Design and Construction of a Reinforced Earth Fill Cairns Cityport Project – Northern Reclamation

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Summary: In terms of soft ground engineering Cairns poses significant challenges. Historically reclamation has involved dumping fill over the tidal mudflats until it stops falling down and sinking. The need to minimise environmental impacts on the Great Barrier Reef Marine Park and its associated Fish Habitant Areas precludes the use of these environmentally insensitive reclamation methods. When an engineering brief requires 4m of rock revetted fill to be placed over the mudflats in twelve weeks during a tropical wet season – the general consensus is that "it cant be done". This paper outlines what can be achieved at "the eNZ of the earth" (ie. Far North Queensland) when local engineers (the authors) and local contractors overcome foundation problems, stability problems, contractual timing issues, a history of previous failures and significant environmental constraints.

INTRODUCTION

The Cairns Port Authority's Cityport project involved the upgrading of the CBD waterfront area to create a more amenable and sustainable environment for visitors and locals. A major component of the project comprised expansion of the existing Marlin Marina which required reclamation of land to the north east of the existing Pier complex. The Cairns City Council's Esplanade project involved reclamation of land to the north west of the existing Pier complex. The Northern Reclamation project was created to allow an early completion of the link between the Esplanade project and the Cityport project. The early works comprised most of the reclamation to the north of the Pier complex including partial completion of the rock revetments. The area of the Esplanade Project reclamation, the Cityport Northern Reclamation, plus other areas of previous reclamation are shown on Figure 1.

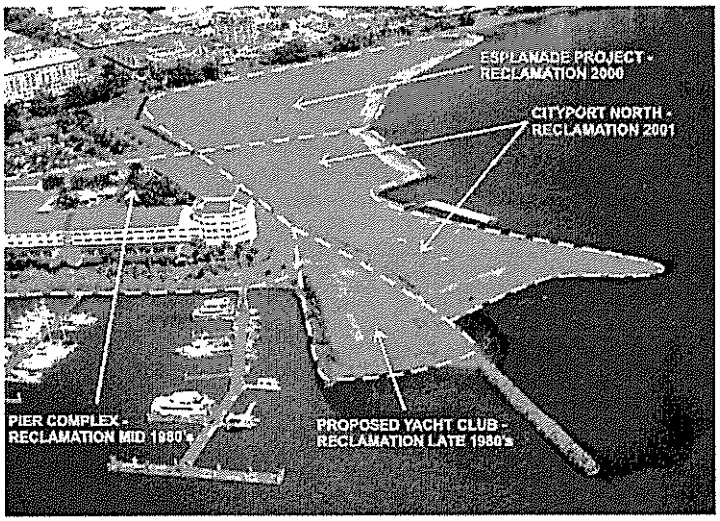


Figure 1. Aerial view of reclamation areas.

PREVIOUS RECLAMATIONS

The general area of the project site is underlain by 5m to 7m of very soft, highly compressible marine "muds". The mud is a potential acid sulfate soil (ie. it has the potential to generate acid on disturbance and oxidation). The shear strength of this material is very low (ie. about 5 to 8 kPa within the top 2m). Various methods of reclamation have been used over the years and were probably adopted on the basis of geotechnical expertise available at the time and the environmental constraints (or lack of constraints) that applied at the time.

Reclamation for the main Pier complex during the mid 1980's was carried out by bulk filling with "rocky" fill in 3m lifts over a layer of geofabric. This method of reclamation was considered to be totally inappropriate for the Northern Reclamation due to the potential for mud displacement, stability concerns and the "unengineered"nature of the fill created.

Reclamation along the north side of the Pier complex during the late 1980's was carried out in a more engineered manner when compared to the main Pier complex reclamation. Again "rocky" fill was placed over a layer of geofabric, however on this occasion a staged approach was adopted with an allowance for consolidation and consequent strength gain to occur after each stage of filling. This method of reclamation created an "engineered" fill and may have been appropriate for the Northern Reclamation if time was available (ie. years rather than months).

