LIGHT SOLIDIFICATION OF KUALA PERLIS DREDGED MARINE SOIL
VIA ADMIXTURES OF GGBS – CEMENT AND SAND:
1-D COMPRESSIBILITY STUDY

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DEDICATION

Dedicated to the Lord,
Beloved father, mother and brother
ACKNOWLEDGMENT

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Thank you.
ABSTRACT

Great quantities of dredged marine soils (DMS) have been produced from the maintenance of channels depth, anchorages and for harbour development. Most of the DMS are disposed in the sea and land. DMS have the potential to pose ecological and human health risks and it is also considered as a geowaste. Malaysia is moving towards the sustainability approach and one of the key factors to achieve it is to reduce waste. Backfilling is the basic phase for every construction therefore it shows the importance of creating artificial land in this study. Thus, this geowaste should be generated as a new resource to substitute soil for civil works such as for artificial land creation. Moreover, there is no proper guideline for beneficial reuse of DMS in Malaysia. This study is to identify the improved settlement and rate of consolidation in treated DMS and also the relationship between the compressibility parameters. DMS is referred to as a cohesive soil which includes clayey silt, sandy clay, silty clay and organic clay. This type of soil has low strength and high compressibility. Compressibility of soils is an important engineering consideration. This is due to the fact that soils subjected to increased effective stress would decrease in volume hence resulting in surface settlement. The objectives were achieved through literature review analysis and also laboratory test which was one dimensional oedometer test. A brief introduction about a skeletal framework for beneficial reuse of DMS in artificial land creation was discussed as having a well-managed DMS handling system and pre-treating it if necessary to work as a soil for civil works are important as well. On the other hand, treated DMS with more ground granulated blast furnace slag (GGBS) gives a lower settlement compared to specimen with higher percentage of cement in a treated soil. Thus this shows that cement content can be reduced in soil solidification when GGBS is added. The optimum binder ratio found was 3:7 where 3 is cement and 7 is GGBS. Optimum sand ratio was 10%, 50% and 75% of coarse grain soil. The specimen which complied the settlement criteria are 3C7G_20,50_CS and 3C7G_20,75_CS. Thus this mix design can be applied for civil works such as embankment and backfilling.
ABSTRAK

Kuantiti besar tanah kerukan laut (DMS) telah dihasilkan dari penyelenggaraan saluran, penabatan dan untuk pembangunan pelabuhan. Kebanyakan DMS dilupuskan di laut dan tanah. DMS mempunyai potensi untuk menimbulkan risiko kesihatan terhadap ekologi dan manusia dan ia juga dianggap sebagai sisa pembuangan. Malaysia sedang menuju ke arah pendekatan kelestarian dan salah satu faktor utama untuk mencapainya adalah untuk mengurangkan sisa. Penambakan adalah fasa asas bagi setiap pembinaan oleh itu ia menunjukkan betapa pentingnya mewujudkan tanah buatan dalam kajian ini. Oleh itu, sisa pembuangan ini akan dihasilkan sebagai sumber baru untuk menggantikan tanah untuk kerja-kerja awam seperti untuk penciptaan pulau buatan. Kajian ini mencadangkan satu rangka kerja awal untuk digunakan semula DMS dalam penciptaan tanah buatan dan juga untuk mengenal pasti penyelesaian yang bertambah baik dan kadar penyatuan dalam DMS dirawat. DMS disebut sebagai tanah yang padu yang merangkumi kelodak liat, tanah liat berpasir, tanah liat berkelodak dan tanah liat organik. Ini jenis tanah mempunyai kekuatan yang rendah dan kebolehmampatan yang tinggi. Kebolehmampatan tanah adalah satu pertimbangan kejuruteraan penting. Ini adalah disebabkan oleh hakikat bahawa tanah tertakluk kepada peningkatan tegasan akan berkurang dalam jumlah itu menghasilkan penyelesaian permukaan. Objektif telah dicapai melalui analisis kajian literatur dan juga ujian makmal yang merupakan salah satu ujian oedometer dimensi. Penggunaan semula DMS memerlukan pemahaman prosedur pengurusan daripada mendapatkan semula DMS dengan permohonan di lokasi. sistem pengurusan dengan baik untuk memindahkan DMS dan pra-rawatan jika perlu untuk bekerja sebagai tanah untuk kerja-kerja awam adalah penting juga. Sebaliknya, dirawat DMS dengan lebih tanah letupan pasir sanga relau (GGBS) memberikan penyelesaian yang lebih rendah berbanding dengan spesimen dengan peratusan lebih tinggi simen di dalam tanah yang dirawat. Oleh itu, ini menunjukkan bahawa kandungan simen boleh dikurangkan dalam pemelajaran tanah apabila GGBS ditambah. Nisbah pengikat optimum dpati adalah 3:7 di mana 3 adalah simen dan 7 adalah GGBS. nisbah pasir optimum adalah 10%, 50% dan 75% daripada tanah berbutir kasar. Spesimen yang dipatuhi kriteria penyelesaian adalah 3C7G_20,50_CS dan 3C7G_20,75_CS. Oleh itu reka bentuk campuran ini boleh digunakan untuk kerja-kerja awam seperti benteng dan penambakan.
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LIST OF SYMBOLS AND ABBREVIATIONS

