Design of Surfing Reefs

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ABSTRACT
The current status of multi-purpose surfing reef development is evolving. Projects worldwide are in various stages of completion and lessons have been learned from each. This paper considers continuing developments in reef design and reef engineering construction, and the need for blending of the two aspects.

INTRODUCTION
Multi-purpose surfing reefs for coastal protection and public amenity have come of age. For about 9 years, we have been researching and disseminating information about reefs and their benefits (BLACK et al., 1997; MEAD AND BLACK, 1999; BLACK, 2001; MEAD AND BLACK, 2000B; BLACK, 2004). In that period, a transition in attitudes has occurred from disbelief to common acceptance and there is a general understanding of the fact that “if you block the waves on a reef offshore, the beach will be protected”.

Even the simple rectangular reefs built by Japanese engineers have led to salient development and beach widening (e.g. PILARCZYK, 2003), although more sophisticated shapes will optimize the benefits of the reef. On the Gold Coast Reef (BLACK and MEAD, 2001a), video monitoring has confirmed its coastal protection benefits (TURNER et al., 2001). In some instances of strong longshore currents, negative impacts may occur through compression of the surf zone currents if the reef is placed in the wrong position cross-shore (BLACK, 2003a). However, there are thousands of cases of natural reefs which have salients or tombolos in their lee, and people are looking at their own environment and seeing reefs/islands which are virtually always backed by a wider beach (Fig. 1).

With the acceptance of multi-purpose reefs worldwide as a coastal protection measure, plus the potential to include public amenity and recreational aspects, reefs are now coming close to construction. Final detailed studies through field research, physical and numerical modeling are being undertaken (e.g. BOGLE et al., 1999; GREEN AND BLACK, 1999; PHILLIPS et al., 1999; SAYCE et al., 1999; MOORES, 2001; AAGARD et al., 2002; BRYAN et al., 2003; BLACK, 2003b; BEAMSLEY AND BLACK, 2003; SCARFE et al., 2003; RANASINGHE et al., 2004; BLACK et al., 2005). The penultimate stage in the sequence is to produce the quality of engineering that will match the scientific design work. In the last 3 years, innovative techniques have been considered in consultation with the major engineering and geotextile companies.
This paper considers the design and construction of surfing reefs, and examines two multi-level reef cases developed to satisfy particular constraints, which are to optimize volume and maximize wave breaking height and quality respectively.

**REEF DESIGN**

The designing of reefs is “harder than you think”. Indeed, it’s surprising how many people still believe that a 45° wedge “boomerang” dropped in the ocean will lead to a perfect left and right breaking barrel. Nothing is further from the truth (BLACK and MEAD, 2001; MEAD, 2003).

There are numerous subtleties, particularly when trying to minimize volume (i.e. construction cost) while retaining maximum surfing potential. Similarly, reef shape has a strong influence on the coastal protection aspects, through rotation (BLACK and MEAD, 2001b) and dissipation of waves (BLACK, 1999; TURNER et al., 2001b). Each component in the reef design, such as crest height, arm lengths and orientation, foci, structure depth, width and volume, must be blended with the specific physical environment in which the reef is to be placed. The aspirations of the stakeholders can also determine outcomes.

Several hundred different reef designs have been tested numerically using the 3DD Suite of Numerical Models (© BLACK, 2001), and there are some basic and complex rules that cannot be denied. The most important basic rule is that the reef is a holistic system; every part of the reef is joined to every other part through wave refraction, shoaling and breaking (MEAD and BLACK, 2001 a&b). A focus, for example, can take energy into the peak, but the same component can leave a wave shadow down the reef (BLACK et al., 1998; Black and Mead, 2001). A steeper reef face designed to make the wave break harder, can actually cause...
the smaller waves not to break. This is due to the increased height/depth ratio for breaking as seabed gradient increases (BLACK and ROSENBERG, 1992). Moreover, poor alignment of the reef isobaths or shape of the reef face may lead to irreparable damage to the straight-crestedness of the wave, as it propagates along and past the reef, negatively impacting on surfing wave quality (BLACK et al., 2004).

