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Reclamation of Pond F using the "sand raining technique" – A case history

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ABSTRACT: The increasing demand for hardstand area at East Arm Port in Darwin necessitated the reclamation of Pond F, a large tidal pond located to the rear of the berths. Reclamation was accomplished using a combination of innovative filling, ground improvement and traditional earthworks techniques. Sand was placed on saturated, compressible muds by the "sand raining technique" using a small cutter suction dredge to prevent mud waving and ASS generation. This was followed by accelerated consolidation using prefabricated vertical drains; a first for Darwin. Subsequent earthworks including an 18-month surcharge period ensured satisfactory delivery of the reclaimed pond to meet the projects time and cost objectives. Following removal of the sur-charge, the reclaimed area was developed into a block-paved refrigerated container or reefer terminal; its current and end use. This paper presents the innovative methodology adopted to overcome the geotechnical issues within the pond.

1 INTRODUCTION

1.1 *General*

Coastal industrial reclamations to meet increasing import and export demand are undertaken at most ports in Australia, with each reclamation project providing their own unique set of challenges.

The reclamation of "Pond F (Figure 1)", a tidal pond created during the construction of Darwin's East Arm Port in the late 1990's, certainly provided its own set of challenges given that the pond contained very soft marine dredge spoil over natural, potentially ASS generating marine muds, and that all engineering work had to be carried out without disturbing day to day port operations.

1.2 *Project site*

The East Arm Port (EAP) is located approximately 5.5 km directly southeast of the Darwin CBD and was opened for use in 2001. Pond F is located within the confines of the EAP between the wharf face and the railway line with hardstand areas to the northwest and southeast. The pond is generally rectangular and has approximate plan dimensions 110 m by 250 m.

1.3 *Background*

Pond F has been in existence since the construction of the EAP in 1999. Several efforts were made to infill the pond in the intervening period, primarily to provide increased hardstand area for use in the export and import of goods from the wharf. As a consequence numerous surveys, investigations and analyses were undertaken.

In 2011 a concerted push by the Department of Infrastructure (DoI), Northern Territory Government, led to investigations, options analysis and a design that finally allowed the reclamation of the pond with-out the requirement to first remove the in situ marine mud and dredge spoil.

Figure 1. East Arm Port showing Pond F (as of 2011)

2 OPTIONEERING

As a first step, based on desktop study critical aspects were identified and possible options were examined.

2.1 *Desktop study*

During the "optioneering" stage prior to the reclamation, available information was reviewed. The salient findings of the review are as follows:

- Chemical analysis of marine mud from within Pond F. The analysis showed that the soils have an acid sulfate soil (ASS) potential.
- A geotechnical investigation and report (November 2009) provided detailed borehole logs and laboratory test results from Pond F. The report also included three options for reclaiming Pond F.

  - ➢ The first option was by dredging the marine mud and filling the pond with engineered fill. However, the report went on to say that this option may negatively impact on the stability of the southwest and northwest slopes of Pond F.
  - ➢ A second option was to mud wave the marine mud into the centre of the pond and dredge the material from there, followed by filling with engineered material. However, the issue of dealing with the potential ASS soils remained.
  - ➢ The third option was to fill over and encapsulate the marine mud, thus minimising problems associated with its removal. (However, there was no mention of vertical drains or settlement monitoring included in this option).

2.2 *Review of various options*

From this data it was clear that an "encapsulation type" reclamation strategy was most appropriate for Pond F. Five reclamation options were investigated (Table 1).

Figure 2 provides a schematic comparison of time versus cost for the five options. Whilst Option 1 is clearly the most cost effective compared to the other options, significant budget and program risks related to uncontrolled and geographically variable consolidation during and post surcharge make this option less than attractive, especially as program clarity was a requirement at the start of the project.

