

# ASSESSMENT OF METHODOLOGIES FOR REBURIAL OF EXCAVATED ACID SULFATE SOFT SOILS WITHIN SHELL COVE BOAT HARBOUR ZONE

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## ABSTRACT

A study was carried out to assess the practical aspects of placement of excavated disturbed Acid Sulfate Soft Soils (ASSS) within the future Shell Cove Boat Harbour excavation zone at the proposed Shell Cove Boat Harbour development. The objective of the work was to assess and comment on the methodology from a geotechnical perspective for the placement of ASSS material 'in the moist' rather than as 'dredged slurry', during Stage 2 of construction. Two large field trial cells (approximately 15m by 15m at base, and 4.5m high) were constructed to practically observe, test and assess different placement scenarios. The following three scenarios were assessed:

- Placement of untreated ASSS material
- Placement of Agricultural lime treated ASSS material to modify soil shear strength and consistency
- Placement of Hydrated lime treated ASSS material to modify soil shear strength and consistency

Track rolling via long reach excavators and swampy dozers were utilised to place, spread and remove the large air voids between clumps/clods of the ASSS material within the trial cells. The neutralisation capacity of the various limes for treatment of Acid Sulfate Soil was also assessed in a preliminary manner. It should be noted that the focus of the work from the addition of lime was on geotechnical modification/stabilisation aspects rather than assessment of Acid Sulfate Soil neutralisation capacity.

Shear strength of ASSS material was assessed using a hand-held shear vane. The shear strength of the soils was measured at the borrow pits prior to excavation of material. It was then compared with the measured shear strength of the soil in different layers placed within the trial cells for different scenarios. Comments are provided in relation to the effects of the mixing agent on the shear strength of the soil.

Construction of bunds within harbour excavation zone including bund sizing and stability of bund to be used by earthmoving plant was also assessed and commented on. Change in soft soil pH due to addition of agricultural and Hydrated limes was also assessed. Waiting time to place subsequent layers within the cells and the effect of weather conditions on the placed soft soils within trial cells is also discussed to some extent in this paper.

Utilisation of a new type of long reach excavator not previously used in Australia is also discussed. This innovative construction technique enabled the excavator to travel directly onto soft disturbed soils and to spread the soils within the harbour excavation zone in a manner that provided enormous cost and time savings for the client.

## 1 INTRODUCTION

The Shell Cove Boat Harbour is a large integrated new harbour development located 100km south of Sydney, NSW. After commencement of Stage 1 of construction in 2013, and continuation of construction of Stage 2 in 2014, the site is now in the final stage of construction (Stage 3) and completion is due in late 2019. An extensive investigation and design program was carried out and a number of novel techniques were used to investigate and model the future design conditions. This paper discusses one aspect of this work.

This paper discusses the approach adopted, results of and lessons learnt from a full-scale field trial to assess the practical aspects of the placement of excavated disturbed Acid Sulfate Soft Soils (ASSS) within the future Shell Cove Boat Harbour excavation zone at the proposed Shell Cove Boat Harbour development. Large volumes of

ASSS material (about 500,000m<sup>3</sup>) required excavation and reburial below the water table and ASSS management became an extremely important driver of construction activities.

The objective of the work was to assess and comment on the methodology from a geotechnical perspective for the placement of ASSS material ‘in the moist’ rather than as ‘dredged slurry’. Two large field trial cells (approximately 15m by 15m at base, and 4.5m high) were constructed to practically observe, test and assess different placement scenarios. The following three scenarios were assessed:

- Placement of untreated ASSS material
- Placement of Agricultural lime treated ASSS material to modify soil shear strength and consistency
- Placement of Hydrated lime treated ASSS material to modify soil shear strength and consistency

The first aim of this trial was to establish whether the ASSS materials could be trafficked upon initial placement of non-treated Unit 3B ASSS material. If swampy dozers could not traffic the non-treated Unit 3B ASSS material, the second aim of the trial was to establish what form of stabilisation could potentially be used to allow swampy dozers to traffic the materials.

It should be noted that this paper does not discuss in detail the treatment of ASSS from an environmental/neutralisation perspective, but does comment on the effect of neutralisation in a preliminary manner. However, this aspect of work is acknowledged as highly important and should be evaluated in parallel to any geotechnical treatment measures where ASSS is to be treated.

## 2 BACKGROUND AND REVIEW WORK

### 3.1 PREVIOUS WORK

Morrison and Tait (2007) carried out an assessment of the consolidation behaviour of the Acid Sulfate Soil (ASSS) from the Shell Cove Boat Harbour. The assessment was in relation to removal of the ASSS material by a cutter-suction dredge, transported as a slurry by pipeline and then disposed into a dewatered disposal cell.

The following parameters were adopted:

- $c_c$  is compression coefficient,
- $e_0$  is initial void ratio,
- $c_v$  is coefficient of consolidation in vertical direction, and
- $c_h$  is coefficient of consolidation in horizontal direction.

In their assessment, based on the laboratory and insitu testing results, different values of compression ratio ( $c_c/(1+e_0)$ ) and coefficients of consolidation ( $c_v$  and  $c_h$ ) were used to best estimate the self-weight consolidation behaviour of the ASSS material in form of slurry. To assess and estimate the duration of the consolidation, both cases for the vertical consolidation (without wick drains) and horizontal consolidation (with wick drains) were assessed and the outcomes discussed.

Morrison and Tait (2007) reported that for an initial thickness of the slurry ranging between 1.5m to 4.5m, the estimated time for 95% Degree of Consolidation (DOC) ranges between about 5 to 295 months and 4 to 26 months for the cases of vertical drainage and horizontal drainage, respectively (depending on the initial thickness of the slurry and the value of coefficient of consolidation, and whether wick drains were used or not).

Large volumes of water would be introduced to the material if a cutter-suction dredge is used, and wick drains would likely have been necessary to achieve practical consolidation timeframes. The technique was assessed as very costly. It was therefore decided to investigate alternative ASSS excavation and placement measures. It was decided to not place the ASSS material as slurry within the excavation zone and instead attempt to place the material “in the moist”.

“In the moist” means excavating the ASSS material using conventional earthworks techniques such as excavators and transporting and tipping the soils within the excavation zone using dump trucks. This “in the moist” method results in different soil parameters than those reported by Morrison and Tait (2007).

It was theorised that:

- the rate of the material placement would increase dramatically if more conventional earthworks techniques are used.
- providing soil (treated or untreated) has an appropriate moisture content and shear strength when it is placed within the Boat Harbour excavation then it is possible that swampy dozers could potentially track over the soils in layers.
- using swampy dozers would allow some compactive effort to be imparted to the material and significantly speed up placement of the ASSS materials.

