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Geotechnical Aspects of Land Reclamation and Ground Improvement

Edited by
Myint Win Bo and Eltayeb Mohamedelhassan



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Preface

Growing populations and expansion of cities around the world have resulted in shortage of land. In addition, most established cities around the world were historically and strategically selected to be in coastal regions near the river mouth to facilitate both inland and overseas transportation by river and ocean respectively. Due to the scarcity of land at coastal regions around the world, land reclamation is commonly carried out for the future expansion of various infrastructure facilities, such as residential, commercial, industrial and institutional developments as well as transportation hubs like seaports and airports. In some cases, land reclamation is also carried out for agricultural land development, flood prevention and environmental control and protection. Whenever land reclamation is carried out, geomaterials such as sand and gravel are used to fill up the underlying geomaterial such as seabed soils. Unfortunately, soft soil is present at coastal regions, especially around the mouths of rivers, often requiring the use of ground improvement to eliminate significant future settlement from occurring. The combination of geomaterials such as prefabricated vertical drains with preloading techniques is one of the most widely used ground improvement methods in land reclamation projects. Geomaterials such as geotextiles are also used for separation and filtration purposes in coastal protection works. Since land reclamation deals with geomaterials in many aspects, geotechnical engineering involves several steps of land reclamation and ground improvement processes, beginning with the desk study (cradle) and ending with completion and commissioning of completed land reclamation works (grave). Due to the fact that geotechnical engineering plays a major role in land reclamation and ground improvement projects, the editors have chosen to publish *Geotechnical Aspects of Land Reclamation and Ground Improvement* by compiling chapters from around the world to highlight the importance of this subject matter.

This book is formed as a collection of chapters from projects around the world where significant land reclamation works were carried out over the past few decades to fill the gap of land shortage for infrastructure development. A total of twenty chapters is presented in this book by authors from Australia, Japan, Hong Kong, Singapore, Malaysia, Indonesia, India, Canada, UK and USA.

Myint Win Bo (Chapter 1) describes the process of land reclamation in detail. Ikua Towhata (Chapter 2) presents a historical review of land reclamation projects in Japan. Reusing waste material in land reclamation is described by Jian-Hua Yin, Ze-Jian Chen, Pei-Chen Wu and Kai Liu (Chapter 4) and Yi Lu, Chengyuan Xiong, Eng-Choon Leong and Abolfazl Baghbani (Chapter 18). Jarvis Tyrell Curry (Chapter 20) and Zhang Yaodong, Xiao Huawen, Xie Hua and James Lam (Chapter 17) describe shoreline and embankment stability.

While geotechnical investigation in land reclamation is explained in detail by Laifa Cao (Chapter 11), assessment of performance of soft ground using in situ testing methods such as CPTu is demonstrated by Paulus P Rahardjo (Chapter 13).

Research and analysis of the ground improvement process and design are discussed by Kok Shien Ng and Yee Ming Chew (Chapters 15 and 16), while Maki Ito, Shahid Azam and Wayne Clifton (Chapter 12) present their work on an artificial neural network approach for prediction of slurry compressibility.

Several authors present either case studies or experimental research related to ground improvement works. Among others, Babak Hamidi (Chapter 5) presents the application of ground improvement in the context of Australian reclaimed ports. Many other ground improvement processes are discussed, such as the application of biocementation by Nilanjana Banik and Rajib Sarkar (Chapter 8) and Shashank B Subramanyam and Devendra Narain Singh (Chapter 10), while Mohamed G Arab and Mohamed A Shahin (Chapter 9) present biogeotechnical engineering in general. While applications of electrokinetic remediation in land reclamation are described by Ikrema Hassan (Chapter 7), laboratory testing principles for the electrokinetic consolidation method are discussed in detail by Peter To and Nagaratnam Sivakugan (Chapter 6). Ground improvement using special materials such as geopolymer and nanoparticles are presented by Hayder H Abdullah and Mohamed A Shahin (Chapter 3) and Shumsun Nahar Siddique and Eltayeb Mohamedelhassan (Chapter 14), respectively. A state-of-the-art review on geosynthetic double-encapsulated annulus stone columns for improving the performance of soft clays is presented by Mohammed Shakeel Abid, Deendayal Rathod and Sai K Vanapalli (Chapter 19).

