

Port of Hastings Development Project

Dredged Materials Management Ground Treatment Options

Port of Hastings Development Authority

April 2015

Final Working Draft

8A30022


In May 2016 the Special Minister of State asked Infrastructure Victoria to provide advice on the future capacity of Victoria's commercial ports. Specifically, the Minister has asked for advice on when the need for a second container port is likely to arise and which variables may alter this timeline. The Minister has also asked for advice on where a second container port would ideally be located and under what conditions, including the suitability of, and barriers to investing in, sites at the Port of Hastings and the Bay West location.

In undertaking this task, Infrastructure Victoria reviewed work that was completed as part of the Port of Hastings development project before it was cancelled in 2014. This document forms part of the initial work undertaken for the proposed port development at Hastings. Infrastructure Victoria considers that much of the previous Hastings work, although preliminary in nature, is relevant and suitable for informing a strategic assessment. Therefore, Infrastructure Victoria has made the reports previously commissioned for the development project part of the evidence base on which Infrastructure Victoria will use in providing the Minister with advice.

The opinions, conclusions and any recommendations in this document are based on conditions encountered and information reviewed at the date of preparation of the document and for the purposes of the Port of Hastings Development Project.

Infrastructure Victoria and its consultants have used the information contained in these reports as an input but have not wholly relied on all the information presented in these reports.

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CONTENTS

	Page
1 INTRODUCTION	1
Background	1
1.1 1	1
1.2 Dredged Material Management	1
1.3 Objectives and Scope	2
2 TECHNICAL FACTORS INFLUENCING THE SELECTION OF GROUND IMPROVEMENT TECHNIQUES	3
2.1 In situ materials to be dredged	3
2.2 Influence of dredging processes	3
2.2.1 Cutter suction dredger (CSD) with hydraulic transport	4
2.2.2 Backhoe dredger (BHD)	4
2.3 Performance Requirements	4
2.4 Dredging, Construction and Port Delivery Programme	5
3 TREATMENT METHODOLOGIES FOR CSD GENERATED SLURRY PONDS / LAGOONS	7
3.1 Discharge into closed cell settlement pond with no treatment (do nothing option)	7
3.2 Discharge into shallow areas for natural dewatering (“ripening”)	7
3.3 Accelerated Consolidation	8
3.3.1 Capping layer and construction platform	8
3.3.2 Installation of drainage	10
3.3.3 Application of surcharge load	11
3.4 Admixtures	12
3.4.1 Mass stabilisation (including shallow cement mixing)	12
3.4.2 Cemented Soil Placement	13
3.5 Electro Osmosis	13
3.6 Evaluation of Improvement Techniques	14
4 TREATMENT METHODOLOGIES FOR CSD GENERATED SAND / CLAY BALLS	16
4.1 Preload Surcharge with or without Vertical Drains	17
4.2 Vacuum Consolidation	18
4.3 Vibrocompaction / Vibroflotation	18
4.4 Vibroreplacement (Stone Columns)	19
4.5 Dynamic Compaction	20
4.6 Dynamic Replacement	21
4.7 Rapid Impact Compaction	22
4.8 Impact Rolling	22
4.9 Deep Soil Mixing	23
4.10 Jet Grouting	24
4.11 Controlled Modulus Columns	25

4.12	Deep Foundations or Piling	25
4.13	Evaluation of Improvement Techniques	26
5	TREATMENT METHODOLOGIES FOR BACKHOE DREDGING	29
6	CONCLUSIONS	30
7	REFERENCES	32

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1 INTRODUCTION

1.1 Background

In 2012 the Victorian Government established the Port of Hastings Development Authority (the Authority) to investigate the development of a second container port at Hastings. The Authority is progressing staged planning of the Port of Hastings Development Project (the Project) from 2014 to 2018, culminating in a preliminary business case and environmental and social impact assessment. It is envisaged that the container port will begin operations in the mid-2020s with a capacity of 3 million twenty-foot equivalent (TEU) per year, increasing to 9 million TEU by 2060

1.2 Dredged Material Management

Port Development will require a significant quantity of capital dredging. The management of dredged material is a key component of the port development as it will be one of main drivers for capital expenditure. Management of dredged material will also be a key consideration in the environmental impact assessment for the project.

It is intended that, if feasible, a proportion of the dredged material will be beneficially reused as fill within land reclamation. The management of this proportion of the dredged material falls within the scope of the Dredging and Reclamation Design work package (WP 26). The remainder of the dredged material, considered either unsuitable for use as reclamation material or surplus to the volumetric requirements of reclamation, will be disposed of elsewhere. Management of unsuitable and surplus material (hereafter referred to as DMM material) falls within the scope of the Dredged Material Management (DMM) work package (WP 22).

Materials placed in the land reclamation area and DMM materials disposed of on land will each require ground improvement. See the flow diagram in Figure 1 below.

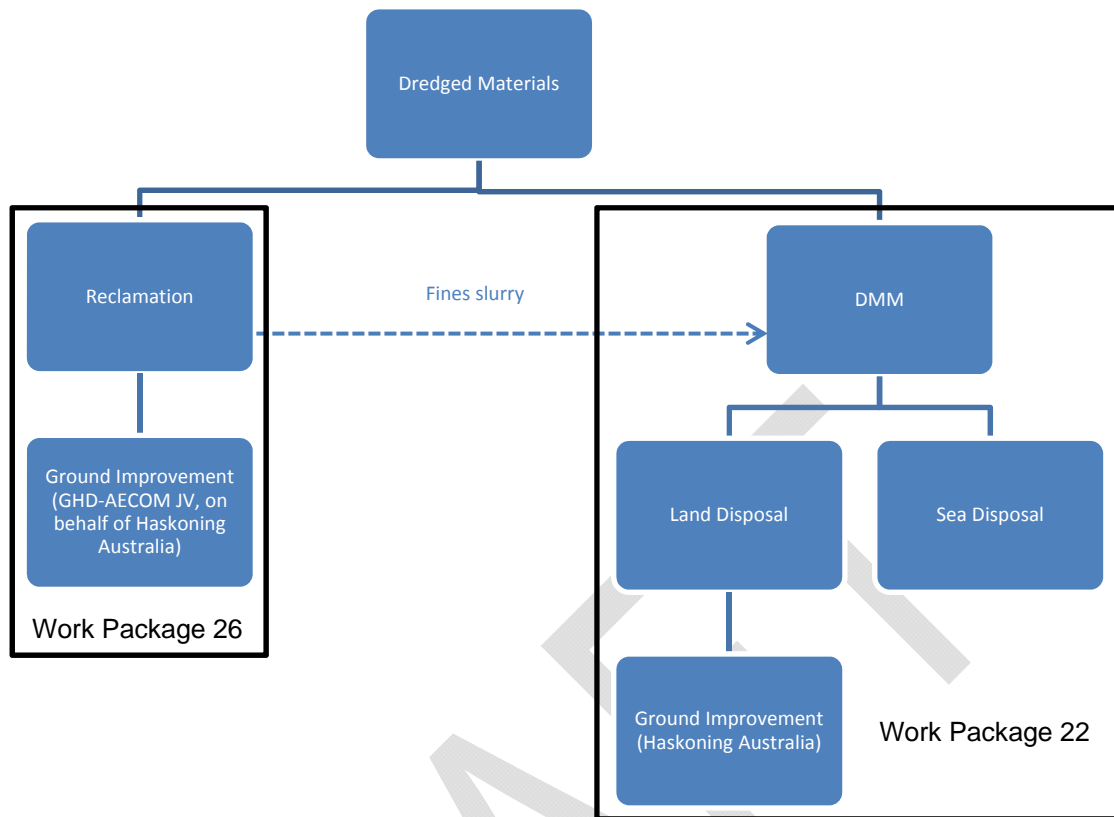


Figure 1 – Total dredged materials management and ground improvement flow diagram

1.3 Objectives and Scope

This Report outlines possible methodologies for ground improvement of dredged materials transported to land as part of the Dredged Materials Management (DMM) work package (WP22). A similar Report has been prepared by the GHD-AECOM Joint Venture (JV) (WP26) setting out possible ground improvement methodologies for the dredged materials transported to the reclamation area (AECOM GHD JV, 2015).