THE MULTI-LEVEL REEF

Mt Maunganui
One of the several reefs designed for Mt Maunganui (in the Bay of Plenty of New Zealand’s east coast) has small volume and is particularly suited to moderate wave climates. Described as a “Double-sided Multi-level Reef in the Delta Reef category”, it makes an “A-frame” wave with a left and right tubing barrel (Fig. 2a,b). The reef shape is symmetrical about the centre and consists of 2 zones. There is a leading offshore “focus zone” which is low amplitude (with gradient of 1:20 to 1:50). This is backed by a pointed horseshoe-shaped breaking zone (with gradient of 1:20 to 1:10). In the design shown, the breaking distance is a minimum of 50 m on each side, but ride length increases with swell height. The lower level acts as a focus but also acts to condition the waves by starting the shoaling process before reaching the breaking zone (MEAD and BLACK, 2001 a&b).

The volume of the reef in Figure 2b is minimized to only 5000 m$^3$. Variations that could be applied include some loss of symmetry by favouring the left or right, widening the crest, increasing the length of the breaking zone (by adding to the rear of the reef on either arm, e.g. Fig. 2a), or accentuating the focus. Another adjustment (particularly for sites with different depths) would be to alter the depth location where the focus zone intersects with the breaking zone. To put into practice, these alterations would need to be tested individually within the guidelines of the design criteria. Double-sided reefs have the advantage of being suitable for more surfers (2 riders per wave, rather than 1). The focus on the front acts for both sides of the reef, thereby effectively making the cost of the focus cheaper to construct in relation to the benefits it brings. The reef is more compact than many designs.

Figure 2a. A generic design for the Mount Maunganui Multi-level Reef. Underlying depths are taken from recent surveys provided by the University of Waikato, Coastal Marine Group. The reef crest is at 0.5 m below CD and the seabed is 3.5 m deep around the crest, making the highest section of the reef approximately 3 m high. The reef is about 90 m x 80 m in plan.
The other benefit is that the reef is more resilient in the presence of a broad spectrum of input wave angles. When the swell is more north, one side of the reef gets quicker (for the better surfers) and the other side is slower (for the weaker surfers), and vice versa. Thus, the reef will cater well for many different input swell directions, indeed better than the single-sided reef.

The overall profile of the reef is concave. However, the convex “bull-nose” shape (Fig. 3) is separately applied to each of the two levels. This has the effect of reducing volume and construction complexity, while improving reef stability.

Figure 2b. |The 1:30 scale model of the Mount Maunganui Reef, front and middle section only (© ASR Ltd, 2004).

Figure 3. Convex “bull-nose” profile. The gradient of the profile decreases as the depth reduces. The dashed line shows an equivalent linear profile. The deeper “thin” section of the linear profile at the front of the reef is hard to construct and so the bull-nose overcomes this problem and reduces volume.
Numerical modeling predicts peel angles from 55° to 35°. With a tubing wave on the peak, the wave is ranked at 6-7 (Table 1). Combined with the relatively short ride which makes it easier to surf successfully through the tube, relatively low peel angles have been chosen. Physical model tests, conducted at scales of 1:30 in ASR’s Raglan wave basin, confirm the presence of the A-frame (Fig. 4a) and the tubing character at the peak (Fig. 4b). The wave peels down the reef, as anticipated, with best results at low tide.

The reef is numerically predicted to create an interference and dissipation pattern in its lee which will improve surfing sand banks at the beach, and the reef will protect the coast by wave breaking dissipation (e.g. BLACK et al., 2003).