This book is edited by Dr Myint Win Bo, who has extensive experience in land reclamation and ground improvement projects around Asia (Singapore, Indonesia and South Korea), UK and Canada, and Dr Eltayeb Mohamedelhassan who is also an expert in ground improvement techniques. This book should prove useful to practising engineers, project managers and researchers who are involved in land reclamation and ground improvement projects as well as students and contractors alike.

About the editors

Myint Win Bo is President/Chief Executive Officer of Bo & Associates Inc. Canada. He is a Fellow of the Geological Society, and a Fellow of the Institution of Civil Engineers. He is also an Adjunct Professor at York University, Canada, University of Regina, Canada, and Toronto Metropolitan University, Canada. Dr Bo has authored six textbooks and is an Editor for five international journals including *Environmental Geotechnics* and *Geotechnical Research*, both published by ICE. His works have been cited more than 8100 times in the referred journals and proceedings.

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Acknowledgements

As several authors around the world contributed chapters in this compilation, *Geotechnical Aspects of Land Reclamation and Ground Improvement*, the editors wish to acknowledge and thank all contributing authors.

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The author would like to thank his mentors the late Dr A Vijiaratnam, former Chairman of SPECS Consultants Pte Ltd, Singapore, and Mr Law Kok Hwa, former Senior Vice President of PSA Corporation, Singapore, for their guidance and support throughout his career and during the implementation of several land reclamation projects in Asia.

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Finally, but not least, the author would like to express his appreciation to his wife Win Myint Than, daughters Htet Ei Bo and Thanda Bo, son Kyee Soe Bo and granddaughter Ariana Salamati for the understanding and support given to him during the preparation of this book and throughout his career.

Dr Myint Win Bo

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Chapter 1
Geotechnical aspects of land reclamation and ground improvement

Myint Win Bo

Bo & Associates Inc., Canada

Abstract

Land reclamation is usually carried out to create or expand land for future infrastructure developments around expanding cities. Future developments are generally for residential, commercial, industrial and institutional infrastructure including transportation hubs like seaports and airports but can also include many other uses such as agricultural land development, flood protection or environmental protection and so on. Land reclamation is usually accompanied by ground improvement works both for underlying soils and/or filling soils. Since land reclamation and ground improvement are carried out using geomaterials, geotechnical engineering plays a major role. Geotechnical input is required throughout, from the beginning to the end of the land reclamation works. This chapter describes the geotechnical aspects of land reclamation and ground improvement where geotechnical engineering works are carried out or provide input at every stage of the land reclamation and ground improvement process, highlighting the importance of geotechnical engineering.

Keywords: geomaterials; geotechnical engineering; ground improvement; infrastructure development; land reclamation

1.1. Introduction

Land reclamation is the process of creating new land from the sea, rivers or lake beds, transforming water bodies into habitable or usable land. This practice is undertaken for numerous reasons, spanning agriculture, urban development, industrial expansion, creating land for airports and seaports and even environmental restoration.

1.1.1 History of land reclamation

In ancient Egypt, the rulers of the Twelfth Dynasty (c. 2000–1800 BC) undertook a far-sighted land reclamation scheme to increase agricultural output. They constructed levees and canals to connect the Faiyum with the Bahr Yussef waterway, diverting water that would have flowed into Lake Moeris and causing gradual evaporation around the lake's edges, creating new farmland from the reclaimed land (Wordie, 1999). A similar land reclamation system using

dams and drainage canals was used in the Greek Copaic Basin during the Middle Helladic Period (c. 1900–1600 BC). Another early large-scale project was the Beemster Polder in the Netherlands, adding 70 km^2 (27 sq mi) of land in 1612. In Hong Kong, the Praya Reclamation Scheme added 20 to 24 hectares (50 to 60 acres) of land in 1890 during the second phase of construction. It was one of the most ambitious projects undertaken during the era of colonial Hong Kong. Some 20% of land in the Tokyo Bay area has been reclaimed, most notably Odaiba artificial island. The city of Rio de Janeiro was largely built on reclaimed land, as was Wellington, New Zealand.