### 3.2 PLACEMENT OF NON-TREATED ASSS MATERIAL

Placement and subsequent performance of non-treated soft soil material within the Boat Harbour over-excavation zone depends on the following factors:

- Soil type and percentage of clayey material;
- Soil particle size;
- Insitu moisture content;
- Degree of disturbance;
- Thickness of each layer placed;
- Waiting time between the placement of each layer;
- Climate conditions;
- Machinery used for placement; and
- Experience of construction staff.

Insitu moisture content of soil is one of the most important factors affecting the practicality of the placement and compaction of soft soils due to its effect on undrained shear strength. Due to the soil being excavated from different depths with different void ratios and varying moisture content, assessment of the soil conditions when it is excavated, transported and placed within the excavation cell was foreseen as difficult to assess unless a field trial was carried out. In addition to the practical observation of the performance of a Swampy Dozer travelling over the material, measurement of the undrained shear strength of the disturbed and mixed soil was used as a key indicator of soil improvement.

The field trial attempted to assess the combined effects of all the above items in a practical way.

### 3.3 PLACEMENT OF LIME TREATED ASSS MATERIAL

Treatment using lime was chosen as the most likely technique for stabilisation due to the common use of lime to treat clay subgrades in pavements and the potential neutralising capacity of the lime to treat acidic soils such as the ASSS materials used onsite.

Based on published information from Austroads (2006), it was assessed that three different limes could potentially be used to modify, dry, and stabilise soft clayey soils as follows:

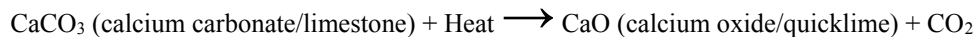
- Hydrated lime
- Quicklime
- Hydrated lime slurry

Table 2 summarises and compares some of the key parameters of different limes.

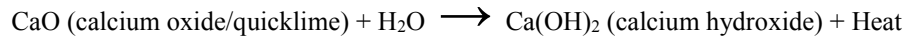
**Table 2: Properties of Quicklime, Hydrated Lime, and Slurry Lime (from Austroads, 2006)**

	Hydrated lime	Quicklime	Hydrated lime slurry
Composition	Ca(OH) <sub>2</sub>	CaO	Ca(OH) <sub>2</sub>
Form	fine powder	granular	slurry
Equivalent Ca(OH) <sub>2</sub> /unit mass	1.00	1.32	0.33 to 0.56
Bulk density (t/m <sup>3</sup> )	0.45 to 0.56	1.05	1.25

Quicklime (calcium oxide) is produced by heating limestone to temperatures above 900 °C to drive off carbon dioxide. The chemical equation is:



Hydrated lime is produced at temperature below 350 °C when calcium oxide (quicklime) reacts with water. For the hydration of 1 tonne of pure quicklime (calcium oxide), approximately 320 litres of water is required. The chemical equation is:



Application of any of the above limes has several advantages and disadvantages:

### 3.3.1 Quicklime:

**Advantages:** Compared to hydrated lime, quicklime is a more concentrated lime containing 20% to 24% more available lime oxide content. Therefore, if the moisture content of the mix is enough to allow full hydration of the lime, 3% of quicklime has an approximate effect as 4% of hydrated lime. Bulk density of quicklime is greater than hydrated lime (see Table 1), therefore less volume of quicklime is required. Quicklime is the best lime to be used for drying soft soils due to higher chemical reaction of lime with water and higher heat production. Compared to hydrated lime, quicklime has larger particles generating less dust during application.

**Disadvantages:** Approximately 32% (of lime weight) of water is required to convert quicklime to hydrated lime. This can be an issue in the areas where limited water sources are available. Quicklime is also much more dangerous when using as an additive. Reaction of lime, particularly quicklime, with water generates heat which can cause thermal burns to eyes and skin. This reaction and lime dust can create breathing issues if proper protective equipment is not worn.

### 3.3.2 Hydrated Lime

**Advantages:** Compared to the lime slurry, dry hydrated lime can be applied more rapidly and can be used to dry soft soils containing high moisture contents, but it is not as effective as quicklime unless higher percentage of lime is used. However, it is a safer product to use compared to Quicklime.

**Disadvantage:** Particles of the hydrated lime are fine and create dust during the application. Stray dust can drift offsite causing impacts to the general public (cases of washing on clothes lines damaged by drifting quicklime dust have been reported). Therefore, application of hydrated lime in populated zones is generally unsuitable.

### 3.3.3 Slurry Lime

**Advantages:** Slurry lime is a dust free lime and requires less additional water compared to quicklime and hydrated lime. It is also easier to spread it and to achieve even distribution through the soil.

**Disadvantages:** Higher cost and slower application rate are the main disadvantages of slurry lime. It is also not practical to use slurry lime to dry the soils and to modify soft soil with high moisture content.

### 3.3.4 Agricultural Lime

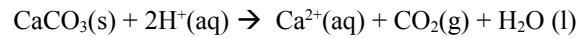
Based on experience with treatment and neutralisation of Acid Sulfate Soils, a fourth type of lime, fine powdered agricultural lime, was also investigated through the trial.

The effects of Agricultural (Ag) Lime on soil (Wikipedia, 2018) are:

- Increasing the pH of acidic soil - in other words, soil acidity is reduced and alkalinity increased
- Providing a source of calcium and magnesium for plants
- Permitting improved water penetration for acidic soils
- Improving the uptake of major plant nutrients (nitrogen, phosphorus, and potassium) of plants growing on acid soils

Fine powdered Agricultural Lime is commonly used to neutralise ASSS materials (ASSMAC 1998) but acts in a buffering capacity, active when the pH lowers. The Agricultural Lime used was pure ground calcium carbonate (limestone), unheated/treated, and comprises 98% CaCO<sub>3</sub> and 0.9% MgCO<sub>3</sub>.

Ag Lime reacts with acids as follows:



It was assessed that whilst the use of Ag Lime to stabilise soils for geotechnical purposes is not commonly done and may not achieve any strength gain, a field check of this effect was assessed to be worthwhile given carrying out such a trial in conjunction with the main trial was relatively cost effective. Also, a field check of the effectiveness of the required percentage of Ag Lime necessary to achieve neutralisation of the ASSS was to be investigated which provided valuable data for future ASSS Management onsite.

### 3.3.5 Summary

Selection of any of the above limes depends on the following factors:

- Type of the soil requiring treatment;
- Soil moisture content;
- Climate conditions;
- Population in the proximity of the site;
- Workers experience;
- Cost of project;
- Available machinery;
- Volume of lime needed; and
- The purpose of treatment (Modification and drying and/or stabilisation, or neutralisation).

