Geotechnical investigation

Nauru Solar Panel Facility

for Elemental Group Power and Renewables

Rev 2 - 24/10/2017

BTW COMPANY

SURVEYING | ENGINEERING | PLANNING & ENVIRONMENT

Nauru Solar Panel Facility

for Elemental Group Power and Renewables

Reviewed

Report Author

Mathew Dickey
Civil / structural engineer

16/10/2017
Date

Reviewed by

Ian Steele
Principal Civil Engineer (MIPENZ, CPEng, IntPE 255539)

16/10/2017
Date

17866
Rev 2 - 24/10/2017

SUMMARY

BTW Company Ltd, in conjunction with Elemental Group Power and Renewables, have been engaged to complete a geotechnical investigation of an inland site located on the island of Nauru for the New Zealand Ministry of Foreign Affairs and Trade (MFAT).

It is proposed to install solar panels on the flat areas of the site, and the geotechnical investigation has been completed to provide recommendations on the best-suited foundation option(s) for the solar panel structures, for the purposes of informing a construction tender to build the facility.

Nauru has a history of phosphate mining, and the site is within the extents of previously mined ground. The original (pre-mining) ground conditions of the site were likely limestone pinnacles with deep depressions. Following extensive mining of phosphate from the depressions, the site has been remediated into six relatively flat pad areas through an assumed combination of breaking down the pinnacles and backfilling the depressions with compacted granular fill – consisting of crushed rock (in varying particle sizes) and gravel/sand.

The field geotechnical investigation of the site was completed on 29th and 30th September 2017, and included excavated test pits and dynamic cone penetrometer testing over the flat pad areas within the site.

