Coastal Engineering for Climate Change Resilience in Eastern Tongatapu, Tonga

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Increasingly large amounts of funding are becoming available for climate change (CC) adaptation projects throughout the Small Island Developing States (SIDS), which is due to the recognition that these nations contribute <1% of CO_2 emissions that are driving CC, although are some of the planet's most vulnerable areas. The Global Climate Change Alliance: Pacific Small Island States (GCCA: PSIS) project is funded by the European Union and managed by Secretariat of the Pacific Community (SPC). The project was developed to support the governments of nine smaller Pacific Island states, namely Cook Islands, Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Niue, Palau, Tonga and Tuvalu, in their efforts to tackle the adverse effects of CC and sea level rise (SLR). In this project, the environmental impact assessment was from the perspective of what impact are the coastal protection solutions having on the coastal environment and coastal processes in order gain better understanding of the performance of such structures in tropical island locations.

The purpose of the GCCA: PSIS project was to promote long-term strategies and approaches to adaptation planning and pave the way for more effective and coordinated aid delivery to address CC at national and regional levels. A range of national CC adaptation projects were undertaken within the nine Pacific Island locations. Projects ranged from increased water security through to building capacity to address coastal protection. eCoast developed strategies in the Marshall Islands and Tonga that were focused on 'buying-time' through managed advance, with the impact assessment considering how well these strategies perform. The former was based on developing methodologies that remote atoll island villages (which comprise much of the outer Marshall Islands) could apply to construct suitably robust causeways that will maintain connection between parts of the atoll islands that are breaking down/apart due to the impacts of SLR. The Tongan project is described below.

Two trial projects were developed for north eastern Tongatapu (Figure 1), which combined hard and soft engineering (i.e. 'hybrid' solutions) to provide climate change resilience. The projects focused on investigating the efficacy of their application in different physical environments and comparing the design parameters in a temperate context versus a tropical coral sand coast, as well as assessing the impacts of these solutions in terms of their performance in 'buying time'. Coastal engineering has been developed for temperate coastlines in Europe, America and Australasia, which are significantly different than coral coastlines in terms of their range of physical processes and parameters. As a result, the application of temperate engineering on coral coasts has often resulted in failure and/or knock-on effects to the adjacent coast. Through varying physical parameters of the prescribed interventions for each site, and monitoring the results through time, the impacts/responses can determine the efficacy of the interventions and develop design parameters that are suitable for similar tropical locations in other areas of the Pacific Islands.

