Development of a Multi-Purpose Breakwater/Reef at Maqai Eco Surf Resort, Qamea Island, Fiji

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Abstract
A breakwater/reef and channel/lagoon development has been designed to alleviate the current ecological damage of the coral reef flat and lagoon, and the health and safety hazards involved with access to the Maqai Eco Surf Resort. At present, foot and boat traffic impact on large areas of the reef during access at both low and high tides, while wave penetration at high tide causes vigorous boat movement and makes it difficult and dangerous to board and leave boats (there is no road access to the resort). In addition, at low tide access is restricted with a landing bay located almost a kilometre from the resort, which is cause for concern should an emergency occur. Thus, the breakwater/reef development is aimed at focussing foot and boat traffic to protect the surrounding reef, providing a safe all-tide boat access, with the addition of providing a learner's surfing break at higher tidal levels. To date, Stage 1 of this three stage project has been completed. This paper describes the design/impact aspects of the project and results of Stage 1 of the development.

Keywords: Coral reef protection, multi-purpose reefs, safe boat access, surfing.

1. Introduction

Maqai Beach Eco Resort is situated on a 99 year Tourism lease of the 5 acre Wainimaqai site, located on the south western tip of Qamea Island, north eastern Fiji (Figure 1). Qamea Island has no roads, all access is by boat. The resort is well described on its website (www.maqai.com):

> *"Qamea is a land of tropical mountains, rainforest, white sand beaches and true Fijian villages. It has life and culture and traditional island atmosphere. Maqai is a beautiful Qamea beach enclosed by two rocky points, overlooking multiple reef breaks and set at the base of virgin jungle mountainside.*
>
> *Maqai Beach presents a one-of-a-kind cultural and adventure experience in this new and remote location. We offer a rare style of tourism that is very much integrated with local custom and lifestyle. The Maqai crew is a young, fun-loving group of remarkable locals who wish to share their island homeland with their guests."*

The resort opened in February 2009, and has quickly grown in popularity, both due to the unique atmosphere provided by the mixture of the beautiful location and the engaging local people that run the facility, as well as the high quality surfing waves in the area (Figure 2). However, access to the resort during low tide is an issue for both health and safety and protection of the local marine ecology. Similarly, at high-tide, although boats can access all the way to the beach, the steepness of the beach and the waves that penetrate over the reef at high-tide mean that the waves break hard and the boats move up and down vigorously creating a health and safety hazard for guests and staff moving on and off the vessels.

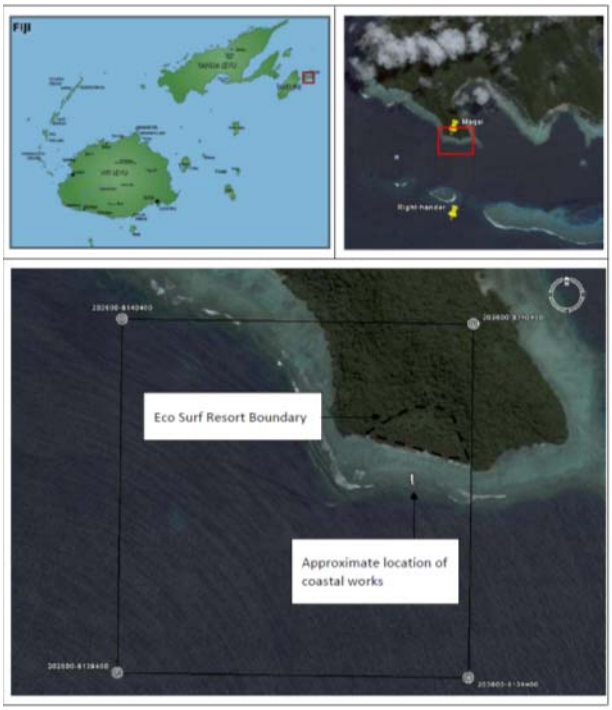

Figure 1. Site location map. (Source, Google Earth).