### 3.3.6 Summary

Of the three type of lime used for geotechnical treatment, Hydrated Lime was chosen as the preferred additive due to the relative safety of use in construction whilst also being able to dry the soil and increase soil strength.

Fine powdered agricultural lime (Ag Lime) was also chosen as an additional additive for the reasons stated above.

## 3 FIELD TRIAL WORKS

The future harbour floor was originally designed to be excavated to about RL -4.0m (AHD). However, the logistics of doing this in a complex geological environment were initially quite challenging and significant excess ASSS materials were to be produced from the harbour excavation.

It was known that high value engineering fill materials needed to be sourced for bridging, structural, and preload fills in adjacent areas. Therefore, rather than only excavating the harbour to RL-4.0m (AHD), it was theorised that over-excavation of the harbour floor area could be carried out to provide most of these high value engineering materials and to provide storage volume for disposal of ASSS materials below water level (rather than to offsite disposal areas). The main issue with doing this was how to emplace the ASSS materials in the harbour floor area.

The concept of staged over-excavation deeper than the harbour floor, removal and placement/stockpiling of the high value engineering fill materials and placement of ASSS within disposal cells was formulated, and this method of construction was investigated as part of the field trial.

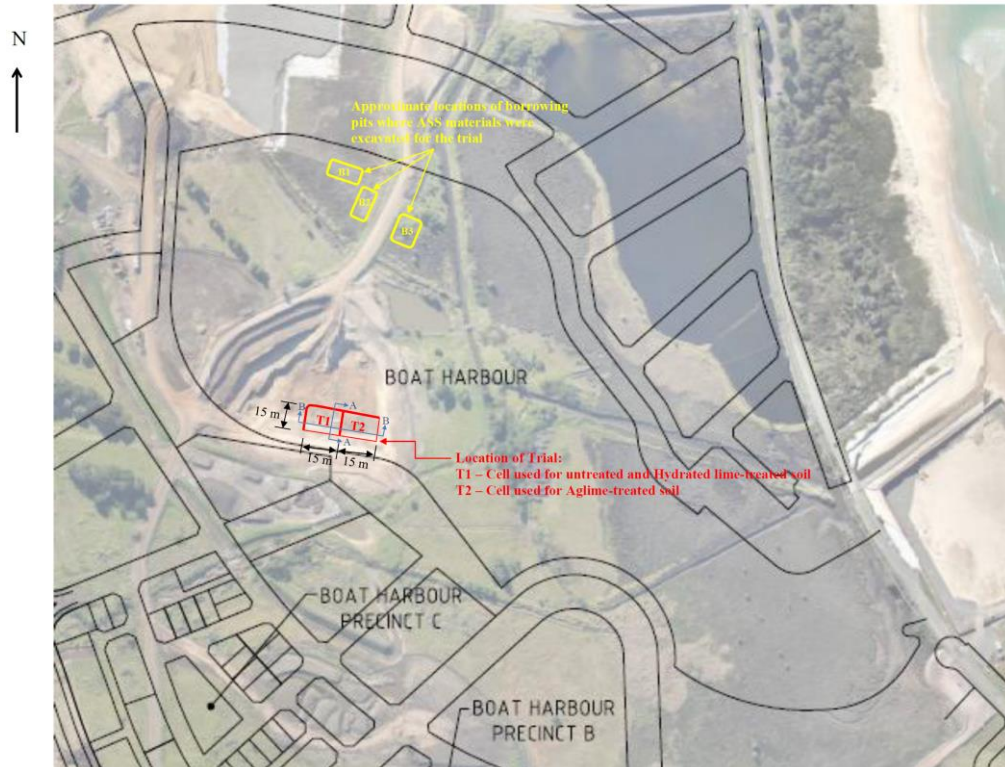
At the time of the field trial, the proposed Boat Harbour was designed to be excavated to a depth of RL-8.5m (AHD). The excavated Boat Harbour zone was then designed to be refilled back to -4.0m RL mainly using ASSS material. The field trial was carried out to assess the practicality and workability of the placement of non-treated ASSS material and lime-treated ASSS material at these depths onsite.

### 4.1 TRIAL AREA, BUND SIZING AND GENERAL ARRANGEMENT

The trial area was carried out within the Stage 1 portion of the Boat Harbour construction site in 2013. The site was chosen as the trial floor and base areas were entirely within residual soil or weathered rock. Groundwater

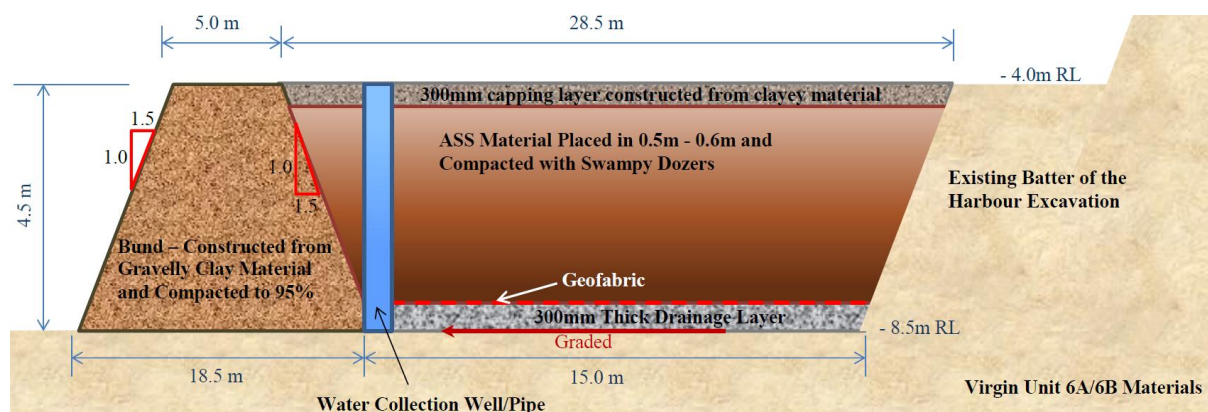
continuously flowed upwards from the floor area but was being controlled through drainage to sumps and pumping.

Figure 1 shows the approximate location for the trial. It was divided into two cells which were located within excavated western portion of the Boat Harbour. The size of each cell was approximately 15m × 15m at the base. Coarse drainage rockfill was placed over the floor area of each cell and the rockfill was interconnected to allow dewatering to occur and prevent upwards saturation through from the floor of each bund.



**Figure 1 - Location of Trial Cell and ASSS borrow areas within Shell Cove Boat Harbour footprint**

Figures 2 and 3 show the typical cross sections of the cells and size of the bunds. These figures show the planned final cross sections of the cells filled with ASSS material and capped with a clayey capping layer. However, each cell was only filled by two soil layers having a total thickness of approximately between 1.5m to 2.0m.



