BRACED EXCAVATION IN SOFT GROUND — SOUTHEAST ASIA

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INTRODUCTION

This paper is one of the "member society" reports prepared for the Technical Committee on Underground Construction in Soft Ground (TC-28) of the International Society for Soil Mechanics and Foundation Engineering. The Southeast Asian Geotechnical Society (SEAGS) is one of the member society of the ISSMFE and has members from many countries who do not have independent national society. For reasons associated with the formation and activities of the SEAGS, Southeast Asia is defined in this paper as comprising Hong Kong, Malaysia, Singapore, Thailand and Republic of China (Taiwan).

The total land area of these countries covers about one million sq km. With a population of more than 100 million, the Southeast Asia has become the most rapidly developing region in the world in the past two decades. Deep excavation is invariably a vital part of economic development and urban construction. Many highrise buildings incorporate basements. With the increasing scarcity of usable land and soaring price, deeper and deeper basements are being built. The deepest basement construction in Taipei had reached six levels. In addition, transportation facilities are also going underground. Rapid transit systems in Hong Kong, Singapore and Taipei have involved a significant amount of braced excavation works. Some of the world records in deep excavation have been made in this region (Moh, 1988).

GENERAL GEOLOGY AND ENGINEERING PROPERTIES OF SOFT SOIL

Due to geographic nature, all of these countries have long coastal line. Most economic development and population distribution are near the coast. Therefore the most important landform in the region is the low flat deltaic plains which occupy an appreciable portion of the total usable land area. "Soft" soils of sedimentary origin become one of the most commonly encountered soil deposits in construction.

The distribution and property of recent sedimentary clays in Southeast Asia has been extensively studied since 1970s. Most of these marine deposits are young in age, i.e. less than 10,000 years and vary in thickness from very thin to abut 30m. The extent of the deltaic deposits varies from a few kilometers to more than 100km. The common features or engineering characteristics of these deposits are high natural water content, high compressibility and low strength. The groundwater table is generally very close to the natural ground surface which is another important factor for geotechnical engineering consideration. These deposits are found extensively in the Chao Phraya Plain in Thailand, coastal regions of Malaysia, Singapore, Hong Kong, and Taiwan. Among the deposits mentioned herein, the Bangkok Clay appears to have been studied most extensively. During the past 20 years, more than 500 publications, including journal and conference papers, research reports, theses and dissertations, and other articles have been written and published on the geology, properties and behavior of the Bangkok Clay. The Bangkok Clay has certainly attained world-class status along with London Clay, Leda Clay, Oslo Clay and Boston Blue Clay. A state-of-the-art report covering the engineering behaviour of the Bangkok Clay, marine clays in Singapore and Malaysia was prepared by Balasubramaniam et al (1985). The distribution and engineering characteristics of the Taipei silt formation, which is the major soil deposit in the rapidly developing Taipei Basin in Taiwan, are summarized in Moh & Ou (1979). Detailed geotechnical mapping has been made in the ROC for Taipei City (Moh & Associates, 1987). This mapping system has provided significant assistance in the planning and preliminary design of many major infrastructure projects in Taipei. Recently more sophisticated tests and advanced analyses have been conducted in order to obtain an insightful understanding of the deep excavation performance in soft Taipei soils.

UNDERGROUND CONSTRUCTION IN SOUTHEAST ASIAN COUNTRIES

Brace excavation is widely used in the Southeast Asia. Current underground construction practices in Southeast Asian countries are briefly summarized as follows:

Hong Kong

Because of the shortage of land in Hong Kong, basement construction is commonplace for residential and commercial developments. There are many projects requiring excavation of around 20m depth in soft ground for the construction of 4-5 level basements. The deepest excavations in Hong Kong were associated with the construction of the Mass Transit Railways (MTR) in the 70s and 80s where a number of station concourses were constructed in built-up areas requiring excavations in soft ground varying from 25-35m deep (McIntosh et al, 1980). For deep excavations, diaphragm walls are often used as the support system. The deepest diaphragm wall supported excavation is the 35m deep excavation for the MTR construction of Tin Hau and Causeway Bay Station. Both top-down and bottom-up construction methods are common. Sheet piles are often used for shallower excavations, generally no more than 15m deep. The deepest sheet pile supported excavation is MTR Shek Kip Mei Station, where excavation is between 18-24m. Most of the excavations are strutted. The use of anchors is relatively rare because of the difficulties in obtaining permission from owners of adjacent lots. Nevertheless, there were still quite a number of major excavation works in Hong Kong having employed anchors to retain the excavations. Examples include constructions of Bank of China, Eastern Harbour Crossing, Sun Hung Kai Centre, New World Hotel and a number of MTR stations. Other than diaphragm wall and sheet piles, there are many other support systems adopted for the excavation works, such as, caisson walls, contiguous pipe pile walls, and soldier pile and lagging wall.

