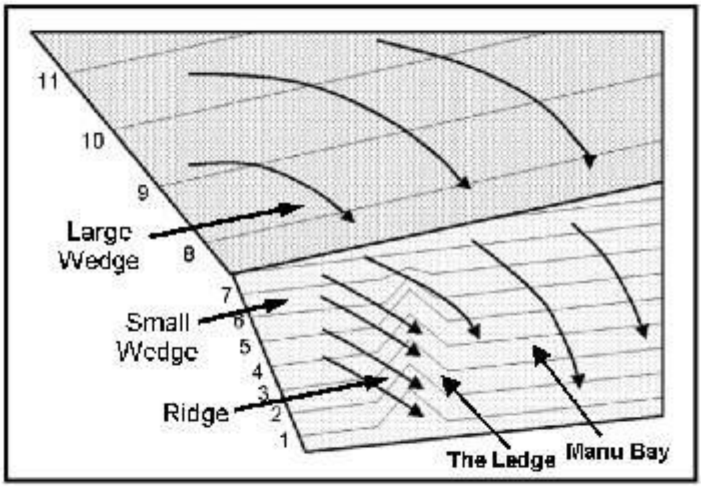

Figure 2. Schematics of Manu Bay surfing break. At a macro-scale the break is made up of a large scale wedge, small scale wedge and a ridge (after Scarfe, 2002a).

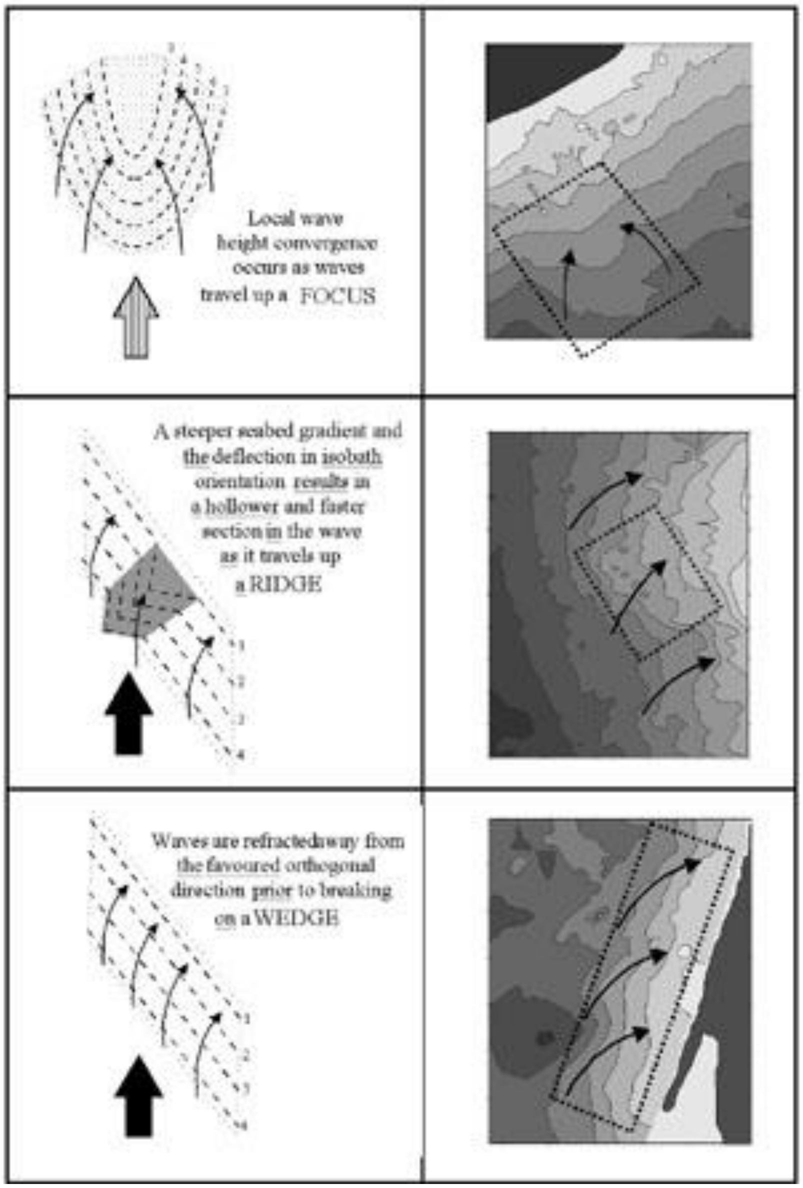

Figure 3. Schematics of a focus, ridge and wedge reef components (after Mead and Black, 2001a).