The use of admixtures such as cement, lime, PFA (pulverized fuel ash) or GGBS (ground granulated blast furnace slag etc) to improve engineering performance of soft soils is becoming commonplace, especially in coastal areas. Significant additional investigation with a rigorous testing regime would be required to progress the design and specification for this method, which would have significantly delayed the tendering process and subsequently delayed delivery. Specialist ground improvement contractors would likely be required to complete the work.

Table 1: Summary of reclamation options discussed for Pond F

	Option	Risk	Duration
1	Backfill Pond F with rock to above water level, earth fill to wharf level and construct a surcharge	Significant risk of **differential settlement** and **uneven consolidation** during surcharge (post-construction settlement) with this option due to the varying thickness of the compressible layer. Potentially protracted period of consolidation and settlement under surcharge to achieve primary consolidation	> 2 years
2	Backfill Pond F with sand to above water level, install PVD (vertical drains), earth fill to wharf level and construct a surcharge	The risk of differential settlement is greatly reduced as with this method as the PVD will allow drainage and therefore settlement during construction.	< 2 years
3	Pre-treat the mud within Pond F by admixture stabilisation (cement, PFA, lime etc.), backfill with rock to above water level, earth fill to wharf level.	By completely stabilising the marine mud, this method will also minimise the risk of post-construction settlement. The site would be ready for use immediately. Likely to be **expensive** relative to backfill and surcharge only.	Completion during construction
4	Backfill Pond F with rock to above water level, dynamically compact, earth fill to wharf level	Dynamic compaction of around 5 m of rock fill will perform well. However, **post-construction settlement** may occur where the compressible materials are thicker.	Completion during construction
5	Pre-treat the mud within Pond F by admixture stabilisation (cement, PFA, lime etc.), backfill with rock to above water level, dynamically compact or replace, earth fill to wharf level	Belt and braces approach with a very low risk of uneven settlement. The site would be ready for use immediately, but likely to be the **most expensive** option.	Completion during construction

Similarly, the use of dynamic compaction to improve the in situ mud would require the use of specialist ground improvement contractors. Significantly, this method may have impacted on the day-to-day running of the Wharf as laydown areas would be required for large plant and rock stockpiles.

It was considered that although “handover” and project delivery would be sooner for Options 3, 4 and 5, possibly within 12 months of commencement, costs would likely be significantly higher - possibly in the order of double the cost of a surcharge reclamation option.

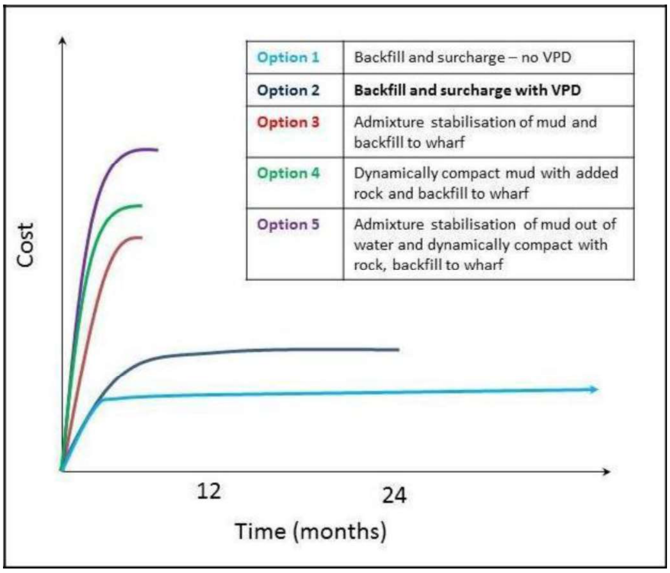

Figure 2. Schematic comparison of time versus cost for various options.

Option 2 was chosen as the preferred method of reclamation because:

- The risk of differential settlement is significantly reduced where prefabricated vertical drains (PVD) were used, compared to a surcharge alone without drains
- The site could be handed over for use within 2 years
- The option is the most cost effective for the least amount of risk
- The work could be completed without significant impact to the Wharf operations

3 GEOLOGICAL SETTING

The geotechnical model for Pond F was based on earlier investigations at EAP by various consultants (Douglas Partners, 2009; Aurecon, 2011). Table 2 summarises the geotechnical setting for Pond F.