1.1.2 Land reclamation projects around the world

In recent years, many land reclamation projects have been carried out for airport and seaport expansion, land expansion for residential and commercial infrastructure development, expansion of shorelines for coastal roads, bridge abutments, environmental restoration, wetland redevelopment, creation of agricultural lands, and flood and shore protection. Throughout history, various countries have embarked on ambitious land reclamation projects that reflect their unique needs and aspirations. Several notable land reclamations have been carried out across the globe, including

- The Netherlands
  - Markermeer and Ijsselmeer Polders
  - Zuyderzee works
- Singapore
  - Marina Bay and Marina Bay Sands
  - Changi Airport expansion
  - Tuas land reclamation
  - Jurong Islands reclamation
  - Pulau Tekong land reclamation
  - East coast land reclamation
  - Semakau Land reclamation
- Hong Kong
  - Central Waterfront
  - Hong Kong International Airport at Chek Lap Kok
- Japan
  - Tokyo Bay
  - Kansai International Airport
  - Yokohama coastal areas
- South Korea
  - Incheon Free Economic Zone
  - Incheon International Airport
  - Incheon Seaport
- Indonesia
  - Jakarta Bay reclamation
  - Pantai Indah Kapuk
  - Ancol Baru
- China
  - Caofeidian land reclamation project
  - Xuanmen land reclamation project
  - Yangshan deepwater port

- India
  - Seven Islands of Bombay
  - Uttar Pradesh Sodic Land Reclamation III Project
  - Coastal Road (Mumbai)
- Bahrain
  - Durrat Al Bahrain
  - Bahrain Bay
- Dubai, UAE
  - Palm Jumeirah
  - The World Islands
- Qatar
  - The Pearl-Qatar
- USA
  - Battery Park City, New York
  - San Francisco Bay

1.2. Geotechnical aspects of land reclamation and ground improvement

Land reclamation involves sourcing of geomaterial as a fill, dredging, filling and cutting of existing and/or newly deposited geomaterial to form the shape required, as well as treating or improving the underlying geomaterial to minimize the consolidation settlement or to accelerate the settlement. Therefore, both base materials and fill materials are geomaterials. Improvement to accelerate the consolidation process and/or to reinforce the formed slopes requires the utilization of human-made geomaterial such as geotextiles, as well as the use of rocks in shore protection. Therefore, geotechnical engineering plays a major role in land reclamation and ground improvement.

Generally, there are three main stages involved in land reclamation and ground improvement, namely

- Preliminary stage
  - preliminary desk study
  - preliminary investigation
  - design of land reclamation and ground improvement
  - preparing contract documents and specifications
- Land reclamation stage
  - implementation of land reclamation
  - detailed ground investigation
  - geotechnical instrumentation
  - shore protection
  - environmental control
  - quality control
- Ground improvement stage
  - ground improvement
  - pilot testing for exhibited design for ground improvement
  - performance monitoring and verification
  - assessment of ground improvement.

1.3. Preliminary stage

1.3.1 Preliminary study

During the preliminary study stage, the information required for geotechnical aspects is gathered for feasibility studies. Existing information related to geotechnical aspects is obtained from the public domain or existing literature including

- topography and bathymetric survey maps
- area photography and digital maps
- geological maps
- hydrogeological maps
- hydraulic and wave action maps
- tidal fluctuation maps
- existing ecosystem information
- past activity of land use including the surrounding area
- potential existing infrastructure which is likely to be affected
- existing geotechnical investigation and borehole data, if any.

Based on the information obtained from the preliminary study together with outcomes from other aspects such as coastal engineering, environmental engineering and economic and cost engineering, site selection and feasibility studies are carried out.

1.3.2 Preliminary investigation

In the planning stage, geological formation, seabed characteristics (such as type of seabed, shoreline geomorphology, fluctuation of sea levels) and availability of borrow sources (such as fill materials, aggregates and armor rocks) and so on are studied.

Large-scale surveys are carried out to collect the information required for land reclamation and ground improvement. Preliminary investigations are carried out, including

- bathymetric survey
- geophysical survey
- magnetic survey to locate possible explosive material left and buried under the seabed
- preliminary geotechnical investigation
- geotechnical laboratory testing
- preliminary geotechnical characterization.

Bathymetric surveys are used for volume estimation of fill material whereas geophysical surveys are used for preliminary profiling of underlying soils and rocks, which are again verified and confirmed by the preliminary geotechnical ground investigation.