Malaysia

Braced and anchored steel sheet pile walls are the most widely used form of support for excavations with depths down to about two basements. Contiguous bored piles are installed for deeper excavations (more than two basements) and harder formations. Diaphragm walls are sometimes used in difficult ground and for excavations involving depths greater than three basements if proven more economical than bored pile walls. Contiguous bored pile and diaphragm walls are also used when noise pollution is in question and when support of adjoining structures is important. Conventional bottom-up construction methods are used. Top-down construction is seldom carried out. Currently a 24m excavation is planned for the Kuala Lumpur City Centre twin 85-story towers which will be the deepest excavation in Malaysia.

Singapore

Sheet pile wall is considered as the most commonly used temporary retaining system for excavation work in Singapore. The use of diaphragm wall has become popular in the recent years because of the deep excavation involved and the stringent requirements imposed on deep excavation work at close proximity to the existing MRT structures. The amount of diaphragm walls installed in Singapore covering the period 1990 to 1992 is about 200,000 sq. m per year. Horizontal struts, rakers and anchors are the common systems for excavation support. Both conventional method of construction and top-down construction are adopted for substructure construction in Singapore. The longest anchor used for braced excavation works is about 48m long at Singapore River for the Central Expressway Phase II Project. The deepest diaphragm wall installed in Singapore is about 65m for the Bugis Station (MRT 301A) Contract. More recently, diaphragm walls reaching 55m have been installed for the Bugis Junction Redevelopment Project.

Thailand

Internally braced excavation is the only supporting method in Bangkok Clay. Struts are used, but anchorages have not been successfully used. Regulation also prevents the use of anchorage, especially in the thick soft clay deposits.

Sheet pile is effectively used to the excavation depth about 5-6m (sheet pile 12-14m long) with one level of strut bracing at 3m intervals. Due to its low cost, it is also used for 8 to 10m excavation where the sheet pile is 16 to 18m long with 1-2m penetration into the underlying stiff clay. Jet grouting is sometimes applied to reduce lateral deformation which is normally the case. Preloading of struts to reduce elastic deformation of strut is hardly used. Braced excavation is adopted even when the width of excavation exceeds 60m.

Diaphragm wall, 0.6 to 0.8m in thickness, is generally used for deep excavation deeper than 8m (up to 21m). Conventional method and top-down method have been used. The tip of diaphragm wall is usually in the stiff clay or sand (18 to 36m). Strut spacing is about 5m and two to three levels are used. "T" shape diaphragm wall is currently adopted to serve as the cantilever wall for 8-10m excavation. Diaphragm wall with special type of joint is generally used for permanent wall. Secant wall is sometimes used in Thailand due to its cheaper price. But secant pile is not used as the permanent wall.

Republic of China (Taiwan)

Braced excavation is widely adopted for underground construction in Taiwan. Diaphragm walls are generally used for deep excavations such as for building basements and the Taipei Rapid Transit Systems (TRTS) cut-and-cover tunnels and underground stations. The amount of diaphragm walls installed is difficult to estimate. As an indication, the on-going TRTS construction alone requires at least 45km of diaphragm walls to support excavations.

The length of diaphragm wall more than 50m is not uncommon in Taiwan. A circular ventilation shaft for the TRTS has 35m depth of excavation and 65m length of diaphragm wall. The LNG Receiving Terminal of the China Petroleum Corporation located in the southern part of Taiwan entails construction of a diaphragm wall system for the 64.5m diameter and 44.8m high underground tanks in a reclaimed land. The installed diaphragm wall is 1.2m thick with a length of 54.5m.

Sheet piles are widely used for shallow excavations (e.g. Woo et al, 1987). Use of sheet piles for ancillary structures of the TRTS such as station ventilation shafts and entrances are common.

Struts are generally used as internal bracings. Use of anchors is not very popular due to the soft nature of soil deposits within the Taipei Basin and limited available (permissible or encroachable) space in the city area. But it is worth mentioning that the construction of the basement for the New National Taiwan University Hospital Complex used ground anchors with a maximum length of 63.4m which is probably the longest anchor ever used in Asia (Moh, 1988).

The conventional bottom-up method of construction is the most widely adopted method. However, the top-down and semi-top-down methods are also popular due to consideration for minimizing settlements or concern for protection of adjacent buildings. In the case of the TRTS, a number of constructions have adopted the top-down or semi-top-down methods in order to minimize traffic impacts. Moh and Chin (1993) mentions typical cases in Taipei where different methods of construction are used.