Table 2: Summary of the geotechnical setting at Pond F

Material Type	Typical Thickness	Description
Fill	Varies (~>10m)	Variably compacted clayey gravel, cobbles and boulders of the Burrell Creek Formation The existing EAP structure
Dredge Spoil	Varies (~2.0m)	Typically, fine SAND and SILT Pumped into Pond F during maintenance dredging of berth pocket, potential ASS, saturated and prone to consolidation when loaded
Marine Mud	Varies (~7.0m)	CLAY, Sandy CLAY and Clayey SAND In situ, potential ASS, saturated and prone to consolidation when loaded
Burrell Creek Formation - Residual Soil	Varies (~1.0m)	Gravelly CLAY / Clayey GRAVEL In situ
Burrell Creek Formation - Rock	Bedrock	Fine to coarse feldspathic metagreywacke; minor PHYLLITE / META-SILSTONE, slate and mudstone with lenses of volcanilithic pebble conglomerate, quartz-mica schist In situ.

3.1 *Geotechnical condition of pond*

The EAP structure is comprised of fill derived locally from rocks of the Burrell Creek Formation, which is founded upon in situ “bedrock”.

Marine alluvium within Pond F has been in situ since before construction of the wharf. The water within the pond is tidal and is hydraulically connected to the harbour. Typically, the water level within the pond is 0.5 m above the level of surrounding harbour.

Dredge spoil from maintenance dredging of the berth pocket has been historically pumped into the pond, forming a layer of fine sand and silt of variable thickness over the marine mud. In addition, minor ad-hoc end-tipping of material over the side of the pond had also occurred.

The geotechnical profile is depicted schematically in Figure 3

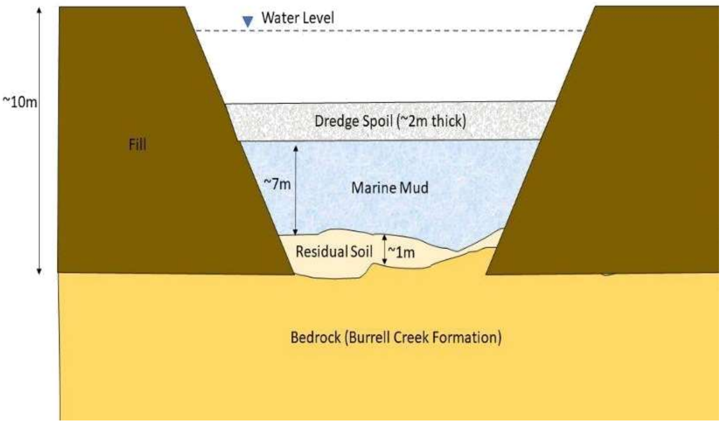

Figure 3. Schematic depiction of geotechnical profile

4 GROUND IMPROVEMENT

Saturated compressible soils, such as dredge spoil and marine mud, can experience significant settlement and consolidation when loaded. Often during planned earthworks, a preload or surcharge is put in place be-fore loading (preloaded) to preconsolidate such soils, thus limiting subsequent post-construction settlement. However, depending upon the properties of the soils being preloaded and the weight of the preload applied, this process can take years to complete satisfactorily. Ground improvement with surcharge and installation of PVD is a common method used to accelerate this process.

The performance criteria for the newly reclaimed Pond F was to support a load of 100 kPa with an al-lowable settlement of not more than 400 mm over 20 years.

4.1 *Stage 1 – Placement of sand using raining technique*

Sand was introduced into Pond F using three distinct methods.