C  - cement
C\textsubscript{2}S  - Dicalcium silicate
C\textsubscript{2}SH\textsubscript{x}, C\textsubscript{3}S\textsubscript{2}H\textsubscript{x}  - hydrated calcium silicates
C\textsubscript{3}A  - Tricalcium aluminate
C\textsubscript{3}AH\textsubscript{x}, C\textsubscript{4}AH\textsubscript{x}  - hydrated calcium aluminates
C\textsubscript{3}S  - Tricalcium silicate
C\textsubscript{4}AF  - Tetracalcium alumino-ferrite
Ca(OH)\textsubscript{2}  - hydrated lime
Ca\textsuperscript{2+}  - Calcium ion
CaO  - Calcium Oxide
CO\textsubscript{2}  - Carbon dioxide
c\textsubscript{v}  - coefficient of consolidation
DMS  - Dredged marine sediments
\( e \)  - void ratio
\( e.g. \)  - for example
Fe\textsubscript{2}O\textsubscript{3}  - Iron Oxide
G\textsubscript{x}  - Specific gravity
G\textsubscript{o}  - Maximum shear modulus
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<td>i.e.</td>
<td>in other words</td>
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<tr>
<td>K⁺</td>
<td>Potassium ion</td>
</tr>
<tr>
<td>K₂O</td>
<td>Potassium Oxide</td>
</tr>
<tr>
<td>k</td>
<td>Permeability</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
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<tr>
<td>Mg²⁺</td>
<td>Magnesium Oxide</td>
</tr>
<tr>
<td>MgO</td>
<td>Magnesium Oxide</td>
</tr>
<tr>
<td>mm</td>
<td>milimeter</td>
</tr>
<tr>
<td>mᵥ</td>
<td>coefficient of volume compressibility</td>
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<tr>
<td>M₀</td>
<td>Constrained modulus</td>
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<tr>
<td>Na₂O</td>
<td>Sodium Oxide</td>
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<tr>
<td>NCL</td>
<td>normal consolidation line</td>
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<td>OPC</td>
<td>Ordinary Portland cement</td>
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<tr>
<td>RECESS</td>
<td>Research Centre for Soft Soils</td>
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<tr>
<td>SiO₂</td>
<td>Silica</td>
</tr>
<tr>
<td>SO₃</td>
<td>Sulphur Trioxide</td>
</tr>
<tr>
<td>SO₄²⁺</td>
<td>Sulfate ion</td>
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<tr>
<td>t</td>
<td>tonne</td>
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<tr>
<td>tₑ₀ᵖ</td>
<td>End of primary consolidation time</td>
</tr>
<tr>
<td>UTHM</td>
<td>Universiti Tun Hussein Onn Malaysia</td>
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<tr>
<td>Symbol</td>
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</tr>
<tr>
<td>( w )</td>
<td>moisture content</td>
</tr>
<tr>
<td>( W_s )</td>
<td>dry weight</td>
</tr>
<tr>
<td>( W_w )</td>
<td>wet weight</td>
</tr>
<tr>
<td>XRF</td>
<td>X-ray Fluorescence</td>
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<tr>
<td>( \varepsilon )</td>
<td>Vertical strain</td>
</tr>
<tr>
<td>( \rho )</td>
<td>density</td>
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<tr>
<td>( \sigma_v' )</td>
<td>effective stress</td>
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CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia has 10 major ports and 59 minor ports to cater for commercial purposes as it is surrounded by international waters and strategically located along the primary shipping routes (Khalid, 2006).

Figure 1.1: Ports in Malaysia (www.searates.com/maritime/malaysia, 2015)

To maintain the waterways, dredging has to be carried out. 4 million m$^3$ of sediments for maintenance dredging of ports and jetties are dislodged in the year 2013 (Chan, 2014). Significant quantities of dredged marine soil (DMS) have been
generated from the maintenance of channels depth, anchorages and for harbour development.

Disposing large quantities of dredged materials is often one of the greatest challenges faced in a dredging project. When these materials are treated as a waste, the selection of disposal destination often becomes controversial (International Association of Dredging Companies, IADC, 2009). This is because pollution and health risk can be caused if disposed either in land and water. In the case of Malaysia, the normal practice is to dispose the dredged materials in allocated offshore dumping sites.

However, the benefits of the dredging project can be enhanced through the use or re-use of the dredged material for a beneficial purpose (International Association of Dredging Companies, IADC, 2008 and Stollenwerk et al., 2012). In recent years, many researchers have demonstrated that these materials have added value and are not wastes (e.g. Makusa, 2012; Azhar et al., 2014; Chan et al., 2012). Efforts in finding uses, application for these materials and for coordinating the supply of these materials with a concurrent demand are now growing. These includes the construction of Haneda airport, Japan (International Association of Dredging Companies, IADC, 2009), land reclamation works in Chek lap kok Airport of Hong Kong and Arabian gulf off the coast Dubai (Randall et al., 2011). Some of the potential reuse options include beach replenishment with sand, use in buildings or coastal works and land reclamation (Cronin et al., 2006). Thus, this geo-waste should be reused as a soil for civil works.