Reclamation for the Esplanade project in 2000 was carried out using sand placed in relatively thin layers (locally known as the "pan cake" filling procedure). This method of reclamation created an engineered fill and was appropriate for the Esplanade project where very flat 1V:6H batters were proposed prior to construction of a piled seawall. Even though the sand was placed in a controlled manner, mudwaves occurred during the reclamation and were of environmental concern at the time.

PROJECT SPECIFIC CONSIDERATIONS

Overall project timing required the reclamation to be carried out in a period of about 12 weeks. This tight time frame precluded the use of a traditional staged surcharging approach. A condition imposed by Government authorities for the works was that minimal disturbance (mud waves, heave or settlement) was allowed to occur in the Trinity Inlet Fish Habitat Area which is within 5m of the site at its closest point.

At the conceptual design phase the use of a geosynthetic reinforced sand and rock fill was proposed to meet the following geotechnical, environmental and construction challenges.

- Poor foundation conditions
- Stability problems during and after construction
- Settlement of the fill.
- Potential for disturbance to the Fish Habitat Area.
- Potential for acid sulfate soils to be exposed.
- Short construction period during the tropical wet season.
- Trafficability over the mud.
- Working in areas of tidal inundation.

The conceptual design was adopted and detailed design was carried out for the contractor.

REINFORCED FILL

The reinforced fill essentially comprised a basal layer of geotextile and geogrids followed by layers of geogrid at 1m spacing. The reclamation required the use of the following materials.

Sand Fill	42,750m^3	Bidim A44 and A24 Geotextiles	14.630m^2
Rock Fill	6,620m^3	Tensar RE120 and RE80 Geogrid	16,715m^2
Armour Rock	1,320m^3	Tensar SS30 Geogrid	4,900m^2

Details of the reinforced fill are shown on Figure 2.

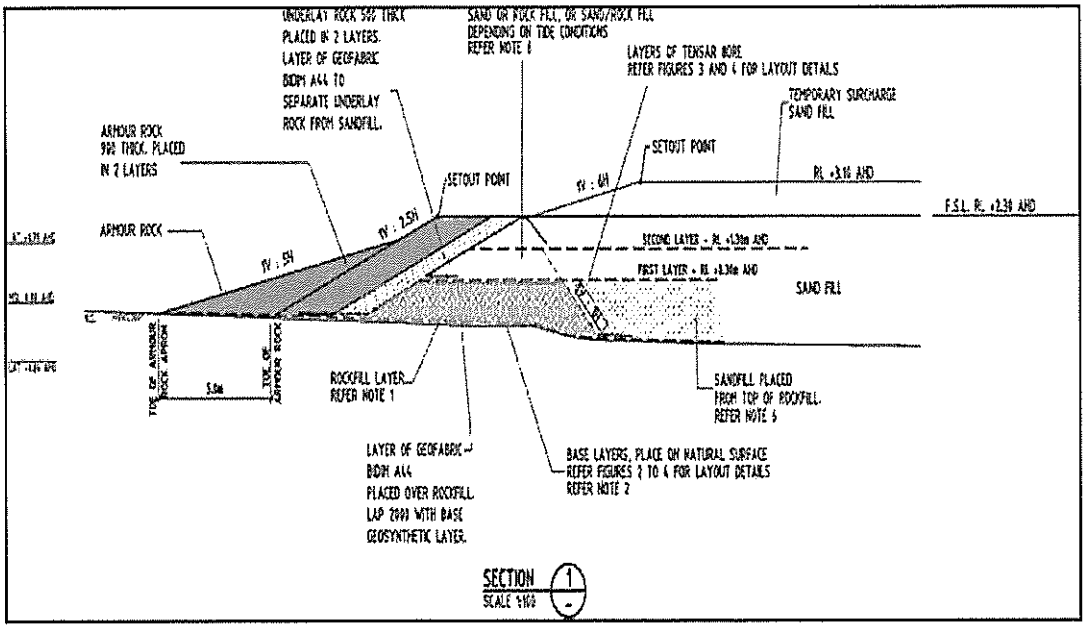


Figure 2. Typical section of revetment and geosynthetic reinforced fill – note that this section was taken from design drawings and its reference to figures and notes do not apply to this paper.