2 TECHNICAL FACTORS INFLUENCING THE SELECTION OF GROUND IMPROVEMENT TECHNIQUES

The selection of suitable ground improvement techniques for the DMM material disposed of on land will be influenced by a number of technical factors. The key technical factors include; the composition and consistency of the DMM material, the final ground performance requirements of the DMM material treatment areas, any space limitations for the treatment areas and the project programme requirements (including dredging and construction programme). These factors are the subject of, or will be dependent on the outcomes of, other work packages currently being undertaken.

The following sections discuss the key influencing factors for the selection of ground improvement methodologies for the DMM material.

It is noted that there are other factors, both technical and non-technical which will impact the selection of ground improvement techniques. These include, but are not limited to, environmental impacts, cost implications, noise, vibration, and visual amenity.

2.1 In situ materials to be dredged

The characteristics of the in situ ground at the site are discussed in the geotechnical interpretive report (AECOM GHD JV, 2014). It is anticipated that the dredging will encounter the following geological units, with soil descriptions in terms of composition and consistency paraphrased from the interpretive report:

- Quaternary marine deposits - typically comprise very loose and loose carbonate and siliceous Sand, soft and very soft silty Clay and sandy Silt, and loose and very loose silty Sand and clayey Sand.
- Baxter Formation - including variable silty Sand, silty Clay, clayey Sand, sandy Clay, Sand, clayey Silt and Clay materials with the predominant material types being clayey Sand, sandy Clay, silty Sand and silty Clay. The Clay and Silt materials are generally stiff to very stiff and the Sand materials are generally medium dense to dense; and
- Sherwood Formation – consisting of Sand, silty Sand, Silt, sandy Silt, silty Clay and clayey Silt, with local fine to medium grained carbonate shells and shell fragments. Sand materials are medium dense to very dense consistency, clay and silt materials are typically of stiff to hard consistency but also include zones of softer material.

Work is currently underway to further characterise and quantify the in situ material within the areas to be dredged.

2.2 Influence of dredging processes

The dredging process will significantly alter the dredged material characteristics from their in situ state. Suitable dredging techniques are being considered, and a work method options process is currently underway. The two dredging techniques which are currently considered

most suitable for disposal of DMM materials to land are cutter suction dredger (CSD) with hydraulic transport of dredge material to settling ponds, or backhoe dredger (BHD) with mechanical removal of material, transport by barge to shore, removal from the barge by long reach excavator and trucking to a disposal site.

2.2.1 Cutter suction dredger (CSD) with hydraulic transport

It is assumed at this point that the material discharged from the CSD would consist of sand, clay balls and a volume of clay slurry. The sand and clay balls would settle out relatively quickly, the clay slurry would remain largely in suspension and travel with the water flow, settling out more gradually. Consequently, segregation of the sand/clay balls and the clay slurry would occur naturally. Depending on the design of the initial containment area, it is possible that some clay slurry will be trapped with the sand and clay balls.

The conceptual layout of areas to be treated or improved would be:

- Settlement ponds containing high moisture content clay slurry. Treatment methodologies for these areas are discussed in Section 3; and
- Containment areas holding the loose clayey silty sand and clay balls of varying strength. As noted above, some clay slurry may be trapped within these materials; the slurry could be evenly distributed or form lenses. Treatment methodologies for these areas are discussed in Section 4 below.

There is ongoing work as part of other work packages which will further document the anticipated characteristics of the discharged CSD materials.

2.2.2 Backhoe dredger (BHD)

The BHD process would reduce the disturbance of the in situ materials compared to use of a CSD and would not result in large amounts of water being added to the DMM materials. It is considered for the BHD methodology that the dredged material would be end dumped into specific areas for treatment on land. It is envisaged that the material as dumped would be a mixture of:

- Disturbed Quaternary marine deposits;
- Disturbed clayey silty sands from the Baxter and Sherwood formations;
- Pieces or clumps of stiff clay from the excavation of the Baxter and Sherwood formations. These materials will be slightly disturbed but will retain some of their in situ strength.

The treatment methodologies for these materials are discussed in Section 5.

2.3 Performance Requirements

The performance requirements for the areas where DMM material will be disposed of will be a major factor in selecting what ground improvement techniques are required. The performance requirements essentially define the purpose for the ground improvement and establish the level of improvement that will be required.

The performance requirements for the DMM material disposal areas have not yet been defined. It is considered that the requirements will depend, among other things, on the volume of DMM material to be disposed of, the area required to treat and dispose of the material, and the availability of land to the port.

The performance requirements for the DMM materials disposal areas could vary from no ground improvement to needing to be ready in the short term for use within the port precinct. The performance requirements for three possible end uses have been considered below.

- **Restricted access land** – This land would not be useable for any material purpose, nor would it be safe for people or animals to enter. There would be no specific end product performance requirement and the material would be placed in an uncontrolled manner.

For a considerable time this area would be unsafe for people to enter due to the risk of becoming trapped or sinking. It would have to be suitably fenced off to stop people or animals entering the area and would be an ongoing risk to the port until the ground had consolidated sufficiently such that the entry risk was acceptable. This may take decades.

A variation of the above approach would be to plan the disposal area to be developed into a wetland.

- **Public Recreational Space** – This land would be land open to the public for uses as recreational areas, parkland, sports fields etc.

The main performance requirement for this land use is public health and safety specifically that it is safe for trafficking by people and passenger vehicles. High bearing capacity would not be required; there would not be strict settlement criteria as any settlement could be efficiently managed by ongoing maintenance.

- **Varying levels of industrial use.** The detailed requirements would be driven by further port planning.

The performance requirements would be set in terms of allowable settlement, bearing capacity, and pavement characteristics. The reclamation and ground improvement would need to be well engineered and well managed to achieve this end use.

There are numerous options for the end use of DMM material treatment areas; these will be further defined during the planning process. This will in turn define the product requirements in terms of the engineering characteristics of the DMM material treatment area.

2.4 Dredging, Construction and Port Delivery Programme

The dredging programme, construction programme, and delivery of land parcels are likely to be major considerations in terms of choosing appropriate ground improvement techniques.

This will mainly be a consideration for the high fines content soils where traditional ground improvement methods may take long periods to achieve suitable outcomes. In practice, the time taken to achieve ground improvement will need to be balanced against the economy of the method.

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3 TREATMENT METHODOLOGIES FOR CSD GENERATED SLURRY PONDS / LAGOONS

As discussed in Section 2.2.1, the CSD process would generate significant volumes of disintegrated clay mixed with high volumes of water (clay slurry) which would need to be contained within settlement (or slurry) ponds. After filling of the settlement pond, the clay particles would start to fall out of suspension and form a 'settled' clay slurry, with supernatant water above. The clay slurry would be less than normally consolidated and be characterised by extremely high water content and compressibility, and practically no shear strength.

A list of options for treatment of the clay slurry is presented below.

- Discharge into closed cell settlement pond with no treatment (do nothing option)
- Discharge into shallow areas for natural dewatering ("ripening")
- Accelerated Consolidation
- Admixtures
- Electro Osmosis

3.1 Discharge into closed cell settlement pond with no treatment (do nothing option)

The materials could be discharged into closed cell settlement ponds without any further ground improvement. This would involve; the filling of settlement ponds in an uncontrolled manner, draining of supernatant, then leaving the clay slurry in the pond.

This land would not be useable. This area would be unsafe for people to enter due to the risk of becoming trapped or sinking. It would have to be suitably fenced off to stop people or animals entering.

It would be many, many years (probably more than 20 years) before the land area could be considered for reuse. The area may be suitable for development of wetlands.