1.2 Problem Statement

Malaysia is moving towards sustainable development and one of the key factors to achieve this is by reducing wastes. DMS are generally considered a geowaste which commonly to be disposed (OSPAR, 2005). However, disposal of the DMS offshores can lead to serious and irreversible impact on the marine ecosystem, while disposal on land often causes excessive costs and takes up land space (Symons et al., 2007 and Chan et al., 2012). Tourism is the main economic contributor to the country’s development. The sampling site in this study is Kuala Perlis as shown in Figure 1.2.
Kuala Perlis jetty terminal is an attraction point for tourist as it is one of the main route to Langkawi. In order to maintain the waterway depth for the passerby ships, maintenance dredging is being done once a year. Once dredging is done, the DMS is being dumped in a permissible distance from the shore and pollutes the sea. Thus, this geowaste could be regenerated as a new resource to substitute soil for civil works such as for embankment and land reclamation. The geowaste usually clay, silt or sand. Clay is referred to as a cohesive soil which includes clayey silt, sandy clay, silty clay and organic clay. This type of soil has low strength and high compressibility. Compressibility of soils is an important engineering consideration. This is due to the fact that soils subjected to increased effective stress would decrease in volume hence resulting in surface settlement (Schroeder et al., 2004). Thus, the addition of cement or other binder and granular materials could improve the weak soil with reduced settlement. Therefore, this shows that solidification of this geowaste could be a beneficial reuse for application in land reclamation.

Figure 1.2: Kuala Perlis jetty area (Retrieved on: Google earth, coordinate: 6° 24' 0" North, 100° 8' 0" East, 2016)
1.3 **Research Objectives**

The aim of this research is to examine the compressibility behaviour and relationship between the consolidation parameters of DMS for beneficial reuse purposes. The objectives to be achieved are:

i. To determine 1-D compressibility characteristics of lightly solidified DMS from Kuala Perlis using GGBS-cement and sand admixtures.

ii. To identify the improved settlement and consolidation rate of the solidified DMS as mentioned in objective i.

iii. To establish the relationship between the 1-D compressibility parameters.

1.4 **Scope of Research**

The main test conducted was 1-Dimensional oedometer consolidation test. In order to solidify the soil, binding agents and a type granular material were used. They were cement, ground granulated blast furnace slag and sand. These materials were chosen because they are readily available in Malaysia. The test was conducted to identify the compressibility behaviour, rate of settlement with the time and also the relationship between the consolidation parameters. The soil sample was collected at Kuala Perlis. The entire laboratory test programs were conducted in Geotechnical Engineering Laboratory, Environmental Laboratory, Environmental Analytical Laboratory, and RECESS facilities. All the results were analyzed according to the relevant standard and specification.

1.5 **Significance of Research**

The reuse of dredged marine soils could help reduce the volume of disposal in open sea. Furthermore, high maintenance cost due to the frequent dredging activity also can be reduced. This research shows the importance of reusing DMS in land reclamation rather than dumping it back into the sea. DMS is admixed with binder and granular materials to be solidified and to act as an acceptable soil for civil works.
Waste and pollution can be reduced and new productive way of reusing DMS can be created.

1.6 Organization of Thesis

Chapter 1: Introduction
This chapter discusses the background of this research, current situation and problem statement of the study. There are also objectives, scope and its significance of research.

Chapter 2: Literature Review
This chapter discusses the elaboration, information and previous studies by other researchers which are related to this study. It contains important information of the sources. It gives a new interpretation of old material or combine new with old interpretations mainly about reusing dredged marine soil and guidelines to manage the dredged material after retrieval.

Chapter 3: Methodology
This chapter illustrates the flow and method of research starting from planning to implementations that have been carried out as well as related standards and guidelines on the laboratory works.

Chapter 4: Result Analysis
This chapter contains the overall result of this study. All the results obtained were discussed and analysed to show the new discovery of the research.

Chapter 5: Conclusions and Recommendations
The overall conclusion of the study, goal achievement and recommendations for further research were included.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Dredging is the relocation of underwater sediments and soils for the construction and maintenance of waterways, harbours and ports. Excavation, transport and disposal of sediments are the three main stages of dredging activities (Manap and Voulvolis, 2015). Dredging activities generates large volume of dredged marine sediment (DMS). DMS can be a valuable resource although most of it currently being disposed back into the sea due to economic, logistic and environmental constraints (CEDA, 2010).

