United Nations Development Program

Nanumea Detailed Design Report
Tuvalu Coastal Adaptation Project
19 March 2021

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Acknowledgements

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1. INTRODUCTION

1.1 General

Consisting of nine islands and atolls spread over 750,000km², Tuvalu is the fourth smallest nation in the world in land area and has a population of just over 10,000. It is one of the most vulnerable countries in the world to the impacts of climate change and particularly sea-level rise and the possibility of intensifying storm events. Recent cyclones have caused population displacement, significant loss and damage of infrastructure as well as destruction of agricultural resources, contamination of ground water and changes in shoreline systems. Such impacts negatively affect the wellbeing of communities and long-term sustainable development aspirations. In response to this increasing challenge, the Government of Tuvalu (GoT) and the Green Climate Fund (GCF) have jointly committed US$38 million for the Tuvalu Coastal Adaptation Project (TCAP).

Three main islands have been selected for the proposed GCF project: Funafuti, Nanumea and Nanumaga. Nanumea was selected due to the severity of the damage incurred following the passage of Tropical Cyclone (TC) Pam in 2015. The funding application proposed that TCAP resources finance locally appropriate coastal protection measures along the high value zone (1330m) in Nanumea. The lack of a landing facility suitable for a large dredge or working vessels limits the coastal protection infrastructure that may be constructed on Nanumea. As such, a combination of both soft and smaller 'hard' measures including dune restoration, nearshore detached breakwaters and modular seawall construction have been recommended. Subsequent feasibility studies including hydrodynamic and coastal process modelling, ESIA, geotechnical investigations and stakeholder consultations led to the selection of the recommended coastal adaptation measures for Nanumea.

1.2 Project and report objectives

TCAP will build coastal resilience which is an urgent national priority. The project will address the financial and capacity constraints at all levels – from technical to community awareness. TCAP was approved in June 2016 and the project implementation commenced in September 2017. The project will run until September 2023. TCAP has 3 main outputs:

Output 1: Strengthening of institutions, human resources, awareness and knowledge for resilient coastal management.

Output 2: Vulnerability of key coastal infrastructure is reduced against wave induced damages in Funafuti, Nanumea and Nanumaga.

Output 3: A sustainable financing mechanism established for long-term adaptation efforts.

The following body of work progresses Output 2, which has two main task areas or Activities:

- Activity 2.1: Coastal protection design. Site-specific assessments and ESIA undertaken in all islands in a participatory manner.
- Activity 2.2: Coastal protection measures implemented.

The objective of this report is to provide detailed design parameters and present the finalised coastal protection measures on Nanumea ready for construction (implementation). This report is designed to be read in conjunction with the IFC drawings attached in Appendix A.
1.3 Report background

This report has brought together the findings of several investigations used to inform the design and implementation of the TCAP Nanumea coastal protection design, these investigations include, but are not limited to:

- TCAP Concept Design Report (UNDP, 2020)
- Nanumea Concept Design Report (Bluecoast, 2021)
- Nanumea Detailed Design Technical Note: Reeftop Barrier and Seabee Seawall Design for Nanumea (UNDP, 2021)
- Nanumea Environmental and Social Impact Assessment (SPC, 2020a)
- Nanumea Geotechnical Investigation (SPC, 2020b)

These investigations accompany extensive stakeholder consultation, site investigations and interviews with contractors working in the region to inform the detailed design presented herein.

1.4 Report outline

The structure of this report can be summarised as follows:

- Section 2 presents the design life, a brief description of the site as well as the basis of design
- Section 3 presents a description of the Nanumea coastal protection designs and associated aspects
- Section 4 presents an overview of the project’s proposed implementation
- Section 5 provides a summary of the key findings of the Detailed Design and recommendations.
2. BASIS OF DESIGN

2.1 Design Life

The Australian Standard Guidelines for the design of maritime structures (AS 4997-2005) specifically excludes the design of "coastal engineering structures such as rock armoured walls, groynes, etc."

The Berm Top Barrier design presented in the Concept Design Report adopts buried geosynthetic mega containers (GMC) for the core of the structure. Geotextile containers were originally expected to have a service life of at least 25 years in their earlier design iterations. Recent improvements in geosynthetics have been reported to increase design life to more than 40 years (Bettington, 2018). This has been adopted as the design life of the BTB structure.

The concrete reeftop barriers and Seabee seawall have been designed with a design life of 50 years.

2.2 Design event

A 100-year Average Recurrence Interval (ARI) value has been adopted for the stability of any structures. The return event for overtopping design of the BTB and Seabee seawall is a one-year ARI based on safe average overtopping volumes for pedestrian access behind the structure crest after EurOtop (2018).

2.3 Site

Nanumea is one of the nine atolls and islands within the Tuvalu archipelago. It is the most northerly atoll within the archipelago, located at approximately 5°40’S, 176° 6’E. Nanumea is a boomerang shaped atoll with a narrow central lagoon system, as shown in Figure 1. The atoll has three major sand islands named Nanumea, Temotuoliki and Lakena. Nanumea is the largest island and covers the south-east portion of the atoll forming a V-shape with two distinct limbs either side of a central lagoon.

Nanumea is located approximately 450km to the north west of Funafuti. The island has a an unprotected, 500m long, 25m wide boat channel (American Channel) cut at a depth of -1m to -4m below tide gauge zero (TGZ) into the reeftop midway along the western coast of the island connecting the ocean to the southern lagoon. There are several jetties and a small port within the lagoon that services smaller vessels capable of navigating the narrow channel.
2.3.1 Bathymetry and topography
A marine Light Detection and Ranging (LiDAR) survey was undertaken of all Tuvalu’s nine islands in August 2019 (acquired by TCAP, 2019). The resultant dataset provided a high resolution topographic and bathymetric digital earth model (DEM) to a depth of approximately
40m, the bathymetry and topography at the project site on Nanumea’s western coast is provided in Figure 2.

Figure 2: Topographic and bathymetric contour map of proposed TCAP coastal protection site on Nanumea’s western coast taken from FUGRO Marine LiDAR survey, August 2019.

2.3.2 Geomorphology

The reef islands of Nanumea are comprised of unconsolidated biogenic sediments formed by the physical abrasion (under wave action) and biological breakdown of calcium carbonate–secrating organisms that dwell on the adjacent coral reef system. Waves and currents deposit the coral sand and rubble onto the islands. The location, planform configuration, size, and elevation of islands reflect both the interaction of oceanic swell with reef structures and the availability and grade of sediment for island building (Masselink et al., 2020).