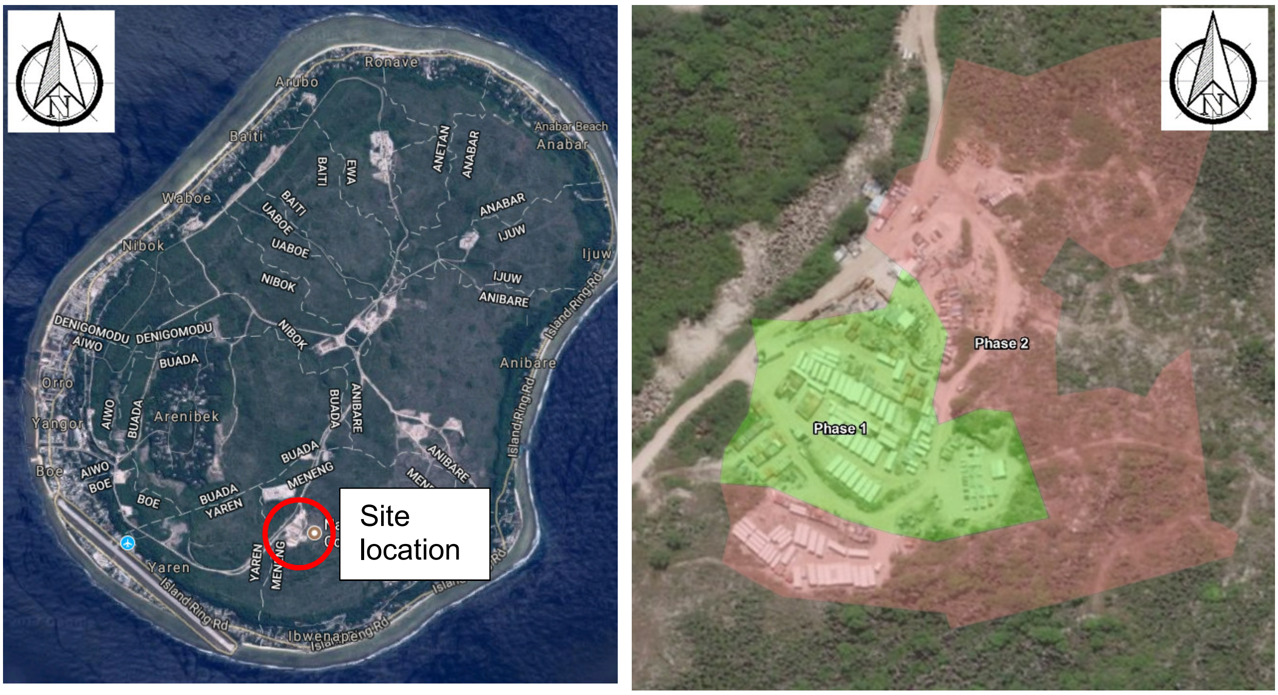

Figure: Left – Site location. Right - Soil investigation completed over phase 1 (green area)

The sub-soil conditions of the flat areas consist of hard, granular/rock soil, well suited for the construction of shallow foundations. The ground will generally provide 300 kPa ultimate bearing capacity.

Figure: Typical excavated ground conditions in test pits

Foundations constructed by either excavation or driving piles will likely prove difficult and expensive due to the hard, granular ground conditions observed over the site extents. Therefore, a pre-cast foundation with minimal excavation into the existing soil would likely be easier to construct compared to an excavated, cast in-situ foundation.

The recommended foundation to support the solar panels (based on the geotechnical investigation findings) is pre-cast concrete ground beams spanning one-way between panel support posts, as discussed in Section 3 of this report. Driven piles/supports, like those used at the initial site on the island are likely to be not possible due to the more compact ground at the proposed site.

Other foundation types may be possible, and this report does not limit those options.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

1.1 Project Scope and Background

BTW Company Ltd (BTW), in conjunction with Elemental Group Power and Renewables (Elemental), have been engaged by the Ministry of Foreign Affairs and Trade (MFAT) to complete a geotechnical investigation of an inland site located on the island of Nauru. It is proposed to install solar panels on the site, and the geotechnical investigation has been completed to provide recommendations on the best-suited foundation option for the solar panel structures, for the purposes of informing a construction tender to build the facility.

Power generation within Nauru is currently heavily dependent on diesel power generators. The Nauru climate is suited to support power generation through solar panels as a sustainable and environmentally friendly alternative to diesel generators. A small bank of solar panels has been constructed at another site on the island and is currently in successful operational in Nauru. The proposed inland site is intended to be become part of a large scale solar panel bank. This report details the geotechnical investigation results for the proposed solar panel development site, and interprets the results to form recommendations on the best-suited foundation option for the solar panel structures.

1.2 Nauru

Nauru is a relatively small, isolated island in the South Pacific Ocean just south of the equator, located at Latitude -0.5284 and Longitude 166.9342. The island area is approximately 21 km^2 with a population of approximately 13,000 residents (2016). The island has been mined extensively for phosphate, with secondary phosphate mining still being completed on the island. A satellite aerial view of the island is displayed in Figure 1.1.

Figure 1.1: Google Maps satellite view of Nauru (Investigated site location circled red, existing solar site circled yellow)

The island is primarily developed on the coastal perimeter and surrounding the inland 'Buda Lagoon'. The majority of the inland section of the island is relatively undeveloped, with terrain consisting of limestone pinnacles and large depressions with vegetation. Figure 1.2 displays typical inland terrain of the island. The proposed solar development site is located opposite the Nauru Australian Immigration Detention Centre.

Figure 1.2: Photo of typical inland terrain on Nauru

1.2.1 Climate

The Nauru climate is a typically warm, tropical climate with temperatures ranging between 26-32°C year-round. The dry seasons are typically between December to February and June to September, with rainy seasons typically in the remaining months. Due to the location of the Nauru island, typhoons are uncommon.

The climate of Nauru is well catered to successfully produce power from solar panels, and the low-risk occurrence of typhoons and general strong winds minimises the risk of weather damage to the panel structures.

1.2.2 Geology

The Nauru island was created from a hotspot on a section of the Pacific plate. A volcano formation with a coral atoll formed the island. The current island geology consists of dolomite limestone outcrops in the form of high pinnacles and deep depressions.