2.2 Dredging

Dredging can be described as underwater excavation of soils. It is necessary to maintain existing waterways, ports and water channels. The need of increase in waterway depths might be due to the increased demand for transporting people, equipment, materials and commodities by water. Besides that, dredging process is also used in flood control measures to maintain or improve the river or channels flow capacities. Dredging is also performed to reduce the exposure of fish, wildlife, and people to contaminants and to prevent the spread of contaminants to other areas of the water body such as surface runoff and atmospheric deposition (National Oceanic and Atmospheric Administration NOAA, 2014). There are three types of dredging which are capital dredging, maintenance dredging and remedial dredging. Capital
dredging is the dredging carried out in a new location and materials that has never been dredged out. Maintenance dredging is conducted where channels or constructions works has to be at their desired dimensions with a time frame (USACE, 2004) whereas remedial dredging is done to improve the quality, human health and environmental protection purposes (Bray and Cohen, 2010).

2.3 Types of dredging equipment

There are few categories for describing types of dredgers. The types of dredgers are described by four classifications which are Mechanical dredgers, hydraulic dredgers, mechanical/hydraulic dredgers and hydrodynamic dredgers referring to Table 2.1. Production rates for dredgers vary widely depending on the circumstances, the material to be dredged and the transport and disposal methods applied. Other factors, such as weather and sea state, ship traffic, depth and thickness of material being removed, also affect dredging production rates (IADC, 2010).

<table>
<thead>
<tr>
<th>Types of dredgers</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical dredger</strong></td>
<td></td>
</tr>
</tbody>
</table>
| Grab/Clamshell dredger | • Clamshell dredgers can be used in sands, some types of clay, gravel, cobbles and occasionally broken rock  
• Dredge in fairly deep waters and able to do precise spot dredging |
| Backhoe dredger | • Barge-mounted for dredging, generally non-self-propelled and can have a moderate production rate  
• Hydraulically operated rams for movement, positioning and excavating  
• Dredge a broad range of materials |
<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dipper dredger</strong></td>
<td>- A powered shovel mounted on a barge&lt;br&gt;- Suited for dredging strong rock and highly compacted materials</td>
</tr>
<tr>
<td><strong>Hydraulic dredgers</strong></td>
<td><strong>Plain suction dredger</strong>&lt;br&gt;- Great depths using ladder mounted centrifugal pumps to enhance production at deeper depths and water jets to fluidise the material to be dredged&lt;br&gt;- Suitable or used for channel or harbour construction projects</td>
</tr>
<tr>
<td><strong>Dustpan dredger</strong></td>
<td>- Used on river systems&lt;br&gt;- High bed loads or suspended solid concentrations of sand and small gravel&lt;br&gt;- Capable of moving large volumes of material from localised areas using a suction head shaped much like a dustpan</td>
</tr>
<tr>
<td><strong>Hydraulic &amp; mechanical dredgers</strong></td>
<td><strong>Cutter suction dredger</strong>&lt;br&gt;- The cutters excavate the material into suitably sized material. This is then sucked into the suction pipe as a solid/water slurry and pumped to the surface&lt;br&gt;- Cutter suction dredgers (CSDs) are used for dredging rock and hard clays. This CSD is self-propelled</td>
</tr>
<tr>
<td><strong>Bucket wheel dredger</strong></td>
<td>- Bucket-wheel dredgers are mainly used in the mining industry&lt;br&gt;- Bucket-wheel dredgers rotate perpendicular to the axis of the suction pipe</td>
</tr>
<tr>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| **Trailing suction hopper dredger**     | - Self-propelled ships with hoppers or dredged material storage internal to the hull  
                                         - They dredge whilst underway, travelling at low speeds.  
                                         - Flexible in terms of the material to be dredged, placement alternatives, and the ability to work in protected and unprotected waters |
| **Hydrodynamic dredgers**               |                                                                                                                                           |
| **Water injection dredger**             | - For maintenance dredging  
                                         - Uses water pressure to fluidise the bottom material to be removed, creating dense fluid slurry  
                                         - Slurry is then transported from the excavation site by means of currents either induced by the density gradient between the slurry and that of water, or by naturally occurring currents |
2.4 The Dredging Process

The dredging process consists of the following four elements (USEPA, 2012 Vlasblom, 2003, Eisma, 2005 & PIANC, 2002):

i) Excavation

This process involves the removal of sediments which consist of soils and rocks from the water body. A dredger is normally used to excavate the material either mechanically, hydraulically or by combination of both (see Table 2.1).

ii) Transportation of excavated materials

This process is about transporting the dredged materials to a storage area or disposal site. There are 2 types of transportation which are via water and land. It is generally achieved by one of the following methods:-

- Self-contained hopper dredger
- Barges
- Pipelines
- Trucks
- Conveyor belt

iii) Storage

Storage comes before the treatment process. Dredged materials can be stored for disposal or reuse but depends on quantity and the place of storage.

iv) Reuse or disposal of dredged materials

Dredged materials should go through treatments process such as solidification before being reused or disposed according to Malaysian law and regulations. Table 2.2 explains about the available rules and regulations, dredging stakeholders and dredging permit criteria in Malaysia. The rule and regulations in Malaysia only has a law for contaminated land and it is stated very briefly about disposal of dredged material under that section.
Table 2.2: Available criteria of dredging related rules in Malaysia