Figure 3 shows a map of the topography (Figure 3a) and cross-sections through Nanumea Island (Figure 3b & c). Figure 4 shows a cross-section of a typical atoll to highlight the structural elements observed on Nanumea (Kench et. al., 2009). Major structural elements of the atoll’s morphology include:

- lagoon (20–25 m) and reef rim with islands, reef flat, and reef crest
- sand aprons, depositional features created by unidirectional (reef to lagoon) sediment transport, are found on the lagoon-ward edge of the reef flats
- on the islands western coastline, reef flats are around 300 to 350m wide with a high ridge or berm (4-5m above MSL) on the ocean side (left) that gently grades down to the lagoon with no ridge present on the lagoon side (right).

- the islands eastern side has a beach ridge/berm that only rises 2-3m above MSL, the higher western berm (Figure 3a) is due to this coastline having a higher energy wave climate including longer period swells and cyclones (see Section 2.4.2).

- the inner stable areas of such islands are comprised of mainly unconsolidated carbonate sediments; sand, gravel and cobble with an upper layer of dark organic rich “topsoil”.

- The perimeter shoreline system of the islands are typically dynamic and subject to seasonal and event driven, wave, tide and longshore processes. On Nanumea, the majority of shores are comprised of coarse sands with outcrops of raised solidified “beach-rock” apparent in many areas.
Figure 3: Atoll and reef island morphology and structure. (a) elevation maps of Nanumea showing the topography of the entire atoll. (b) Cross-section of Nanumea atoll showing major structural elements. (c) Western island (village) commonly 50–100m wide with a high ridge on the ocean side.

Figure 4: Cross-section of a typical atoll showing major structural elements including deep lagoon (20m) and reef rim with reef crest, reef flat, islands and sand apron identified (source: McLean and Kench, 2015)

Further geomorphological and geotechnical information on Nanumea is provided in the Geotechnical Report (SPC, 2020b).

2.4 Design inputs

2.4.1 Water levels

Nanumea experiences a semidiurnal tidal regime. The mean tidal range is 0.7m during neap tides and 1.7m during spring tides, with a maximum range of 2.5m. No long-term water level measurements have been undertaken at Nanumea. The closest tide gauge is located around
460km to the south east at Tuvalu Port. Due to its relative proximity to Nanumea, similar orientation and geomorphology, the tidal regime at both locations is considered similar. Figure 5 presents tidal planes reduced to Tide Gauge Zero (TGZ) at Funafuti following the levelling program undertaken by Department of Lands and Survey Tuvalu associated with the 2019 lidar survey.

Figure 5: Tidal plane at Nanumea with respect to Tide Gauge Zero (TGZ) at Funafuti Port.

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Water level</th>
<th>Recorded Height (m TGZ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2100 Sea Level Rise¹</td>
<td>0.75m</td>
<td>Highest Astronomical Tide (HAT) 3.27</td>
</tr>
<tr>
<td>Wave setup</td>
<td>0.97m</td>
<td>Mean High Water Springs (MHWS) 2.80</td>
</tr>
<tr>
<td>HAT Nanumea</td>
<td>3.27m TGZ</td>
<td>Mean High Water Neap (MHWN) 2.27</td>
</tr>
<tr>
<td>IBE max²</td>
<td>0.28m</td>
<td>Mean Sea Level (MSL) 1.94</td>
</tr>
<tr>
<td>Design Water Level</td>
<td>5.27m TGZ</td>
<td>Mean Low Water Neap (MLWN) 1.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean Low Water Neap (MLWS) 1.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lowest Astronomical Tide (LAT) 0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tide Gauge Zero (TGZ) 0.00</td>
</tr>
</tbody>
</table>

Table 1: Calculated design water levels for Nanumaga coastal protection works

2.4.2 Waves

Deep water

There is no long-term recorded wave data for Nanumea. Wave climate information for Nanumea presented in Figure 6 and Table 2 has been determined based on a long-term regional model hindcast (Oceanum). Nanumea’s wave climate is dominated by swell waves (wave periods above 8s). Locally generated seas (wave periods below 8s) only occur on average 5% of the time. The annual average significant wave height (Hs) is 1.7m, with a slight increase in the wet season. The dry season is dominated by easterly wind swells generated by the trade winds as

¹ IPCC 2019 upper limit of RCP8.5 range
² maximum recorded value of Inverse Barometric Effect (IBE)
well as intermittent and longer period south south-west swells. In the wet season the southerly swells are less frequent and of lower energy, with a greater frequency of waves generated in the northern sectors.

The largest waves primarily occur in the wet season and arrive from the west and/or the north-west and are the result of tropical cyclones action in the southern hemisphere (latitudes 8°-12°).

Table 2: Offshore wave climate statistics for Nanumea from Oceanum dataset.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistic</th>
<th>Long term averages (42-years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All seasons</td>
</tr>
<tr>
<td>Significant wave height ($H_s$) [m]</td>
<td>Mean</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>20%ile</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>75%ile</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>99%ile</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>99.5%ile</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>6.8</td>
</tr>
<tr>
<td>Peak wave period ($T_p$) [s]</td>
<td>Mean</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>20%ile</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>75%ile</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>99%ile</td>
<td>17.8</td>
</tr>
<tr>
<td></td>
<td>% of time sea ($T_p &lt; 8s$)</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>% of time swell ($T_p &gt; 8s$)</td>
<td>95%</td>
</tr>
<tr>
<td>Peak wave direction ($D_p$) [°TN]</td>
<td>Weighted mean</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>60</td>
</tr>
</tbody>
</table>
Village wave climate
The wave climate at the deep-water reef edge of the south-western village coast was determined through a process of wave transformation using the SWAN wave model. A full range of wave climate statistics for the village reef edge location are displayed in Table 3. The total wave climate wave rose and the overall and seasonal wave roses for swell waves (Tp>8s) are provided in Figure 7. The village wave climate is influenced by two key factors. The first component is moderate wave energy from south-east and south-west swells, which occur around 28% of the time.

The second component comprises high to extreme ‘cyclonic’ wave energy from the west which occurs less than 0.3% of the time annually and 7% of the time in the wet season. For these cases, the 50th and 90th percentile wave heights are 3.3m and 4.4m respectively, with peak
Wave periods typically between 10s and 16s. These large and extreme waves have been isolated and presented in Figure 8, showing their predominant origination from the west.