3.2 Discharge into shallow areas for natural dewatering ("ripening")

A technique that can be used to improve the properties of dredged clay slurries is to discharge the material into shallow containment areas to allow the material to naturally dewater within a reasonable timeframe. This process can be referred to as "ripening". The aim of this process is to improve the characteristics of the clay slurry to a workable state so it can be used in other applications.

Additional measures to improve the "ripening" process can include:

- Preparing treatment areas with underdrainage, e.g. a sand bed, to accelerate the drainage and drying of the slurry. This approach of course needs a supply of clean sand;

- Discharging to settlement ponds, decanting of the supernatant water, then removing the slurry and mixing with other material, such as sand or lime admixtures (see section 3.4) in a separate area to form an engineered material. In certain cases the sand underdrainage layer can be blended with the overlying clay material.

Advantages: Shallow containment areas which do not require large bunds could be used. Additional consumable elements or fill (as would be the case with consolidation technique) are not required. It is relatively cheap. The final product will have improved properties from the initial slurry which should allow it to be workable for further compaction and use on site or removal from site for use in other ways.

Disadvantages: Large amounts of land are required during the ripening process¹. After ripening the materials will not be suitable to build on. The mixed material is still likely to have a high fines content and will require careful handling and compaction to provide a useable end product.

3.3 Accelerated Consolidation

Consolidation techniques improve the characteristics of fine grained soils by increasing settlement of the soils. This reduces the moisture content which in turn increases the strength and decreases the compressibility of the soils. The amount of settlement that can be achieved in a certain time frame is a function of the loading which is applied to the soil, the drainage conditions, the thickness of the compressible layer and the permeability of the soil.

The three main elements that need to be considered for a consolidation ground improvement scheme for the DMM slurry materials are: the construction of a capping layer or working platform over the surface of the materials, installation of additional drainage, and application of a surcharge load. These elements are discussed in more detail below.

3.3.1 Capping layer and construction platform

The slurry pond would first have to be capped with a layer of material to limit surface disturbance and provide a stable platform. The capping layer would need to have sufficient bearing capacity to support the loads from the construction equipment required to install the vertical drains and move the surcharge material around the site (see sections 3.3.2 and 3.3.3 below).

The process of constructing the capping layer would be inherently difficult and may be dangerous owing to the extremely low strength of the clay slurry. There are a number of methods that can be used for construction of the capping layer. Some methods used in example projects are outlined below.

The New Kitakyushu Airport reclamation comprised of dredged clay slurry on top of soft marine clay foundations. This project is of particular interest because it involved reclamation

¹ The typical effective depth of containment areas for ripening is between 1 and 2m. As such, the area of land required for this technique would be 0.5 to 1m² per 1m³ of slurry materials generated.

using dredged clay slurry and hence construction of a capping layer directly onto this material. The capping layer was constructed by placing geotextile over the dredged material, then hydraulically placing sand over the geotextile (Watabe, 2008). See Figure 2 and Figure 3 below.



Figure 2 – Installing geotextile on dredge slurry, New Kitakyushu Airport (Watabe, 2008)



Figure 3 – Hydraulic placement of sand over geotextile, New Kitakyushu Airport (Watabe, 2008)

The Changi East Reclamation Project in Singapore included the reclamation of a large slurry pond. As with the New Kitakyushu reclamation, this project is of particular interest because it involves ground improvement of poor quality dredged slurry material. To construct the capping layer sand was spread across the top of the slurry pond containing 20m of clay slurry using specially designed sand spreaders which could place sand in 20cm lifts (Chu et al, 2009). Schematics of the specially designed spreader pipes are shown in Figure 4 and Figure 5 below.

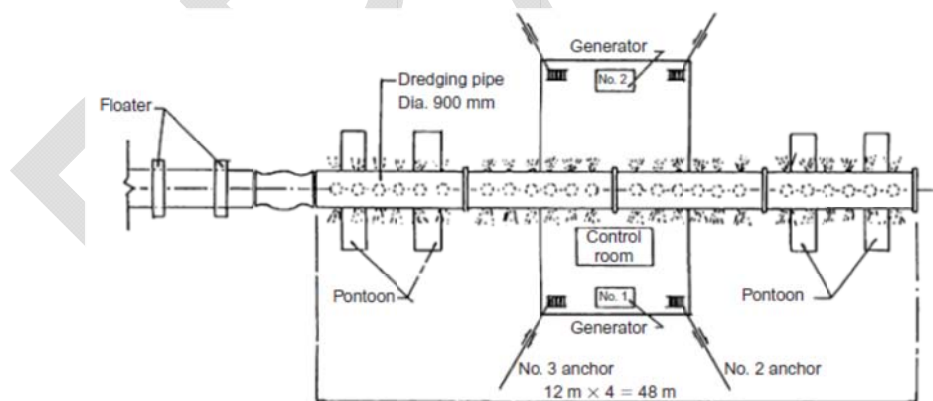


Figure 4 – Layout of specialised sand spreader for construction of a working platform of the Changi East slurry pond reclamation (Chu et al, 2009).

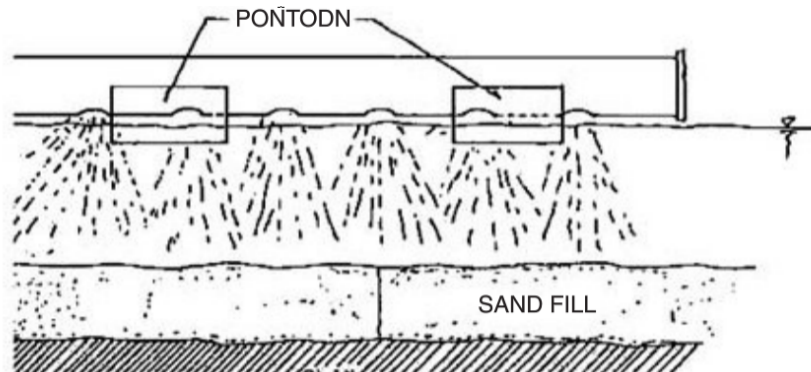


Figure 5 – Schematic of sand placement for construction of the working platform at Changi East Reclamation (Chu et al 2009).

Some other potential methodologies for constructing a capping layer are filling large sandbags on top of the founding material (see Figure 6) and using light equipment to construct the capping layer by hand (see Figure 7). These techniques have been used to construct capping layers on very soft to soft marine clays. They would likely require some strengthening of the surface of the slurry (possibly achieved by installing a geotextile or geogrid, or using chemical additives to form a surface layer).



Figure 6 - Construction of capping layer / working platform using giant sand bags (Pantai Indah Kapuk Jakarta, 2014).



Figure 7 - Construction of capping layer / working platform using light equipment (Pantai Indah Kapuk Jakarta 2014).

3.3.2 Installation of drainage

It is likely that vertical drains would need to be installed to increase the overall permeability of the clay slurry. This, together with surcharging with additional fill, will lead to an increase in the rate of settlement that can be achieved within the construction period. Figure 8 and Figure 9 show the installation of prefabricated vertical drains (PVDs) at the Mubrak Al Kabeer Seaport in Kuwait and Pantai Indah Kapuk in Jakarta.



Figure 8 – Installation of PVDs at Mubrak Al Kabeer Seaport Kuwait.



Figure 9 - Installation of PVDs at Pantai Indah Kapuk Jakarta.

The ground improvement of settlement ponds is unique from typical ground improvement projects because the construction team has control over the deposition of the material. This could allow the installation or implementation of ground improvement components during the deposition of the dredged material. For example, if the settling ponds had to be lined, a drainage layer with horizontal drains directly connected to vacuum pumps could be installed at the base of the settlement ponds prior to filling.

3.3.3 Application of surcharge load

A surcharge load is placed on top of the capping layer. This surcharge can be in the form of a physical surcharge or vacuum surcharge or a combination of both.

The surcharge normally exceeds the maximum design loads in order to effectively reduce the surcharge period and reduce the amount of ongoing settlement after finishing construction. The duration of the surcharge will depend on the spacing of the vertical drains, the permeability of the natural soil and the level of acceptable long term settlement.