**Figure 2 - Planned work - Section A-A of the Trial**

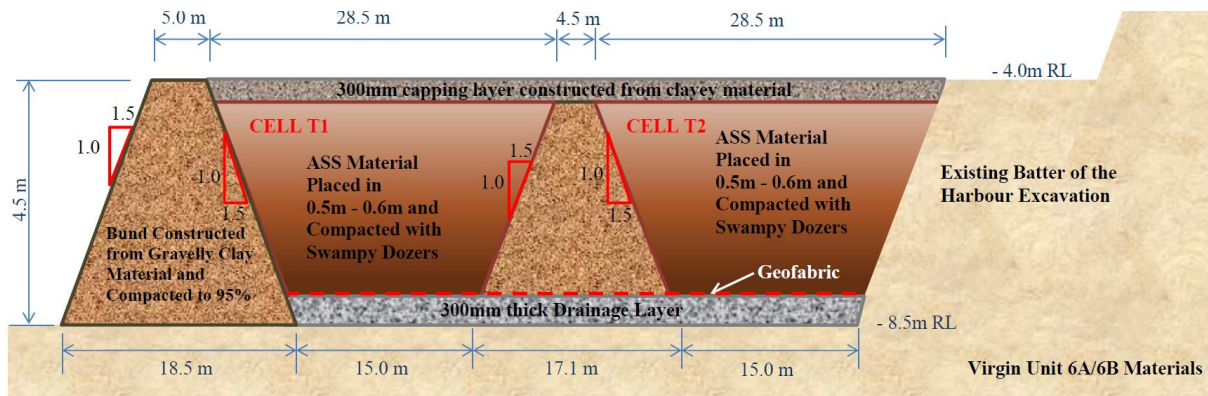


Figure 3 - Planned works - Section B-B of the Trial

The final thickness of fill material placed within each cell during trial work is shown in Figure 4.

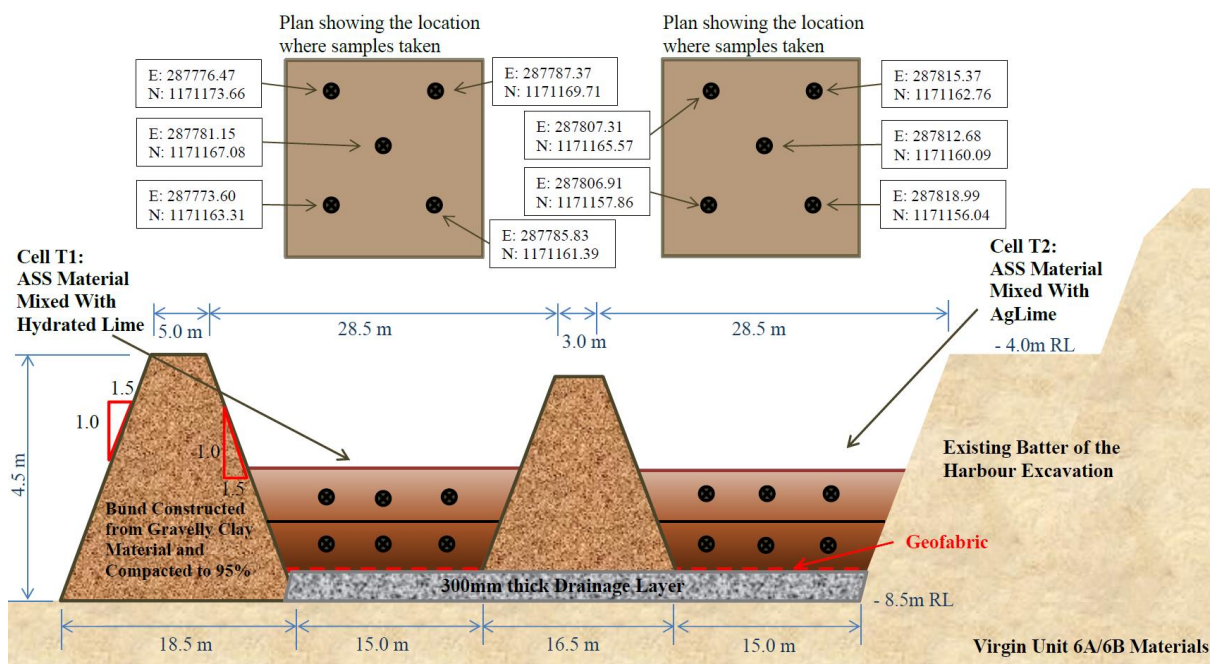


Figure 4 - Actual works - Section B-B of the Trial

NOTE:  
 (1) Samples for pH testing were taken from app. 50mm to 100mm below the surface of each layer.

Bunds were constructed using gravelly clay materials (Unit 4) by placing and compacting them in layers no more than 250mm thick. Each layer was compacted to a minimum dry density of 95% of Standard Compaction. Batter slopes of the bunds were constructed to a slope not greater than 1.5H:1V.

An assessment of the stability of the bund construction with Slope/W assuming a 25kPa uniformly distributed load at the crest assessed the Factor of Safety to be in excess of 1.3. It should be noted that during movement of the long reach excavator over the constructed bunds, some damage to the top of the bunds occurred. Formation of the bunds by leaving in-situ materials in place (rather than reconstruction of filled bunds) could potentially reduce this effect due to the presence of rock strength materials within some portions of the bunds.

#### 4.2 GENERAL FILLING ACTIVITIES ADOPTED FOR PLACING ASS MATERIAL

To construct the bunds and to place the ASSS material within the trial cells, the following procedure and steps were adopted to best achieve the objective of the trial:

- 1) Three bunds (northern, western, and middle bunds, see Figure 1) were constructed to bund and divide the trial area to two cells (See Cells T1 and T2 in Figure 1 and Photo 1(a) and Photo 1(b)).
- 2) The southern and eastern bund walls and the bund floor comprised insitu soil and rock that had been formed as permanent works for the future harbour excavation. It should be noted that the floor of the bund area was at about RL-8.5m AHD. Significant groundwater was flowing out of the bund floor areas during the trial, requiring continual dewatering.
- 3) The northern, western and middle bund walls were constructed using controlled fill materials. In-situ density testing on the compacted material was carried out by the contractor to make sure that the adequate degree of compaction achieved for each layer before placing and compacting the next layer.
- 4) Photo 1(a) and Photo 1(b) shows the trial cells after completion of the bunds. Photo 1(b) shows the location of the pump that was installed at the north-east corner of cell T2 to pump the collected water out of the cells;
- 5) After constructing the northern and western bunds and before constructing the middle bund, a 300mm thick drainage layer was placed at the base of the cells passing under the middle bund (see Figures 2 and 3). This layer was placed to drain the water towards the water collection location at the north-east corner of the cell T2 (see Figure 2 and Photo 1) where the water was collected and pumped out of the cell and was tested for the acidity to be neutralised when and if necessary prior to discharge. This drainage layer was constructed using crushed rock;
- 6) A Geofabric layer was then placed on top of the drainage layer to prevent ASSS material migrating into and clogging the drainage layer (see Photo 1);
- 7) ASSS materials were then excavated from the borrow locations (see Figure 1 and Photo 2) using a long reach excavator and transported to the trial cells by trucks. The material was then dumped within the cells and spread by long reach excavator (see Photo 3 and 4);
- 8) For the lime-treated soils, a small excavator was used to spread one bag of Aglime or Hydrated lime (weighing about 1.0 tonne which was approximately 4% of the soil dry density) per truckload of ASSS materials. Each truckload was a Moxy truck capable of holding about 40 to 50 tonnes of soil. The lime was placed on top of the truck load when it was dumped within the cells, and then mixing of the soil with lime was carried out by a long reach excavator;
- 9) Following placement of enough material for one layer (approximately 1.0m thick) within each cell (and mixing with lime for the lime-treated cases), a long reach excavator was used to better mix the soil and spread it over the cell to achieve a relatively uniform thickness across the cell. The long reach excavator was also used to compress and compact the soil as much as possible using back of its bucket.
- 10) The above steps were repeated for the placement of second layer within each cell after carrying out pH and Hand Vane Shear testing from the already placed layer. Before placing the second layer, a swampy dozer was used on top of the first layer to see whether it could easily travel and properly move/push the material above the first layer.



(a)



(b)

**Photo 1: Trial cells after completion of the bunds.**



**Photo 2: Extent of excavation for borrowing pit B1 and location of Jarosite layer.**



**Photo 3: ASSS material midway through being dumped within trial cell by trucks.**



**Photo 4: Long reach excavator spreading and compacting soils within trial cell T1.**

### 4.3 DETAILED FILLING ACTIVITIES ADOPTED FOR PLACING ASS MATERIAL

Three borrow pits (B1, B2, and B3, see Figure 1 for the locations) were used to source the required ASSS material for the trial works. The borrow pits were generally excavated to a depth of 2.5m below the existing ground surface level (after stripping off the vegetation) at the time of excavation. The borrow pits excavated through Actual Acid Sulfate Soil (AASS) and Potential Acid Sulfate Soil (PASS). The following is a summary of the activities carried out in relation to the excavation of the borrow pits:

- 1) Excavation of the pits started at borrow pit B1. Excavation started from its western side and progressed towards the east on 2 September 2013. Photo 4 shows the excavated pit (completed to the entire extent on 3 September 2013) and the location of the Jarosite layer. Excavated material from this pit (which comprised a mixture of AASS and PASS) was transported and placed within cell T1 on the same day. After placing the material within cell T1, it was attempted to use a swampy dozer to spread and compact the material across the cell but this was not successful as the material was too moist, disturbed and had low shear strength (not enough to support the pressure of the swampy dozer), and the dozer sank into the material after few passes. Photo 5 shows the swampy dozer when it stuck within the material and attempted to get out of the cell.



**Photo 5: Unsuccessful attempt of swampy dozer to spread and compact untreated material within cell T1**

- 2) Following unsuccessful attempts of the swampy dozer to travel on top of the material, a long reach excavator was used to spread and compact the material within the cell. Photo 6 shows cell T1 after placement of the first layer (untreated ASSS material) which was spread and compacted using the long reach excavator. The average thickness of this layer was approximately 1.0m.



**Photo 6: First layer of untreated ASSS material placed within cell T1**

- 3) On 3 September 2013, excavation of the borrowing pit B1 continued further to the east and the excavated ASSS material (mixture of AASS and PASS) was transported to cell T2 where it was planned to place lime-treated material. Because of the availability of the Agricultural lime (which was already being used to neutralise the Acid Sulfate Soil) onsite, it was decided to initially examine the effectiveness of the Aglime to modify and dry the soil. It was already understood that Aglime is more environmentally friendly than hydrated or quicklime in terms of its ability to neutralise ASSS material whilst being much less soluble in water. However, the extent of its effectiveness from a geotechnical perspective was not clear. Following the placement of the material within the cell, adopting the same procedure as it was adopted for cell T1, approximately 4% (based on the soil dry density) Aglime was spread and mixed with the soil. A small excavator was used to spread and mix the lime with ASSS material. Photo 7 shows the process of spreading and mixing the lime with soil using a small excavator.



**Photo 7: A small excavator spreading and mixing Aglime with ASSS material for the first layer placed within cell T2**

- 4) After placing the material within the cell, a long reach excavator was used to better mix and then spread and compact the material across the cell to achieve a relatively uniform 1.0m thick Aglime-treated ASSS material layer. Photo 8 shows how the long reach excavator carried out mixing, spreading, and compacting the material within cell T2.



**Photo 8: Long reach excavator mixing Aglime with ASSS material and then spreading and compacting it for the first layer placed within cell T2**

- 5) The ASSS material used and placed for the first layers within both cells T1 and T2 was a mix of AASS and PASS. This mixture was placed within cell T1 without any treatment and within cell T2 as Aglime-treated material. It was then planned to use only PASS material and treat it with Aglime and then place it as second layer within cell T2. So, on 9 and 10 September 2013 the second borrowing pit (B2, see Figure 1) was excavated to source the PASS material required for the second layer to be placed within cell T2.
- 6) On 10 September 2013, the pump installed within cell T2 was not functioning for about 2 to 3 hours resulting ground water inflowing and filling both cells T1 and T2 and the water covered the surface of a portion of the material placed within these cells. Photo 13 shows the cells during the period when the pump was not functioning. The pump was fixed and started operating and the water was drained off the cells before placing additional material in. When the water was completely drained off the cells then PASS material excavated from borrowing pit B2 was transported, dumped, and mixed with about 4% Aglime and then spread and compacted into the trail cell T2 to form the second layer (approximately 1.0m thick) within this cell adopting exactly the same procedure as it was adopted to place the first layer within this cell.
- 7) As discussed above, the original plan was to use Hydrated lime to modify and dry the ASSS material for the trial works. After observing that the untreated and Aglime-treated ASSS materials did not obtain the minimum required shear strength (even after few days) to support the load of the swampy dozer, it was decided to change the functionality of the cell T1 to be used to test Hydrated lime-treated ASSS material. Therefore, following steps were carried out:
  - On 12 September 2013, about 4% Hydrated lime was mixed with the ASSS material already placed within cell T1 using a small and a long reach excavators. The small excavator first spread the lime on the surface of the material within the cell and then the long reach excavator was used to mix, spread and again compact the material within the cell. Photo 14 shows the long reach excavator during the process of mixing Hydrated lime with the first layer of ASSS material placed within cell T1;
  - It was decided then to leave this material for few days to dry out and to gain shear strength and then attempt the swampy dozer to see whether it can travel on top the material or not. Unfortunately, there was a heavy rain few days after placing this layer and water filled the cell (see Photo 15). As

a result, the material became too wet and the swampy dozer could not attempt to travel on top of the material as it was planned;