<table>
<thead>
<tr>
<th>Rules and regulation</th>
<th>Dredging Stakeholders</th>
<th>Dredging permit criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Contaminated Land Management Framework</td>
<td>• Department of Environment</td>
<td>• Dredged site above 50 hectares require detailed EIA</td>
</tr>
<tr>
<td>• Contaminated Land Management and Control Guidelines No.1,2 &amp;3 by DOE (Department of Environment Malaysia 2009)</td>
<td>• Ministry of Transport</td>
<td>• If dredging area is less than 50 hectares, State’s DOE may require EA, EMP, EM or EMnP (Government of Malaysia 5th November 1987) -</td>
</tr>
<tr>
<td></td>
<td>• Department of Irrigation and Drainage</td>
<td></td>
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<tr>
<td></td>
<td>• Marine Department</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Fisheries Development Authority of Malaysia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Port administrator and companies</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dredging contractors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Specialist consultants</td>
<td></td>
</tr>
</tbody>
</table>

2.5 Problems related to dredging

The cost of dredging varies according to the technology and equipment used, estimated volume, type of dredged material, distance from excavation to disposal site, time and distance of mobilization and demobilization, and disposal method. The high cost has always been the main problem for port operators, who are responsible for dredging and maintaining deep channels, but also need to spend funds to expand or build new terminals in order to cater for growing trade activities (Anderson and Barkdoll, 2010; Williams, 2008). Table 2.3 shows the comparison of problems faced in dredging internationally and in Malaysia.
Table 2.3 Comparisons of problems of dredging faced internationally (Manap, 2013)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>The US</th>
<th>The UK</th>
<th>France</th>
<th>Malaysia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dredging problems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Economic and environmental problems:</strong></td>
<td></td>
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<tr>
<td>- Trends in the shipping industry toward larger vessels requiring deeper draughts</td>
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<tr>
<td>- The result of years of dismissing environmental problems as irrelevant</td>
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<td></td>
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<tr>
<td>- High cost of sediment remediation</td>
<td></td>
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<tr>
<td><strong>Managerial problem:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Conflict between stakeholders from federal, state and local political leadership during dredging</td>
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<td></td>
</tr>
<tr>
<td><strong>Environmental problem:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Loss of natural habitat</td>
<td>- The deteriorating water quality</td>
<td>- Harbour sites are located in sheltered zones where tides, streams, swell, and wind cause the trapping of sediments that becomes an obstacle for the access of ships to the harbour infrastructures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- The deteriorating water quality</td>
<td>- Polluted dredged material</td>
<td>- Social problem:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Beneficial use of dredged material</td>
<td>- Conflicts on defining what constitutes waste to describe dredged sediments</td>
<td>- Dredging involves many stakeholders including the community and each stakeholder has a view and some interests can diverge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Conflicts on defining what constitutes waste to describe dredged sediments</td>
<td></td>
<td>- The late involvement of environmental protection is responsible for blockings, loss of money and loss of time</td>
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<td></td>
</tr>
<tr>
<td><strong>Managerial problem:</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>- Potential friction between EU Directives and international conventions</td>
<td>- Other Directives on environmental protection, including Habitats and Birds Directives and Waste Framework Directive, lead to delays or cancellation of projects and to increase costs</td>
<td>- Social and economic problem:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Other Directives on environmental protection, including Habitats and Birds Directives and Waste Framework Directive, lead to delays or cancellation of projects and to increase costs</td>
<td></td>
<td>- Public participation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Economic vs the Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Managerial and environmental problem:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Conflict of power distribution (State vs Federal) that cause delays</td>
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<tr>
<td></td>
<td></td>
<td>- No mandatory action for monitoring</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- No incentives for mitigation measures</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>- Difficult to enforce EIA 1987 Order</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Lack of cumulative impact analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Illegal sand dredging</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Environment aspect was not included during pre-planning stage</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Lack of baseline data/evidence based documents</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Social problem:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
2.6 Dredged Marine Soil (DMS)

Dredging can be described as underwater excavation of soils. It is necessary to maintain existing waterways, ports and water channels. The need of increase in waterway depths might be due to the increased demand for transporting people, equipment, materials and commodities by water. Besides that, dredging process is also used in flood control measures to maintain or improve the river or channels flow capacities. Table 2.4 shows some of the international definition of DMS.

<table>
<thead>
<tr>
<th>International Organisation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oslo-Paris Convention (OSPAR)</td>
<td>Sediments or rocks with associated water, organic matter etc., removed from areas that are normally or regularly covered by water using dredging or other excavation equipment.</td>
</tr>
<tr>
<td>London Convention</td>
<td>Materials dredged that is by land and coastal waters</td>
</tr>
</tbody>
</table>

The soil excavated from the waterways, whether from the sea, river or port is known as dredged soil. Mostly, such dredged materials consist of sands, silts, clay and other material from underwater (Table 2.5). In Malaysia, the dredged soils have yet to be recycled and reused, but mainly disposed in designated open water, upland or onshore. However, for soils which contain contaminants, the placement options should be considered in terms of environmental sensitivity and responsibility (IADC, 2012).