Physical surcharge is applied by placing additional material on top of the capping layer. The physical surcharging is generally cheaper when compared with vacuum surcharge and can be carried out using whatever suitable material is available at the site. Surcharge construction and removal is normally phased across a site to avoid the problem of having to import large volumes of fill for surcharging purposes and then at the end of construction being required to dispose of significant volumes of surcharge fill following improvement. The approach of phasing the surcharge construction is commonly referred to as a “rolling” surcharge.

Vacuum surcharge involves applying suction to the ground which acts as an equivalent surcharge to the foundation material. Vacuum surcharging can apply large surcharge loads to the soil and does not require any additional fill at the site; it can also be used in conjunction with physical surcharging if required. The disadvantage of vacuum surcharging is that it is limited to a vacuum load of approximately 80kPa, is expensive and can be hard to maintain.



Figure 10 – Surcharge mound with settlement monitoring marker visible (Pantai Indah Kapuk Jakarta).



Figure 11 – Vacuum surcharging (Sai Gon Hiep Phuoc Container Terminal, Vietnam).

Advantages: Ground improvement by accelerated consolidation (including construction of a working platform, installation of drainage, and application of a surcharge load), may be cost effective if a higher end use for the DMM land area is required. It would significantly reduce the volume of the slurry over time. Other DMM materials may be able to be used for surcharge loading.

Disadvantages: The main challenge is the construction of a capping layer or working platform of a suitable strength to allow installation of the vertical drains and placement of surcharge without punching through into the materials below.

3.4 Admixtures

Using admixtures to stabilise soils is a relatively common ground improvement method. The method involves the mixing of cement, lime or other binders into the in situ ground, which react with the soil to improve its engineering characteristics.

The admixture hydrates using the natural moisture in the ground, drying and strengthening the soil as it does so. It also has a physical binding effect that adds to the improved characteristics of the soil.

3.4.1 Mass stabilisation (including shallow cement mixing)

Mass stabilisation involves the mixing of cement or other binder into the in situ ground. There are a number of mixing techniques available, which are selected on the basis of site conditions and equipment availability. The different techniques involve variations of using dry versus slurry binders, and the setup of the mixing tool.



Figure 12 - Mass stabilisation of dredged sediments (Allu Finland Oy 2007).



Figure 13 – Lime mixing from a barge for preparation of a trafficable platform (Watabe, 2008).

Advantages: The construction sequencing progressively creates a working platform as the process is taking place. This reduces the risks and cost associated with working platforms or capping layers as is required with the accelerated consolidation technique. The technique is relatively fast and delivers a useable working area sooner than using consolidation techniques.

Disadvantages: It is an expensive technique that requires a large amount of cement chemical or other binders to be sourced and brought to site.

3.4.2 Cemented Soil Placement

Cemented soil placement involves mixing of cementing agent into the soil (or sediments) prior to placement. The cement can be mixed into the soil using a number of techniques, some including mixing on a barge and pneumatic placement such as the pneumatic flow mixing method (Sato and Kato, 2002).

Advantages: Admixtures could potentially be added during transportation of the dredged material, eliminating issues with construction of a construction working platform or tracking equipment on the slurry ponds.

Disadvantages: High water content of the dredged material generated by the CSD, and the existence in the dredge pipeline of sand and clay balls in addition to the (target) clay slurry would likely make this technique ineffective.

3.5 Electro Osmosis

Electro osmosis is a dewatering technique that involves applying a current to saturated soils through electrode systems with pumps to remove collected water.

Anodes and cathodes are installed into the soil which induces pore water flow from the anode to the cathode in the soil medium. The water is collected at the cathode and pumped out.



Figure 14 – Before and After Electro Osmosis (Zhuang et al, 2013)

Advantages: High speed for improvement.

Disadvantages: Installation of electrodes will require the construction of a working platform or be carried out from a floating platform. High energy consumption, expensive set up costs, and corrosion of electrodes are issues that need to be considered.

3.6 Evaluation of Improvement Techniques

An evaluation of the treatment methodologies presented in sections 3.1 to 3.5 is presented in Table 1 below. The table presents a summary of various features of each improvement method including long term performance, cost, time, construction risk, and area required.

Table 1 – Evaluation of Treatment Methodologies for CSD Generated Slurry Ponds / Lagoons

	Treatment Method	End Product / End Use	Cost	Time	Construction Risk with Carrying Out Treatment	Limiting Depth for Containment Area
1	Discharge into closed cell settlement pond with no treatment (do nothing option)	<ul style="list-style-type: none"> Low strength, high moisture content fines slurry in settlement ponds. Not suitable for building on. May be suitable for development of wetlands. 	<ul style="list-style-type: none"> Low cost option because the only costs associated with the technique are construction of the containment areas. 	<ul style="list-style-type: none"> In the short term no substantial improvement will occur. In the long term (likely in excess of 20 years), some natural improvement of the material would occur. 	<ul style="list-style-type: none"> Construction risks are minimal because there is no need to drive equipment over the material. The main risks are associated with construction and maintenance of the containment area. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
2	Discharge into shallow areas for natural dewatering ("ripening")	<ul style="list-style-type: none"> 'Ripened' clay materials with improved engineering characteristics from the original slurry. Suitable for removal and reuse, but the high fines content will require careful handling and compaction. 	<ul style="list-style-type: none"> Moderate cost option The majority of costs will be due to the construction of the containment areas and managing / handling the ripened material. 	<ul style="list-style-type: none"> Generally 1 to 2 years to naturally ripen to a workable state. Can be accelerated by the use of admixtures or underdrainage in the treatment areas. 	<ul style="list-style-type: none"> Construction risks are minimal because there is no need to drive equipment over the material. The main risks are associated with construction and maintenance of the containment area. 	<ul style="list-style-type: none"> The depth would be between 1-2m. This will result in large areas being required to carry out this treatment method.
3	Accelerated Consolidation	<ul style="list-style-type: none"> Competent clay, beneath a granular capping layer. The engineering characteristics of the material can be designed to meet a moderate to high specification end use, if required. 	<ul style="list-style-type: none"> High cost option. Specialised equipment will be required to construct the working platforms, install the vertical drains, and place geotextile (if required). 	<ul style="list-style-type: none"> Anticipated to be in the order of 1 to 4 years depending on the approach taken and characteristics of the slurry. 	<ul style="list-style-type: none"> High construction risks associated with constructing the working platform and installing the vertical drains. If vacuum surcharging is to be used, this will require careful design and construction of the containment area to minimise the vacuum losses. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
4	Admixtures - Mass stabilisation (including shallow cement mixing). Suitable in combination with another method, such as 2.	<ul style="list-style-type: none"> The use of this technique in combination with another method (such as 2) would achieve improved engineering characteristics of the material above that if just the initial method was used. 	<ul style="list-style-type: none"> There would be additional costs associated with the consumables and labour. 	<ul style="list-style-type: none"> The time to achieve the improvement will generally decrease (from just the initial treatment method). 	<ul style="list-style-type: none"> There are some minor additional construction risks associated with the handling of admixtures and process of mixing. 	<ul style="list-style-type: none"> There are a number of different variations to this method which would each have different limiting depths.
5	Admixtures - Cemented Soil Placement	N/A (not likely suitable due to high water content of dredge slurry).				
6	Electro Osmosis	<ul style="list-style-type: none"> Competent clay in the containment area. The engineering characteristics of the ground will improve, but some further consolidation by applying a surcharge load may be required for moderate to high specification end use, if required. 	<ul style="list-style-type: none"> High costs associated with installation of electrodes, energy consumption and maintenance of electrodes. 	<ul style="list-style-type: none"> Anticipated to be in the order of 1 year depending on the approach taken and characteristics of the slurry. 	<ul style="list-style-type: none"> High construction risks associated with installing the electrodes and pumps into the slurry. Also risks for maintaining electrodes and pumps. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.