INVESTIGATIONS OF SEDIMENT DYNAMICS

Investigating sediment dynamics in the coastal area involves a complete understanding of bathymetry, wave and current patterns and sediment types found at the beach. Phillips *et al.* (1999; 2001) have been looking at sediment dynamics around the Raglan surfing breaks. Among other techniques, periodic digital side scan surveys and hydrographic transects have been undertaken. The side scan images (Figure 4) appear as aerial photographs of the seafloor geology. The boundaries of reef and sand are clear. Scouring and infilling around the reefs is evident with certain reef features acting as groins to trap sand. The side scan used was a Klien with Isis Sonar data acquisition and image processing system.

Scarfe (2002a) showed with a time series of surveys at Raglan that up to 0.5 m of sediment can be eroded and accreted per month from sand bars as they move onshore and offshore. This significant change in the shape of the sea floor over time affects the preconditioning of surfing waves. Meso-scale focus components were seen to appear and disappear over time as successive swells accumulated or scoured around the reef.

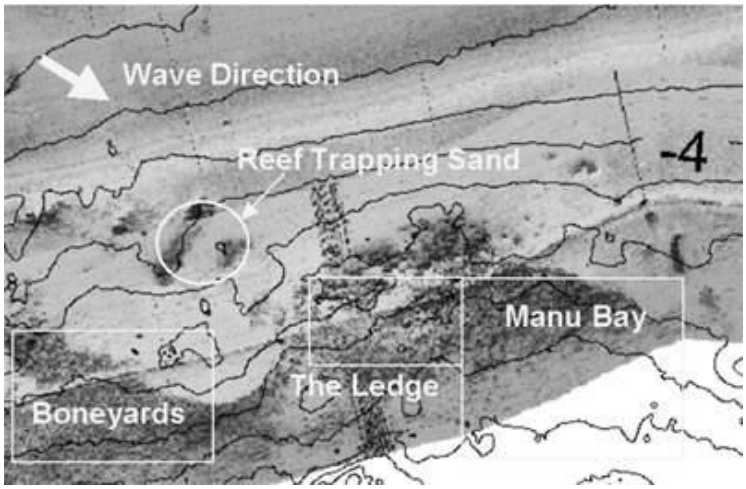

Figure 4. Side scan imaging (Phillips *et al.*, 2001) of Raglan with 1 m contours (Scarfe, 2002a). The sediment-reef boundary is very clear and the effect of the reef on sediment accumulation and scouring is evident.

NUMERICAL MODELLING OF WAVES

Numerical models are essential for coastal studies. They can be used to predict many wave, tide and current scenarios that otherwise are impossible to measure in reality. Sediment movements and budgets can be predicted based on current patterns. The models consist of many complex theoretical and empirical formulae that represent physical processes that happen at beaches. Many of these formulae include water depth making it critical to accurately chart bathymetry.

Model investigations at Raglan by Scarfe (2002a) used the rapid-solution monochromatic and spectral numerical wave refraction model Wbend (Black and Rosenberg, 1992). It was possible to simulate wave scenarios that were not observed during the field experiments. Also wave orthogonals, or changes in direction as the wave approaches the shore, were extracted allowing peel angles to be calculated.

The effect of different reef components on wave refraction and shoaling was investigated for various wave conditions (Figure 5 and 6). The ridge component (Figure 2 and 6) creates a fast heavy wave section known as The Ledge. Numerical simulations show the wave breaks with a lower peel angle than the rest of Manu Bay because of the ridge feature.

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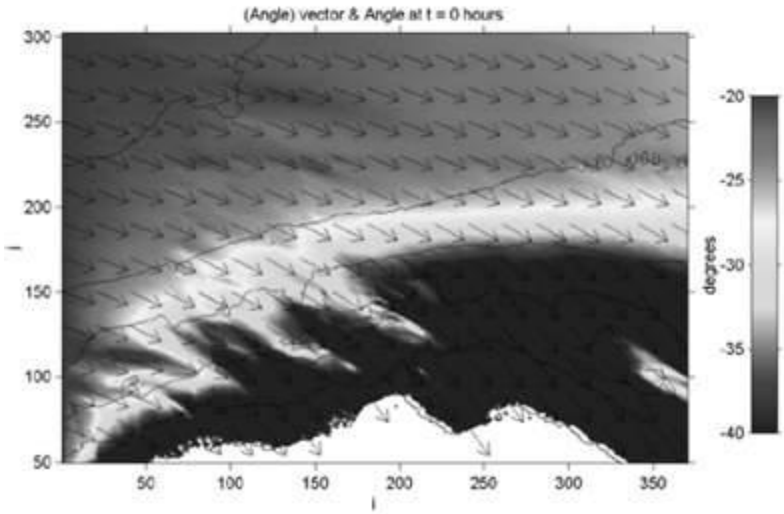

Figure 5. Numerical model simulation showing how the large wedge component on Raglan headlands shelf orientates the waves at Raglan to the favoured orthogonal direction. This simulation is of a 2.0 m, 12 second wave from 110° when the tide is 2.0 m above chart datum (after Scarfe, 2002a).