STABILITY

Inherent with foundations comprising very soft clays are the problems associated with stability, both during construction and post construction. The most minor form of instability that could be expected to occur would be the formation of mud waves (ie. localised slips within the mud induced by the loads imposed by filling). At the other extreme would be a large scale failure through the soft clay and overlying fill induced by surcharge loads such as construction machinery or stockpiled fill materials, or even post construction loads such as buildings or other infrastructure.

Analyses were carried out to evaluate factors of safety against instability for the initial stage of filling, at the completion of filling, and to ensure an adequate factor of safety was achieved for long term stability. The minimum factors of safety adopted for the project were 1.2 for the initial stage of filling, 1.3 for the profile on completion of constsuction and 1.5 for long term stability. In order to achieve the adopted factor of safety for the initial stage of filling a staged construction was proposed. This required each layer of reinforced fill to be placed and for a two week delay prior to placing the next layer. This period worked well as this was about the time required to place the entire layer and return to the start to place the next layer.

SETTLEMENT

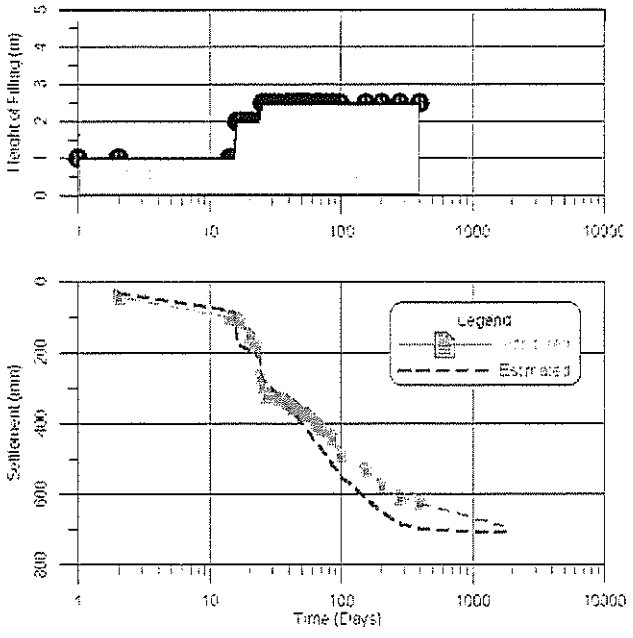
Again inherent with foundations comprising very soft, highly compressible clays are the problems associated with settlement (ie. compression and consolidation of the foundation by the loads induced by the reclamation fill). In the simplest terms, for each 1m of fill placed at the site, settlements of up to 300 mm could be expected. In complex terms the critical issue was the time over which the settlement would occur. This is particularly important when assessing preload options (ie. filling to just above the design level and allowing the estimated settlement to occur).

At this site every 0.1m depth of material required is equal to about 1.200m^3 of fill. It was therefore important to optimise preload design such that the "correct" amount of settlement occurs. In a preload situation under-estimating settlement requires topping up the fill and inducement of additional settlement from the new fill. Whereas, over-estimating settlement requires removal of excess fill.

For this project the challenge posed by settlements and preload design was met by back analysing the results of settlement monitoring for the adjacent Esplanade reclamation. However experience gained on other soft ground projects was also required as only post construction settlements were monitored at the Esplanade reclamation (ie. the settlement of the surface of the fill following completion of filling). There was a misconception by some engineers in Cairns that the Esplanade reclamation did not settle the design amount. Given that the settlement that occurred during construction was not monitored it is considered likely that up to 300mm of the total settlement expected at the Esplanade project occuired during construction. This amount of material had to be removed following preloading to achieve the design level.

Based on settlement predictions for the Northern Reclamation the design filling level was set 0.3 m lower than the filling level of the adjacent Esplanade reclamation. This was equivalent to about 3600m^3 of sand and brought about significant cost savings.

Monitoring of the Northern Reclamation fill commenced on the first day of filling and monitoring confirmed the predicted settlement of about 300 mm during filling. At the end of monitoring the total settlement was also heading towards the amount predicted. A plot of predicted and measured settlement is presented as Figure 3.