The dredged soils are very similar to soft clay on land, with low loadbearing capacity, high compressibility and low permeability. These properties make the soil unsuitable for construction activities. Besides, continuous disposal of the material, whether offshore on inland, does not promote sustainable practice, considering that the material could be reused, and that the dumping procedures almost always incur one or other environmental concerns (Butt et al., 2008). Thus, if the dredged material is to be reused as a geo- material, the naturally weak and soft soil need to be treated. A possible solution is the solidification technique, where binders are admixed with
the wet soil to dry and stiffen it chemically. The use of improved soil (a mixture of dredged soil and converter slag) for land reclamation was practised in Japan (Matsumoto et al., 2014). Besides, treated soil has also been used for land reclamation in the Central Japan International Port and in the Port of Brisbane, Australia (Ganesalingam et al., 2011). This is an example of evidence that dredged materials can be treated to improve its suitability, either by improving its environmental properties or providing economic benefits (IADC, 2012).

Table 2.5: Particle size distribution of DMS

<table>
<thead>
<tr>
<th>Reference</th>
<th>Dredged Area</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azhar et al., 2014</td>
<td>Marina, Melaka</td>
<td>59 %</td>
<td>16 %</td>
<td>20 %</td>
</tr>
<tr>
<td>Azhar et al., 2014</td>
<td>Tok Bali, Kelantan</td>
<td>75 %</td>
<td>19 %</td>
<td>4 %</td>
</tr>
<tr>
<td>Ganesalingam et al., 2011</td>
<td>Port of Brisbane</td>
<td>41 %</td>
<td>38 %</td>
<td>5 %</td>
</tr>
<tr>
<td>Vinothkumar and Arumairaj, 2013</td>
<td>Coimbatore, India</td>
<td>56.68 %</td>
<td>14.17 %</td>
<td>29.15 %</td>
</tr>
<tr>
<td>Wang et al., 2013</td>
<td>Dunkirk Harbour, France</td>
<td>14.5 %</td>
<td>74.7 %</td>
<td>10.8 %</td>
</tr>
</tbody>
</table>
2.7  DMS Management Framework

Management generally is the function that coordinates the efforts of people to accomplish goals and objectives using available resources efficiently and effectively. The principles of management are planning, organizing, command, coordination and control (Force, 2010). On the other hand, a framework is a set of broad concepts that guide research. DMS management framework is important and necessary for beneficial use of DMS as the guidelines in Malaysia are not systematically documented. It is essential to have this management framework because DMS is hazardous and poses health and environmental effect. Almost all existing guidelines said that treatment of contaminant in the soil is the most important stage in managing DMS (USACE, 2006; PIANC, 2009 and IADC, 2012). Half of them gave equal importance to management in transporting and storing of DMS stage. Transporting and storing hazardous material is very dangerous and a guideline should be developed regarding that process. The major stages which should be included in a DMS management framework of beneficial use are transportation, storage and treatment. Table 2.6, 2.7 and 2.8 shows the importance of those stages.
Table 2.6 Importance of Transportation

<table>
<thead>
<tr>
<th>Mode of transportation</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Comments</th>
<th>References</th>
</tr>
</thead>
</table>
| Pipelines              | • Less impact to surrounding infrastructure and environment  
                          • More cost effective  
                          • Both hydraulic and mechanical dredging approaches  
                          • Closed circuit system | • Leakage if not connected properly | Pipelines are the most reliable mode of transportation to be used for direct usage or disposal of DMS. It can transport the DMS easily without polluting the environment and also any infrastructures. While transporting process is going on, it will not disturb any passerby ships. | Erftemeijer & Lewis, 2006  
                          Eisma, 2005  
                          Vlasblom, 2003  
                          IADC, 2014  
                          USEPA, 2012  
                          PIANC, 2002 |
| Barges                 | Self-unloading  
                          • Used when need to be discharged within the water body  
                          • Equipped with doors or valves  
                          • Can be used with mechanical dredges | • Can be unloaded in sea only  
                          • Stationary  
                          • Risk of spillage | Barges are an open container to fill the DMS by using mechanical dredge equipment to lift the DMS from the water and place it into the barge. As for the self-unloading it can be only used for disposal but for non self-unloading barge, it can be towed by boat or ship to the shore and then transfer it to a truck to store it for reusing purpose. | Vlasblom, 2003  
                          Eisma, 2005  
                          USEPA, 2012  
                          PIANC, 2002 |
|                        | Non self-unloading  
                          • Can be unloaded in sea or land  
                          • Can be used with mechanical dredges | • Stationary  
                          • Risk of spillage | | |
| **Hopper dredges** | • Can move about freely  
• Can dredge any kind of material  
• Can work in any calm or turbulent water  
• Can work in both deep or shallow areas | • Not particularly suited to removing thin layers of (contaminated) sediment.  
Hopper dredger is involved since the dredging process itself and is attached pumps to suck the DMS and is not dependent to the anchor and can move about. So after dredging, this dredger can move to the disposal site to dump the DMS or if to reuse the DMS, it can be transported using pipelines. Cutterhead dredger and other hydraulic dredges has the same function | IADC, 2014  
Vlasblom, 2003  
USEPA, 2012 |
| **Truck** | • Loaded mechanically at any density  
• Destination is flexible | • Need more trucks considering the amount of DMS  
• Spillage  
• Noise | Truck is the road transport to move DMS from after collecting from the water to the storage or landfill and so on.  
Eisma, 2005  
Hayes, 2004  
USEPA, 2012 |
| **Conveyor belt** | • Continuously able to transfer large amount  
• Environmental effect is quite low | • High cost  
• Fixed alignment | This method is least used because of the high cost and not really flexible. In most cases, material dredged mechanically will be assist by this conveyor belt  
Eisma, 2005  
USEPA, 2012  
PIANC, 2002 |
## Table 2.7 Importance of Storage

