

# **Engineered Reuse of DREDGED MARINE SOILS from Malaysian Waters 1**

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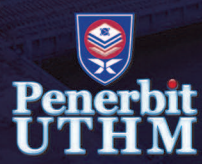
**Abstract:** This book sheds some light on the often neglected geowaste from our waters, the dredged marine soils. Extracted in large volumes with no discernible reuse plan and management, the soils are disposed-off in designated dumpsites inland or offshore, inevitably raising marine environmental and safety concerns. It is, therefore, necessary to explore the possible reuse of dredged marine soils in an engineered, informed manner to mitigate any risks of further negative environmental and social consequences. The chapters are arranged in such a way as to give readers an overview of the dredging industry and regulatory outlines, followed by the material's characterization and time-dependent hardening or thixotropy behavior, an inherent property of the soil which could be expeditious for reclamation works. It would serve as a peeping hole into the latent potential of the dredged marine soils, sparking ideas and innovations to transform the otherwise geowaste into a worthy construction material.

**Keywords:** Dredged, marine soil, innovation, construction



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**2022**

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First Published 2022

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Perpustakaan Negara Malaysia      Cataloguing-in-Publication Data

Engineered Reuse of DREDGED MARINE SOILS from Malaysian Waters. 1 / EDITORS CHEE-MING CHAN, MOHAMMAD ZAWAWI ROSMAN.

ISBN 978-967-0061-15-3

1. Soils.
  2. Dredging spoil.
  3. Marine sediments.
  4. Government publications--Malaysia.
- I. Chan, Chee-Ming. II. Mohammad Zawawi Rosman.  
631.4

Published & Printed by:  
Penerbit UTHM  
Universiti Tun Hussein Onn Malaysia  
86400 Parit Raja,  
Batu Pahat, Johor  
Tel: 07-4538529/8698  
Fax: 07-453 6145

Website: <http://penerbit.uthm.edu.my>  
E-mail: [pt@uthm.edu.my](mailto:pt@uthm.edu.my)  
<http://e-bookstore.uthm.edu.my>

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(MAPIM)

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# *Preface*

This book sheds some light on the often neglected geowaste from our waters, the dredged marine soils. Extracted in large volumes with no discernible reuse plan and management, the soils are disposed-off in designated dumpsites inland or offshore, inevitably raising marine environmental and safety concerns. It is, therefore, necessary to explore the possible reuse of dredged marine soils in an engineered, informed manner to mitigate any risks of further negative environmental and social consequences. The chapters are arranged in such a way as to give readers an overview of the dredging industry and regulatory outlines, followed by the material's characterization and time-dependent hardening or thixotropy behavior, an inherent property of the soil which could be expeditious for reclamation works. It would serve as a peeping hole into the latent potential of the dredged marine soils, sparking ideas and innovations to transform the otherwise geowaste into a worthy construction material.

# *Prologue*

In this compilation of research work on the dredged marine soils from Malaysian waters, readers are given an overview of the dredging processes, machinery, related rules, and legislation, as well as an impact on the environment as the consequences of dredging and disposal of the dredged materials. It is followed by a characterization study of the soils, especially in terms of physical and chemical properties, which significantly influence the resulting engineering responses. Focus is next directed at the time-dependent self-hardening mechanism or thixotropic hardening of the fine-grained dredged marine soils, i.e., clay and silt, which could potentially be adopted as an improvement technique for strength and stiffness enhancement on site. In a nutshell, this book lays down the fundamental engineering characteristics, background, and context for reusing dredged marine soils from Malaysian waters.

# Chapter 1

## Introduction to dredging and dredged marine soils

M. Zawawi Rosman  
Chee-Ming Chan

### 1.1 Background

The excavation of dredged marine soils (DMS) in the open channel is termed dredging activity. This activity is required to satisfy various needs of marine infrastructure especially, such as maintenance, navigation, mining, construction, and environmental improvement works (Bray et al., 1997). DMS are geomaterials that may comprise rock, clay, organic matter, and other debris gathered through dredging (Dubois et al., 2008).