Firstly, to avoid mud-waving and / or exposure of the potential ASS muds to an oxidising environment, sand was evenly spread over the mud by means of a small cutter suction dredge (see Figure 4) placed within the pond itself. This novel and innovative “raining technique” served to cover and encapsulate the mud. Following removal of the dredge machine from the pond, sand could then be pushed into the pond and onto the sand to just above water level with-out disturbance to the material beneath. Finally, sand was placed using traditional earthworks techniques and built up to RL +2 m.

As the water within Pond F is tidal (typically 0.5 m above the levels of the surrounding harbour), the introduction of permeable sand simply displaces the water. Figure 4 shows the process of sand placing from a floating pontoon fed from a small cutter suc-tion dredge.

Figure 4 (A) Cutter suction dredge within the pond pumping sand to (B) a pontoon depositing material over soft soils. (C) Quarried sand was transported to site and carefully placed into the pond for dredging and transportation. (D) A closer view of the pontoon showing the diffuser spreading sand upon the soft muds

Figure 5: PVD Installation (A), ongoing earthworks (B) and placement of surcharge (C)

4.2 *Stage 2 – Drainage layer installation*

Following completion of the placement of sand into the pond, a 0.5 m thick layer of coarse aggregate was placed - separated from the sand by a layer of geofabric.

The coarse aggregate layer served not only as a drainage layer for the soon to be installed VPD's but also provided a robust trafficking layer for the PVD installation rig and other earthmoving equipment on the surface of the reclamation. Figure 5A shows the Stage 2 installation. Prefabricated vertical drains were installed by specialist subcontractors to depths of between 12.5 to 16 m below the level of surface of the drainage layer (RL +2.5m) in a 1.4 m triangular pattern. The PVD's were 100 mm wide, 3.4 mm thick and were composed of a plastic strip with drainage channels, wrapped in a nonwoven geotextile filter fabric. The geotextile filter prevents soil particles from entering the channels and clogging the drain.

The PVD's were hydraulically pushed vertically into the ground though the drainage and sand layers and into the compressible muds beneath until the desired depth. As the mandrel which contained the wick drain was withdrawn back into the mast of the rig, the undamaged wick drain is left in place within the soil mas. The drains provide a much shorter and more direct route for water to escape from the saturated muds, thus significantly accelerating consolidation from the surcharge. Following installation of the VPD's approximately 0.5 m of immediate settlement was recorded.

A second of layer of separating geofabric was then placed on the drainage layer and earth filling commenced (Figure 5B). This was undertaken in the usual way with material trucked-in, placed and compacted in accordance with the earthworks specification for the project. Filling continued until a level of approximately RL +5.25 m was achieved (Figure 6).

During earth filling approximately 0.5 m of further settlement was recorded. A 4 m high rock surcharge was placed in two stages, with approximately two thirds placed before December 2012 and the final third in April 2013 (Figure 5C). The surcharge provided sufficient load to consolidate and improve the in situ compressible material to meet the end criteria at hand over time.

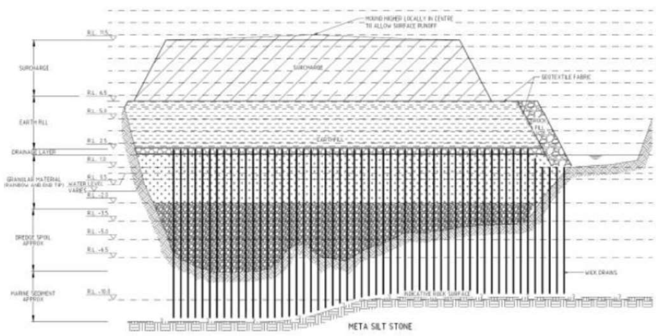

Figure 6. Typical section of Pond F ground improvement.

4.3 *Instrumentation and monitoring*

Five settlement plates were installed on the drainage layer prior to earth filling. The purpose of the settlement plates was to record settlement during and post construction. One of the plates (SP2) was positioned on top of the sand layer prior to the insertion of VPD's, while the rest were positioned on the drainage layer after the VPD's were inserted. As is common during earthworks projects, one plate was damaged (SP5) being knocked over by plant.