<table>
<thead>
<tr>
<th>Mode of Storage</th>
<th>Description</th>
<th>Comments</th>
<th>References</th>
</tr>
</thead>
</table>
| **Temporary Storage** | • Less than a year  
• Quantity of DMS to be stored must not exceed the quantity of material that can managed at the site.  
• Minimise the amount of material returned by spillage, erosion or other discharged to waters of the state. | • Can be stored for reusing depends on when and where.  
• Storage area has been minimized as it takes up space and a lot of cost. Thus application for beneficial reuse is done for example: after dredging, while its being transported through pipeline, there’s a treatment plant build so that the DMS will be treated and straight away being transferred to onsite applications. It will be cost effective if it is a mega project. | • Stollenwerk *et al.*, 2012  
• USACE, 2009  
• Welp *et al.*, 2002  
• HTAC, 2007 |
| **Long-term Storage** | • More than one year, constitutes disposal  
• Must be located entirely above the high water table.  
• Must meet all the rules and regulation stated | | |
## Table 2.8 Importance of Treatment

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preloading</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>Placement of load prior to the real construction load in order to drain the water out vertically</td>
<td>• Basic dewatering process</td>
<td>• slower</td>
<td>Stapelfeldt, 2006</td>
</tr>
<tr>
<td>Preloading</td>
<td></td>
<td></td>
<td></td>
<td>Das, 2011</td>
</tr>
<tr>
<td>Vacuum</td>
<td>Surcharge load is replace by atmospheric pressure. This is to accelerate the consolidation. Horizontal drains are connected to a vacuum pump</td>
<td>• no extra fill material</td>
<td>• Might have leakage</td>
<td>Stapelfeldt, 2006</td>
</tr>
<tr>
<td>preloading</td>
<td></td>
<td>• construction time shorter</td>
<td></td>
<td>Chai, 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• environment friendly</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>• no risk of slope instability</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td><strong>Vertical drain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand drain</td>
<td>Filling sand into a hole in the soft ground</td>
<td>• Accelerates consolidation</td>
<td></td>
<td>Indraratna, 2000</td>
</tr>
<tr>
<td>Fabric encased</td>
<td>Sand filling in a filter jacket</td>
<td>• Shorten the length of the drainage path (spacing)</td>
<td></td>
<td>Stapelfeldt, 2006</td>
</tr>
<tr>
<td>sand drain</td>
<td></td>
<td>Accelerate the dissipation of pore water pressure</td>
<td></td>
<td>Das, 2008</td>
</tr>
<tr>
<td>Prefabricated</td>
<td>Synthetic filter jacket surrounding a plastic core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertical drain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand compaction</td>
<td>Compacted sand/gravel column</td>
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<td><strong>Geotextiles</strong></td>
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<td></td>
<td>Flexible textile fabrics of controlled permeability used to provide filtration, separation or reinforcement in soil, rock and waste material.</td>
<td></td>
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<td>Kamble Zunjarrao B, 2014</td>
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<td>Tack.WY, 2007</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Morgan et al., 2009</td>
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<td></td>
<td></td>
<td>Schaefer et al., 1997</td>
</tr>
<tr>
<td><strong>Stabilisation</strong></td>
<td>Mechanical stabilisation</td>
<td>Altering the physical nature of native soil by either vibration or</td>
<td></td>
<td>Schaefer et al., 1997</td>
</tr>
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</table>
compaction or by incorporating other physical properties such as barriers and nailing

| Chemical stabilisation | | Makusa, 2012 |
|------------------------|---------------------|
| Stabilised with cementitious materials (cement, lime, fly ash, bitumen or combination of these). The stabilized soil materials have a higher strength, lower permeability and lower compressibility than the native soil. | Will have a filler or cementitious effect on the soil. | Used according to the soil type |
| | | Makusa, 2012 |
| | | Sharma et al., 2012 |
| | | Kołodziejczyk et al., 2012 |
| | | Jong & Chan, 2013 |

