Review of Existing Multi-Functional Artificial Reefs

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Abstract
Costs, benefits and performance of existing surfing and multi-functional artificial reefs have varied considerably. This paper compares details of the 6 reefs completed or under construction to determine the total costs and performance as well as construction issues. The investigation was undertaken as part of the design and construct contract for a multi-functional artificial reef project.

1 Introduction

Coastal engineers have been aware of the need to include surfing into design of coastal structures and there are numerous examples in Australia, and worldwide, where coastal protection works have improved surf amenity. Most artificial "surf" reefs to date have been constructed in Australia. However, the design of such structures is difficult as there is a lot of conflicting information on the performance of the existing reef projects.

Despite considerable interest in multi-functional artificial reefs (MFAR), only 4 have been totally completed to date, and a further 2 commenced:

Completed as at 1-3-07

- Bargara, Queensland, Australia 1997
- Cables, Western Australia, Australia 1998-99
- Narrowneck, Queensland, Australia 1999-00
- Pratte's Reef, El Segundo, USA 2000-01

Near Completed as at 1-3-07

- Mount Maunganui, NZ 2005 - ??

Construction commenced as at 1-3-07

- Opunake, NZ 2006 -???

Detailed technical monitoring reports have been published on all of the completed reefs, except Bargara. This published technical data, with additional research and observations, has been used in this review of the following reef characteristics:

- Location and site conditions (waves and tides)
- Design - size and shape
- Construction materials and methods
- Costs [total & $/m3]
- Performance
  - Coastal protection / salient
  - Safety
  - Amenity created e.g. surfing, diving and fishing
- Comments and lessons learned

2 Bargara Reef

2.1 Location and site conditions

Bargara is located at the northern end of Hervey Bay in Queensland. Waves are generally < 1 m. The most common occurring swell is 0.2 – 0.4m with periods of 6 – 9 sec [BPA, 1986]. Tides are semi diurnal with a spring tidal range of about 2.5m

2.2 Design

The site is on the north side of a headland and is effectively a ½ V. The objective was to smooth the existing bathymetry to give a break that was rideable without abrupt interruptions [Pitt, 2005].

No modeling was carried out. Local knowledge was used to relocate / break boulders that were observed to be adversely impacting on the break. These boulders were also used to fill holes to further improve the wave quality for surfing. The initial works were monitored on the "full scale model" and additional works have been "designed" [Figure 1]. [Redgard, 2006]

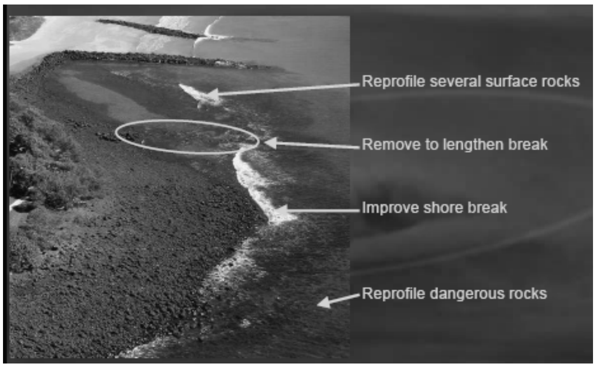

Figure 1 Bargara Reef Phase 3 [Source: Greg Redgard]

2.3 Construction materials and methods

The rocky headland was groomed at low tide using a large excavator to move the existing basalt boulders (Figure 2). No additional materials were required to be imported. The rock volume moved is very difficult to estimate, but is approximately 300m^3.

Figure 2 Excavator moving boulders at low tide (Source: Greg Redgard)

2.4 Cost

Costs incurred to date have been ~A$10,000, including approvals, but not including considerable time contributed by the community (Redgard, 2006). This is equivalent to ~A$30/m^3.

2.5 Performance

No scientific monitoring has been done. It is obvious, however, that the work is producing an improved and safer, longer point break [Figure 3] near high tide with swells of over about 1m and light and / or offshore winds. The number of surfable days is relatively low, but expectations of the surf quality do not appear unrealistic and it is seen as successful in improving the surf quality and increasing the number of surfable days. (Redgard, 2006)

There have been no reports found of any serious injuries. The reef works would have had no significant affect on coastal processes on the rocky headland.

Figure 3 Surf at Bargara (Source: Greg Redgard)

2.6 Comments

The following comments and conclusions can be made:

- The emphasis has been to "improve" local conditions, not create a new surfing location. With realistic expectations, the project is generally seen as successful at a local level.
- The reef only works at high tides.
- The avoidance of expensive modeling and use of community involvement, simple construction methodology and local equipment has resulted in a low total and unit cost.
- The site is rough boulders, but there have been no reports of injuries.
- Monitoring would be very beneficial.