There is some 100 m of reef flat between the edge of the reef and the beach (Figure 3), with the inner 40-50 m being sand pockets in undulating remnant reef, and the outer 40-50 m comprised of sharp remnants of dead coral and some live corals (small stag-horn, branching, flat and encrusting species) in the central area of the beach/reef. At present, boat and foot traffic occur over an area of some 50-100 m width in the middle of the resort beach/reef during mid-high tide, while foot-traffic

occurs across this area at low tide (e.g. surfers dropped off that paddle to the reef edge and then walk across the reef to the beach) and boats can access the beach from the east during neap tides, but not at low spring tides (Figure 3). Access by foot at low tide is from the bay to the east, some 750 m (Figure 3).

Figure 2. The main break 1 km offshore from Maqai.

The consequences of the current access to Maqai Beach Eco Resort include:

1. Damage to the living coral and other reef flora and fauna over a 50-100 m wide area of reef flat from the reef edge to the beach by both boat and foot traffic;
2. Damage to the living coral from the eastern access to the beach (some 750 m) by both boat and foot traffic;
3. Health and safety issues due to cuts and abrasions during low tide (foot traffic from the edge of the reef), and from the vigorous boat movements at the beach during high tide, and;
4. Health and safety issues during an emergency during low tide, i.e. there is no fast and easy access from the island (to the hospitals at Dreketi or Taveuni); it is some 750 m from the resort to the low tide boat mooring to the east.

Figure 3. Access for Maqai at high tide is across the reef (100 m wide area – orange box), and at low tide from the mooring to the east (750 m – yellow line). (Source, Google Earth).

To address these environmental conservation and health and safety issues, a breakwater/reef and associated all-tide boat-channel and mooring area was proposed. By providing a protected boat access that will be operational in all tides and most weather conditions, damage to the reef ecology is greatly reduced and health and safety issues are minimized. The breakwater/reef has the additional function as a learner's surfing break during the higher tidal phases. Learner surfing breaks are something of a rarity in many areas of Fiji, and in the present case will provide additional stimulation to the atmosphere of the resort allowing other visitors to experience the "stoke" of catching a wave, similar to that brought to the resort by the more experienced surfers that ride the outer reef breaks.

This paper describes the planned 3-stages of the safe boat access development, the results of Stage 1 of the development, and tests with Expando© for channel and lagoon development.

2. The Proposal

The proposal included a ~40 m long breakwater reef to be constructed on the offshore part of the reef flat, directly in front of the main building at the resort (Figure 1 and 4). The structure is comprised of SoftRock™ geo-containers filled with local sand – SoftRock™. This geo-container material is a non-woven fibre that is proven very robust in the surf-zone and is environmentally inert (i.e. the materials are non-toxic and do not leach compounds). The SoftRock that will be used is 1209RP, which has a tough outer layer of vandal-resistant material that is conducive to colonization by marine organisms [1].

This method of breakwater construction was considered because large rock and heavy machinery are not common or inexpensive in the outer islands and due to the potential to add a 'soft' surfing structure for learners.