Table 3: Village wave climate statistics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistic</th>
<th>Long term averages (42-years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All seasons</td>
</tr>
<tr>
<td>Significant wave height (Hₚ) [m]</td>
<td>Mean</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>20%ile</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>75%ile</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>1.87</td>
</tr>
<tr>
<td></td>
<td>99%ile</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td>99.5%ile</td>
<td>3.18</td>
</tr>
<tr>
<td></td>
<td>Max</td>
<td>6.77</td>
</tr>
<tr>
<td></td>
<td>% calm (Hₚ &lt;= 0.1m)</td>
<td>42%</td>
</tr>
<tr>
<td>Peak wave period (Tp) [s]</td>
<td>Mean</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>20%ile</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>75%ile</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>99%ile</td>
<td>17.9</td>
</tr>
<tr>
<td></td>
<td>% of time sea (Tp &lt; 8s)</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>% of time swell (Tp &gt; 8s)</td>
<td>74%</td>
</tr>
<tr>
<td>Peak wave direction (Dp) [TN]</td>
<td>Weighted mean</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>Standard deviation</td>
<td>40</td>
</tr>
</tbody>
</table>
Figure 7: Annual wave rose and overall annual, wet season and dry season swell wave roses (Tp > 8s) and for the village Nanumea.
Figure 8: Wave rose showing large and extreme wave events at the village (> 3m Hs).

2.4.3 Currents

At the time of writing there has been no water current measurements in the vicinity of Nanumea. Offshore (deep water) currents are expected to be minimal (<1m/s) and are mostly associated with oceanic circulation or with surface currents being driven by the trade winds.

Nearshore currents on the reef tops are expected to be associated with wave processes across the reef flats as well as tidal flows in and out of the small lagoon through the American Channel. When waves arrive perpendicular to the reef crest, wave breaking and wave setup over the reef drives currents towards the lagoon. When waves arrive at an oblique angle to the reef crests and island shorelines, longshore currents travel in both directions along the west coast of Nanumea. During south south-west swells, net northward longshore currents would be expected, ultimately slowing into the lagoon. This is expected to also drive a net northerly longshore transport of sand along the shoreline when wave heights are large enough. During the wet season when intermittent storms result in westerly wave events, these longshore processes are expected to reverse with currents and sediments flowing toward the islands southern tip.

2.4.4 Wind regime

The wind climate at Nanumea was assessed using data extracted from the CAWCR dataset. The wind roses in Figure 9 and wind climate statistics in Table 4 show prevailing winds are dominated by easterly trades of moderate strength. The range of wind directions is relatively larger during the wet season, with stronger wind speeds originating from the west. Relative to the predominant wind direction, the western coast of Nanumea is positioned on the leeward side of the island.

Table 4: Wind climate statistics for Nanumea.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Statistic</th>
<th>All seasons</th>
<th>Wet (Nov-Apr)</th>
<th>Dry (May-Oct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed [m/s]</td>
<td>Mean</td>
<td>5.1</td>
<td>5.1</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>20%ile</td>
<td>3.3</td>
<td>3.1</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>50%ile</td>
<td>5.1</td>
<td>4.9</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>75%ile</td>
<td>6.4</td>
<td>6.4</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>90%ile</td>
<td>7.8</td>
<td>7.9</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td>99%ile</td>
<td>10.7</td>
<td>11.9</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>99.5%ile</td>
<td>11.9</td>
<td>13.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Max</td>
<td>23.7</td>
<td>23.7</td>
<td>13.4</td>
<td></td>
</tr>
<tr>
<td>Wind direction</td>
<td>Weighted mean [°N]</td>
<td>101</td>
<td>128</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>Standard deviation [°]</td>
<td>50</td>
<td>58</td>
<td>33</td>
</tr>
</tbody>
</table>
Figure 9: Annual, wet season and dry season wind roses for Nanumea.
3. COASTAL PROTECTION DESIGN

3.1 Overview

Full details on the design process and iterations of the Nanumea coastal protection can be found in the Nanumea Concept Design Report (Bluecoast, 2021) and is summarised in the following section. Appendix A: provides the IFC detailed design drawings. Table 5 provides an overview of the key parameters of the Nanumea coastal protection design.

Table 5: Overview of TCAP design parameters for Nanumaga coastal protection works

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Design value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berm Top Barrier design</td>
<td>1,330m total length</td>
</tr>
<tr>
<td></td>
<td>5.5-7.5m TGZ height at crest</td>
</tr>
<tr>
<td></td>
<td>37,100m³ total volume (2019 DEM)</td>
</tr>
<tr>
<td>Seabee Revetment design</td>
<td>180m overall length</td>
</tr>
<tr>
<td></td>
<td>8.9m TGZ crest height</td>
</tr>
<tr>
<td>Reetop Barrier design</td>
<td>Seven 25m long FRC concrete RTB</td>
</tr>
<tr>
<td></td>
<td>35m offshore of current shoreline</td>
</tr>
</tbody>
</table>

Figure 10: Site plan of the TCAP Nanumaga coastal protection design
3.2 Structure details

Berm Top barriers (BTB) are to be constructed of buried Geotextile Mega Containers (GMC) laid end to end. The GMC are to be ‘keyed in’ to the surface of the storm berm on Nanumea’s west coast by excavating the topsoil layer by around 500mm. A layer of geotextile material is to be placed in the excavation footprint and pinned to the ground. The GMC is to be positioned and hydraulically filled from locally sourced (TYPE B) sediment. The whole structure is to be buried under replaced and locally sourced (TYPE A) sand at an angle of natural repose (30-35°) and revegetated with native vegetation and larger (palm or coconut) palms on the horizontal extremities of the works.

The BTBs are to be located at the crest of the natural storm berm, not in the usual active shoreline zone. The geosynthetic bags are intended to remain buried and will be vegetated to become a reasonably seamless raised part of the natural berm system. This means that should wave attack wash away the vegetated outer layer the geosynthetic bag will remain as an immovable line of defence. Thus, the BTB will augment natural berm height and if subject to damaging wave conditions will persist. Even in the highly unlikely event that a BTB inner geosynthetic bag was punctured, it contains beach sand. This will simply become additional volume to the natural berm.

A typical section of the BTB is shown in Figure 11.

