Engineering Geology 178 (2014) 58–69

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

3D geological modelling and geotechnical characteristics of Phnom Penh subsoils in Cambodia

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ARTICLE INFO

Article history:
Received 23 September 2013
Received in revised form 5 June 2014
Accepted 7 June 2014
Available online 19 June 2014

Keywords:
Geological modelling
Geotechnical properties
In situ test
Undrained shear strength
Phnom Penh subsoils

ABSTRACT

Subsoil characterisation is an important task in both geotechnical and geological engineering. In recent years, a number of subsurface investigations have increased as a result of infrastructure construction in Phnom Penh City in Cambodia. Although there had been investigations on the geotechnical characteristics of the subsoils, understanding soil characteristics and 3D modelling of geological structures of Phnom Penh subsoils have not yet been tackled. This research aims to conduct a 3D geological modelling by means of commercial software called Groundwater Modelling System (GMS), as well as provide an insight into the geotechnical properties of Phnom Penh subsoils. Over 1,200 soil boring log data were employed to build the 3D soil stratigraphic system in Phnom Penh City. The engineering properties of the Phnom Penh subsoils such as physical properties (i.e., grain size distribution and Atterberg limits) and engineering properties (i.e., compressibility, undrained shear strength and internal friction angle) have been highlighted in this paper. Finally, the analysis results of geotechnical data can be used to construct some useful empirical correlations such as the relationship of the undrained shear strength to the SPT-*N* value.

1. Introduction

Subsoil characterisation is of major importance for both geotechnical and geological engineering involved in earthworks, structure foundations, mineral and hydrocarbon exploration, ground water modelling, prediction and understanding of natural hazards, and remediation of environmental issues. Studies on the geotechnical properties and the three-dimensional (3D) geological structures of the subsoils have drawn much attention in recent decades (Akpokodje, 1987; Akpokodje, 1989; Dassargues et al., 1991; Jones and Wright, 1993; Lemon and Jones, 2003; de Rienzo et al., 2008; Tonini et al., 2008; Hettiarachchi and Brown, 2009).

With regard to geotechnical properties, two important considerations to be scrutinised are whether construction will cause excessive soil deformation and/or instability due to shear failure. Thus, an understanding of the compressibility and the shear strength behaviours of soils is an important factor in geotechnical analysis and design. To handle these matters, an extensive number of in situ tests such as field vane shear test (FV), standard penetration test (SPT) and cone penetration test (CPT), as well as laboratory tests including consolidation test, unconfined compression test (UC), and direct shear box test (DSB) have been developed.

Additionally, studies on subsurface stratigraphy using the framework of 3D geological modelling have attracted much attention of many researchers in recent decades to overcome the complex nature of the ground subsurface. With advances in computer technology, visualisation of 3D geological structures has become an emerging research direction, which fosters information visualisation into the geoscientific field of research (Martti and Markku, 1983; Wu et al., 2005; Gallerini and De Donatis, 2009). Many 3D solid models have been proposed to elucidate the geometrical representation of geological structures, and perform the visual analysis of spatial inhomogeneity for geological properties (Lemon and Jones, 2003; Thierry et al., 2009; Zhu et al., 2012). A comprehensive introduction to the computer representation of complex geological objects was given by Akpokodje (1987) to handle 3D seismic ray-tracing and velocity inversion problems. Several modelling approaches which were suggested to simulate stratified geological objects generated from different types of data such as boreholes, cross-sections, contours, and geological maps (Jones and Wright, 1993; Lemon and Jones, 2003; Ming et al., 2010; Zhu et al., 2012) went on to examine a 3D geological solid modelling and presented a new approach coupling with missing strata for sedimentary stratigraphic systems.

There have been increasing subsurface investigations as a result of infrastructure construction in Phnom Penh City in recent years.

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http://dx.doi.org/10.1016/j.enggeo.2014.06.010
0013-7952/

Although investigations on the geotechnical characteristics of subsoils have been carried out by several government and non-government sectors, understanding and modelling 3D geological structures have not yet been tackled. Therefore, the main contributions of this study are to conduct 3D geological modelling by means of commercial software called Groundwater Modelling System (GMS) and to provide an insight into the geotechnical properties of Phnom Penh subsoils (Touch, 2011).

Moreover, geological and geotechnical data from over 1,200 boreholes were utilised to construct 3D soil stratigraphic system in Phnom Penh City, Cambodia. The horizon method, suggested by Lemon and Jones (2003), was selected for this study due to its simplicity and efficiency in building solid models directly from boreholes with minimal user intervention. The engineering properties of Phnom Penh subsoils such as index properties, compressibility and shear strength behaviour have been highlighted in this study. Therefore, this work might be the first 3D geological and geotechnical database which comprehensively presents subsoil conditions of Phnom Penh City.