Figure 7 summarises the settlement readings taken between installation and April 2013. The plates positioned on the drainage layer have settled around

0.5 m, whereas SP2 which was positioned on the sand prior to the insertion of VPD's has settled over 1.0 m.

Settlement graphs in Figure 7 show that primary consolidation had practically ceased by April 2013. Based on Asaoka method (Asaoka 1978) the surcharge was removed during December 2013, much earlier than anticipated.

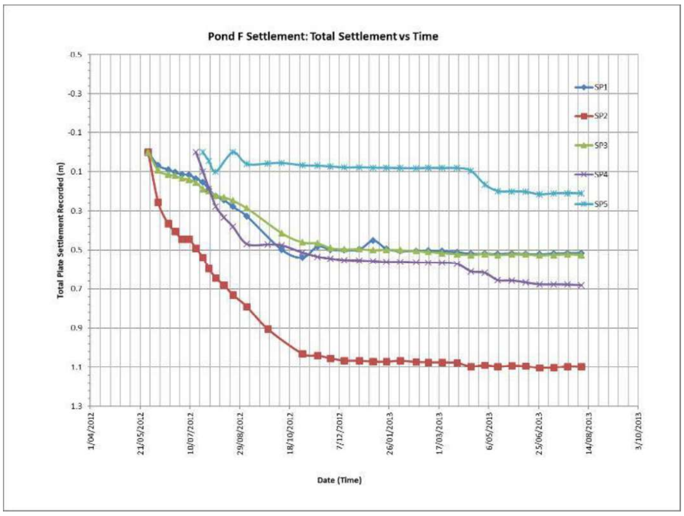

Figure 7. Settlement of fill with time

5 CHALLENGES DURING CONSTRUCTION

5.1 *Wharf operations*

A prerequisite of the project was to ensure that the reclamation did not affect the day-to-day running of the wharf. This was achieved by implementing traffic management strategies to ensure vehicular movements relating to the transport of materials into the site did not interfere with the import or export of goods into the wharf.

5.2 *Granular material production*

During the 2012 wet season, heavy rains damaged the haul road used to transport the sand material from the quarry to the wharf, resulting in several weeks delay in completing the end tipping portion of the reclama-tion. This was overcome by forging ahead with the earthworks component on the areas that had already been filled with sand and subsequently drained.

5.3 *Two-stage surcharge construction*

Financial constraints warranted the cessation of the construction of the rock surcharge approximately two thirds of the way through the process. The final third of the surcharge was constructed April/May 2013. This presented a challenge with respect to completion of primary settlement as the site has not been under a uniform load. In fact, Figure 7 shows a minor reacti-vation of settlement from some of the settlement plate readings following completion of the surcharge. This feature was managed by continued regular settlement monitoring significant further settlement was not observed.

6 CONCLUSIONS

Pond F was reclaimed in 2012 by encapsulating compressible, saturated in situ soils comprising marine mud and dredge soil with sand. The sand was initially placed on the mud using a novel "sand raining technique" utilising a cutter suction dredge machine. This avoided mud waving and stopped exposure of the mud to air to limit the potential for acid sulfate soils generation. Following encapsulation, sand was placed within the pond until out of the water and safely trafficable. Subsequent works including PVD installation and earthworks followed.

Results of settlement plate monitoring showed that primary consolidation had ceased by April 2013, with only secondary or creep settlement expected. Sur-charged was removed during December 2013, much ahead of schedule, and subgrade was ready for pave-ment construction.

The innovative methodology undertaken in this design allowed the land to be available for use by the Port and the projects time and cost objectives were met. The additional economic benefits of not interrupting daily wharf operations and bringing forward the availability of the hardstand are difficult to quantify but arguably would be measured in millions of dollars.

7 ACKNOWLEDGMENTS

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