TREATMENT METHODOLOGIES FOR CSD GENERATED SAND / CLAY BALLS

Discussions have been held with the JV regarding suitable ground improvement methodologies for the sand and clay balls materials, for application to both the reclamation and the DMM materials. The work being undertaken for the *Reclamation Ground Improvement Methodologies* work package (WP 26) is currently considering ground improvement techniques for the sand and clay balls materials for use in the reclamation (a high performance end use). This work should provide a preferred approach in terms of ground improvement options for DMM material transported to land, in situations where a similar higher performance end use is proposed, refer AECOM GHD JV, 2015.

The *On Land (DMM) Treatment Methodologies* work package must consider ground improvement techniques for the sand and clay balls materials deposited on land in situations where lower performance end uses may apply.

With regards to presenting a list of treatment or ground improvement methodologies in this case, it is considered that the materials could be dealt with in three possible ways:

- Storage in the containment bunds without any further treatment (do nothing option);
- Removal from containment bunds, spreading into shallow layers, drying, and compaction using conventional compaction equipment. If necessary the properties of the material could be further improved by the addition of lime or cement.
- Storage in deeper containment areas (say 3 -10m) and improved using more conventional ground improvement techniques. Options that could be considered suitable for improvement of the dredged materials are listed below, and are discussed in more detail in Sections 4.1 to 4.12 of this report.
 - Preload surcharge with or without vertical drains
 - Vacuum consolidation
 - Vibroflotation or vibrocompaction
 - Vibroreplacement (stone columns)
 - Dynamic compaction
 - Dynamic replacement
 - Rapid Impact Compaction
 - Impact Rolling
 - Deep Soil Mixing
 - Jet grouting
 - Controlled Modulus Columns
 - Deep foundations or piling

4.1 Preload Surcharge with or without Vertical Drains

This technique involves the placement of a surcharge for a period of time to accelerate the consolidation of soft natural clays or fills. Prefabricated vertical drains can be installed to accelerate consolidation times in soft natural soils or low permeability fill material if required (typically installed on a triangular grid at a spacing of 1.0 to 2.0 metres). The process including installation of prefabricated vertical drains is illustrated in Figure 15.

The surcharge normally exceeds the maximum design loads in order to reduce the surcharge period. The duration of the surcharge will depend on the spacing of the drains (if used), the permeability of the natural soil and the level of acceptable long term settlement. Surcharge construction and removal is normally phased across a site to avoid the problem of having to dispose of significant volumes of surcharge fill at the end of construction. As noted earlier in the report this technique is commonly referred to as a “rolling” surcharge.

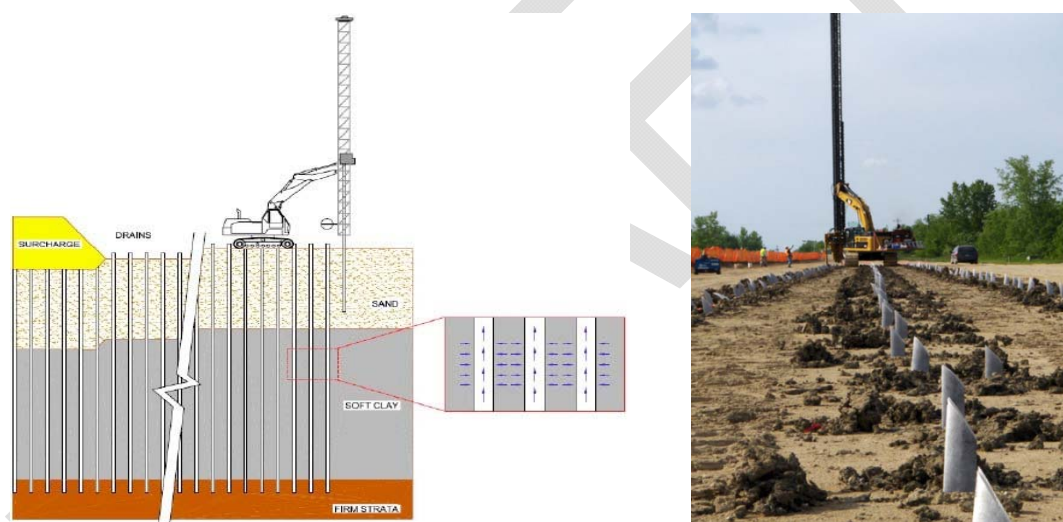


Figure 15 Prefabricated Vertical Drains Installation and Operation

Application to CSD Generated Sand / Clay Balls in DMM

It is considered that preload surcharging could be used to reduce the voids between the clay balls and sand which may be created during deposition of the material, and consolidate the clay balls. Depending on the exact composition of the DMM materials and the layout of the containment areas, it may be possible to use the DMM material as a physical surcharge.

The need for vertical drains would be governed by the permeability of the placed material which would be a function of the sand to clay ball ratio.

4.2 Vacuum Consolidation

Typically, vacuum consolidation is implemented by installing vertical drains, sealing the system using an impermeable membrane, then applying a vacuum to reduce pressure in the drains hence reducing pore water pressure in the soils.

Vacuum consolidation is an effective method of ground improvement under suitable conditions, typically soft saturated clays with low permeability and high water table. In less than ideal conditions, the efficiency can be greatly reduced and implementation becomes impractical.

Application to CSD Generated Sand / Clay Balls in DMM

The mixed nature of the dredged sand / clay balls materials (relatively high granular content for the consideration of the use of vacuum consolidation) containment area, issues with creating an effective seal within the bund and base of the containment areas, this method is not considered a suitable ground improvement option. The main reason includes the practical issues with maintaining the vacuum.

4.3 Vibrocompaction / Vibroflotation

Vibroflotation is used to densify predominantly granular soils so as to increase strength and stiffness and to reduce the liquefaction potential. This technique requires a special vibroflot probe that is jetted into the ground using high pressure water jets (see Figure 17 and Figure 18). The probe vibrates as it is gradually withdrawn from the ground creating a compacted cylinder of the surrounding soil as it does so.

Vibroflotation treatment is usually carried out on a triangular grid at a spacing of between 2.5 and 5 metres. It is most effective in clean sands and gravels, for soils with fines content over 15% the technique becomes significantly less effective. An excerpt from Krish and Bell, 2013 showing the range of soil types that can be treated with vibrocompaction versus vibroreplacement is presented in Figure 16 below.

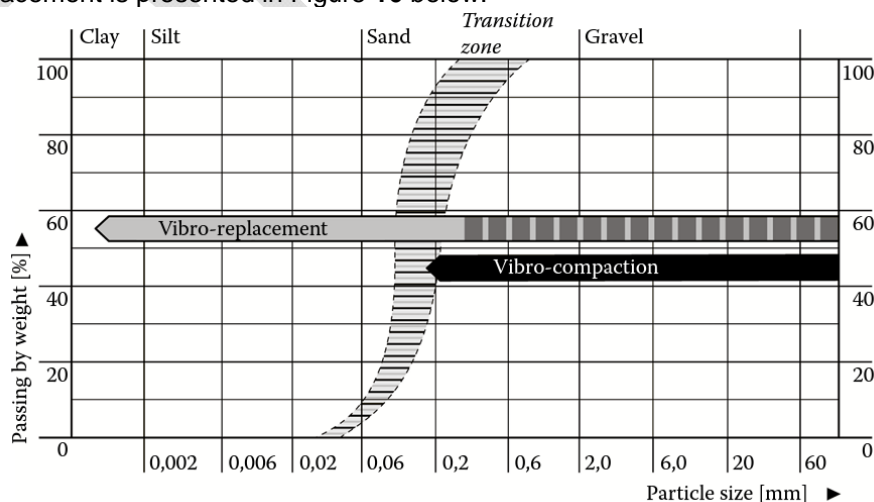


Figure 16 - Range of soil types treatable by vibro compaction and vibro replacement (from Krish and Bell 2013)

In soils where there is a high fines content, the addition of stone can be used to create stone columns to stiffen the ground. This is referred to as vibroreplacement or stone columns and is discussed separately in Section 4.4 below.