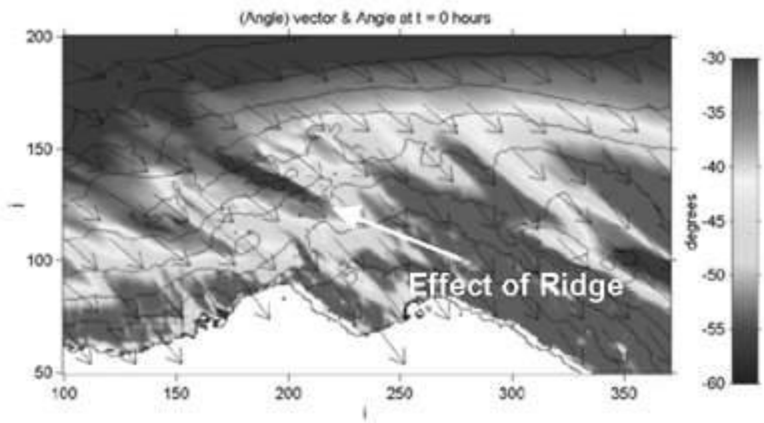

Figure 6. Numerical model simulation showing how the Manu Bay wedge cause wave refraction while waves pass over the ridge without any modification to direction. This simulation is of a 2.0 m, 12 second wave from 110° when the tide is 2.0 m above chart datum (after Scarfe, 2002a).

MONITORING COASTS USING A MODIFIED PROJECTIVE TRANSFORMATION

Various researchers (Lippmann and Holman, 1989; Bailey and Shand, 1993; Kempema and Holman, 1994; Plant and Holman, 1997; Aarninkhof and Holman, 1999; Boogle, 2000; Turner, *et. al.*, 2001) have used digital images to monitor shoreline evolution, beach morphology and other coastal processes. The non-metric photogrammetric techniques employed enables meaningful information to be obtained without the expertise, equipment and software required when using metric techniques. Moores (2001), Scarfe (2002a) and Scarfe *et al.* (2002) applied non-metric techniques to the study of surfing waves by extracting digital images from video footage. Moores (2001) calculated surfer speeds and the length of wave sections from relative points within the images.

Scarfe (2002a) and Scarfe *et al.* (2002 and 2003) developed a modified projective transformation to precisely measure the absolute positions of breaking waves relative to the bathymetry. When using a projective transformation it is assumed that all features on the image lie on the same plane. The rise and fall of the tide changes the plane that measurements of wave locations should be made from. This can lead to large errors when measuring absolute positions because they are projected away from the true position, particularly when the camera elevation is low and tide ranges are large (Figure 7). Therefore, the elevation of the measurement plane needs to be included in calculations for high accuracy measurements from images of the coast.

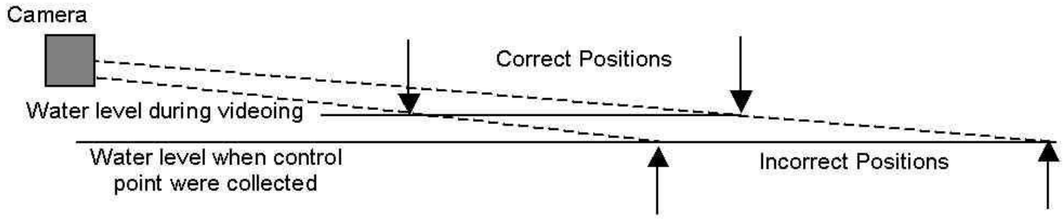

Figure 7. Effect of changes in tide level on calculated positions (after Scarfe, 2002a).

To correct to the changing object space plane as the tide rises and falls Scarfe (2002a) developed a simple extrapolation method. This method involves gathering control data when the tide is approximately low and when the tide is approximately high. When making subsequent measurements from the video images two transformations are done, one using the low tide control and one using the high tide control yielding two coordinates. The rate of change in northing and easting are determined and a corrected position (Figure 8) is calculated using Equations 3 and 4.