3 Cables Reef

3.1 Location and site conditions

Cables Reef is located at Perth, Western Australia. Tide is diurnal with a spring tidal range of 0.4m. Mean wave conditions are characterized by a significant wave height (H_s) of 2.0m and a spectral mean wave period (T_m) of 8.8s although there is considerable seasonal variability (Lemme et al, 1999).

3.2 Design

Engineering for the final design and construction of the project was coordinated by the WA Department of Marine and Harbours. The Centre for Water Research at the University of Western Australia assisted the Department in the design aspects. A large number of comprehensive studies were undertaken and the outcomes have been published (Pattiaratchi, 1997).

The final reef shape (Figure 4) chosen was a "Boomerang shaped" reef with a nose ½ angle of approx. 45deg. Crest height was set at -1m LAT for safety. To minimize volume, the reef was on a natural nearshore rocky reef.

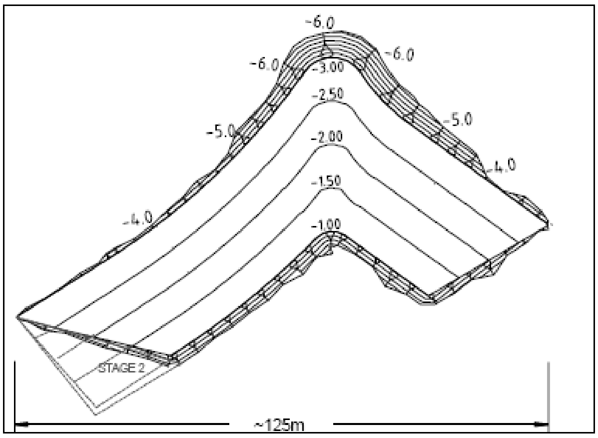

Figure 4 Cables Reef - initial shape and extension (Source: tender documents, 1999)

3.3 Construction materials and methods

Detailed construction design was undertaken by the WA Dept of Transport with project management by Egis consulting. The reef was constructed with 5,500m^3 of 1.5t and 3.0t stone. The contract was awarded to WA Limestone with construction being undertaken using a barge transporting the granite stone material from Fremantle Harbour (Figure 5).

Figure 5 Excavator placing rock at Cables (Source: Pattiaratchi, 2003)

3.4 Cost

The total cost was $1.8M (DPI, 1999). This is equivalent to ~A$327/m^3.

3.5 Performance

Monitoring of the reef has been carried out by Bancroft [1999] and Pattiaratchi [2003]. They concluded that the reef was performing according to design, with swell as low as 0.5m breaking on the reef in low tides. In 1999, the reef was considered to be "surfable" 142 days of the 178 days it was breaking. (Figure 6)

Figure 6 Surf at Cables

3.6 Comments

The following comments and conclusions can be made:

- The location has abundant swells and a low tide variation that are suitable for a surfing reef.
- The project appears to have "improved" surfing conditions when swell, tide and wind conditions are suitable.
- The reef does provide a quality surf wave at times, but it has not gained a reputation as a great surf spot. Part of the reason for this appears to be that:
  - There are a number of good surf breaks in the area
  - When conditions favour the reef, a number of other local breaks work as well
  - The reef takeoff area is about 300m offshore [other natural breaks are closer to shore]
- No reports of injuries have been noted.

4 Narrowneck Reef

4.1 Location and site conditions

Narrowneck Reef is located on the Gold Coast, Queensland. It is part of the Northern Gold Coast Beach Protection Strategy (Gold Coast City Council). The site experiences high wave energy and a nett northerly sand transport rate of ~500,000m^3 pa. Average Hs is about 1.0m but Hm has exceeded 12m since construction. Tide is semi-diurnal with a spring tidal range of 1.3m

4.2 Design

The primary function of the reef was coastal protection, with "improved surfing" as a secondary objective. The final design (Figure 7) was determined by ICM based on the recommendations of the Uni of Waikato , additional numerical and physical modeling by WRL [Uni of NSW] and Griffith Uni and extensive monitoring.

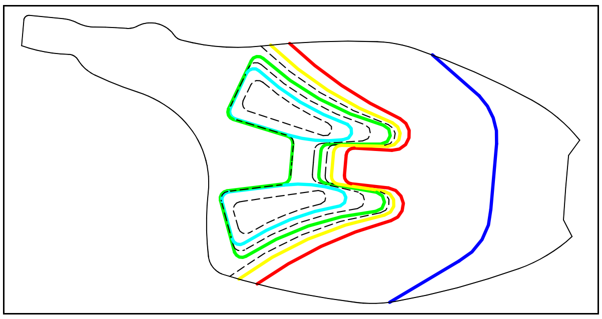

Figure 7   Narrowneck design; black = original footprint, colours = design contours after monitoring

The reef is a flared V-shape with a nose ½ angle of ~13deg separated by a bridged central paddle channel. Design crest height was reduced to -1m LAT [from 0.0m LAT recommended by Uni of Waikato] due to concerns regarding safety – surfers and rips. The reef volume is very large [approx. 70,000m^3].