The island was a seabird rockery, and due to the depressions on the island's surface, large deposits of phosphate were created. These large deposits led to the extensive mining operations that have been carried out since the early 1900's.

1.2.3 Mining history

The large deposits of phosphate on Nauru were discovered in the late 1800's. Extensive mining of the phosphate began in the early 1900's, and continued throughout the 20th century largely by strip mining, and more recently secondary (deeper) phosphate mining has been undertaken.

1.3 Site Description

This investigation and report focuses on the ‘Phase 1’ area identified by the green hatching below in Figure 1.3. This area of the site has been remediated and flattened following phosphate mining, to form five relatively flat areas. The five flat areas located within the site are identified and labelled in Figure 1.4.

Phase 2 area of the site (identified by the red hatching) consists primarily of limestone pinnacles with depressions (typical geology for the island). One flat area exists within the Phase 2 extents that has been flattened and remediated following mining (labelled as area 4 in Figure 1.4).

Figure 1.3: Aerial view of site indicating Phase 1 (green hatch) and Phase 2 (red hatch) areas.

Figure 1.4: Aerial view of the site identifying indicative locations of the existing level pad areas on the site

Figure 1.5: Photo of Area 1 (looking in the northern direction)

2 GEOTECHNICAL INVESTIGATION

A geotechnical site investigation was completed on 29th / 30th September 2017. This section discusses the findings of the geotechnical testing.

A total of eleven test pits were excavated across the flat pad areas of the site, ranging from 500 mm to 1600 mm depth below existing ground level. Dynamic cone penetrometer (DCP / Scala) testing was attempted; however, refusal of the penetrometer was reached within 50 mm penetration at all existing ground locations tested.

The typical soil profile of the flat areas on the site was compact grey/brown coloured gravel/sand with rock inclusions (varying rock particle sizes). The flat areas appeared to have been created through breaking the limestone pinnacles, and backfilling the depressions with crushed rock and other compacted granular fill until a level pad was achieved.

Hand augured borehole and shear vane testing could not be completed at the site due to the nature of the soil encountered (very hard with large rock inclusions).

2.1 Excavated Test Pits

A total of eleven test pits were excavated in locations shown in Figure 2.1, and labelled test locations (TL) A through K. Table 2.1 provides test pit depths and descriptions.