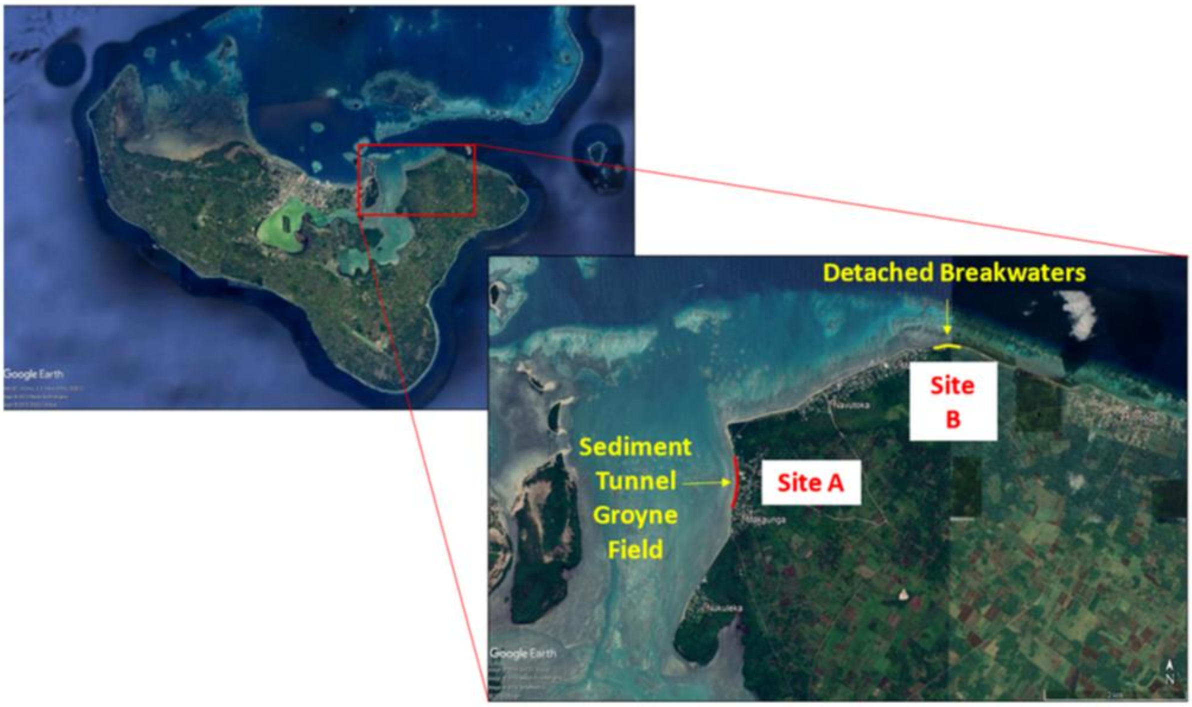

Figure 1: Locality map of 2 sites in north eastern Tongatapu

Both sites A and B are subject to erosion and inundation which is due to a combination of:

- historical sand-mining;
- removal of mangroves;
- damage to the fringing reef ecology (by humans and pigs) – coral beach sand is biogenic and created by the fringing coral reefs and the organisms that consume the coral. Over-fishing, pollution and other forms of damage break the 'sand-engine' that naturally nourishes the beaches with sand; and
- SLR.

Together, these factors have resulted in reduced beach height and width (some 20 – 30 metres of retreat since 1967 from aerial image analysis) and removed sediment from the system faster than it can be replenished.

An important aim/factor associated with the project was the recognition of the inevitability of a need to retreat from these coastal sites due to their low-lying nature. The works were developed to 'Buy Time', 20-30 years, in order to plan for the retreat and relocation of the villages.

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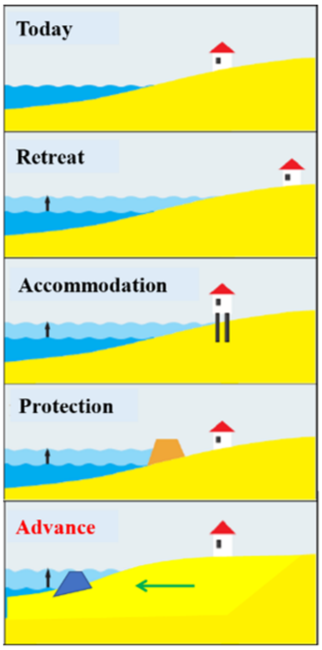

Responses to SLR – including managed advance to 'Buy Time':

- The responses required to protect human life and property fall broadly into three categories: retreat, accommodation, and protection. However, managed advance is being applied more and more often in some cases.
- Retreat involves no effort to protect the land from the sea. The coastal zone is abandoned and ecosystems shift landward. This choice can be motivated by excessive economic or environmental impacts of protection. In the extreme case, an entire area may be abandoned.
- Accommodation implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded. This option includes erecting emergency food shelters, elevating buildings on piles, converting agriculture to fish farming, or growing flood or salt tolerant crops.
- Protection involves hard structures such as sea walls and dikes, as well as soft solutions such as dunes and vegetation, to protect the land from the sea so that existing land uses can continue.
- Managed Advance Response. The application of 'Buying-Time' in order to prepare for the inevitable managed retreat for low-lying coastal areas.

The options at the two sites were developed in conjunction with the communities in a similar manner set out in the MfE (2017) *Coastal Hazards and Climate Change: Guidance for Local Government*, which included multiple public meetings and workshops to determine what was happening and what was valued by the local community.

At the tidally dominated site (Site A - Makaunga and Talafo'ou), groynes with varying permeability placed at varying intervals along the beach were trialled, while detached breakwaters of varying lengths at varying intervals were trialled at a more exposed wave-dominated site. Both trials included beach re-nourishment, sand retention structures and planting of coastal species ('hybrid' solutions), as well as a detailed monitoring programme.

Five years after implementation, several important findings have emerged at the tidally-dominated site of the groynes:

- the 95% permeable groynes and 45% permeable groynes are working well in the northern part of the site without causing downcoast 'groyne-effects';
- the southern groynes where there is less wave energy are more suited to fully closed groynes;
- *semi-permeable* groynes with a spacing that agrees with temperate design parameters (i.e. groynes should be spaced at ~3x their across-shore length) were found to be very effective at retaining re-nourished sand and widening the beach; and
- the groynes and associated beaches are being utilised by the local people, especially since there is now no scarp and rocks in these areas as they have been covered by the accumulated sand.