4.3 Construction materials and methodology

ICM developed the construction methodology and the contract was awarded to local firm McQuade Marine. The reef was constructed using over 400 mega sand-filled geotextile containers supplied by ELCO Solutions [then SoilFilters Australia], filled, and dropped into place using a hopper dredge, Faucon [Figure 8].

Figure 8 Placing containers from a split hull hopper dredge at Narrowneck

The seabed at the inner section of the reef can vary by up to 2m due to the migration of the storm bar. A very large storm bar had formed over the back half of the reef prior to construction and a sequenced construction was undertaken with top-up after migration of the bar shoreward [and resulting "settlement" of the reef].

4.4 Cost

The total cost of the reef to date, including design studies, top-up and replacement of damaged containers is A$2.8M (US$2.1M). This equates to a unit rate of ~A$40/m^3.

4.5 Performance

Considerable monitoring of the reef has been carried out and a number of monitoring reports have been published (GCCM, 2004). Despite a number of storm wave events, the reef has proven been effective in stabilizing the beach and a salient is generally present (Turner, 2006).

Wave breaking occurs ~50% of the time – generally for waves >1m at MLWS and >1.8m at MHWS. Good surf [Figure 9] is experienced regularly on the reef when wind, waves and tides are suitable. It is noted that the surf very rarely looks like either the numerical or physical models as there is often multi-swell / wave conditions and wind factors. When there is a clean swell without wind, the modeling is replicated in the real world.

Figure 9 Surf at Narrowneck (Source ICM)

Prior to initial settlement of the reef [with a crest height of -0.5m LAT], the reef formed a very hollow but hazardous wave that often sucked dry at the break point. Prior to top-ups, when crest heights have been lower than -1.5m LAT in locations, waves tend to be more spilling.

It has also been observed that the reef interacts with the adjacent bar formations, creating more favourable natural conditions. With the normal sand bars, the waves tend to break on the reef and then link into the shorebreak, significantly extending ride length [rides over 200m have been recorded].

The reef has provided a suitable substrate for development of a diverse ecosystem and has become a popular location for fishing and diving. As a result it has been designated as a no anchoring zone. The type of geotextile used promotes soft growths [such as algaes] that do not present a safety hazard to surfers.

4.6 Comments

The following comments and conclusions can be made:

- The project appears to have achieved the objective of improving surfing conditions when swell, tide and wind conditions are suitable.
- The reef does provide a quality surf wave at times, but it has not gained a reputation as a great surf spot. Part of the reason for this appears to be that:
  - Very high expectations and initial media ‘hype’ followed by negative media.
  - There are a number of world-class surf breaks in the area
  - When conditions favour the reef, a number of other local breaks work as well
  - The reef takeoff area is about 250m offshore [other natural breaks are closer to shore]
- Selection of geotextile type influences the type of marine flora and fauna.
- Suitable construction methodology using efficient gear and experienced operators resulted in a very low unit cost.
- If constructed on a sandy seabed, fluctuations in the seabed can have significant impacts on reef “settlement” and performance
- Crest levels are important for safety considerations, although no reports of injuries have been noted.
- Reef generally improves surf quality on adjacent bars. It is possible for the reef break to link with the bar break and extend the ride length.
- Vessels can damage sand-filled geotextile containers.
- The surface of the reef is now rough. Wave quality is not affected by hollows it is affected by isolated high spots.
- Despite a number of storm wave events (Hm up to 12m) coastal protection has been effective.

5 Pratte's Reef

5.1 Location and site conditions

Pratte’s reef is located at El Segundo, California. The wave climate is generally <1m. Tides are semi-diurnal with a tidal range of approx 1.6m.

5.2 Design

The surfing reef was designed by Skelly Engineering. The shape [Figure 10] is a delta type with a nose ½ angle of 45deg and crest height of -1.8m MLLW [later raised to -0.9m MLLW].