Figure 17 Vibroflotation Rig



Figure 18 Vibroflotation Rig with Two Vibroflots

Application to CSD Generated Sand / Clay Balls in DMM

Due to the mixed nature of the dredged sand / clay balls materials (relatively high fines content for the efficient use of vibroflotation) it is considered that this method of ground improvement is not likely to be effective or economical.

4.4 Vibroreplacement (Stone Columns)

Vibroreplacement or stone columns are an extension of the vibroflotation method (described in Section 4.3) which can be used to achieve ground improvement in soils for which vibroflotation will be ineffective. The stone columns are installed using the same or similar probe that is used for vibroflotation, which can deposit and compact materials into the void created by the probe as it is withdrawn.

During construction of the stone columns, the probe is vibrated into the ground to laterally displace the soil forming a cavity, upon removing the probe gravel is deposited and compacted within the cavity. The main difference between the techniques is that coarse granular fill is inserted into the hole created by the vibroflot probe and this material is then compacted by the probe (rather than compacting the in situ material). This technique creates stiff inclusions within poorer ground (often on a triangular grid at a spacing of 2.5 to 5 metres). These columns reduce ongoing settlements and increase the ground's bearing characteristics, and will provide additional vertical drainage paths. It is important to note that they do not eliminate long term settlement.

When constructing stone columns over poor soils, typically the vibroflot will have to work from a working platform constructed from competent granular fill. After the installation of each row of stone columns the working platform will be extended to cover the next columns and allow the construction of the next row. The thickness and batters for the working platform will be dictated by the strength of the underlying soils, the stone column

replacement rational and the quality of the fill material used to construct the working platform.

The construction staging described above allows the rapid construction of stone column areas without the need to wait for consolidation or grouts to set. In addition to providing instantaneous stiffness to the soils the granular inclusions will create additional drainage path thus enhancing the drainage characteristics of the soils.

Application to CSD Generated Sand / Clay Balls in DMM

Stone columns can be used to improve a wider range of materials than simple vibroflotation. The technique can be used effectively in soft to firm clays and silty sands in which vibroflotation will be ineffective. In inhomogenous soils it can provide some densification to granular pockets of soil. As such, it is considered that stone columns could be used to improve the clay ball / sand mixture from the CSD.

The design of the stone column system, in terms of area of replacement would be dependent on the final use and loading conditions for the DMM treatment area. The stone columns would be installed through the depth of fill to the more competent underlying soils, which would presumably form a suitable bearing stratum. CIRIA C572 notes, *“Typically, vibro is used to treat areas of shallow heterogeneous fill overlying less compressible soils. The dense stone columns reinforce the ground and should reduce total and differential settlement under foundation loading to acceptable values.”* As such it is considered a likely suitable method for treatment of the materials to achieve a medium specification end use.

It is noted that a source of suitable crushed rock aggregate for the stone column material would be required. The volume of stone required would be dependent on the condition of the placed material and the performance requirements for the area.

4.5 Dynamic Compaction

The dynamic compaction technique simply involves the repeated dropping of a large weight through a large distance onto the ground surface. A modified conventional crawler crane with can be used to lift and drop the weight (see Figure 19 and Figure 20). This technique is simple and effective at shallow depths but is depth limited. For example, dropping a 20 tonne weight through a distance of 20 metres will have little effect on soils below a depth of about 10 metres.

It is noted that dynamic compaction can be effective on a wide range of loose, partially saturated fills. Although will not eliminate long term settlement issues in clay fills.

Application to CSD Generated Sand / Clay Balls in DMM

Typically, dynamic compaction is used to density sand fills. CIRIA C572 discusses the performance of dynamic compaction on clay and heterogeneous fills. It notes that *“long-term settlement can be a particular problem for clay fills and for fills containing biodegradable materials. Dynamic compaction should improve the properties of such fills in most cases, but is unlikely to eliminate long-term movement.”*

Considering the anticipated composition of the CSD generated sand / clay balls to DMM, dynamic compaction may be able to achieve densification of the granular content of the fill whilst also improving the characteristics of the clay balls. Adequate drainage would need to be provided to allow the slurry water to drain and prevent significant excess pore pressures developing during dynamic compaction.

A significant working platform would need to be constructed to track the required equipment, and significant amount of good fill would be required to compact into the reclamation. It is noted that environmental impacts of noise, vibration, and fly material are greater than with other ground improvement methods.



Figure 19 – DC weight being lifted (Pantai Indah Kapuk Jakarta).



Figure 20– DC weight being dropped (Pantai Indah Kapuk Jakarta).

4.6 Dynamic Replacement

Dynamic replacement is essentially a slight variation to dynamic compaction, which allows the technique to be used on soft cohesive soils. Rather than compacting the in situ soil, granular fill material is driven into the soil using the tamping weight. This creates a large diameter column of stiffer granular material within the soft clay matrix.

This technique is generally used on soft soils where compaction of the in situ soil cannot be achieved by dynamic compaction.

Application to CSD Generated Sand / Clay Balls in DMM

Considering the mixed nature of the dredged sand / clay ball mixture of the DMM material, it is not likely that 'Dynamic Replacement' in a conventional sense (i.e. pillars of imported fill

punched through the DMM material to the top of natural ground surface) would be achievable. The reader should instead refer to the discussion of Dynamic Compaction in Section 4.5.

4.7 Rapid Impact Compaction

Rapid Impact Compaction (RIC) achieves improvement of the ground by impacting the ground surface in a similar manner to Dynamic Compaction. The main difference being that the load is transferred into the ground via a steel loading plate, the load is much lower than with Dynamic Compaction, and the rate of impacting and the number of impacts is much high with rapid impact compaction than with Dynamic Compaction.

Krish and Bell 2013 noted, *RIC typically employs a 7-tonne weight dropped repeatedly through a 1.2 m height onto a 1.5 m diameter steel articulated compaction foot. Whilst the energy per blow is not large (typically 8.4 tonne-metres), the equipment permits a large number of impacts to be applied at a rate of about 40 blows per minute for typical treatment depth of up to 3.0 m. Weights from 5 to 12 tonnes are used worldwide.*

Rapid Impact Compaction is generally more suited to generally granular fills and can be effective up to 4m depth in favourable ground conditions. In clay fills it is less effective particularly at depth.

Application to CSD Generated Sand / Clay Balls in DMM

Rapid Impact Compaction may be a suitable method for improving the DMM materials if placed in shallower bunds. The efficiency will depend on the ratio of clay balls to sand and strength of the clay balls within the bunded areas.

4.8 Impact Rolling

Impact rolling is described in the Interpretive Report (AECOM 2014) as follows “*Impact rolling involves the use of a non-circular roller to impart a high level of energy into the ground when towed at relatively high speed (10 to 12 km/hr). A number of proprietary 3, 4, or 5 sided rollers are available on the market (see Figure 9-9). The benefit of impact rolling is that it can improve ground to a greater depth than compaction with conventional earthworks equipment, with reported depths of influence of up to 4 m, but with 2 m being more typical.*”

It is understood that Impact Rolling is generally more suited to granular fills with the higher range of reported depths of influence being achieved in these materials. In clay fills, it is less effective particularly at depth.

Application to CSD Generated Sand / Clay Balls in DMM

As with Rapid Impact Compaction, Impact Rolling may be a suitable method for improving the DMM materials if placed in shallower bunds. The efficiency will depend on the ratio of clay balls to sand and strength of the clay balls within the bunded areas.

4.9 Deep Soil Mixing

As the name suggests, deep soil mixing involves the mixing of cement or other binders into the in situ ground. The cement or other binders hydrate using the natural moisture in the ground, drying and strengthening the soil as it does so. As it hydrates, the cement also binds the soil, creating stiff columnar inclusions within the ground. These can either act as individual columns (like stone columns or CMCs) or they can be joined together to take more structural forms such as buttresses to resist horizontal loads. Additionally, large scale mass stabilisation systems can be used to mix the whole soil mass.