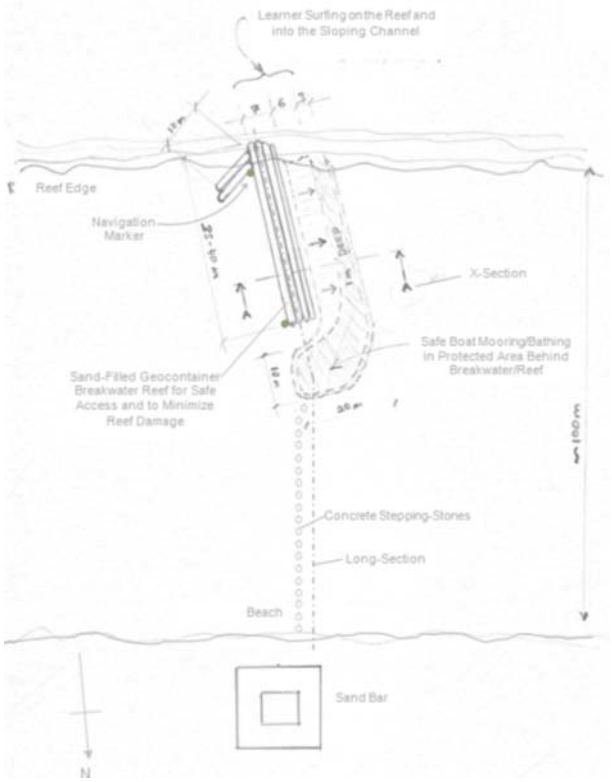

Figure 4. The all-tide boat access for Maqai Eco Resort.

Construction is proposed in 3 stages, as shown in Figure 5. The first Stage is construction of the breakwater reef, which is comprised on 6 geo-containers, 4x 38 m long containers and 2x 10 m long containers. 3 of the 38 m long containers and both of the 10 m long containers are "T0.5's", which have dimensions of 1.6 m wide by 1.0 m high. The remaining 38 m long container is a "T0.25", which is 0.7 m high by 1.0 m wide.

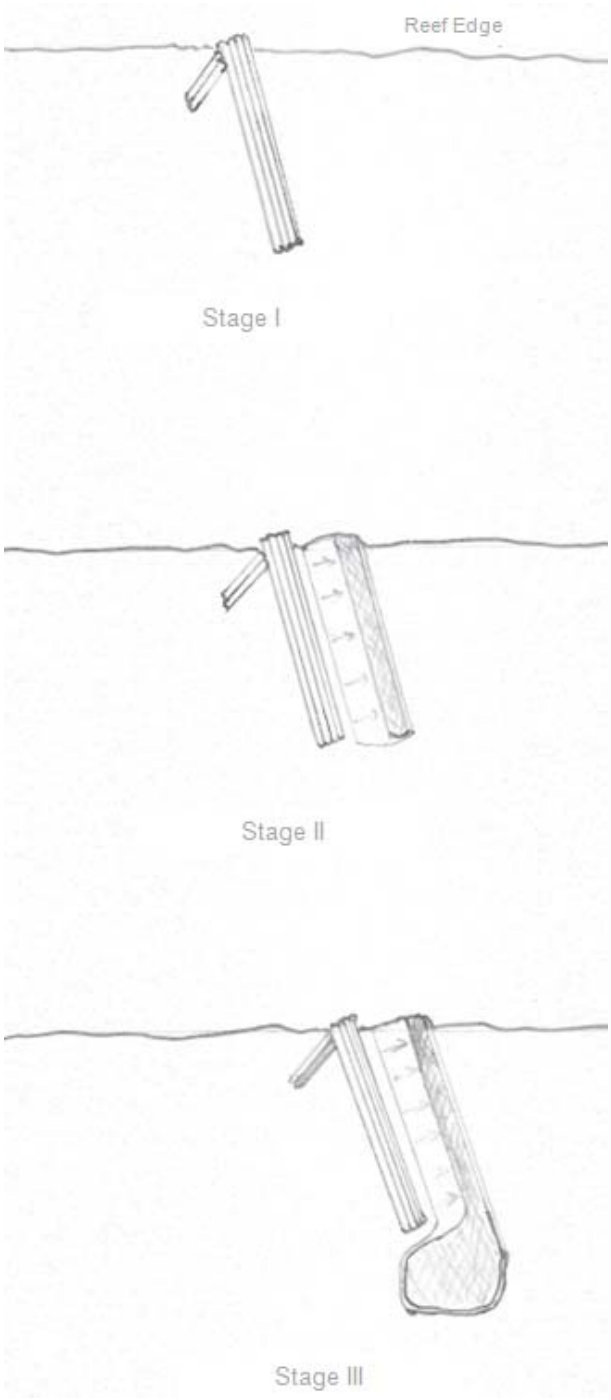

Figure 5. The 3 Stages of construction.