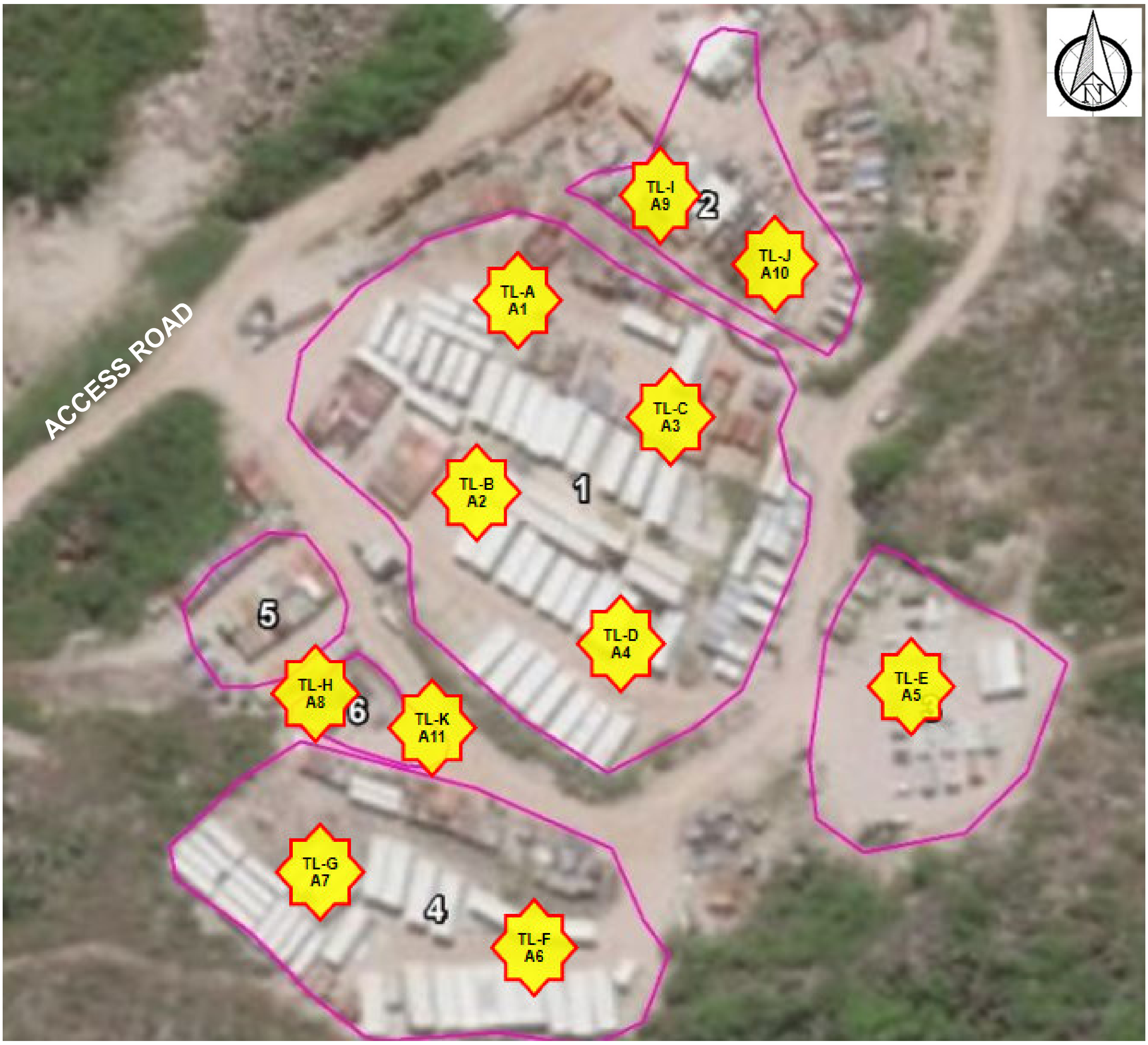

Figure 2.1: Test pit location plan

A small local excavator, estimated at 1.8 tonne (see Figure 2.2) was used to excavate the pits. A soil profile typical over the site is shown in the right-hand photo shown in Figure 2.2 .

Extensive photos of the test pits are attached to this report within Appendix A.

Figure 2.2: Excavator used for test pits (left TL-E/A5). Typical soil profile of test pits across site (right Test pit TL-A:A1)

The site soil conditions of the flat areas at the site are typically hard, compact granular fill with large rock inclusions. Limestone pinnacles were exposed on occasion in the test pit excavations, and appeared that the flat areas have been created by breaking down the limestone pinnacles to pad level, and backfilling the depressions by compacting crushed rock and other granular fill (such as sand/gravel).

Relatively softer sand backfill between limestone pinnacles was exposed in two test pit excavations, and excavation of these pits was significantly easier to excavate (compared to the other test pits).

Table 2.1: Test pit descriptions

Test Location (Refer to Figure 2.1 for locations)	Depth below existing ground	Description
TL-A	0 – 1000	Compact grey/brown coloured gravel/sand with rock inclusions (200 mm maximum rock particle size). Very hard material to excavate. Minor silt inclusions creating a brown colouring to the sand.
TL-B	0 – 1100	Compact grey gravel/sand with rock inclusions (200 mm maximum rock particle size). Very hard material to excavate.
TL-C	0 – 500	Rock pinnacle with some compacted grey gravel/sand. Breaking rock to excavate to 500 mm depth – very hard material.
TL-D	0 – 700	Rock pinnacle with some compacted grey gravel/sand. Breaking rock to excavate to 500 mm depth – very hard material.