Table 1. ASR’s degree of difficulty ranking for surfing reefs.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Description</th>
<th>Peel Angle</th>
<th>Low gradient breaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3</td>
<td>Beginning surfers able to perform basic manoeuvres. Soft breaking waves (spilling breakers), no tube ratio.</td>
<td>60-70°</td>
<td>Bells Beach Indicators</td>
</tr>
<tr>
<td>4</td>
<td>Intermediate skilled surfers beginning to initiate and execute standard surfing manoeuvres on occasion. Steep faced, but rarely tubing; vortex ratio 2.8-3.1</td>
<td>55°</td>
<td>Kirra Point, Burleigh Heads</td>
</tr>
<tr>
<td>5-6</td>
<td>Competent surfer able to execute standard manoeuvres consecutively and advanced manoeuvres on occasion. Some tube sections; vortex ratio 2.2-2.8</td>
<td>40-50°</td>
<td>Bingin, Padang Padang</td>
</tr>
<tr>
<td>7</td>
<td>Top amateur surfers able to perform consecutive advanced manoeuvres. Fast and hollow tubing) waves; vortex ratio 1.9-2.2</td>
<td>30°</td>
<td>Pipeline, Shark Island</td>
</tr>
<tr>
<td>8-9</td>
<td>Top world surfers able to perform consecutive advanced manoeuvres under extreme and dangerous conditions. Very fast, square, spitting waves; vortex ratio 1.6-1.9</td>
<td>&lt;27°</td>
<td>Pipeline, Shark Island</td>
</tr>
</tbody>
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ASR’s Surfing Difficulty Ranking Scale
Figure 4a. Wave pool model of the Mount Maunganui Reef showing the A-frame take-off.

Figure 4b. Wave pool model of the Mount Maunganui Reef showing the tubing ride on the left and right.

**Boscombe**

With a larger available budget for construction, a more sophisticated Multi-level Reef was developed for Boscombe in Bournemouth, England (Black et al., 2004). The critical aspect at Boscombe is the very small wave climate and small directional spread, and so the design was
based around optimising the number of surfing days by ensuring that the reef would have the largest possible waves down the full length of the breaking section.

The small wave climate precludes the top level rankings of 7-8, except in rare circumstances, and so the “surfing difficulty ranking” was set in the range 4-5 (Table 1). The hollowness and speed of the wave are defined by seabed gradients and peel angles. For a reef ranking 4-5 on the ASR scale, seabed gradients should be lower than 1:15 to 1:20. Peel angles, which determine the “speed” of the surfing ride, should be a minimum of 50° and an average of around 60°. The reef was designed incorporating these specifications, with a crest height of 0.5 m above CD (i.e. out of the water at low tide), volume of 15,000 m$^3$ and footprint of 10,000 m$^2$.

The reef has some subtle, but important, features (Fig. 5). Once again, it consists of two “levels”. A low gradient “conditioning platform” spreads out in front of the breaking section to draw in the wave energy and thereby increase breaking wave height. Above this is the “breaking segment”, which is a steeper gradient (semi-circular) ridge that acts to make the wave break with speeds and intensities that match the required reef ranking of 4-5.

Figure 5. Reef designed for Boscombe in Bournemouth, England.

Subtle gradients in the lower level ensure that the wave energy is drawn smoothly up onto the full length of the breaking segment. There are three key features. First, the focus is offset and staggered. This brings extra wave energy into the shadow zone half way down the circular arc. The shadow is created by the focus, which draws energy into the take-off peak and away from adjacent parts of the wave. However, by staggering the focus as shown, energy is taken onto the peak and also brought in from the side to replenish the height losses, and thereby
eliminate the shadow. The second feature is the slow upward gradient of the platform towards the rear of the breaking zone. This brings further energy from the side of the reef into the rear region, thereby ensuring that wave height remains at its maximum along the full length of the reef. A third benefit of this design is that waves will also break on the lower level with slower peel angles, when the swell is large at low tide.

CONSTRUCTION

It mostly takes about 3-5 years to develop a reef through to construction. There are phases of development from feasibility, through detailed design, environmental consents, fund raising and construction that impact on the duration of the process. Of the many projects currently in various stages of completion, four reefs may be built in the next 12-18 months. These are at Mt Maunganui, Opunake and Wellington in New Zealand and Oil Piers in Ventura, California (BLACK et al., 2003a, MEAD et al., 2003a,b,c). The Mt Maunganui Reef is currently being tendered for construction, while Oil Piers is planned for construction in June/July 2005. A reef for Bournemouth (England) (BLACK et al., 2004) is planned for development in their summer of 2006, while a reef at Borth (Wales) (BLACK et al., 2003a) is moving into the final stages of detailed design and funding approval. Other reefs are mooted for Britain, Costa Rica, Brazil, Australia, New Zealand and South Africa.