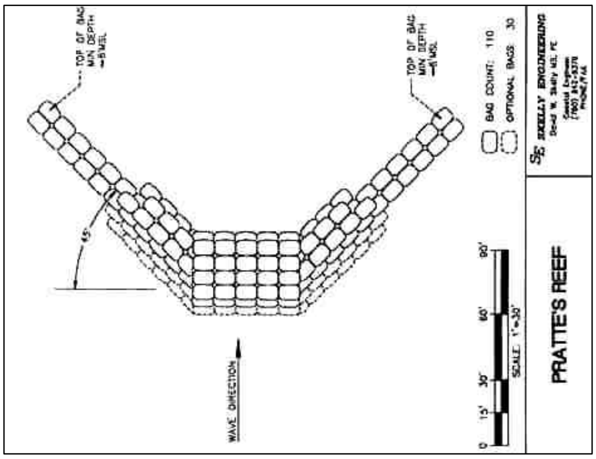

Figure 10 Pratte’s design

5.3 Construction materials and methodology

Two types of woven geotextiles were used – polyester and polypropylene. For safety and budget constraints, the reef was designed and constructed of ~14t sandbags that could fit snugly into the back of a standard tip truck tray. Once filled, they were loaded onto the barge and towed to site to be placed by a barge-mounted crane [Figure 11]. Final reef volume was only ~1,350m^3.

Figure 11 Placement of sandbags at Pratte’s

5.4 Costs
The total budget for this project was only US$300,000 (~A$285/m^3).

5.5 Performance
Detailed monitoring was undertaken [Borrero and Nelsen, 2003]. While they noted that Pratte's has generally not performed to expectations, there are some good photos of wave breaking at the reef [Figure 12], and public comments suggest that it is "epic" in the right conditions [1-5 times per year].

Figure 12 Surf at Pratte's

Surveys and dive inspections show that seabed variations and damage to the bags were likely responsible for significant lowering of the reef, affecting the wave breaking.

5.6 Comments
The following comments and conclusions can be made:

- The project is generally not seen as successful
- There are a number of good surf breaks in the area
- Insufficient budget to make the reef of adequate size.
- Seabed fluctations and damaged containers lowered the reef - major cause of the reduced effectiveness for surfing

6 Mount Maunganui
Mt Maunganui is located on the west coast of New Zealand's north island. Waves are generally <1m high and tidal range is >2.5m. The reef was designed by ASR using [small scale] physical and numerical modeling. It is a basic V shape with a nose ½ angle of ~40deg and a crest height of -0.4m LAT. (see design at www.asrltd.co.nz)

The reef is being constructed using sand-filled geotextile containers strapped to a webbing grid in two halves prior to deployment on the seabed by divers and filling by a pump powered by a barge-mounted excavator. As at March 2007, construction has been very slow due to site conditions and costs [NZ$1.6M] had been considerably over budget [NZ$0.8M]. The reef is presently partially covered with a storm bar and construction is only 80% completed. (see construction newsletters at www.asrltd.co.nz)

7 Opunake
Opunake is located on the west coast of New Zealand's north island. Two reefs are proposed and construction of the first reef started in March 2006. The reef is being constructed of large sand filled geotextile containers filled using a pump and hopper located on the headland. Construction is presently awaiting suitable conditions for the construction methodology. (see design at www.asrltd.co.nz)

8 Conclusions
It is possible to combine coastal protection and "improved" surf conditions at a reasonable cost. However, in most cases, public expectations have not been fulfilled.

In the design, the following issues are important:

- Crest height is important for surf, safety and in determining coastal protection.
- The size and location of the reef is important.
- Public expectations need to be realistic.
- Construction methods need to practical - A very smooth surface is not necessary, but isolated high spots should be avoided.
- Seabed changes need to be considered.
- Numerical modelling tends to overstate the performance of surf reefs - Wind, wave and tide range and seabed levels may limit surfability to certain conditions.

9 References

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Table 1: Reef comparison

SURF "REEF" PROJECTS	Date constructed	COUNTRY	VOL [m3] approx	TYPE	total A$	$/m3 A$	Construction method	Tide Range [approx]	Average Wave climate Hs
Completed Projects									
Bargara	1997	Australia	**300**	Rock	$10,000	**$33**	Reprofiling existing rocks on headland with excavator at low tide	3.7m	<1m
Cables	1998- 99	Australia	**5,000**	Rock	$1,400,000	**$280**	Rock placed with excavator from barge	0.8m	Summer 1-2m winter 1.5 - 2.5m
Narrowneck	1999-2000	Australia	**70,000**	SFGC non-woven	$2,800,000	**$40**	150 - 450t mega sand filled containers filled in hopper dredge and dropped.	2m	1m
Prattes	1999-01	USA	**1,350**	SFGC woven	$385,000	**$285**	14t sand filled containers filled on shore, loaded on barge and placed by crane from barge	1.6m	<1m
Partially Constructed					***est***				
Mount Maunganui	*2005 -??*	*NZ*	***6,000***	SFGC non-woven	*$1,454,545*	***$242***	*mega sand filled containers attached to web, anchored and filled in situ [20% construction outstanding]*	*>2.5m*	*<1m*
Opunake	*2006 -??*	*NZ*	***?***	SFGC non-woven	*$760,000*	***??***	*mega sand filled containers attached to web, anchored and filled in situ [construction stalled?]*	*>3m*	