Generally, a bathymetric survey is usually carried out to determine the seabed depths and elevations. Together with post-filling and land-forming surveys, the gross volume of fill imported can be obtained.

This information is essential for gross volume requirements for fill material to form land. In addition, this information is also used for land reclamation design considering settlement, slope stability and so on. These aspects will be discussed in the later sections.

Large-scale ground investigation is usually carried out such as subsurface investigation using geophysical surveying to determine the approximate subsurface formation profile. Preliminary borrow sourcing investigation can also be carried out during preliminary stage.

Volume estimation is possible using information obtained from bathymetric and geophysical surveys. Detailed investigations using geotechnical ground investigation methods to determine accurate quantity and quality can be carried out using in situ testing and sampling. Details of geotechnical ground investigation in land reclamation projects are described by Bo and Choa (2004) and Bo *et al.* (1998a), including

- conventional boring and standard penetration testing (SPT)
- cone penetration tests (CPT)
- window sampling
- vibro-coring.

In general, prior to land reclamation investigations, the extent of borrow source and their quality can be determined. For example, CPT can classify the type and quality of borrow materials without obtaining samples. Bo *et al*. (2001b) described the application of CPT in land reclamation and ground improvement projects. Other investigation methods require sampling of borrow soils to carry out laboratory testing to determine their quality.

Preliminary geotechnical ground investigation consists of wider spaced boring, sampling and in situ testing. Geotechnical laboratory testing is carried out on both disturbed and undisturbed samples. Characterization of soils and rocks is carried out using geotechnical investigation and laboratory testing data. Details of geotechnical ground investigation and laboratory testing will be described in detail in the later chapters of this book.

1.4. Design of land reclamation and ground improvement

The design process of land reclamation and ground improvement works is carried out using the information collected during the preliminary investigation stage.

1.4.1 Estimation of short- and long-term settlement to assist in fill volume requirement

In many cases, the magnitude of settlement at various stages of land reclamation and ground improvement are extremely important in order to be able to estimate the actual quantity required for filling, including volume loss occurring during different stages. Many land reclamation projects carried out over soft clay commonly encounter settlement as high as 2–3 m which could translate into volume loss of up to 3 million m^3 for a land reclamation area of 100 hectares.

In many cases, payment for land reclamation filling works are paid based on pre- and post-survey for various stages of land reclamation. Certain volume losses are absorbed by the contractor whereas other volume losses are covered by the owner. For example, the settlement occurring up to the first level of fill which is known as the general fill level, (which is usually a couple of metres above mean sea level) to form a platform for ground improvement work, is usually absorbed by the contractor. Therefore, the longer the duration of filling during general filling works, the greater the volume loss, which will be a disadvantage to the contractor and an advantage to the owner. Volume loss occurring above the general fill level is generally absorbed by the owner.

1.4.2 Ground improvement design to eliminate long-term settlement

In addition to the magnitude of settlement, the time rate of consolidation is important for scheduling and managing contractual aspects. Therefore, ground improvement design plays a major role in accelerating the consolidation process and predicting the time rate of consolidation.

1.4.3 Design of the densification of fill material to improve the bearing capacity of fill material and to minimize liquefaction potential

Ground improvement for deep compaction works are generally designed by applying empirical methods, mainly based on past experience as exhibited design. Design verification and required modifications are made during the initial stage of compaction works by implementing trial compactions.

1.4.4 Design of temporary and permanent slopes, shore protection structures

Design of both temporary and permanent slopes as well as shore protection structures such as rock berm, breakwater, retaining structures require geotechnical design input.

In any case stability analyses are deemed necessary. Design of shore protection works involves both short- and long-term slope stability analyses for various kinds of shore protection slopes and various kinds of shore protection structures. Most stability analyses involve total stress analysis assuming undrained conditions soon after construction. Effective stress analyses are only carried out when the stage construction technique is applied, or the structure is constructed with a marginal safety factor and the safety margin is expected to increase during the construction stage.

Most design processes involve the application of both finite difference and finite element modelling (Arulrajah *et al*., 2005). These are powerful tools to predict both magnitude and time rate of settlement with and without vertical drains and to find accurate factors of safety for various kinds and geometry of slopes, embankments and retaining structures.

The design process of land reclamation, shore protection and ground improvement are widely discussed by Bo and Choa (2004).