There is a common belief among surfers that the next reef should be “world class”. It is our view that this will require the combination of design and construction to be closely amalgamated in order to take the computer design and make it a reality in the water. At the Gold Coast, the two stages were separated (we designed the reef and had no responsibility for the construction). The method of construction was mega-containers dropped from a split-hull barge to form the reef shape. The reef remains incomplete with segments of it still several metres deeper than the design (Fig. 6).

However, the reef is currently meeting the coastal protection goals and surfing has been good in larger swells (Fig.7). The reef was designed to Rank 6-7 on the ASR scale from 1 to 10 (HUTT et al., 2001), but it is presently breaking around 4-5 over shorter segments. The Gold Coast City Council is committed to completing the reef, and each year the surfing quality is reported to be improving (MCGRATH, 2002). However, the construction method (while economic) lacks sophistication. The main problems confronted by the construction engineers were differential settlement (with sand being able to erode from between the bags and allowing bags to sink) and steps (irregularity in the reef face) leading to altered surfing wave quality.
Figure 6. Comparison of designed and actual depths on the Gold Coast Reef. Upper panel: Reef design. Middle panel: Depths in March 2001. Lower panel: Depths in April 2001. There are large differences between the designed and actual depths, as the reef construction has not been completed by the engineering team. However, the reef is providing coast protection, enhanced ecology and improved surfing.
For the Mt Maunganui Reef, a higher quality reef face, eliminating gaps between the bags, is required. This level of vertical tolerance is greater than previous offshore coastal protection structures have required and so advances in engineering need to be made. At Mt Maunganui, the method of construction is expected to involve geobags sewn to match the reef shape in “elements”, that are sections of the reef. The geotextile elements are laid on the bed with precision positioning and filled by sand slurry in situ, using pumps with hoses attached by divers. A similar method is being adopted at Oil Piers.

DISCUSSION

Reef designs
Every project has required a different reef shape in order to cater for the different wave climates, surfer aspirations, coastal protection requirements and budget. There are many successful reef designs and many that don’t work. Reef design continues to advance, with shapes now responding to individual conditions – e.g. small wave climate, fast, tubing, long or variable rides, low volume, optimised coastal protection. In this paper, we examined two reefs for surfing and coastal protection: one with low volume and another for small wave climates. Both were multi-level, using the principle of a low-gradient platform to draw wave energy onto selected parts of the reef where the breaking occurs on a steeper gradient “breaking zone”. Each of these zones has special features, particularly at Bournemouth where the small wave climate made it essential to design a shape that would maximize wave height along the full length of the reef.

The reef shapes have similarities to artificial reef designs at Gold Coast Reef (BLACK and MEAD, 2001) and a reef for Dubai (MOCKE, 2003). The similarity to the Gold Coast Reef in plan becomes evident by joining the two halves of the reef and considering the front section alone. The similarity to Mocke’s design work is most apparent in his “piriform platform-lens” design, although he did not incorporate sophisticated structure in the platform. However, as noted above, different designs are applicable to different locations. The Delta shape and multi-level structure are strikingly similar to some world-class natural reefs. In plan, the Delta shape relates closely to the famous Pipeline/Backdoor combination in Hawaii (MEAD, 2000). The multi-level structure is very similar to Bingin in Bali. As described by MEAD and
BLACK (1999), Bingin consists of a focus, platform and breaking section with length scales and gradients that are close to the Mt Maunganui Reef.

The cross-section profiles are reproduced in natural sand bar profiles at Kirra Point, Burleigh Heads and many natural beach bars (Fig. 8) (MEAD and BLACK, 2001a&b; BLACK et al., 2003). The characteristic that recurs is the steeply rising sand bar face, lying on a lower gradient rising seabed, and flattening off again at the crest; essentially a two level reef with bullnose segments. The orientation of the reef to the wave approach direction is also similar to common directions when Kirra is breaking best. Mount Maunganui’s wave climate is very similar to the Gold Coast climate (MEAD and BLACK, 1999).