![Figure 11: Typical section of Berm Top Barrier (top) and GMC detail (below)](image)

Table 6: Geosynthetic container design sizes

<table>
<thead>
<tr>
<th>Type</th>
<th>Height (mm)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMC</td>
<td>1,500 – 2,100</td>
<td>20,000</td>
<td>1,500 – 4,800</td>
</tr>
</tbody>
</table>
3.2.1 Alignment and crest levels

Generally, the alignment of the BTB has been designed to follow the natural alignment of the storm berm on Nanumea’s west coast. The alignment can be seen to meander along its length (Figure 10), this is to provide sufficient barrier from private and public infrastructure and roadways. The final alignment is expected to change during construction due to new infrastructure having been built since original design, however the objective of the design is to increase the level of the highest landform of the island (storm berm) by an additional 1500mm (minimum). The height of the finished BTB will be between 5.5-7.5m TGZ.

3.2.2 Durability and maintenance

There is potential that the BTB may be overtopped during extreme wave and water level events in excess of the design event. It is recommended that the BTB be inspected after any significant overtopping event or if any GMC units are exposed. In these instances, maintenance is to be undertaken to repair any tears or holes in the GMC unit and to fill any areas where erosion has occurred from approved borrow areas.

The geotextile used for the construction of the units will be designed to be vandal and UV-resistant, TEXCEL 1200R or similar. Full geotextile specifications are provided in the IFC drawings (Appendix A). Even though this design intendeds to bury the geotextile containers they are designed to withstand exposure to wave action, sunlight, high volumes of pedestrian traffic and recreational fishing, etc; however, there is potential for the bags to be damaged by impacts from large debris during very large events. Should units become exposed or damaged, the Government of Tuvalu Public Works department (PWD) will be trained in the repair of the units.

3.2.3 Drainage

The BTB has been designed to reduce inundation and overtopping events from the ocean. During rainfall events, drainage patters will be altered very little from their current arrangement, as the BTB will be placed atop the highest existing landform (storm berm). During construction, it is imperative that the excavation footprint is built such that water discharged through the hydraulic filling process of the GMC units runs to the ocean and not the village.

3.2.4 Borrow areas

The borrow area for the estimated 37,100m³ of fill required for the Nanumea Coastal Protection works was identified in the morphological assessment undertaken in the Nanumea Concept Design Report (Bluecoast, 2021). Nourishment should not be taken from the active beach system on the island’s shorelines. Likewise, material should not be taken from the islands core (inactive sediment), as this material is effectively providing the limited land resource available to the local community. Figure 12 provides an indication of approved sand sources based on identified depositional environments at the end of the sediment transport pathways. Final sand resource areas will be confirmed prior to construction nothing current island morphology and approval from UNDP.
Figure 12: Sand sources for beach nourishment and construction material (Priority 1 – orange).

Table 7: Prioritised sand sources for nourishment and construction material on Nanumea.

<table>
<thead>
<tr>
<th>Sand source</th>
<th>Resource potentially available (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Priority 1:</strong></td>
<td></td>
</tr>
<tr>
<td>Depositional areas at the end of transport pathways that are unlikely to affect island stability</td>
<td>1A. Lagoon sand aprons: 1,000,000m$^3$ (assuming 5m dredge depth with barge mounted excavator)</td>
</tr>
<tr>
<td></td>
<td>1B Lagoon deposit of eastern side of Nanumea: 100,000m$^3$ (assuming 4m excavation depth using land-based excavator)</td>
</tr>
<tr>
<td><strong>Priority 2</strong></td>
<td>2A. Southern tip: 48,000m$^3$ (using land-based excavator)</td>
</tr>
</tbody>
</table>

Hydraulic dredges may present some mobilisation challenges at Nanumea Lagoon, therefore non-hydraulic dredging and excavation methods also need to be considered in this environment. The following is a list of extraction methods that have been used for the winning of sediments from depositional fans and sand aprons within atoll lagoons:
An excavator mounted on a small, spudded barge can be used to source sand from the lagoon sand aprons.

Land-based (hydraulic) excavators can be used where applicable.

Drag-line or clamshell operated from a shore-based long-arm crane.

Pontoon-based cutter suction dredge.

Submersible drag flow pump with cutter head.

Images of these extraction methods being used in atoll lagoon environments are provided in Figure 13.

Due to the actual volumes involved in on-going sand replenishment activities and the infrequent nature of these events, it is recommended that this is undertaken by non-hydraulic (i.e., no dredging) techniques by suitably skilled local workers, the Tuvalu Public Works Department or Kaupule. This would most likely be via small dump trucks loaded manually by excavator at the sand resource location and placed on the foreshore between the groynes and used to cover the BTBs in the first instance, with priority being placed on reburial of any exposed GMC units.

Sediment size requirements for GMC, fill and nourishment purposes is defined in Table 8.

**Table 8: Sediment size requirements for the Nanumaga Coastal Protection works**

<table>
<thead>
<tr>
<th>Fill Type</th>
<th>Properties</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TYPE A</strong></td>
<td>≥90% passing 75mm sieve</td>
<td>Fill over GMC units</td>
</tr>
<tr>
<td></td>
<td>300mm maximum particle size</td>
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</table>
3.2.5 Unexploded Ordinance (UXO)
In 2015 Golden West Humanitarian Foundation under grant from United States Department of State conducted a joint mission with the Tuvalu Police Service to locate, recover and dispose of Explosive Remnants of War (ERW) throughout Tuvalu. The team located and destroyed two-thousand-five hundred Smalls Arms Ammunition and one 155mm High Explosive Projectile on Nanumea. The team also identified one 500-pound General Purpose Bomb in the Nanumea Lagoon, this ordnance was not destroyed and the survey team recommended all persons avoid the immediate area until such time the ordnance is removed or destroyed. The presence of ERW on Nanumea is a risk for construction works on Nanumea. It is recommended prior to any excavation or dredging work contractors undertake sufficient investigations to manage this risk appropriately.

As a standard safety precaution prior to conducting any excavation work, contractors should, as a minimum, investigate the construction or excavation footprint with a metal detector or magnetometer. The geotechnical investigations (SPC, 2020b) observed four empty artillery shells on the beach adjacent to the TCAP project site. Local knowledge of any burial or dump areas will be important to ascertain during construction.