Test Location (Refer to Figure 2.1 for locations)	Depth below existing ground	Description
TL-E	0 – 1500	First excavation not possible to excavate (likely rock pinnacle). Offset test location 1500 mm and excavation successful on second location. Compact grey/brown coloured gravel/sand with rock inclusions (100mm maximum rock particle size). Hard material to excavate. Minor silt inclusions creating a brown colouring to the sand. Granular material surrounded by hard rock pinnacle (likely excavating natural depression).
TL-F	0 – 600	Compact grey/brown coloured gravel/sand with rock inclusions (400 mm maximum rock particle size). Hard material to excavate. Minor silt inclusions creating a brown colouring to the sand.
TL-G	0 – 500	Compact grey/brown coloured gravel/sand with rock inclusions (200 mm maximum rock particle size). Hard material to excavate. Minor silt inclusions creating a brown colouring to the sand. Large pinnacle/rock at 500 mm depth that could not be excavated.
TL-H	0 – 1600	Grey/brown coloured gravel/sand with rock inclusions (400 mm maximum rock particle size) with minor silt inclusions creating a brown colouring to the sand. Granular material surrounded by rock pinnacle (presumably excavating through a natural depression that has been backfilled). Traces of pumice in the backfill. Granular material was softer than typical for the site in this location.
TL-I	0 – 900	Compact grey/brown coloured gravel/sand with rock inclusions (400 mm maximum rock particle size). Hard material to excavate. Minor silt inclusions creating a brown colouring to the sand.
TL-J	0 – 900	Compact grey/brown coloured gravel/sand with rock inclusions (400 mm maximum rock particle size). Hard material to excavate. Minor silt inclusions creating a brown colouring to the sand.
TL-K	0 – 1500	First excavation not possible to excavate (likely rock pinnacle). Offset test location 1500 mm and excavation successful on second location. Grey/brown coloured gravel/sand with rock inclusions (100 mm maximum rock particle size) with minor silt inclusions creating a brown colouring to the sand. Granular material surrounded by rock pinnacle (presumably excavating through a natural depression that has been backfilled). Traces of pumice in the backfill.

2.2 Penetrometer Testing

2.2.1 Proposed site

Dynamic Cone Penetrometer (DCP's) (Scala) testing was attempted in a 10 m x 10 m grid over the full extents of Area 1 (location shown in Figure 1.4). The penetrometer reached refusal before penetrating 50 mm below existing ground level at all locations tested.

On identification of the large rock inclusions and limestone pinnacles in the excavated site test pits, penetrometer testing of the remaining site was not completed, as was not successful and deemed less than useful for this soil type (DCP's cannot penetrate hard rock).

2.2.2 Existing solar site

One DCP test was completed just outside the western perimeter fence of the existing solar panel development that has been constructed on the island (approximately 1.6 km west of the proposed solar panel site). Refer to Figure 2.1 for the penetrometer test location. The penetrometer did not meet refusal at this site, and was driven down to 1200 mm below existing ground level, averaging approximately 10 mm / blow over the full soil profile tested (correlating to an indicative CBR of approximately 23).

The testing of the existing site was completed to provide a general comparison of ground conditions between the two sites and to assist in the recommendation of foundation type.

Figure 2.3: Approximate location of the dynamic cone penetrometer test completed on the existing Nauru solar panel development (circled red)

2.3 Borehole and Shear Vane Testing

Manual Auger boreholes and shear vane testing were attempted, but could not be completed on the site due to the hard granular/rock soil conditions.

2.4 General Site Soil Summary and Classification

The original ground conditions of the site (pre-mining) would have likely been limestone pinnacles with deep depressions (refer to Section 1.2.2). Following mining of the phosphate (from the depressions), flat areas have been created through a (likely) combination of breaking down the pinnacles and backfilling the depressions with compacted granular fill – consisting of crushed rock (in varying particle sizes) and gravel/sand.

The approximately 300 mm upper layer of soil over all locations tested on the site appeared to be very firm and well compacted. This is likely the result of regular heavy traffic over the site from the previous mining operations.

The site locations tested demonstrate that soil conditions have adequate bearing capacity to support the relatively light-weight solar panel structures. Allowable bearing capacities would easily meet or exceed 100 kPa (Ultimate bearing capacity of 300 kPa, with a factor of safety of 3)

Recommended foundation types are discussed in Section 3.