- The rain water gathered within the cells was pumped off the cells after being there for few days. Then, on 25 September 2013 (which was 13 days after mixing hydrated lime with the first layer placed within cell T1), a swampy dozer attempted trafficking on top of the treated material with success. It should be mentioned that at that time still some water existed within the north-east corner of the cell (that was not drained from the previous water covering the soil within the cell) and the material over there was completely loose in a form of a thick slurry; however, the rest of the material was dry enough and gained enough shear strength through addition of hydrated lime to support the pressure of the swampy dozer even after temporary burial beneath rain water (see Photo 16).



**Photo 13(a): Cell T2 filled partially with groundwater that rose from the floor of the cell during a period on 10 September 2013 when pump was not functioning.**



**Photo 13(b): Cell T1 filled partially with groundwater that rose from the floor of the cell during a period on 10 September 2013 when pump was not functioning.**



**Photo 14: Long reach excavator mixing Hydrated lime with layer 1 of ASSS material within cell T1**



**Photo 15: Rain water that filled cell T1 after placing the first layer of Hydrated lime-treated ASSS material**



**Photo 16: Swampy dozer successfully travelling on top of the first layer placed within cell T1 and treated by Hydrated lime**

- 8) On 26 and 27 September 2013, borrowing pit B3 was excavated (and also the southern side of the pit B2) taking both AASS and PASS material and mixing them with about 4% Hydrated lime and placing them within cell T1 as the second layer within this cell. The thickness of this layer was approximately 1.0m. The procedure adopted to place this layer was slightly different from the one adopted to place the previous layers within cells T1 and T2. This time, the Hydrated lime was spread over the dumped material within the cell and then swampy dozer was immediately used to mix, spread and compact the material. The reason doing that was to examine the immediate effect of the Hydrated lime on the material improvement. It was observed that the adopted procedure worked quite well and the swampy dozer could easily mix and spread the material without excessive sinking into the material. However, the following was noted:
- pH testing was carried out onsite to distinguish AASS from PASS; however, the material encountered from borrowing pit B3 looked like there was some ASSS mixed with some alluvial brownish material and also the consistency was somewhat stiffer than the material encountered from borrowing pits B1 and B2;
  - The material encountered from pit B3 had a lower moisture content compared to the material excavated from pits B1 and B2; and
  - Because of the above two reasons, it was decided to excavate some material from pit B2 which was then mixed with the material sourced from pit B3 to achieve a more similar consistency and moisture content between these materials and the material placed within the trial cells for the previous layers.

Photo 17 shows the swampy dozer tracking on the second layer (Hydrated lime-treated ASSS material) placed within cell T1 and spreading and compacting the material.



**Photo 17: Swampy dozer successfully travelling on top of the second layer placed within cell T1 (treated by Hydrated lime) immediately after placement**

- 9) On 9 October 2013, 12 days after placing the second layer (Hydrated lime-treated) within cell T1 the swampy dozer was again driven on top of the material placed into this cell to examine any additional increase in shear strength of the soil. It was observed that the waiting time after mixing Hydrated lime with the soil is an important factor. With increasing the waiting time the material will further dry and gain additional shear strength enabling soil to carry out higher loads with less deflection. Photo 18 visually shows these improvements when the swampy dozer was moving on top of the second layer placed within cell T1. Comparing Photos 17 and 18 clearly shows the effect of time on moisture content decrease and gain in shear strength when soft soil material is mixed with Hydrated lime.
- 10) Considering the above (and noting that the swampy dozer successfully travelled on top of the first Hydrated lime-treated layer placed within this cell) indicates that the procedure adopted to dry and modify the ASSS material using Hydrated lime was successful for the adopted construction procedure and for the weather conditions when the trial work was carried out.



**Photo 18: Swampy dozer successfully travelling on top of the second layer placed within cell T1 (treated by Hydrated lime), 12 days after placement. Note compared to Photo 17, soil surface is tight and strong.**