According to Jong & Chan (2013), DMS is generally considered as geo-waste. Hence, it is dumped rather than reused. However, the successful reuse of DMS as backfill material for land reclamation projects has been reported, including Port of Brisbane in Australia, Tokyo Haneda Airport in Japan, and Changi East in Singapore (Ganesalingam et al., 2013; Watabe & Noguchi, 2011; Arulrajah et al., 2008). Ironically, in Kuala Perlis, Malaysia, approximately 300,000 m<sup>3</sup> of DMS was removed from the seabed and dumped on an offshore site as part of maintenance dredging work (Salim et al., 2012).

Dredged cohesive soils are high in compressibility and water content but low in load-bearing capacity and permeability. If certain structures or development were erected on top of these poor and unimproved made ground, it would risk excessive and non-uniform settlements due to consolidation, as reported by Ganesalingam et al. (2013) as well as Rajasekaran & Rao (2002). Conventionally, similar soft soils can be chemically improved by adding pozzolanic additives, e.g., hydraulic binders like cement and lime (Xiao &

## Chapter 2

# Physical, chemical and biological properties of dredged marine soils

Zarina Shahri  
Chee-Ming Chan

## 2.1 Introduction

This chapter has two main parts: i) developing an environmental management framework and ii) verification of the framework's applicability. The development of the environmental management framework is explained in the first part of this chapter. The second part describes verification of the framework applicability by using actual data of characterization and assessment of dredged marine sediments (DMS) from Lumut (LT), Melaka (MM), Tok Bali (TB), and Pasir Gudang (PG).

## 2.2 Developing an environmental management framework

### 2.2.1 Overview

An environmental management framework was developed by referring to the London Convention-Dredged Material Assessment Framework, Helsinki Commission (HELCOM) Guidelines for the Disposal of Dredged Material at Sea and Oslo-Paris (OSPAR) Guidelines for the Management of Dredged Material (LC, 1972; HELCOM, 2007 and OSPAR, 2009). The proposed framework is essentially an adaptation of these existing established guidelines in accordance with the Malaysian context. This framework is used as guidance for evaluating the potential sustainable reuse of Malaysian DMS. The environmental management framework for Malaysian DMS is developed and shown in Figure 2.1. Components in this framework are discussed in detail in sections 2.2.2 and 2.2.2.1-2.2.2.6.

## Chapter 3

# Thixotropic hardening of dredged marine clay: Marina Melaka, Melaka

Chin-Fah Chu  
Chee-Ming Chan

### 3.1 Introduction

In this study, the changes in shear strength of the Marina Melaka DMS were monitored via vane shear test, while the stiffness was measured using the bender element test. The fall cone test was conducted as a complementary measurement to relate the strength and stiffness change over time. Results of the experimental work are analyzed, presented, and discussed, including correlations established between the relevant parameters. The DMS sample was remoulded and admixed with different water contents in the multiples of the soil's liquid limit (LL), i.e., 0.75, 1.00, and 1.25 LL. These remoulded samples were then left to age, while measurements were performed at predetermined intervals to assess the changes in strength and stiffness with time. This is also known as thixotropic hardening of the soil.

### 3.2 Undrained Shear Strength of Dredged Marine Clay

A Vane shear (VS) test was conducted on the dredged marine clay due to the exceptionally soft nature of the samples. Measurement of the undrained shear strength ( $c_u$ ) was conducted for up to 7 days. The results are as plotted in Figure 3.1. Firstly, it can be seen that  $c_u$  gradually increased with elapsed time. Secondly, the measurement of undrained shear strength at 0.75LL produced a much higher value of undrained shear strength compared to samples at 1.00LL and 1.25LL. According to Seng et al. (2012), the increase in strength is caused by the thixotropic behaviour which results in self-hardening with time. Thirdly, based on results obtained in the preliminary tests, VS test was found to have a limitation in detecting very small

## Chapter 4

# Thixotropic hardening of dredged marine clay: Tok Bali, Kelantan

Hui-Yen Ng  
Chee-Ming Chan

### 4.1 Introduction

This chapter discusses the test results on the thixotropic and lightly induced solidification hardening behaviour of a high plasticity clay (CH) dredged from Tok Bali, Kelantan. The main focus of the study is to evaluate the strength and stiffness gain as a result of the thixotropy effect, or both thixotropy and cementation.