DESIGN PRACTICE OF BRACED EXCAVATION

Generally speaking, the design practices of braced excavation in Southeast Asian countries do not have many significant differences. Both semi-empirical and theoretical approaches are used in engineering design. For constructions with deep excavation and high groundwater table, groundwater is a major concern. Potential problems with piping (in sandy soils) and blow-in (in cohesive soils) are always carefully evaluated. Semi-empirical methods, such as Terzaghi-Peck and Henkel methods, are used to estimate the earth pressures acting on the retaining structure. More theoretical approach, based on the beam on elasto-plastic foundation theory, is applied to estimate the moment, shear and deflection of the retaining structure. It is also expected that the general purpose numerical analysis (such as finite element method, finite difference method, and boundary element method) programs will be increasingly adopted to predict the performance of braced excavation which can take into account the settlement of surrounding area and response of adjacent structures. In Taiwan, attempts have been made to study the excavation behavior by the use of advanced finite element program equipped with sophisticated constitutive model.

INSTRUMENTATION

Instrumentation is a very important part of underground construction. The geotechnical instrumentation practice and its associated emphasis varies from place to place in Southeast Asian countries:

Hong Kong

The monitoring program for movements is generally quite extensive as there is considerable concern on any possible damage to adjacent ground, services and structures. However, there have been very few cases where the loads in the walls/struts were monitored. The monitoring program generally consists of checking the settlement of ground, services and structures. Tilting of structures is often measured. In some critical cases, the ground deflection profile is also monitored by means of inclinometer. Groundwater pressures/levels are checked by piezometers and observation wells. The monitoring frequency is agreed at the design stage, the monitoring results should be monitored closely by suitably qualified resident site staff and report to the designer on a regular and as-need basis.

Malaysia

Wall deflections are measured by precise theodolites. Settlements behind walls are measured by precise levels. Inclinometers have also been used to measure wall deflections. Settlements of adjoining structures and surrounding grounds are measured by precise levels. Tiltmeters are attached to columns and crack width development is measured by Delmag gauge.

Singapore

Most of the braced deep excavations have comprehensive instrumentations. The instruments normally installed are inclinometers, surface settlement points, piezometers, water standpipes, vibrating strain gauges and load cells on struts. Condition surveys of nearby structures are also usually carried out before excavation.

Thailand

Inclinometer is used for measuring lateral movement. Project which uses diaphragm wall for excavation usually have lateral movement measured. A few projects which use sheet pile for the excavation depth exceeding 8m also have inclinometer measurement (e.g. Sutabutr, 1992). Bending moment in the wall and load in struts are not generally measured. Movement of the wall is also measured by conventional surveying method. Normal ground survey for settlement and lateral movement are adopted to observe the effect of braced excavation on adjoining structures. Performance of supported and unsupported excavations in Bangkok subsoils is summarized by Srichaimongkol (1991).

Republic of China (Taiwan)

Instrumentation is almost a routine practice for deep excavation works. Major braced excavations are subjected to extensive instrumentation and performance study. Measurements commonly made include: wall lateral movement, strut loads, total pressure on walls, water pressure, ground settlement, movement of buildings or structures, and heave of excavation base. Almost all kinds of instruments can be used in deep excavation projects have been used in Taiwan. Monitoring program to observe the effect of braced excavation on adjoining structures is always included in the project. Settlement points on ground and pavements are installed at various locations around the excavation. Settlement points and tiltmeters are installed at buildings. Monitoring frequencies are set according to the construction sequence and schedule. Alert levels and action limits are also set as guide to ensure safety of the adjoining structures. Since a large amount of instrumentation readings will be taken during TRTS construction, the major developments on geotechnical instrumentation in Taiwan are on the automation of data collection and the establishment of a comprehensive computer system to collect, transfer, process and store monitoring data (Moh and Chin, 1991).

CODE OF PRACTICE

Except in Hong Kong, there are not any comprehensive codes of practice directly related to design and construction of braced excavation in Southeast Asian countries. In Hong Kong, the Buildings Ordinance and Regulations provides the legal framework for the control of private building development. The major aspects of excavation and lateral support have been well covered (Building (Administration) Regulation 8 (1) bc). Various Practice Notes for Authorized Persons and Registered Structural Engineers also provide guidance on the requirements on submissions to the Building Authority (e.g. PNAP:74 on dewatering). The Geotechnical Engineering Office (formerly Geotechnical Control Office, GCO) of Hong Kong is a unique governmental establishment. The geotechnical aspects of all public and private building developments and civil engineering works are checked and controlled by the Geotechnical Engineering Office. It is probably the largest governmental organization in the world specializing in geotechnical control work. It also provides recommendations on design, construction and performance study of braced cuts in their publications, such as guide to retaining wall design (GEO, 1991) and review of design methods for excavations (GCO, 1990).

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