3.3 Seabee revetment
A Seabee seawall has been proposed for the protection of the central portion of Nanumea’s western coast. The revetment will be founded on the site of a previous revetment structure and constructed from interlocking Seabee units which are concrete hexagonal blocks with a hollow core. The interlocked units act as a blanket with a high structural integrity to mass ratio compared to random placed concrete armour units. The approved layout of the Seabee revetment can be seen in Figure 14, showing the wall return design terminating landward of the BTB on the north and south revetment extents. Table 9 presents the finalised design parameters for the Seabee revetment and individual units, with Figure 15 showing typical section of the Seabee wall and schematic of individual units. It is recommended that each unit is precast off-site from high-strength concrete to the standards detailed in the Technical Specification.

<table>
<thead>
<tr>
<th>Fill Type</th>
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<th>Use</th>
</tr>
</thead>
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<tr>
<td>TYPE B</td>
<td>100% passing 26.5mm sieve</td>
<td>GSC, GMC unit fill</td>
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</table>
Table 9: Design parameters for Nanumea Seabee revetment

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
<th>Comment</th>
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</thead>
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<tr>
<td>Crest Height</td>
<td>6.86m MSL</td>
<td>The crest height has been determined by allowing a maximum overtopping of 0.6 l/s/m during design events</td>
</tr>
<tr>
<td></td>
<td>8.80m TGZ</td>
<td></td>
</tr>
<tr>
<td>Crest width</td>
<td>1m</td>
<td>Flat concrete capping beam</td>
</tr>
<tr>
<td>Seabee thickness, R</td>
<td>500mm</td>
<td>Length of unit</td>
</tr>
<tr>
<td>Seabee width, D</td>
<td>400mm</td>
<td>Outside diameter of unit</td>
</tr>
<tr>
<td>Seabee Inner diameter, d</td>
<td>200mm</td>
<td>Inner diameter of unit</td>
</tr>
<tr>
<td>Toe excavation depth, $h_e$</td>
<td>750mm</td>
<td>Concrete beam</td>
</tr>
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</table>

Diagram of the Nanumea Seabee revetment with details on placement and construction features.
3.4 Reeftop barriers

Reeftop barriers (RTB) are a series of shore-parallel concrete structures to be installed in the nearshore of the western shoreline of Nanumea on the inter-tidal reeftop. The RTB can be classified as detached breakwaters, the general arrangement plan of the units is provided in Figure 16. The RTBs are to be constructed from a number of pre-cast Fibre Reinforced Cement (FRC) units in a controlled environment to the detail provided in the Technical Specification document. Each unit will be ‘keyed-in’ to the reeftop to a depth of 400mm. Each individual RTB unit will be connected via stainless steel reinforcing bars hammered through connecting lugs and driven through the reeftop. The joint recess and reinforced bars will then be grouted to form a continuous 25m long RTB structure. The surface of the structure will be scored during the casting process to produce interstices in the surface finish to promote marine growth. Table 10 presents the design parameters for the reeftop barriers and Figure 17 provides concept sketches and schematics of the units.

Table 10: Design parameters for Nanumea reeftop barriers (segmented detached breakwaters)

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Distance offshore, X</td>
<td>35 m</td>
<td>Distance of breakwaters from shoreline (0m contour)</td>
</tr>
<tr>
<td>Design Parameter</td>
<td>Value</td>
<td>Comment</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>Salient width, $X_s$</td>
<td>25 m</td>
<td>Anticipated salient growth from shoreline (0m contour)</td>
</tr>
<tr>
<td><strong>Depth at breakwater, $d$</strong></td>
<td>-0.4 m MSL</td>
<td>Below Mean Sea Level (MSL)</td>
</tr>
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<td></td>
<td>1.54 m TGZ</td>
<td>Tide Gauge Zero (Funafuti)</td>
</tr>
<tr>
<td><strong>Length of breakwater, $L_s$ / $L_B$</strong></td>
<td>25 m</td>
<td>Length of each breakwater segment</td>
</tr>
<tr>
<td><strong>Gab width, $L_g$</strong></td>
<td>27.5 m</td>
<td>Distance between successive breakwaters</td>
</tr>
<tr>
<td><strong>Height of Breakwater, $H_B$</strong></td>
<td>0.6 m MSL</td>
<td>Mean Sea Level (MSL)</td>
</tr>
<tr>
<td></td>
<td>2.54 TGZ</td>
<td>Tide Gauge Zero (Funafuti)</td>
</tr>
<tr>
<td><strong>RTB dimensions</strong></td>
<td>1250mm</td>
<td>Length</td>
</tr>
<tr>
<td></td>
<td>1000mm</td>
<td>Structure radius</td>
</tr>
<tr>
<td></td>
<td>400mm</td>
<td>Shear key</td>
</tr>
</tbody>
</table>
Figure 16: General arrangement plan of the Reeftop Barriers
Figure 17: Left: Concept sketches of concrete RTB unit. Right: Schematic and RTB detail
4. PROJECT IMPLEMENTATION

4.1 General

The United Nations Development Programme (UNDP), Pacific Office in Fiji act as the Project Management Unit (PMU) for TCAP, implementing the project in partnership with the GoT. Assistance throughout the implementation phase has also been provided by the Pacific Community (SPC) has also been engaged by UNDP to conduct the ESIA, coastal vulnerability and geotechnical components.

The following section describes non-design related aspects of the project implementation.

4.2 Project governance and oversight

TCAP has been led at the highest political level by a Technical Working Group (TWG) comprising key government departments and Non-governmental Organisation (NGO) associations representing vulnerable communities. The GCF financing, through TCAP, will enable the GoT to address the financial and capacity constraints at all levels – from technical to community awareness – that have so far prevented a sustainable coastal protection solution.

TCAP will strengthen institutional and community capacity for sustaining and replicating project results. It is envisaged that the project will help to strengthen governmental capacity for coastal management and its legacy will be a Coastal Management Strategy for Tuvalu with internal agency capacity for its implementation.

4.3 Procurement strategy

Due to the works complexities stemming from the remote location of the project sites, the unique atoll environments and the nature of the construction works in Tuvalu, UNDP have proposed a 3-stage \textit{Interactive Dialogue} Procurement Strategy. The construction works will be tendered as a complete package of works encompassing Funafuti, Nanumea and Nanumaga. The procurement stages are briefly described below:

- Pre-qualification (PREQ): The PREQ procedure is aimed at identifying qualified applicants for the next stage of the procurement process based upon their expertise, financial and technical capacity, and experience in construction in remote undeveloped atoll islands.

- Request for Proposal (RFP): A formal RFP will be issued to pre-qualified tenderers to provide both a formal technical and financial response to the tender. A pre-bid conference will be undertaken prior to the submission of the tenderer’s RFP response.