3 CONCEPTUAL SOLAR PANEL FOUNDATION DESIGN

3.1 Ground conditions – discussion

The flat areas of the site are hard surfaces, prepared well for the construction of typical shallow foundations. Shallow concrete beams or concrete pads are the typical/recommended type of foundation for new structures constructed on the investigated site.

Excavation of the site will likely prove difficult and expensive due to the hard, granular ground conditions observed over the site extents. Therefore, a pre-cast foundation with minimal excavation into the existing soil would likely be easier to construct compared to an excavated, cast in-situ foundation.

Driving piles through the soil profile would likely prove extremely difficult, and this is not a recommended option based on typical equipment used for similar previous solar installations.

3.1.1 Comparison between existing solar panel site and proposed site

The existing Nauru solar panel site was successfully constructed using (primarily) driven steel post foundations. A dynamic cone penetrometer test was successfully completed during the September soil investigation down to 1200 mm below existing ground level at this site (refer to Section 2.2 for test details).

Dynamic cone penetrometer testing at the investigated proposed site could not be successfully completed due to the large, hard rock creating penetrometer test refusal within 50 mm below existing ground level at all locations tested.

Comparison of the penetrometer testing between sites assisted in forming the conclusion that driven piles are not an appropriate solar panel foundation type for the investigated site.

3.2 Possible foundations

Potential foundation types suitable for the proposed solar panels and identified site ground conditions are listed below:

- Reinforced concrete ground beams (extending one-way between panel support posts).
- Shallow reinforced concrete pads (beneath all panel support posts)

The recommended foundation type/design is pre-cast concrete beams that can be shipped to the island and transported to the site in sections. Setout of hold down bolts can be completed accurately when the beams are fabricated, and site construction time will be minimised with a pre-cast option. The existing ground surface on the flat pads of the site has adequate bearing capacity to support the panels with this recommended foundation. A conceptual sketch of the ground beam locations in relation to the proposed solar panels is shown in Figure 3.1.