1.5. Preparing contract documentation and specifications

1.5.1 Contract document preparation

Contract preparation involves legal, economic and engineering aspects. Engineering aspects cover civil, coastal, environmental and geotechnical engineering. Contract documentation covers methods of measurements and both performance and method specifications. Further details of contract document preparation can be found in Bo and Choa (2004).

1.5.2 Preparation of specification

Material, and performance and method specifications are required to be prepared to be able to successfully manage land reclamation projects. The following are typical specifications required for land reclamation and ground improvement projects.

Material specifications

- filling material
- various types of rocks and aggregates for shore protection works

- geotextile for separation
- sheet piles, pipe piles and so on for shore protection works
- prefabricated vertical drains for ground improvement works
- various types of geotechnical instrumentation.

Method specifications

- prefabricated exhibited vertical drain spacing
- pilot testing for ground improvement using vertical drain
- various stages of filling levels and finished levels
- installation of geotechnical instrumentation
- methods of geotechnical laboratory testing
- boring and sampling
- various types of in situ testing
- method of assessment of performance verification of ground improvement works
- method and frequency monitoring of geotechnical instruments.

Performance specification

- required degree of consolidation
- required level of densification of filled ground
- performance of geotechnical instrumentation
- implementation of laboratory programme.

1.6. Land reclamation stage

The land reclamation stage consists of the following steps

- general filling above platform level which is at least a couple of metres higher than mean sea level
- formation of slopes at the edges and construction of shore protection structures
- placing of surcharge
- removal of surcharge after completion of ground improvement for accelerated consolidation.

1.6.1 Implementation of land reclamation

Land reclamation is carried out by applying suitable methods based on seabed elevation, seabed profile, type of seabed soil and current, wave characteristics and so on. There are several land reclamation methods, such as

- direct dumping on the land
- direct dumping in the water
- hydraulic filling
- rainbow hydraulic filling
- sand spreading.

Selection of these methods requires geotechnical input. Selection is based on seabed depth, type of seabed soils, distance to designated dumping areas and types of fill materials and so on. When hydraulic filling and sand spreading methods are used, the application of soil and water ratios should be appropriately considered.

Direct dumping on the land with the help of transportation trucks is usually carried out as nearshore filling or filling above ground after land has been formed above the mean sea level. The direct dumping in the water method is normally used when the seabed is relatively deeper.

Hydraulic filling can be used in any condition if the seabed soils have reasonable strength to withstand hydraulic forces. In many cases, hydraulic filling is carried out from the rehandling pit in which transported fill soils are dumped into the pit by bottom-opening barges. In other cases, hydraulic filling is carried out directly from the cutter suction hopper dredger. Rainbow hydraulic filling is used when the destination of dumping locations is far from the transportation vessel. Sand spreading methods are used when seabed soils are extremely soft.

Types of dredgers and barges used in land reclamation and methods of fillings are widely discussed by Bo and Choa (2004).

1.6.2 Detailed geotechnical investigation

Geotechnical ground investigations are carried out in several stages including

- preliminary stage
- detailed investigation (prior to land reclamation)
- monitoring the progress of improvement and performance monitoring (during land reclamation and ground improvement)
- assessment of achievement (near completion stage of ground improvement)
- final commissioning stage to verify the achievement if any required.

These phases of investigation are described by Bo and Choa (2000) and Bo *et al*. (1998a).

During the preliminary investigation stage, exploration is carried out for potential buried explosives which could have been left during World Wars I and II. If found, these unexploded explosives are removed with the help of professional divers and brought to the surface for controlled detonation. Some can be detonated under water. Generally, a magnetometer survey followed by a metal detection survey are employed.

Prior to land reclamation, geotechnical investigation is carried out to characterize underlying soil formation to be used in the design process of land reclamation, ground improvement, shore protection and retaining structures. In addition, this investigation provides a selection of geotechnical instrumentation locations based on ground investigation data collected.

During land reclamation and the ground improvement process, interim geotechnical investigations are carried out to verify that ground improvement is progressing as expected. These assessments are carried out concurrently with assessment using geotechnical monitoring data, as discussed in detail in the next section.

Post-improvement investigation and investigation during commissioning are carried out to verify the ground improvement.

The following methods of investigation are usually carried out at all stages of geotechnical ground investigation