- Interactive Dialogue (ID): The interactive dialogue allows UNDP and tenderers to discuss the scope and complexities around the project and for tenderers to understand better the RFP requirements. ID offers significant and clear benefits; enabling risk and assumptions to be thoroughly tested, innovative solutions to evolve and the foundations established for ensuring a successful contractual outcome of the tender. After completion of the ID sessions, the offerors are expected to submit their proposals within the stipulated deadline. The evaluation of the proposals including the contract award will follow the standard UNDP RFP process.
4.4 Contract delivery

The works contract will be delivered through UNDP’s standard construction contract. Terms of the contract and any proposed departures by the tenderers will be discussed during the ID phase of procurement in the presence of the UNDP Legal and Procurement Teams as well as the PMU. Contractual discussions and verifications through the ID phase will minimise the risk of contractual disputes during construction as the ID sessions provide an opportunity for both parties to explore contingencies and project risks prior to signing and commencement of works.

4.5 Construction Environmental and Social Management Plan (C-ESMP)

The planned works on Nanumea have the potential to create a variety of impacts through their implementation. These impacts can be either positive (e.g., improved coastal protection for community members) or negative (e.g., loss of trees, impact to structures, impaired beach access or views) depending on the activity and receptors involved. The impact of this project on the physical, biological, and social environment has been assessed and is described in detail in the Environmental and Social impact Assessment Nanumaga and Nanumea undertaken by The Pacific Community – Geosciences, Energy and Maritime Division (SPC, 2020a). The key potential project impacts and risks have been identified as the following:

- Increased water turbidity from dredging works
- Changing access to, and use of, coastal marine environment
- Increased risk of traffic accidents
- Solid waste management
- Use of heavy machinery on the beach leading to increased sedimentation
- Fuel or other hazardous spills
- Noise and dust disturbance

This ESIA contains the recommended mitigation measures for Nanumea for pre-construction, construction, and operational phases to avoid, reduce, or mitigate all identified impacts. The Contractor for the TCAP works will be required to produce a Contractor’s Environmental and Social Management Plan (C-ESMP). The C-ESMP will be the Contractor’s governing document for the implementation of this ESIA’s recommendations during works. The C-ESMP will be reviewed and approved by the TCAP Project Management Unit and disclosed prior to commencement of civil works. A summary of the key environmental and social indicators is provided in the table below.

Table 11: Environmental and Social Indicators and parameter considered under each indicator during the impact assessment (Source: SPC: 2020a)

<table>
<thead>
<tr>
<th>Environmental and Social Indicator</th>
<th>Factors to be considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quality</td>
<td>• Water quality of coastal marine environment</td>
</tr>
<tr>
<td></td>
<td>• Quantity and quality of surface water</td>
</tr>
<tr>
<td></td>
<td>• Turbidity in marine environment</td>
</tr>
<tr>
<td>Environmental and Social Indicator</td>
<td>Factors to be considered</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------------------</td>
</tr>
</tbody>
</table>
| **Erosion, Drainage and Sediment Control** | • Sedimentation build up in coastal marine environment  
• Management of project site run off  
• Existing erosion and sediment deposition regimes in coastal zone |
| **Air Quality** | • Dust generation  
• Air quality |
| **Noise and Vibration** | • Noise nuisance in sensitive areas  
• Vulnerability of property to damage from vibration |
| **Flora and Fauna** | • Vegetation within the direct and indirect project footprint  
• Loss of native fauna  
• Degradation of marine habitats  
• Introduction of new invasive marine or terrestrial species  
• Spread of existing invasive species in project sites |
| **Waste Management** | • Excavation of household waste during construction  
• Disposal arrangements of solid project and construction waste  
• Management of hazardous waste  
• Treatment and disposal of wastewater (black and grey) |
| **Chemical and Fuel Management** | • Storage and handling of hazardous substances  
• Contamination of soils and water from spills |
| **Community Services and Infrastructure** | • Boat landing access (especially challenging on Nanumaga)  
• Water supply facilities  
• Island roads |
| **Land and Resource Use** | • Church location  
• Agriculture and food bearing trees  
• Changing land use  
• Utilisation of private, native land |
| **Social Environment** | • Gender and social inclusion  
• Community perceptions and expectations  
• Employment |
| **Community Health and Safety** | • Gender based violence  
• Worker safety |
5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

This report is the culmination of the design process for the Nanumea Coastal Protection works as part of the TCAP. It finalises the design narrative undertaken in the Nanumea Concept Design Report (Bluecost, 2021) and draws on extensive stakeholder consultation, site investigations and interviews with contractors working in the region. The basis of design, structure parameters and the project implementation framework is presented herein. A safety in design (SiD) investigation which presents a design and construction risk assessment is provided in appendix C for reference.

The Nanumea Coastal Protection works can be summarised as follows:

- 1,330m of Berm Top Barrier (BTB) constructed on the western coast of Nanumea constructed from buried geotextile mega containers (GMC) approximately 20m long, the BTB will raise the height of the storm berm by around 1500mm. The GMC will be filled and buried under 37,100m$^3$ of sediment sourced from the southern tip and lagoon flanks of Nanumea located a maximum of 4,000m from the project site. The BTB will be planted with local vegetation on the crest of the BTB alignment.

- A 180m concrete Seabee revetment will be constructed in the Village centre to replace a file seawall in this location.

- Seven 25m long FRC reeftop barriers will be keyed into the reeftop 35m offshore of the western shoreline of Nanumea.

5.2 Recommendations

The following recommendations are included as the TCAP moves through the implementation stage:

- Any uncertainties or omissions within this Detailed Design Report and associated IFC drawings should be conveyed by the tenderers to UNDP during the ID phase of the procurement strategy.

- The submitted C-ESMP should address as a minimum the risks presented in Table 11 and those detailed in the ESIA (SPC, 2021a).

- A post-construction monitoring and maintenance strategy should be established with clear tasks, roles, training and budget allocated to GoT.