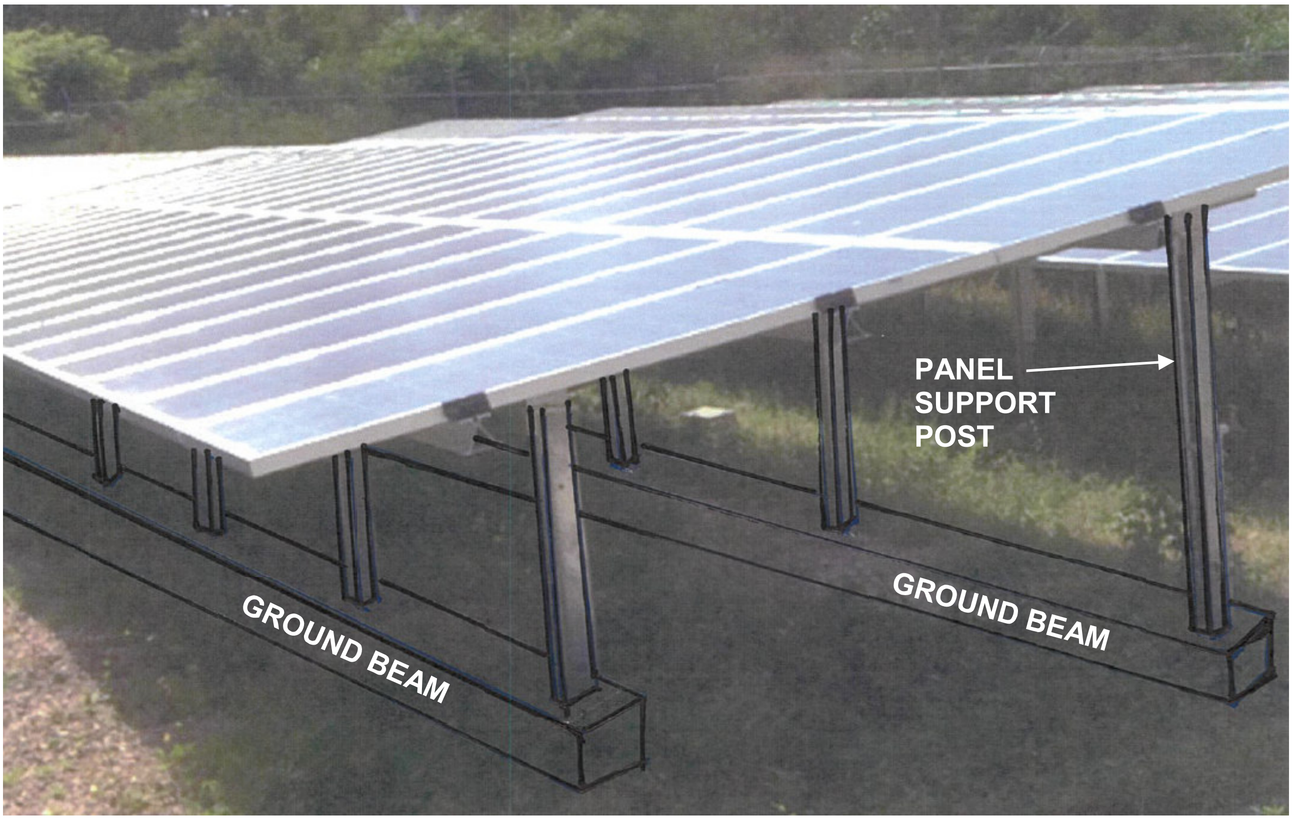

Figure 3.1: Proposed ground beam foundation concept sketch. Ground beams will likely be excavated below existing ground level. Typical hold down bolts cast into ground beam for support post base connection.

The ground beam sizes are subject to detailed design, and will be dependent on the type, dimensions, weight of the solar panels and support system selected, and calculated site wind speed.

The aggregate available on the island to construct cast in-situ beams appears to be of poor quality for making concrete. Due to the hard limestone pinnacle rocks and the compacted granular/rock fill, driving support posts into the ground is not a recommended foundation option for the proposed solar panels.

Other options may also exist based on proprietary or specific design approaches, and this report does not limit those options.

3.1 Distribution

This report has been produced by BTW Company Ltd and Elemental Group Power and Renewables for the use of the Client, and is solely for the clients use for which the report was intended, in accordance with the agreed scope. The reliance/use of this report and/or the information within this report by any person or business which BTW Company Ltd have not given prior consent, is at the persons or business own risk.

3.2 Limitations

The recommendations made within this report have been concluded from results positioned around the site and it is not intended to remove the necessity for the normal inspection of foundation conditions at the time of establishment of the future works.

APPENDIX A SOIL INVESTIGATION RESULTS

<u>Photos of all Test Pit excavations:</u>

Test Pit 1 (Total Depth = 1000mm)

Test Pit 2 (Total Depth = 1100mm)

Test Pit 3 (Total Depth = 500mm)

Test Pit 4 (Total Depth = 700mm)

Test Pit 5 (Total Depth = 1500mm)

Test Pit 6 (Total Depth = 600mm)

Test Pit 7 (Total Depth = 500mm)

Test Pit 8 (Total Depth = 1600mm)

Test Pit 9 (Total Depth = 900mm)

Test Pit 10 (Total Depth = 900mm)

Test Pit 11 (Total Depth = 1500mm)

Soil Report

Client:	Elemental Group	**BTW Job No:**	17866
		BTW Project Manager:	Bruce Chadwick
Location:	Nauru - Existing Solar Panel Development	**Tested By:**	Mathew Dickey
Test Date:	30/09/2017		

Soil Report

Client:	Elemental Group	**BTW Job No:**	17866
		BTW Project Manager:	Bruce Chadwick
Location:	Nauru - Existing Solar Panel Development	**Tested By:**	Mathew Dickey
Test Date:	30/09/2017		

Test Location: TL-A
Scala: S1