There are a number of mixing techniques available, which are selected on the basis of site conditions and equipment availability. The different techniques involve variations of using dry vs slurry binders, mechanical vs jet mixing, and the setup of the mixing tool.

The construction sequencing progressively creates a working platform as the cement columns are installed. This reduces the risks and cost associated with constructing capping layers as is required with many other ground improvement techniques.

The use of deep cement mixing can allow reclamations to be formed on poor quality sites. Deep cement mixing will deliver a useable working area much faster than using consolidation techniques.

Application to CSD Generated Sand / Clay Balls in DMM

Deep soil mixing could be used to improve the whole DMM material treatment area. This could be achieved by installing individual columns in a regular pattern across the whole area.

Alternatively deep soil mixing could be adopted just to support settlement sensitive buildings or other structures. This could be achieved by only treating certain areas that require improved engineering characteristics.



Figure 21 Deep cement mixing at Mubarak al-Kabeer Seaport (RHDHV Internal Photograph)



Figure 22 Deep cement mixing at Mubarak al-Kabeer Seaport (RHDHV Internal Photograph)



Figure 23 Deep Cement Mixing

4.10 Jet Grouting

CIRIA C573 defines jet grouting as “the construction of hard impervious columns in the ground by the enlargement of a drill hole using rotating fluid jets to liquefy and mix grout with, or to excavate and replace, soils”.

There are several variations to the jet grouting method. CIRIA C573 described the general principal of jet grouting as follows.

“The method of jet grouting improve the ground by either:

a. Mixing the grout into the ground material as it is disturbed by the energy of the rotating high-pressure jet of grout or of grout shrouded by air.

or

b. replacing by tremie-pumping grout into the slurry filled cavity created by eroding the ground with rotating high-pressure water and air jets

or

c. combining replacement and mixing using an air-shrouded water jet for eroding the soil and tremie-pumping the grout.”

Typically jet grouting in permanent works is used for supporting specific structures in a targeted manner rather than for large scale ground improvement projects.

Application to CSD Generated Sand / Clay Balls in DMM

Jet grouting is likely to be costly and not considered a suitable method for large scale improvement of the DMM treatment areas.

It may however be a suitable method to support settlement sensitive buildings or other structures. This could be achieved by only treating certain areas that require improved engineering characteristics.

4.11 Controlled Modulus Columns

Controlled modulus columns (CMCs) are essentially unreinforced cement based columns that are installed through poor ground into a competent bearing stratum below. The CMCs are installed using a specially design displacement auger, which is rotated to the required depth then as it is withdrawn grout is injected into the cavity at a controlled pressure. Using the displacement auger is beneficial over a conventional auger because; there is little spoil excavated creating less waste than would be generated by traditional augered piles, and the ground is horizontally compressed resulting in denser ground and higher confining pressures on the cement columns.

After installation of the CMCs, a load transfer platform is constructed over the CMCs / soil matrix. The load transfer platform will generally be a coarse granular layer. The purpose of this layer is to spread the loadings uniformly through the CMCs / soil matrix reducing the likelihood of individual CMCs being overloaded and failing.

Masse, et al, 2011 notes that “CMCs have been installed in a variety of soils including, uncontrolled fill, organics, peat, soft to stiff clay, silt, municipal solid waste, and loose sands. Typically, the CMC is installed through the soft or compressible soils and into dense sand, stiff clay, glacial till, or other competent material that serves as the bearing stratum.”

Application to CSD Generated Sand / Clay Balls in DMM

CMCs have potential application to the DMM material. They could be used to improve the clay ball / sand mixture as a result of the CSD.

The need and design of any CMC system would be dependent on the final use and loading conditions for the DMM treatment area. It is considered that CMCs would likely be an effective improvement method if moderate to high loading conditions were expected. It is noted that they can be expensive due to the amount of grout that needs to be used to form the CMCs.

4.12 Deep Foundations or Piling

Deep foundations or piling are not a method of ground improvement but rather can be used to bypass the need for ground improvement by transferring the loads of the structure directly to a deeper more suitable deeper bearing stratum.

Application to CSD Generated Sand / Clay Balls in DMM

Deep foundations or piling could be adopted for settlement sensitive buildings or other isolated structures. If the surrounding ground is not treated (or is treated but is likely to continue to settle in future), differential settlement is likely to occur between the adjacent ground and the piled structure. Depending on the magnitudes of the relative settlements, this

can be controlled using other complimentary forms of ground improvement or by detailing the foundation design to accommodate such movements.

4.13 Evaluation of Improvement Techniques

At this current stage in the project, the layout and phasing of the port is subject to ongoing change, and the work on the characterisation of the DMM material is still developing. A detailed evaluation of the composition and consistency of the CSD generated sand / clay balls, is therefore not available.

In order to develop this study, a range of different ground improvement options for CSD generated sand / clay ball fill material, have been considered. The different options have then been evaluated given the likely range of proportions of sand to clay balls from the CSD generated material (i.e. each ground improvement technique has been evaluated in terms of its efficiency in 'predominantly sand fill (minor clay balls in a sand matrix)' and 'predominantly clay ball fill'.

An evaluation of the treatment methodologies discussed in Sections 4.1 to 4.12 is presented in Table 2 below. The table presents a summary of various features of each improvement method including efficiency in predominantly sand fill (clay balls in a sand matrix), efficiency in predominantly clay ball fill, cost, construction considerations, and effective depth of treatment. The final solution could be a combination of the options discussed.

Table 2 –Evaluation of Improvement Techniques for CSD generated sand and clay balls

Technique	Efficiency - Predominantly sand fill (minor clay balls in a sand matrix)	Efficiency - Predominantly clay ball fill	Cost	Construction Considerations	Effective depth of treatment.
Preload Surcharge with or without Vertical Drains	<ul style="list-style-type: none"> Preload surcharging will cause initial settlement due to compression of voids and bedding of clay balls into sand matrix. Preloading will not cause significant densification or compaction of high sand content fill. It is not likely that added drainage would provide any significant benefit in this material. 	<ul style="list-style-type: none"> Preload surcharging will cause initial settlement due to compression of voids, rearrangement of clay balls and will also improve the long term characteristics of the clay balls themselves (i.e. consolidate the clay balls). The need for added drainage will be a function of the mass permeability of the soil and the required timing. 	<ul style="list-style-type: none"> Low to moderate cost option. The majority of costs will be due to the earthworks required to move the surcharge around the containment area, and the installation of vertical drains (if required). If suitable surcharge material has to be imported (cannot be sourced on site) the purchase of this material will also be a significant cost that will need to be considered. 	<ul style="list-style-type: none"> There are construction risk associated with tracking equipment required to install the vertical drains and moving surcharge material over the containment areas. A stable working platform is required to safely carry out this technique. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas. Depending on the permeability of the fill materials, vertical drains may need to be installed to make this technique effective on deep containment areas.
Vacuum Consolidation	N/A (See discussions, not considered practical)				
Vibrocompaction / Vibroflotation	<ul style="list-style-type: none"> Effective technique for sand with fines content less than 15%. With increased fines and clay ball content, the effectiveness of this technique will decrease. 	<ul style="list-style-type: none"> Not an effective technique for predominantly clay ball fill material. Typically these soils would be treated with stone columns (see below). 	<ul style="list-style-type: none"> Cost effective technique for granular soils with a fines content less than 15%. Costs associated with fill for construction platform should be considered. 	<ul style="list-style-type: none"> A stable working platform is required to safely carry out this technique, once the ground is improved this would typically be sufficient but may require some additional fill. The technique can allow construction to progress rapidly because it only requires one pass and does not need to wait for grouts or cements to set. This reduces construction risk associated with tracking equipment over partially improved ground. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
Vibroreplacement (Stone Columns)	<ul style="list-style-type: none"> Effective technique for both predominantly granular material and clay material. 	<ul style="list-style-type: none"> Effective technique for both predominantly granular material and clay material. The effectiveness and depth of penetration may be impacted by the volume and strength of the clay balls. 	<ul style="list-style-type: none"> Cost effective technique for granular soils with a fines content less than 15%. Although higher cost compared to vibrocompaction method (above) Costs associated with fill for construction platform and material required for the stone columns should be considered. 	<ul style="list-style-type: none"> A stable working platform is required to safely carry out this technique, once the ground is improved this would typically be sufficient but may require some additional fill. The technique can allow construction to progress rapidly because it only requires one pass and does not need to wait for grouts or cements to set. This reduces construction risk associated with tracking equipment over partially improved ground. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
Dynamic Compaction	<ul style="list-style-type: none"> Effective technique for clean sands. The potentially high fines content and clay balls within the sand may reduce the effectiveness of the technique. 	<ul style="list-style-type: none"> Case studies show it can be somewhat effective in clayey fills but may also require some consolidation type ground improvement to achieve a higher specification end use for the containment areas. More likely to be effective if fill has adequate drainage or only partially saturated to allow excess pore pressures generated during dynamic compaction to dissipate. 	<ul style="list-style-type: none"> High mobilisation costs associated with the crane and equipment and so more economically viable on large scale sites. Some additional fill will be required to fill craters created by the dynamic compaction process, and to create the working platform. Depending on the composition of the material, the depth of craters could be significant thus requiring large amounts of fill. 	<ul style="list-style-type: none"> Construction risk associated with tracking equipment over the containment areas. A significant granular layer of high quality fill will be required. Also issues with the generation of flying debris, vibration and noise. 	<ul style="list-style-type: none"> Up to 10m depending on the composition of the material.