- Wherever possible a UNDP representative engineer should be present during the construction phase to ensure the coastal protection works are constructed as to the specifications presented.
6. REFERENCES


PCCSP, 2015. Current and future climate of Tuvalu

PSLM, 2019a. Tuvalu – Vaitupu 2019 Tide Predictions Calendar. Climate and Oceans Support Program in the Pacific. A Pacific Islands Program supported by the Australian Government and Australian Bureau of Meteorology. GPO Box 1289 Melbourne Victoria 3001 Australia

PSLM, 2019b. Tuvalu – Vaitupu 2019 Tide Predictions Calendar. Climate and Oceans Support Program in the Pacific. A Pacific Islands Program supported by the Australian Government and Australian Bureau of Meteorology. GPO Box 1289 Melbourne Victoria 3001 Australia

Maritime Division of Pacific Community (SPC) by FCG ANZDECC. Kate Walker and Patrina Dumaru, August 2020


Appendix A: Nanumea Coastal Protection IFC Drawings
This is an aerial site plan showing various coastal adaptation measures in a coastal area. The plan includes:

- **BERM TOP BARRIER - MEGA BAG**
- **SEA-BEE WALL AND FILLING**
- **CONCRETE REEF TOP BARRIERS (RTB)**

The plan is marked as an unfinished drawing and is scaled 1:2,500. The horizontal datum is UTM-WGS84 / UTM-Zones EPSG32760, and the vertical datum is CHART DATUM (CD) TGZ.
LONGITUDINAL SECTION EB02

LOCALLY TRIM EXISTING RAISED AREA TO ENSURE MEGA BAGS ARE LOCATED BELOW PATH WITH COVER AS PER DETAIL ON SHEET 06-01

SEAWARD BATTER SLOPE IS INDICATIVE ONLY. REFER TO NOTES ON TYPICAL SECTION SHEET 06-01

GENERAL ARRANGEMENT PLAN AND LONGITUDINAL SECTION
CONTROL EB02 SHEET 1

TUVALU COASTAL ADAPTATION PROJECT (TCAP), NAMUNOA

BLUECOAST CONSULTING ENGINEERS
1890 E. HILLWOOD AVE. #150, MALIBU, CA 90265-8503
PH: 310.453.7500
WWW.BLUECOAST.COM.AU

P19012

UNFINISHED DRAWING
LONGITUDINAL SECTION EB02

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<tr>
<th>Chainage</th>
<th>Existing Surface</th>
<th>Depth to Existing (m)</th>
<th>Top of BT</th>
<th>MEGA CONTAINER</th>
<th>Existing Surface</th>
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<tbody>
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SEAWARD BATTER SLOPE IS INDICATIVE ONLY. REFER TO NOTES ON TYPICAL SECTION SHEET 06-01.
TUVALU COASTAL ADAPTATION PROJECT (TCAP), NANUMEA

GENERAL ARRANGEMENT PLAN AND LONGITUDINAL SECTION
CONTROL EB02 SHEET 4

LONGITUDINAL SECTION EB02

EXISTING SURFACE  MEGA CONTAINER  TOP OF BTB

DEPTH TO EXISTING (m)

CHAINAGE

LONGITUDINAL SECTION EB02

SEAWARD BATTER SLOPE IS INDICATIVE ONLY. REFER TO NOTES ON TYPICAL SECTION SHEET 06-01
LONGITUDINAL SECTION EB04

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SEABED WALL TRANSITION TO MEGA BAG BTB. LOCALLY STEEPEN BATTER TO LIMIT EXTENT SEAWARD.

SEA-BEE WALL NOT SHOWN FOR CLARITY REFER TO PLAN 03-07

APPROX 65m TO BTB CONTROL

SEAWARD BATTER SLOPE IS INDICATIVE ONLY. REFER TO NOTES ON TYPICAL SECTION SHEET 06-01

UNFINISHED DRAWING
### Chainage

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### Plan

Seaward batter slope is indicative only. Refer to notes on typical section sheet 06-01.

General arrangement plan and longitudinal section control EB04 sheet 2.

Survey provided by Horizontal Datum UTM-WGS84 / UTSM60S EPSG32760.

Vertical datum Chart Datum (CD) TGZ.
SEAWARD BATTER SLOPE IS INDICATIVE ONLY. REFER TO NOTES ON TYPICAL SECTION SHEET 05-01.
FOR TOP OF BTB CREST DIMENSIONS REFER DETAIL E4 OPPOSITE

GEOTEXTILE LINER 6m CROSS SECTION LENGTH

Minimum 100mm TOPSOIL COVER TO BE PROVIDED

EXCAVATED KEY SAND, FINE DREDGE SPOIL OR LOCALLY SOURCED BEACH SAND

EXCAVATED WIDTH VARIES

REPLANTING COCONUT TREES (TYP)

EXISTING DWELLINGS WHERE APPLICABLE

THE BTB ALIGNMENT AND CREST HEIGHT SHOWN IN THESE DRAWINGS IS INDICATIVE. ALL CARE MUST BE TAKEN TO ENSURE THE CONTINUITY OF THE CREST OF THE STRUCTURE AT A MINIMUM HEIGHT OF 5.5m TGZ. THIS MAY REQUIRE ADDITIONAL FILL UNDER AND SEAWARD OF THE BTB ALIGNMENT SHOWN IN THESE DRAWINGS PRIOR AND FOLLOWING CONSTRUCTION.

EXISTING SURFACE LEVELS IN THIS AREA MAY VARY FROM THE SURVEY INFORMATION AVAILABLE AT THE TIME OF PREPARING THESE PLANS. PROVIDE ADDITIONAL FILL AS REQUIRED AND EXTEND BATTER AT 1 in 3 TO EXISTING SURFACE LEVELS.

NOTE: LENGTH OF MEGA BAG 20m

OPTION 2 - SAND (MEGA BAG) CONTAINER (TYPE T1)

FAES MEGA BAG TYPE 1 AREA 4.3m²

ASSUMED AREA OF BAG SHOWN 3.8m² (CIRCUMFERENCE OF BAG 8000mm)

SAND FILLED WITH SAND WATER SLURRY VIA FILLER NECK (INTENT TO USE LOCALLY SOURCED SAND)

TUBULAR GEOTEXTILE ENCASEMENT (PREFABRICATED UNIT)

NOTE: SCALE 1:25

NOTE: SCALE 1:10
REPLANTING COCONUT TREES (TYP)