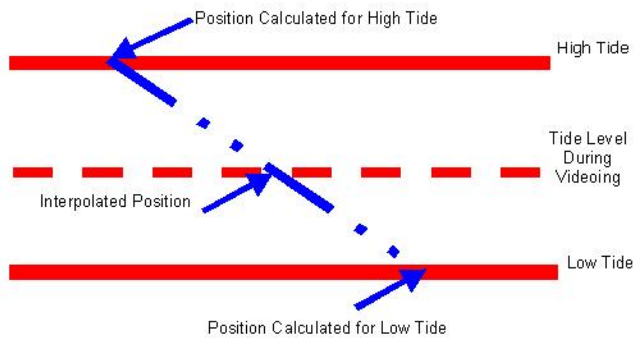

Figure 8. Interpolated position to correct for tidal fluculations (after Scarfe, 2002a).

$Easting_{CORR}=((Easting_{LT}-Easting_{HT})/(Tide_{HT}-Tide_{LT}))*(Tide_{l}-Tide_{LT})$ Equation 3

$Northing_{CORR}=((Northing_{LT}-Northing_{HT})/(Tide_{HT}-Tide_{LT}))*(Tide_{l}-Tide_{LT})$ Equation 4

Where:

$Easting_{CORR}$	= Corrected easting coordinate
$Northing_{CORR}$	= Corrected northing coordinate
$Easting_{LT}$	= Easting calculated using low tide control points
$Easting_{HT}$	= Easting calculated using high tide control points
$Northing_{LT}$	= Northing calculated using low tide control points
$Northing_{HT}$	= Northing calculated using high tide control points
$Tide_{LT}$	= Tide level above datum at low tide
$Tide_{HT}$	= Tide level above datum at high tide
$Tide_{LEVEL}$	= Tide level above datum at time image was take

Images from Scarfe (2002a) of surfing at Manu Bay can be seen in Plate 4. The location of the breaking waves using the described technique were measured and plotted against the bathymetry (Figure 9). This showed how the micro-scale reef components or features create waves sections that break with varying character. Walker (1974) and Hutt (1997) used aerial photography to overlay wave break points with the bathymetry. This video techniques enables more accurate data to be obtained at a lower cost than with aerial photographs.

Plate 4. A sequence of a surfing wave at Manu Bay taken from digital video (after Scarfe, 2002a).

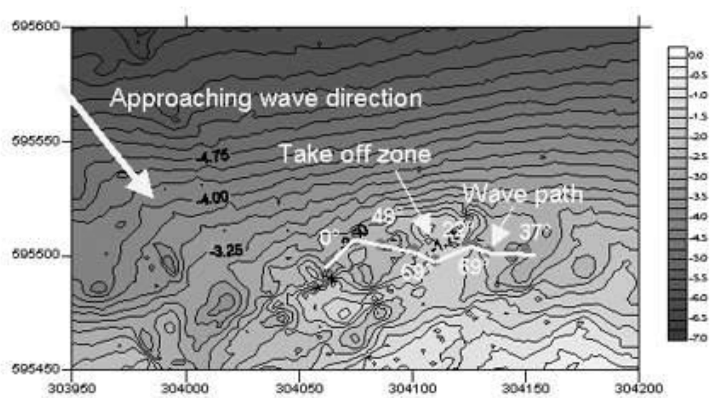

Figure 9. The path of the wave breaking in Plate 4. Micro-scale changes in peel angles that create wave sections are shown (after Scarfe, 2002a).

CONCLUSIONS

Surveying techniques are utilised for many tasks. This paper shows that surveying can be an important tool for non-conventional applications. A methodology for investigating surfing waves is shown here that uses state of the art surveying coupled with oceanographic methods. The research has shown how surfing manoeuvres are controlled by wave parameters such as height, peel angle, section length and breaking intensity. The outcome of the research has been the development of design criteria to incorporate a surfer’s manoeuvre type into the wave sections of artificial surfing breaks. This helps to create reefs that provide an interesting and variable surfing ride that matches the skill level of the surfers who will use the reef. ASRs can be designed for beginners, intermediate, advanced and professional surfers and now there is a better understanding how surf parameters affect a surfing ride. More detail on the influence of surfing wave parameters on manoeuvre type can be found in Scarfe *et al.* (2002).

The techniques developed in this surfing study have wider application than just for artificial surfing reefs. The theory of WLC's has been successfully used here and can be applied in all coastal, estuarine, river and lake hydrographic surveys. The accuracy, initialisation reliability and latency of positions from modern GPS equipment makes measuring WLCs possible. People are slowly adopting the use of RTK GPS to measure WLC corrections or tide and heave but has not yet become widespread. However, the use will increase as people are exposed to the technology and software to support it improves. The modified projective transformation technique can be used in many coastal process studies where objects within the image lie on different planes. This is of particular importance when monitoring shoreline and dune evolution.

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