The volume of sand required to fill the 6 geo-containers is ~200 m^3, which is a relatively small volume of material (e.g. some 10 m by 20 m and 1 m deep). It was proposed that this material is sourced from Maqai Beach, where large deposits accumulate at either end against the rock headlands.

Stage II is the construction of the sloping channel on the western side of the reef structure (Figure 6). It was proposed that this would be constructed manually with pry-bars by the local villagers, who would be contracted for the project, as well as with mechanical means if required. Stage III, the lagoon, will be constructed using a similar means. Finally, concrete stepping-stones will connect the lagoon to the beach, which will be superseded by a low jetty to the edge of the lagoon at a later stage.

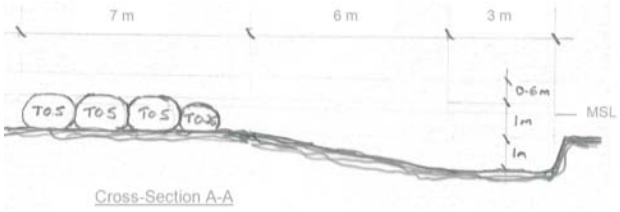

Figure 6. Cross-section of the breakwater/channel.

The orientation of the geo-containers, the stepping down of the geo-container size and the sloping channel were designed to allow for a 'soft' and slow peeling surfing wave for learner surfers [3, 4]. Due to the outer reefs, the waves on the fringing reef at Maqai are generally less than 0.6 m high, are short period (both due to trade-winds decomposition into lower harmonics of the primary wave after breaking on the outer reef, and so are conducive to conditions for learning to surf. The crest height of the breakwater was set up 0.6 m below MHWS to both ensure that the majority of waves break on the structure for the majority of the time and provide protection for the channel and lagoon, and allow learner waves to break over the structure at high tide.

3. The EIA

In order to gain building permits, an Environmental Impact Assessment (EIA) was required.

3.1 Methods

A site investigation was undertaken over a 5 day period from 1 to 4 December 2010. The investigation included:

- Dive survey of the fringing reef face;
- Survey of the reef flat/lagoon;
- Repeated observations of nearshore current speeds and directions;
- Repeated observations of nearshore wave heights, and;
- A GPS survey of the site.

In addition, 3 weeks of tidal data was collected in mid-2010 to provide an estimate of the tidal range at Maqai Eco Surf Resort.

The observations of the reef flat and lagoon focussed on the types and abundance of benthic organisms and the reef substrate.

Along with the above information, hindcast wind and wave data offshore of Maqai were downloaded covering the period from January 1997 to present at 3-hourly intervals. The WaveWatch3 (WW3) wave data and NOAA Global Forecast System (GFS) wind data (which is used to drive the WW3 model), were used to develop offshore wave and wind summaries for design.

As part of the design and impact assessment, consultation with affected parties and the relevant Government Departments was also undertaken (Figure 7).

Figure 7. The consultation meeting at Maqai with representatives from the village land-owners, the District Officer, and the Ministries of Environment, Health and Fisheries.

3.2 Results – Marine Ecology

From the dive, snorkelling and foot surveys, it was found that the reef flat/lagoon area adjacent to the Maqai resort could be divided into 4 areas (Figure 8):

A) Western area – high biodiversity and high topographical complexity;
B) Central are – lowest biodiversity and highest homogeneity;
C) Outer eastern area – high biodiversity and complex topography, and;
D) Inner eastern area – low biodiversity and medium complexity.

These basic classifications indicate that the placement of the proposed all-tide boat access in the central area (B) would likely have the least ecological impacts – this is supported below by the physical properties of the site, which are not detailed here in [for the full EIA, see 5 & 7].