Technique	Efficiency - Predominantly sand fill (minor clay balls in a sand matrix)	Efficiency - Predominantly clay ball fill	Cost	Construction Considerations	Effective depth of treatment.
		<ul style="list-style-type: none"> Unlikely to eliminate long term settlement in high clay content fills. 			
Dynamic Replacement	<ul style="list-style-type: none"> N/A (See discussions, and refer to Dynamic Compaction) 				
Rapid Impact Compaction / Impact Rolling	<ul style="list-style-type: none"> Most effective in granular materials. 	<ul style="list-style-type: none"> Reduced effectiveness in clay materials. 	<ul style="list-style-type: none"> Economical method for shallow containment areas. 	<ul style="list-style-type: none"> Construction risk associated with tracking equipment over the containment areas. Issues with the generation of noise and vibrations. 	<ul style="list-style-type: none"> Effective depth of treatment will depend on the composition of materials being treated. Typically up to 4m effective treatment depth in sands, up to 2m in clay.
Deep Soil Mixing	<ul style="list-style-type: none"> Effective in a range of soil types . Can be designed to achieve high performance final product. Could be used to treat the whole area, or alternatively just used to treat areas required to supporting specific structures with high performance requirements. 		<ul style="list-style-type: none"> High mobilisation costs with specialised equipment required. High costs associated with purchasing cement or other binders. The technique could be used to treat the whole area or alternatively just to support settlement sensitive structures. 	<ul style="list-style-type: none"> Significant working platform required. Construction sequence progressively creates a working platform reducing the risks associated with failures during construction and the amount of fill required. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
Jet Grouting	<ul style="list-style-type: none"> Likely to be effective in both soil types, but it should be noted that the variability of the fill material may create issues with the jetting process resulting in a less controlled product than in homogenous soils. 		<ul style="list-style-type: none"> High mobilisation costs associated with specialised equipment. Costs associated with purchasing cement or other binders should be considered. More typically used to support settlement sensitive structures rather than improve large scale areas. 	<ul style="list-style-type: none"> The technique may generate mixed soil / water / grout runoff depending on the method employed. There may be unpredictable behaviour of the jet grouting because of the variability of the fill materials. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
Controlled Modulus Columns	<ul style="list-style-type: none"> Effective in a range of soil types. Can be designed to achieve high end performance. 		<ul style="list-style-type: none"> High mobilisation costs due to specialised equipment. Costs of grout, and material for the load transfer platform (geogrid or geotextile / high quality crushed rock fill need to be considered). 	<ul style="list-style-type: none"> Minimal amount of spoil because of the use of the displacement auger. Fast and controlled method. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.
Deep Foundations or Piling	<ul style="list-style-type: none"> Suitable and effective for both soil types (this is not strictly a method of ground improvement, and could be used to compliment other ground improvement methods). 		<ul style="list-style-type: none"> Not cost effective to treat large areas. May be suited for supporting specific structures. 	<ul style="list-style-type: none"> Will be dependent on the details of the deep foundation or piling being undertaken. 	<ul style="list-style-type: none"> The practical depth would be limited by the achievable height of the containment areas.

5 TREATMENT METHODOLOGIES FOR BACKHOE DREDGING

Issues to consider for treatment and ground improvement of the BHD materials include:

- The size and strength of the clay pieces will likely cause voids to form during placement.
- The size and strength of the clay pieces will likely hinder the implementation of traditional ground improvement techniques.
- The placement method will limit the height of stockpiles that could be developed.

It is likely that the most suitable approach to treatment of the BHD materials would be to break up the material, spread into thin layers and compact using heavy duty conventional compaction equipment provided that the natural moisture content of the BHD material is close to the optimum moisture content for compaction using conventional compaction equipment. The process could be repeated in successive lifts subject to the ability of trucks and compaction equipment to traffic over the preceding layers.

This method would be weather dependant. It may suffer from delays during periods of persistent / heavy rain fall, alternatively the clay may dry excessively between layers in hot weather.

CONCLUSIONS

This Report outlines possible methodologies for ground improvement of dredged materials transported to land as part of the Dredged Materials Management. The report notes that the selection of suitable ground improvement techniques for the DMM material disposed of on land will be influenced by a number of technical factors including but not limited to:

- the composition and consistency of the DMM material;
- the final ground performance requirements of the DMM material treatment areas;
- any space limitations for the treatment areas; and
- the project programme requirements (including dredging and construction programme).

The dredging process will significantly alter the dredged material characteristics from their in situ state. The two dredging techniques which are considered most suitable for disposal of DMM materials to land are cutter suction dredger (CSD) with hydraulic transport, or backhoe dredger (BHD) with mechanical transport.

A summary of the ground treatment options discussed for the DMM material types generated by the dredging are listed below. The reader should refer to the evaluation tables (Table 1 and Table 2) for a more detailed evaluation of each ground improvement treatment technique.

CSD generated slurry ponds / lagoons:

- discharge into closed cell settlement pond with no treatment ('do nothing option');
- discharge into shallow areas for natural dewatering ('ripening');
- accelerated consolidation (controlled capping layer placement, installation of drainage and application of surcharge load);
- use of admixtures (e.g. cement mixing); and,
- electro osmosis.

CSD generated sand / clay balls:

The report noted that for the onshore disposal of dredged material, lower performance end uses may apply than for the port reclamation area. It was considered that the loose clayey silty sand and clay balls of varying strength within onshore containment areas could be managed in three possible ways:

1. storage in the containment bunds without any further treatment (do nothing option);
2. removal from containment bunds, spreading into shallow layers, drying, and compaction using conventional compaction equipment. If necessary the properties of the material could be further improved by the addition of lime or cement; and,
3. storage in deeper containment areas (say 3m to 10m deep) and improved using more conventional ground improvement techniques. Options that could be considered suitable for improvement of the dredged materials are listed below:

- preload surcharge with or without vertical drains;
- vibroflotation or vibrocompaction;
- vibroreplacement (stone columns);
- dynamic compaction;
- rapid impact compaction;
- impact rolling;
- deep soil mixing;
- jet grouting;
- controlled modulus columns; and,
- deep foundations or piling.

BHD Dredging:

The most likely suitable approach to treatment of BHD dredged materials would be to break up the material, spread it into thin layers and compact it using heavy duty conventional compaction equipment. The process could be repeated in successive lifts subject to the ability of trucks and compaction equipment to traffic over the preceding layers.

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