### 4.2 Cone Penetration Resistance

Thixotropic hardening behaviour of dredged marine clay was determined by fall cone test (FC), vane shear test (VS), and bender element test (BE) at water contents of 0.75LL, 1.00LL, and 1.25LL, where LL is the liquid limit of the soil. Figure 3.1 shows the variation of the cone penetration depth in the soil as a function of time. Generally, plots of the soil with different water contents seem to be parallel to each other. From the figure, it was observed that the cone penetration decreased as time passed. This is due to an increased load resistance of the soil as a result of self-hardening with time or the thixotropic effect.

Figure 4.1, it can be seen that the soil with natural water content, which is 1.89LL, recorded the highest cone penetration depth. This indicates that the shear resistance of the soil at high water content is low and more vulnerable to shear failure as the cone penetrates the soil. However, although the cone penetration depth for 1.89LL decreased as time passed, this improved resistance was not visible till after a couple of days. This can be attributed to 'bleeding,'

## Chapter 5

# Thixotropic hardening of low plasticity dredged marine silt: Tok Bali, Kelantan

Adib Syazwan Ahmad Sakri  
Chee-Ming Chan

### 5.1 Introduction

This chapter presents test results of a dredged marine soil (DMS) remoulded at water contents of 0.90, 1.25, and 1.81LL, where LL is the liquid limit of the soil as explained in earlier chapters. The samples were then subjected to the vane shear (VS) and fall cone (FC) tests to assess the improved shear strength over time, i.e., self-hardening or thixotropy of the soil. A comparative study was carried out with the same soil sample admixed with small cement dosages to achieve light solidification and to examine the shortened time to attain improved shear strength. The cement dosages added were 1, 3, and 5 %. Complementary measurements of P- and S-wave velocities using the bender element test system (BE) were also performed for the cement-treated samples, which were then used to estimate the small strain bulk and shear stiffnesses of the soil under induced solidification.

### 5.2 Natural Dredged Marine Soil (DMS) Behaviour

#### 5.2.1 Shear Strength of Natural DMS

The test samples consist of 3 different water contents ( $w$ ), namely 0.90LL ( $w = 49.06\%$ ), 1.25LL ( $w = 68.14\%$ ) and 1.81LL ( $w = 98.66\%$ ). The test results for 0.90LL and 1.25LL were successfully recorded, but the 1.81LL samples were too soft for shear strength measurements. The laboratory vane shear (VS) apparatus did not show any reading as the blades of the vane failed to engage with the weak soil medium. Hence the shear strength could not be more than  $20 \text{ kN/m}^2$ , which was the spring capacity of the test setup.

## Chapter 6

# Thixotropic hardening of high plasticity dredged marine silt: Tok Bali, Kelantan

M. Nazri Mohd Yusof  
Chee-Ming Chan

### 6.1 Introduction

This chapter presents the test data analysis and discussions on a dredged soil sample of high plasticity silt remoulded at water contents ( $w$ ) in the multiples of the soil's liquid limit (LL), i.e., 1.76LL, 0.90LL, and 1.25LL. Examination of the time-dependent natural hardening of the material, also known as thixotropic hardening, was carried out. A separate set of test specimens were examined by adding 1-5% cement for induced solidification. This was primarily to serve as a comparison between thixotropic hardening and induced solidification effects on the same dredged soils for potential reuse. Both the strength and stiffness improvement were monitored in the present work via vane shear and fall cone tests for the former and bender element measurements of P- and S-wave velocities for the latter.

### 6.2 Natural Dredged Marine Soil (DMS) Behaviour

#### 6.2.1 Shear Strength of Natural DMS

3 samples were prepared for the analysis, which consists of samples with water content of 0.90LL ( $w = 64.8\%$ ), 1.25LL ( $w = 90\%$ ) and 1.76LL ( $w = 126.49\%$ ). The vane shears instrument was adopted to determine the undrained shear strength of the DMS. Referring to Seng and Tanaka (2012), the vane shear test is considered an appropriate method to determine soils of low shear strength, though there is a limit, too, i.e., undrained shear strength no lower than 20 kPa. For instance, the shear strength of the 1.76LL

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# *Epilogue*

This book has presented a general background for dredging works in Malaysian waters and the engineering characteristics expected of the dredged marine soils, which are essentially not very much different from inland fine-grained soils. An examination of the time-dependent thixotropic hardening of clay and silt sediments was also included, indicating the effective yet time-consuming self-treatment possible for these materials reused in reclamation, for instance. All in all, the dredged marine soils were potentially reusable with suitable recommended pre-treatment.