As with many areas of north eastern Fiji, marine life is diverse and abundant. In general it was found that the most abundant and bio diverse marine ecology was located in the inner western side of the reef flat (A – inner), where deeper channels between reef and coral that do not get shallow or go dry, and on the offshore reef edge has it drops off into deeper water. A large range of fish species was observed, mostly in the western inner area and the outer reef edge, including wrasse, anemone fish, puffer fish, parrotfish, damselfish, banner fish, cardinal fish, Moorish idol, perch, butterfly fish, coral trout, perch, lionfish, goatfish, surgeonfish, and rockfish. Schools of trevally and mullet also frequent the western area and reef edge, where large schools of parrot fish are regularly observed feeding on coral and the occasional reef shark ventures in at high tide.

Figure 8. The 4 categories of lagoon ecology at Maqai (Source, Google Earth).

There is also a wide range of coral species comprising the reef adjacent to Maqai Beach. As with the observed fish species, the most abundant and diverse corals are observed in the inner western area (A – Figure 8), and especially on the reef face/slope on the seaward edge of the reef. All the common coral types are abundant: branching, stag horn, massive, encrusting, foliose, cup-shaped, flat (tabulate), and mushroom. In addition, with increasing depth down the reef face a range of soft corals (massive, whips and fans) and a variety of sponges can be found.

Occasional filamentous seaweeds and *Halimeda* sp. are present on the inner reef flat, as well as on the reef face, and nama, or sea grapes (*Caulerpa racemosa*); also flourish seasonally all along the inner reef flats and especially along the north western area beyond Maqai (i.e. NW of Area A). Thus, the marine life around the Resort is an environmental asset that requires protecting.

3.3 Results – Physical Oceanography

The wind and wave climate at Maqai are typical of the South Pacific Islands. While the most dominant winds are from the southeast, the dominant swell direction is from the southwest, i.e. the long period swell that is generated in the Southern Ocean and Tasman Sea that propagates between New Zealand and Australia and

northward to the Fiji Islands (there is a maximum fetch of some 13,700 km to east coast South Africa, i.e. the Indian Ocean).

Like many of the Fijian Islands, there is a fringing reef offshore of Qamea Island and Maqai Beach (Figure 1, top left**Error! Reference source not found.**). As a result, due to both wave dissipation and refraction/diffraction around the fringing reefs, the wave transmission to the reef in front of Maqai beach is much reduced. This was confirmed by observations of wave conditions at Maqai Beach since February 2009 which indicate that largest waves are commonly 0.3-0.6 m at high tide, at which time they break with a heavy plunging motion; during this phase of the tide vigorous boat motion make it difficult and dangerous to get on and off vessels.

Observations of the currents along Maqai Beach indicate a reversal of current flows with incoming and out-going tides, similar to those observed on the outer reefs; these currents are driven by the strong flows north to south (in-coming tide) and vice versa, as seen through the channel between Qamea and Taveuni and the restriction between Qamea and Laucala, which indicates an asymmetry between tidal levels on either side of the islands. Current speeds at Maqai Beach were estimated at 0.1-0.3 m/s.

The impact of these processes on sediment transport at the site is that there is a continual source of sand being introduced from the east and west. This is enhanced by refraction of waves on the 2 basalt protrusions of the reef at either end of the stretch in front of Maqai Beach, i.e. the waves bend around these features and wave-driven currents also deliver sand to the beach (as can be seen in Figure 8). This leads to the beach at Maqai being “over-full”, and rather than a log-spiral curve between the headlands, we have a straight to convex beach. The perched nature of the site also amplifies the situation, i.e. sand delivered by wave and tidal-driven currents is perched on the beach due to dissipation of wave energy on the reef face and across the reef flat.