#### 4.4 TESTING AND RESULTS

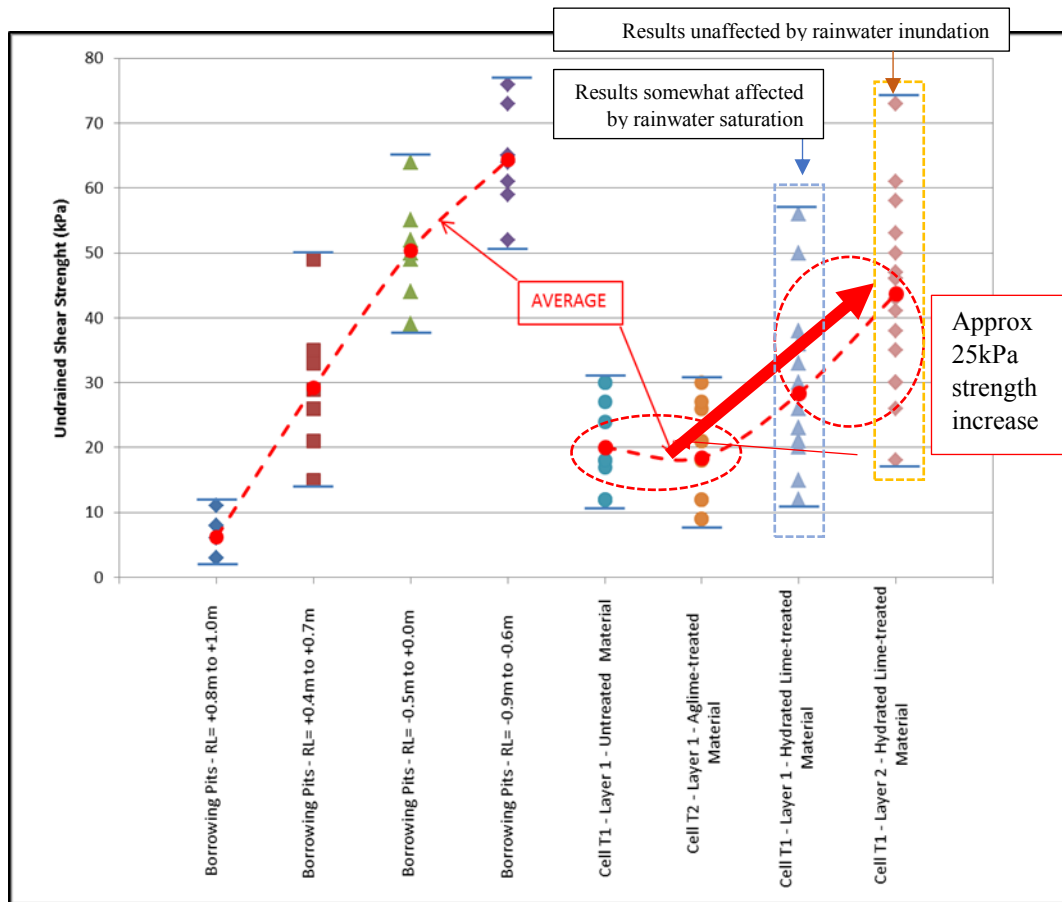
Geotechnical testing included

- Vane Shear tests within borrowing pits B2 and B3 at different depths and within the material placed into the trial cells. In all locations, testing was carried out at about 200mm below the soil surface
- Within the borrow pits, testing was carried out on ‘insitu’ soils that had not yet been disturbed
- Hand Vane Shear testing was used to test the undrained shear strength of the first layers placed into the trial cells T1 (for untreated ASSS material) and T2 (for the Aglime-treated ASSS material).
- Hand Vane Shear Tests were carried out within the first and second layers of Hydrated lime-treated material placed into the trial cell T1 as follows:
  - For layer 1, shear vane strength testing was not carried out straight after mixing with hydrated lime and placement of the layer. Testing was going to be carried out several days afterwards to check the strength gain, but heavy rainfall occurred several days after placement. Testing of layer 1 was carried out on 27 September 2013 *after the layer had been buried/saturated from rainfall* (see photo 15). Therefore layer 1 was left until rainfall had finished and the accumulated water could be removed, which was 14 days after initial placement.
  - For layer 2, shear vane strength testing was carried out on 27 September, immediately after mixing with Hydrated Lime, about 15 minutes after initial placement and track rolling of layer 2 with the swampy dozer.

Figure 6 graphically shows the changes in undrained shear strength of the various soils observed as part of the trial. This figure compares the undrained shear strength within borrow pits and the measured undrained shear strength of the material placed within the trial cells for the cases of untreated and lime-treated material. The following observations are made:

- average shear strength of the in-situ material increased with depth within the borrow pits.
- The strength increase in layer 2 immediately after initial mixing with hydrated lime was significant. There was, on average, a 225% increase in undrained shear strength when comparing initial untreated strength (~20kPa) to strength immediately after mixing with Hydrated Lime (~45kPa). This amount of immediate strength increase made a significant difference to immediate traffickability.
- Based on observation carried out on 9 October 2013, the soil had increased in strength significantly even further. No testing was carried out, as based on visual observations the undrained shear strength was easily sufficient to allow passage of the swampy dozer. It was estimated that an undrained shear strength of greater than 150kPa was achieved in the mixed soil.

- The benefit of using Hydrated lime (compared to the untreated or Aglime-treated material) to increase the undrained shear strength is clear from this testing and from this Figure 6. Hydrated lime is effective in providing strength gain, whereas the addition of aglime treatment showed no increase in strength



**Figure 6: Undrained shear strength measured within borrowing pits and different layers placed within trial cells**

#### 4.5 ENVIRONMENTAL TESTING RESULTS

The pH of the material excavated from the borrowing pits was measured onsite at different depths to assess the approximate boundary between the Actual and Potential Acid Sulfate Soils and to obtain an understanding of the approximate average pH of the ASSS material as a base line before placing them within trial cells. In addition, the pH of the material was measured after a few days or immediately after placement of the material within the cells to assess the approximate average pH of the AASS and PASS material being mixed and placed into the cell with or without treatment with lime (including both Aglime and Hydrated lime). Also, some samples taken from the borrowing pits B1 and B2 were sent to the laboratory for Chromium Reducible Sulfur testing to assess the properties of the Acid Sulfate Soils and to recheck the presence of AASS and PASS material at the location of borrowing pits. During the progress of the trial works, the water collected at the north-east corner of cell T2 was also periodically tested (Testing carried out by Contractor) for acidity in case if neutralisation was necessary.

The pH testing results can be summarised as follows:

##### Borrow Pits

- The initial pH of the AASS ranged between 3.92 and 4.56;
- The initial pH of the PASS ranged between 4.99 and 7.04;

## Trial Cells

Untreated ASSS materials:

- The initial pH of the untreated mixed AASS/PASS soil ranged between 4.45 and 6.63;

Aglime treated materials:

- The initial pH of the Aglime-treated mixed AASS/PASS soil ranged between 4.69 and 6.55;

Hydrated lime treated materials:

- The initial pH of the Hydrated Lime treated mixed AASS/PASS soil ranged between 10.99 and 11.67 within an hour of mixing
- The final pH of the Hydrated Lime treated mixed AASS/PASS soil measured between one to two weeks after initial mixing ranged between 9.20 and 11.30.

Groundwater:

- It should be noted that the main source of water from the pump-out well was the water flowing up and out of the formation (rock materials) below each cell. The volume of water pumped out of the dewatering well was a significant volume of water over the course of the field trial and therefore was expected to be close to pH neutral.
- The pH of the water measured from the pump-out well (as measured by Contractor) ranged between 6.2 and 6.5.

## 4 DISCUSSION

To place the soil “in the moist condition” within an excavation cell, ASSS material needs to be excavated, transported, dumped, spread, and compacted within the excavation zone as rapidly as practicable. This reduces the risk of the exposure of the ASSS material to air and subsequent production of acidic materials through oxidation of pyritic minerals within the soil.

The purpose of the trial was to assess the practicality and workability of the placement of ASSS material within the harbour excavation from a geotechnical point of view as the first priority. The secondary purpose of the trial was to also carry out some acidity testing (for environmental purposes) to generally estimate the effects of the adopted placement procedures on the production of acidic material. This testing was carried out to provide general information and inform responsible parties for the measurement and management of Acid Sulfate materials, as part of an overall Acid Sulfate Soil Management Plan (ASSMP).

### 5.1 GEOTECHNICAL ASPECTS

#### 5.1.1 Workability of untreated, Aglime-treated, and Hydrated lime-treated ASSS material

It was visually and practically observed and assessed that if the ASSS material is placed within the Boat Harbour excavation as untreated or Aglime-treated material, the soil will not have the minimum required shear strength and bearing capacity to support the transferred load from the construction machinery such as swampy dozers. Therefore, after dumping the material within excavation zone, swampy dozers cannot track over and spread or compact the material.