MINIMUM 100mm TOPSOIL COVER TO BE PROVIDED

REVETMENT - SEA BEE WALL

SCALE 1:25

MINIMUM DEPTH OF EXCAVATION

750mm

MAXIMUM DEPTH OF EXCAVATION MAY VARY DUE TO STAGGERED SEABEE UNITS

SEABEE UNIT E9

CONTROL SETOUT POINT

GEOTEXTILE

CONCRETE CROWN UNIT

LOW SEABEE UNIT REFER TO DETAIL E9 ABOVE

GEOTEXTILE

HIGH SEABEE UNIT (EACH THIRD BLOCK) STAGGERED IN ROW

CONCRETE FILLING AT TOE OF SEABEE UNITS

SEABEE UNIT SCALE 1:10

REFER ALSO TO DETAILED PLAN SHEET 06-03

TYPICAL SECTION AND DETAILS SHEET 2

A

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TUVALU COASTAL ADAPTATION PROJECT (TCAP), NANUMEA

UNFINISHED DRAWING
80mm CONDUITS FOR LIFTING SLINGS / CHAINS WITH 25mm CHAMFER ALL ROUND

PROPOSED GENERAL LIFTING ARRANGEMENT (MAXIMUM 30°) FINAL LIFTING DESIGNED BY CONTRACTOR

900mm MIN LAP

900mm MIN LAP

1000mm 400mm

16mm 2205 (MIN 0.2% YIELD 450MPa) SUPER DUPLEX STAINLESS STEEL REINFORCEMENT (VALBURNA OR SIMILAR), BENT AS SHOWN

FEMALE AND MALE BARS TO BE 250mm OFFSET SO THEY DO NOT CLASH WHEN BEING PUT TOGETHER. MIN EACH END OF UNIT.

GROUT FILL CAVITY AFTER DRIVING SHEAR BARS. FILL WITH CONBEXTRA DEEP POUR. MIX DEEP POUR TO A STIFF CONSISTENCY BUT STILL PLASTIC. PLACE INTO SHEAR KEY CONTINUOUSLY UNTIL FULL AND ROD / VIBRATE TO ENSURE FULL COMPACTION.

COMMENCE THE GROUTING WHEN THE TIDE IS BELOW THE UNITS AND GOING OUT. SEAL UP THE SIDES OF THE UNITS WITH FOAM BACKING ROD TO ENSURE AS TIDE COMES UP IT DOES NOT 'WASH OUT' NEWLY INSTALLED GROUT. OKAY TO REMOVE BACKING ROD 24 HOURS LATER.

CONCRETE REEFTOP BARRIER (RTB)

SCALE 1:20

CONCRETE PLACED OVER SEABEE UNITS TO FILL VOIDS WHICH OCCUR BETWEEN STAGGERED LAYOUT

CONCRETE FILLING AT TOE OF SEABEE UNITS

CONCRETE INFILL AT BEND FROM CREST

CONCRETE INFILL AT BEND OVER SEABEE UNITS TO FILL VOIDS WHICH OCCUR BETWEEN STAGGERED LAYOUT

CONCRETE INFILL AT BEND OVER SEABEE UNITS TO FILL VOIDS WHICH OCCUR BETWEEN STAGGERED LAYOUT

TOP OF EXCAVATION BATTER

EXCAVATION REQUIRED FOR UNIT (CROSS SECTIONAL AREA 0.406m²)

1250mm TYP WIDE SURFACE OF RTB UNIT TO BE BEARING ON REEFTOP (IE: TOE IS NOT TO BE TAKING THE WEIGHT OF THE RTB)

25mm CHAMFER ALL EDGES (UNO)

GAP TO BE MAXIMUM OF 20mm

NOTE: STAGGERING OF SEABEE UNITS ON BATTERY SLOPE TO BE WITHIN THIS CORRIDOR

注：当海床的斜坡与海床的水平面重合时，应使用抛光不锈钢无缝管。
### SCALE 1:100 AT ORIGINAL SIZE

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**LEGEND**
- **EXISTING SURFACE**
- **DESIGN FSL**
- **EXCAVATION FOR KEY**
- **FILLING**
- **Mega Container**
- **Excavation for Key**

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**TUVALU COASTAL ADAPTATION PROJECT (TCAP),**
**NANUMEA**

---

**CONTACT**
- **JL**
- **AW**

---

**UNFINISHED DRAWING**

---

**SITE CROSS SECTIONS**

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**SHEET 7**

---

**P19012-AG-CV-08-07**
### Site Cross Sections

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- **EXISTING SURFACE**
- **DESIGN FSL**
- **EXCAVATION FOR KEY**
- **FILLING**
- **MEGA CONTAINER**
- **EXCAVATION FOR KEY**

---

**TUVALU COASTAL ADAPTATION PROJECT (TCAP), NANUMEA**

**UNFINISHED DRAWING**

**SCALE 1:100 AT ORIGINAL SIZE**

**横式控制点**

**控制点EB02**

**坐标系**

**UTM-WGS84 / UTM-60S EPSG:32760**

**海拔基准**

**CHART DATUM (CD) TGZ**

---

**Gold Coast Highway, Burleigh Heads, QLD, 4220, Australia**

**Tel: +61 (0) 412 393 703**

**www.bluecoastconsulting.com.au**
LEGEND

- EXISTING SURFACE
- DESIGN FSL
- EXCAVATION FOR KEY
- FILLING
- MEGA CONTAINER
- EXCAVATION FOR KEY

**CONTROL EB04**

**SITE CROSS SECTIONS**

**SHEET 3**

P19012 AG CV 10 03

**JL**

**MLC**

SURVEY PROVIDED BY

HORIZONTAL DATUM

UTM-WGS84 / UTSM60S EPSG32760

VERTICAL DATUM

CHART DATUM (CD) TGZ

ISSUED FOR

MLC

AW

A 20  0 1 4 5

3 2  0

5

0

SCALE 1:100 AT ORIGINAL SIZE

JL

AW

TUVALU COASTAL ADAPTATION

PROJECT (TCAP), NANUMEA

UNFINISHED DRAWING

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CONSULTING ENGINEERS

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Burleigh Heads

QLD, 4220. Australia

+61 (0) 412 393 703

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1 in 3.0

1 in 3.0

1 in 3.0

1 in 3.0

CH 137

137

CH 140

140

CH 155

155

CH 160

160

CH 173

173

CH 180

180

CONTROL EB04

EXISTING SURFACE

OFFSET (LHS+RHS)

CH 137

CH 140

CH 155

CH 160

CH 173

CH 180

OFFSET (-LHS/+RHS)

EXISTING SURFACE

CONTROL EB04

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- **EXCAVATION FOR KEY**
- **FILLING**
- **MEGA CONTAINER**
- **EXCAVATION FOR KEY**