2. Topographic and geological conditions

Phnom Penh City is a capital of great socio-economic importance to the Kingdom of Cambodia, which was founded in 1431, immediately after the Khmer kings abandoned Angkor (Van, 2003). It is technically situated in the south-central region at the confluence of a great lake named Tonle Sap, Mekong River and Bassac River. From the northwest and northeast, respectively, flow the Tonle Sap and Mekong River, which merge and split into the Bassac River and Mekong River. These rivers flow continuously to the southeast of South China Sea. According to the available digital map provided by the Japanese International Corporation Agency (JICA) and the Ministry of Public Works and Transport of Cambodia in 2003 as presented in Fig. 1, Phnom Penh City is divided into seven districts, which cover 374.43 km^2. Phnom Penh City constitutes an extensive typically flat topography. In the western part, it reaches a height of approximately 20 m above sea level inland and gently slopes continuously toward the east to a minimum of 10 m above sea level at the west end area of the city. The farther eastern areas including the city centre and left bank areas of the Mekong River, the Tonle Sap River and the Bassac River are mostly flat with altitude from nearly 9 m to 11 m above sea level (JICA, 2001). Phnom Penh City remains very vulnerable to flooding because this city was originally established on the high riverbanks and extended into lower plains lying behind the riverbanks, which are actually below flood levels. These low-lying areas have been protected by the creation of successive concentric dikes (Van, 2003). According to the available 1:400,000 scale from the geological map of JICA and the Ministry of Public Works and Transport of Cambodia presented in Fig. 2, most areas are associated with alluvial plain and terrace alluvial deposits in the Quaternary Period, which created loose sediment deposits from flood waters such as silt, sand and clay. Organic deposits (swamps) are also found in the north-eastern part of Phnom Penh City.

3. Three-dimensional geological modelling

3.1. Methodology

Nowadays, 3D viewports are being used for planning purposes in geotechnical engineering. Computers have been developed to store and output geotechnical data from the mid-1970s onwards. This database contains detailed drilling, sampling and measurement information and 3D topology of soil boreholes (Vähäaho, 1998). To meet the requirements of 3D geological modelling, "horizons-to-solids" algorithm has been selected in this study via the Groundwater Modelling System (GMS) software. This subsurface modelling method also employed digital administrative maps and boring log data. ArcGIS software was used to prepare the shape files and boundaries of geological modelling. These maps were then imported and processed by GMS software. Using a conceptual model, GMS can obtain data from ArcGIS data by mapping any important data or information for modelling procedure.

3.2. Data initialisation

Seven districts (Chamkarmon, Prampi Makara, Dangkao, Meanchey, Russey Keo, Tuol Kork and Daun Penh) were selected according to Phnom Penh municipalities as presented in Fig. 1. All validated data

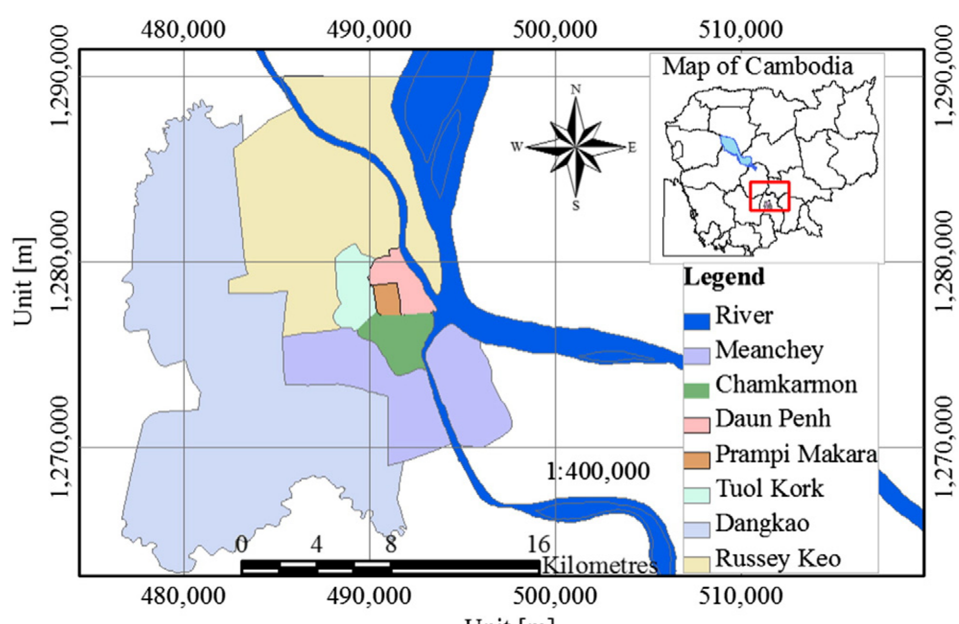

Fig. 1. Phnom Penh Municipality districts map (reproduced from JICA and Ministry of Public Works and Transport of Cambodia, 2003).