Settlement Monitoring at SF 1

Figure 3. Predicted and measured settlement.

CONSTRUCTION CHALLENGES

Construction Timing

A period of about 12 weeks for earthworks construction during the tropical wet season posed a significant challenge. This was overcome by the proposal to construct the reclamation with "clean" sand and gravel allowing filling to be cairied out during wet weather. Filling with "rocky" materials (ie. essentially clayey gravels), as was the case for the previous Pier and surrounding reclamations, was not recommended as these materials cannot be placed and compacted during wet weather.

Trafficability

Movement of even the lowest ground pressure equipment such as swamp dozers would not have been possible on the mud exposed in the reclamation area. Previous experience on the Esplanade reclamation indicated that at least 1m of sand was required for swamp dozers to move over the mud, however the placement of 1m lifts induced mud waves. In order to overcome this challenge, the use of additional geogrid reinforcement in the basal layer was proposed and this allowed excavators to work on fill as thin as 0.5m.

Tidal Inundation

The reclamation required filling in areas as low as RL –1m AHD, which were only exposed at the lowest of low tides. In conjunction with the contractor it was proposed to form the base layers of geofabric and geogrids on site such that a prefabricated roll about 6m wide could be placed to expediate work during periods of lower tides. Placement of prefabricated rolls of geofabric and geogrids is shown on Figure 4.

Figure 4. Working underwater – note workman up to his waist in mud when working off the basal layers.

Fish Habitat Area

At its closest point the reclamation abuts the 5m buffer on a Fish Habitat Area. A condition of approval for the reclamation works was that *the nature and extent of disturbance is limited to a temporary "mud wave" (that may result from adjacent reclamation) extending no more than 20m from the toe of the reclamation area and penetration no more than 15m into the declared Trinity Inlet Fish Habitat Area to a height of no more than 150mm within the declared Fish Habitat Area.*

A 5m wide toe support was proposed around the entire reinforced fill as to reduce the potential for heaving in front of the revetment profile during construction. The "disturbance" criteria were easily met as no significant movement was recorded during survey monitoring along the Fish Habitat Asea.

Potential Acid Sulfate Foundation Soils

Construction of the reinforced fill and associated toe support minimised the potential for mudwaves to form and for potential acid sulfate soils (PASS) to be exposed.

Siltation

With the proposal to use "clean" sand and gravel fill (ie. fill with less than 8% clay and silt sized material) the potential for plumes of silt to form was minimised. The design required the reinforced revetment fill to be placed around the perimeter of the works prior to most of the sand filling. This process contained any "problems" within the site away from the adjacent Fish Habitat Area. Completing the perimeter of reinforced fill around the works is shown on Figure 5

Figure 5. Completing the perimeter of the reinforced fill – note "problems" are contained inside the works.

Potential Acid Sulfate Fill Materials

Sand fill was generated from a sand pit located in a low lying coastal area north of Cairns. Previous experience during the Esplanade reclamation indicated that some of the proposed sand fill may be potential acid sulfate soils (PASS).

Prior to the Northern Reclamation work commencing acid sulfate soils investigations were carried out at all proposed borrow areas at the sand pit. This allowed "pre-validation" of non PASS sand borrow areas. Notwithstanding the "pre-validation" of borrow areas all sand stockpiles were monitored for PASS prior to transpoitation to site.

PROJECT COMPLETION

The first stage (early works component) of the Cityport Northern Reclamation was completed in March 2001. Given the environmental sensitivity of the project, the work was regularly "checked" by the owner and their engineers, the Council and their engineers and two Government bodies. Despite initial scepticism the reinforced fill approach to reclamation was successful. The success was largely due to the ongoing liaison between the designers and the contractor. Prior to and during constsuction this liaison allowed the design to be optimised by adopting stronger layers of geogrid at a wider spacing, and by choosing geogrids which were compatible with readily available constsuction materials. In terms of stability, settlement, and environmental compliance the reclamation has performed as predicted. The completed early works are shown on Figure 6.

Figure 6. Completion of the early works reclamation