Based on the reaction equation for Ag Lime, upon reaction with acids in the form of hydrogen ions ( $H^+$ ), Ag Lime produces water. This is geotechnically adverse: additional water decreases undrained shear strength of soils. This is the reason that no additional strength benefit was gained from addition of Ag Lime to the soil. A slight decrease in strength from ~20kPa to ~18kPa was noted from addition of Ag Lime to the soil as seen in Figure 6 and this supports this conclusion. Therefore it is concluded that if strength increase in ASSS soils is desired, Ag Lime should not be added to soil emplacements as *if Ag Lime is added, a strength decrease below the initial strength will likely occur.*

To overcome this issue, if the material needs to be placed in untreated form and “in the moist” condition, the only practical method was thought to involve excavation of the Boat Harbour floor areas in ‘cells’ leaving in-situ bunds similar to those used in the trial work but comprising in-situ undisturbed soil and rock materials. These bunds can

then be used as access tracks for the trucks and long reach excavators to dump and spread the material. The minimum required width for the bund at the top should not be less than 6.0m to 8.0m to provide safe working access for machinery. The batter slope of bunds involving leaving insitu very stiff to hard soils/weathered rock insitu (compared to bunds constructed as filled bunds as was used for most bunds in this field trial) could allow steeper batters and increased storage volume. A proper arrangement of the bunds and cells needs to be designed to safely place the material within the excavation zone while providing maximum available volume to bury ASSS material under the water.

It was observed that mixing about 4% Hydrated lime with the ASSS material dries and modifies the material enabling swampy dozers to track on and spread and compact (to some extent) the material.

Also, for the Hydrated lime-treated material, the soil moisture content will further reduce with time and also its shear strength will further increase providing better working platform for the machinery. Therefore if a waiting time is planned between the placement of different layers within harbour excavation, this will help with ease of placement of subsequent layers. Comparing Photos 17 and 18 clearly shows the effect of waiting time.

The undrained shear strength increased from about 20kPa up to ~45kPa immediately after addition of Hydrated Lime, and higher strengths were achieved of >150kPa after a ~2 week waiting period. Undrained shear strength is an important factor for design of working platforms and is routinely used in BS8006 (2010). If Hydrated Lime can be successfully added to strengthen such soils then additional construction benefit for other temporary machinery such as tracked excavators and general construction vehicles could be possible.

This trial was limited in scope and different percentages of lime (different to the 4% adopted) could not be added to optimise the additive percentage. It could be possible that a slightly reduced concentration of Hydrated Lime (say 2% or 3%) may achieve a similar outcome to the 4% used in this trial. Further work would be necessary to confirm this. A slight reduction in concentration of added lime would reduce in significant cost savings for works.

### **5.1.2 Consolidation Settlement**

Significantly less consolidation settlement is expected within soils placed “in the moist” compared to those placed in slurry form. Less consolidation settlement is expected from those soils treated with Hydrated Lime compared to those placed in untreated form.

Consolidation behaviour of the ASSS material was not of major interest as the soils were going to be placed within harbour excavation area and not beneath structures or settlement sensitive areas.

The consolidation parameters and behaviour of the following materials would be different:

1. the in-situ ASSS materials
2. the ASSS materials which are transferred to a slurry form
3. the ASSS materials placed into the excavation “in the moist” condition.

The properties of material type 1 and 2 are relatively well known based on insitu testing results and information Morrison and Tait (2007). If the consolidation behaviour of the material excavated and placed into the excavation “in the moist” condition is required, then further assessment would have been required.

## **5.2 ENVIRONMENTAL ASPECTS**

It is known that the soils used for the trial were either Actual or Potential Acid Sulfate Soils.

The initial pH measurements carried out within the untreated and Aglime-treated ASSS mix AASS/PASS material placed within the trial cells does not show major changes compared to the average pH of the in-situ AASS and PASS materials. However, mixing 4% Hydrated lime with the mix AASS/PASS material placed within trial cell T1 shows considerable immediate increase of pH up to approximately 10 to 11.

If Hydrated Lime treatment is to be used for the disposal cells at any construction site, it is recommended that appropriate management measures be adopted to manage potential pH changes.

It is possible that if swampy dozers are used to push around and place the ASSS mixed with Hydrated Lime, that no lime would be necessary for the final layer, as no trafficking of the final layer would be necessary once the soils are filled to the harbour floor level. This also may have the added benefit of provision of an attenuation layer

to potential Hydrated Lime that may be released into the groundwater during subsequent construction flooding of the harbour and over the longer term. There would be cost savings if the final layer of mixed ASSS with the cells is placed without the addition of lime.

### 5.3 ALTERNATIVE METHODS USED DURING CONSTRUCTION

After this trial was carried out, the Contractor proposed a somewhat different method of placement of ASSS in the over-excavated portions of the Boat Harbour. This method involved using a very wide and long track 'swampy long reach excavator'. The ground pressure exerted on the ground underneath each track was less than the pressure of a human foot on the ground and less than that of a swampy dozer.

This long reach excavator was found to be able to work over the placed soils without using any additive. A photo of this equipment is shown in Photo 19.

The use of this equipment meant that significant efficiencies were gained and significantly larger storage of ASSS per metre of excavation depth was achieved. The bulk of ASSS materials were placed in over-excavation areas between 2014 and 2016 using this technique, and some ASSS materials continue to be placed in overexcavation areas in 2018. At the time that the ASSS placement work was first carried out (2014) the authors understood that this was the first time such 'swampy long reach excavator' equipment was used for a civil engineering application in Australia. This was an example of a 'win-win' for the project and the Contractor should be commended for their collaborative approach to developing an innovative solution and technique in this circumstance.



**Photo 19: Picture of long reach excavator used by the Contractor with large, wide and long tracks used to track out over 'in the moist' ASSS untreated soils**

## 5 CONCLUSIONS

This paper has presented information from a series of field trials for reburial beneath harbour water level of Acid Sulfate Soils. Trials were carried out of both untreated soils and soils treated with either hydrated lime or agricultural lime.

The results of the trials indicated that hydrated lime improved the geotechnical properties of these ASSS materials to a level sufficient for tracking over using a swampy dozer, and agricultural lime had no effect on soil strength at all.

During Construction, the Contractor proposed and used a very wide and long track 'swampy long reach excavator'. This long reach excavator was found to be able to work over the placed soils without using any additive. The use of this equipment meant that significant efficiencies were gained and significantly larger storage of ASSS per metre of excavation depth was achieved.

## 6 ACKNOWLEDGEMENTS

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