The results of the monitoring have led to the following adaptive management actions (Figure 2):

- addition of eight 50% closed groynes in the 60 metre gaps;
- rotating half of the open units on the six groynes in the southern area to make them fully closed;
- bringing in 2,000 m3 of sand for the southern groynes (not previously nourished); and
- continued enforcement of pig penning.

Figure 2: The groynes spaced along the beach with varying degrees of permeability (i.e. impermeable, 45% permeable, and 90% permeable).

The detached breakwaters at the wave-dominated site (Site B - Manuka) have also proven to be very effective at sand retention and the creation of a buffer zone, as well as being very cost effective and allowing for better coastal access and amenity (Figure 3). No concrete conclusions were drawn with respect to the location and spacing of the detached breakwaters since they 'over-performed', and all created large tombolos and associated beach compartments. This indicates that the smallest along-shore distances and the largest gaps between breakwaters are likely at the lower end of the design parameter scale and that in this kind of tropical environment they are significantly more efficient than in temperate coastal environments.

Figure 3: The detached breakwaters at Manuka, which have been extremely effective at widening the beach to provide a buffer zone and stop over-topping onto the road. There is now 10 – 30 metre of buffer zone and a series of crescent shaped beaches.

The GCCA: PSIS project was the proud recipient of the 2019 Energy Globe Award, recognised for its outstanding work and contribution towards advancing peer to peer learning in CC adaptation among Pacific communities, specifically the Tongatapu and Palau components of the project. The project won the Energy Globe Award for the project's approach to sharing coastal management experiences through a learning exchange between Tonga and Palau. The SPC, eCoast and counterparts from the Kingdom of Tonga's Ministry for Climate Change hosted representatives from Palau, including planners, engineers and state legislators, and reviewed and discussed first-hand possible coastal planning, management and protection solutions during a visit to Tonga. Developing sustainable coastal protection options for the Tongan sites, presenting the innovative concept of ‘buying time’, and application of similar measures at Rock Island in Palau all contributed towards receiving the award.

During the monitoring programme, a second international aid-funded coastal protection project was undertaken along the coastline adjacent to the detached breakwaters. This provided an interesting contrast to CC resilience and the recognition of the inevitable requirement to retreat/relocate, which is a reality in many Pacific Island locations.

The usual response to coastal erosion in Tongatapu has been the construction of revetments, partly due to the construction of revetments along the Nuku’alofa foreshore more than 20 years ago. In 2018, a 2km long revetment was built adjacent to the Manuka detached breakwater trial site (Site B), with the design replicating the Nuku’alofa revetment. Part of the drive of the GCCA: PSIS managed advanced projects in north eastern Tongatapu was to look at tourism opportunities for this part of Tongatapu. The construction of the revetment negated this possibility, which was constructed with a single access along its length. However, of more interest, with respect to public attitude and associated costs, is the implication of such structures where retreat is inevitable due to low-lying land.

In terms of the best utilization of funds and implementing the most appropriate solution for a site, the revetment at this location is not a Managed Advance Response and does not address the cause of beach loss, quite the opposite; the revetment results in loss of beach access and amenity and exacerbates loss of beach sand. In addition, while the revetment does provide land resilience, it raises the question as to what is the cost to the community and how will it affect their response to inevitable retreat? The perceived ‘safety’ of this kind of structure is also known to encourage more housing development, rather than planning a retreat. Furthermore, the detached breakwaters (including sand transfer and planting) at Manuka were four times more cost-effective than the 2km of revetment (Figure 4). For instance, 8km of coast could have been protected and enhanced with the available funds using more appropriate measures (i.e. a hybrid solution), or most of the funds could have been directed to other projects to increase Tonga’s CC resilience.

Figure 4: The 2km revetment adjacent to the detached breakwaters at Manuka is inappropriate for an area where retreat is inevitable.

This raised issues of the need for an integrated coastal management plan for Tongatapu to provide a consistent and holistic approach to CC resilience. The GCCA: PSIS project is currently in its second phase, known as the Global Climate Change Alliance + Scaling Up Pacific Adaptation (GCCA+ SUPA), and the Government of Tonga has selected coastal protection as the focus sector for its regional project. eCoast is currently developing a coastal resilience strategy for the entire northern coastline of Tongatapu, which is significantly biophysically different from the rest of the island, and includes 10 additional pilot/trial sites. It is scheduled to be completed in early 2021, and similar to the project presented here, the pilot/trail sites will be monitored to determine their impacts and efficacy for consideration in other similar locations (in terms of coastal processes) in the Pacific Islands.