![Figure 8: Profiles I-IV at Kirra Point, surveyed 7 October, 1996. Profiles are taken perpendicular to the seabed contours. Depths are relative to LAT (from MEAD, 2000).](image)

**THE FUTURE**

If quality reefs can be both designed and constructed successfully, there is considerable potential for future expansion of the multi-purpose reef industry and associated scientific research. Heavy engineering solutions are unfashionable due to their intrusiveness and they only exist for land protection, not beach protection (BLACK, 2004). This is particularly true of the dangerous and unsightly rock walls, groynes or breakwater structures positioned within public swimming zones or on the sand. Even nourishment has come under negative community scrutiny in places. Increased grain size has improved durability of the nourishment, but the safety of casual swimmers is reduced, with heavy plunging waves on the steeper beach face. Dissatisfaction also occurs when the nourishment sand is too shelly or silty. Another important transition for the future is the growth in surfing popularity and the aging of surfers, to the point where surfers now hold many senior positions within industry, government and the community. There is a slow recognition by surfers that, as the most consistent users of many beaches, they have obligatory rights in decision making. This power is preventing “single-minded solutions” such as placement of concrete, rocks or other
structures on the foreshore for protection of land, leaving the beach partially or totally
decimated.

The recent public outcry at Palm Beach Queensland (Mead and Black, 2004) is a good
example of inadequate consideration of the surfing lobby. The project goal was to protect the
front row of houses and widen the beach by building offshore a series of three longshore-
parallel reefs. No useful surfing amenity was incorporated in the reef design. The surfers
recognized that the reefs would block the waves on their beach and strongly opposed the
development, which was eventually stopped by the City in response to the protests.
Interestingly at the time, 3 surfers from Palm Beach were in the world top 100 rankings at the
time of the project, and it was estimated that about 100 Palm Beach surfers in total had
reached the top 100 ranking over the history of professional surfing. The growth in “surfer
power” in combination with a strong environmentalist lobby will continue worldwide, forcing
coastal protection projects to seek solutions that meet the aspirations of both the foreshore
land owners and the environmental surfing community when protecting beaches.

To consolidate this trend, some “really good reefs” that are well accepted by surfers need to
be constructed in the ocean. The future rapid growth of the multi-purpose reef industry is now
dependent on quality outcomes, which meet the expectations of surfers and coastal managers.
This can be achieved by blending surfing and beach science with the engineering aspects,
while abiding by some strict design rules. The final stage is to undertake every possible test of
the designed reef before construction, using indicative natural reefs plus mathematical and
physical models, as guiding tools. The engineering is inseparable from reef design, as a
weakness in either will substantially reduce the quality of the waves, and construction needs
to be considered while designing. During recent visits to Indonesia, India, Britain, Portugal,
France, USA and Brazil (to name some examples), all their coastlines are suffering from
developments placed too far seaward, coastal structures which have altered longshore
sediment supply and the impending risks of Climate Change sealevel rise. With a rise in sea
level, there is little doubt that rock walls can only protect the land, while the beach at the base
of the wall will be lost. In this scenario, offshore reefs or breakwaters provide some
“breathing space” (by widening the beach) and so their continuing popularity is assured.
Example benefits of reefs, over traditional high breakwaters, are reduced cost, improved
safety, enhanced amenity and ecology and the elimination of the unwanted visual impact.

CONCLUSIONS
The growth of the multi-purpose reef industry is expected to be substantive with 4 reefs
planned for construction in the next 18-24 months. The benefit of reefs (or low-crested
breakwaters) over traditional breakwaters is reduced cost, improved safety, enhanced amenity
and ecology and the elimination of the ugly visual impact. Of course, there is the potential to
include all forms of surfing, diving, kite- and wind-surfing. Multi-level reefs presented in this
paper have advantages in the cases described, but they are not applicable to all conditions.
Each case is proving to be different, due to the changing wave climate, budget, client
demands, surfer aspirations and the coastal protection requirements. Two reefs presented in
this paper are designed respectively to minimize volume and to optimize wave height in
locations with small wave climates. The reef industry is expected to expand once the ability to
both design and construct the reefs successfully is fully demonstrated.
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