3.4 EIA Conclusion

The EIA concluded that impacts of the development would be minor and temporary due to:

a) The small amount of material being used for construction;
b) The small impacts on the physical aspects of sediment transport, and;
c) The potential for the marine organisms to re-colonise the area impacted as well as the structure.

It was also recognised that development of the all-tide access would further prevent the chronic damage of the wider coral reef environment around the Resort by focussing foot and boat traffic.

4. Stage 1 Construction – Results

Construction was undertaken between April and May 2012 (Figure 9). Containers were filled with a custom-built 16.5 HP dredge-pump system, which was located on the beach, and pumped a sand/water slurry up to 140 m to the containers. Following the filling of the first 10 m long container (i.e. demonstration), the local villagers were able to complete the construction process with minimal supervision. Once filled, container ports were sealed with geo-fabric patches; which is the same technique as used to repair geo-containers if required.

Figure 9. The geocontainer breakwater viewed from the SandBar at Maqai Eco Resort.

It will require the completion of Stages 2 and 3 to provide the all-tide boat access. However, the geo-container structure is also proving useful for both focussing foot-traffic (i.e. surfers enter and exit the water from the structure during lower tidal phases), and beginner surfers (Figure 10). Since the geo-fabric is soft in comparison to the coral reef, beginner surfers can stand on the containers and push off into waves

Figure 10. Full tide on the beginners surfing break at Maqai. The geo-containers can be seen underwater in the left of the photo.

In terms of colonization, the structure has become increasingly covered with marine growth in the past year since construction (pers. obs.). The higher parts of the structure were first covered by filamentous green algae, and have now been mostly superseded by encrusting red algae that make the structure appear more like rock. Lower on the structure there is a range of soft-bodied encrusting species (brown seaweeds, polyzoans, etc.); soft-bodied organisms also dominate the Narrowneck MPR in Queensland, Australia [2]. The pools between the containers are inhabited by a variety of corals and colourful small reef fish.

4.1 Expando Trials

Stages 2 and 3 of the project require the development of the channel and lagoon for all-tide boat access, with the construction of the outer part of the channel also increasing the surfability of the structure through tides.

Initially, it was believed that pry-bars could be used to excavate the channel and lagoon. However, only the top 200-300 mm of reef could be removed in this manner, below this the limestone was too hard to remove. Mechanical options are currently being considered (e.g. concrete breaking equipment), however, the opportunity to trial Expando in a new environment (i.e. underwater) was also taken.

Expando expansion mortar is a powder material that is mixed with water and then poured into 20-25 mm diameter holes drilled in concrete. Within 3-4 hours, the material expands (exerting pressures of up to 14,000 PSI) and cracks the concrete.

Figure 11. A 350 mm deep section of limestone cracked off the construction 'face' with Expando.

In order to use the material in an underwater environment, a method was developed that allowed for the material to be poured into a waterproof sleeve and thus not diluted in situ [7]. The Expando trials used an area of limestone at the foot of the beach which were covered with water (and wave action) during half to full tide, but exposed during low tide for assessment of the results. This method proved effective, as can be seen in Figure 11.

A variety of distances between drill holes were tested during the trial period in order to develop an understanding of the maximum efficient spacing, which could then be used to calculate the total cost of Expando to complete Stages 2 and 3. These costs are currently being compared to those for other methods of construction.

5. Summary

Stage 1 of the project, which is comprised to 6 sand-filled geo-containers to form a breakwater/reef is now complete, and is being colonised by a variety of organisms. This method or coastal construction has proved successful in an area where there are no rocks and/or heavy machinery available. In addition, the construction method is straight-forward and was able to be undertaken by local villagers with minimal supervision. Stage 1 is currently proving successful at focussing foot-traffic across the reef, while providing added tourism benefits in the form of a small learner's surfing wave. Stages 2 and 3 will provide an all-tide boat access, and methods to construct the channel and lagoon for these stages are currently being trialled which has included the development of a new method of underwater rock removal.

6. Acknowledgements

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