<table>
<thead>
<tr>
<th>Vibroflotation</th>
<th>Vibro Compaction</th>
<th>Economy</th>
</tr>
</thead>
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<tr>
<td>This method allows granular soils to be compacted. This method is only used to compact sandy soils.</td>
<td>High performance</td>
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<td>Settlement control</td>
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<td>Hydraulically effective</td>
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<td></td>
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<td>Das, 2011</td>
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<td>Rodriguez, 2015</td>
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<td><a href="http://www.menard.pl/">http://www.menard.pl/</a></td>
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<td><a href="http://www.vibroflotation-ng.com/">http://www.vibroflotation-ng.com/</a></td>
</tr>
</tbody>
</table>

| Vibro Replacement | The technique is used to replace poor or inadequate soil material by flushing out the soil with air or water and replacing it with granular soil. This can be used in various soil types such as clay and sandy soils. |
| Vibro Displacement | This procedure is used with no or small amounts of water used during the technique. The probe in inserted into the soil and it will displace it laterally as the new soil column is being formed and compacted. |
| | | |
2.8 Development of DMS management framework

The development of the framework was based on the Local Planning Groups and Development of Dredged Material Management Plans Guidance (National Dredging Team USA, 1998) and adapted from the Environmental Management Framework development by Shahri (2016). Figure 2.1 shows the flow of planning process and further refined by comparing the plan with the existing established framework. There are 3 stages in developing a framework which are as follows (Shahri, 2016):

i. Collected and comparison of all established DMS frameworks.
ii. Selection of components to be compatible with Malaysian’s needs.
iii. Develop the management framework by adapting the components selected.

Figure 2.1: Basic steps in planning process (National Dredging Team, 1998)
2.8.1 Basic Steps in Planning Process (National Dredging Team, 1998)

An effective dredged material management plan will require close coordination and planning at all governmental levels and with all pertinent aspects of the private sector. National Dredging Team (1998) has proposed the basic step of planning on decision making of a plan selection. The basic process is composed of six major planning steps. The process assures that awareness of the basic assumptions employed, the data and information analysed, the areas of risk and uncertainty, the reasons and rationales used, and the significant implications of each alternative to the selected plan, or any of its components. The recommendations should identify all agreements and procedural requirements necessary to provide, at a minimum, 20 years of dredged material management. Following are the steps in planning process which begins with specific problems and opportunities.

Step 1 is to develop a list of statements that express the understanding and concerns of Local Planning Group members regarding existing and future problems and opportunities related to dredged material management for their planning area.

Step 2 describes both the existing conditions and those conditions most likely to prevail without a plan. This clearly shows all relevant dredged material management information for the planning area (e.g., dredging quantities and quality of material, economics, disposal management activities, etc.). The potential for solving problems and realizing opportunities is determined during this step too.

Step 3 is the formulation of alternative plans. To formulate alternative plans in a systematic manner and ensure that all reasonable alternatives are evaluated. Usually, a number of alternative plans are identified early in the planning process and become more refined through additional development and subsequent iterations.

Step 4 is about evaluating the effects of plans. Evaluate the effects of each alternative plan by determining the difference between the conditions that will prevail without a plan in place and with each alternative plan in place.

Step 5 is to compare the alternative plans. The comparison of plans, or trade-off analysis, focuses on the differences among the alternative plans as determined in the evaluation phase.
Step 6 is selecting a plan. After consideration of the various plans, their effects, and public comments, the Planning Group will select an alternative that will be their recommended plan.

Based on the gathered information of DMS Management in Malaysia, the necessary steps in this planning process were adopted in creating the DMS Management Framework. First, the problems were identified. A proper framework in handling DMS which covers the flow of handling the DMS starting from retrieval up to reusing. The framework would contribute towards reusing the DMS in land reclamation with specific criteria such as settlement limitation, strength and bearing capacity. The disposal will be the last option. Thus the DMS management framework was developed after considerations of the problems and effects of the DMS. The steps in developing the framework is as shown below in Figure 2.2.

![Diagram of planning process steps]

Figure 2.2: Adaptation of Basic steps in planning process
2.9 Preliminary DMS Management Framework

Management generally is the function that coordinates the efforts of people to accomplish goals and objectives using available resources efficiently and effectively. The principles of management are planning, organizing, command, coordination and control (Fayol, 1976). On the other hand, a framework is a set of broad concepts that guide research. DMS management framework is important and necessary for beneficial use of DMS as there are no proper guidelines for it in Malaysia. It is essential to have this management framework because DMS is hazardous and poses health and environmental effect. Almost all existing guidelines said that treatment of contaminant in the soil is the most important stage in managing DMS. Half of them gave equal importance to management in transporting and storing of DMS stage. Transporting and storing hazardous material is very dangerous and a guideline should be developed regarding that process. The major stages which should be included in a DMS management framework of beneficial use are transportation, storage and treatment as shown in Figure 2.3. The discussion about developing a framework is just based upon past related works, thus just a skeletal base of just framework was created. A well organised framework will be established in the future work.
REFERENCES


Bray, N. & Cohen, M. (2010), *Dredging For Development*.


