Application of piled raft concept in a design of foundations for MRT Orange Line Project

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ABSTRACT

In recent decades, piled raft foundation concepts have been considered as an economical design. In MRT Orange Line Project, piled raft concepts are applied for underground station structures since base slab of the station is resting on stiff clay or dense sand. The foundation system of deep station excavation in MRT Orange Line Project, Bangkok, Thailand comprises of the diaphragm walls, base slab and bored piles or barrettes. Soil underneath the base slab may carry some portion of load and therefore load is taken partly by soil bearing resistance and partly by diaphragm walls and piles. Structural analysis model based on the beam-on-spring foundation method has been used to model the pile-soil interaction with the spring attached with base slab, diaphragm wall and piles. The results indicate load shared to the piled-raft system. The number of piles and length of diaphragm wall can be significantly reduced without compromising safety as well as performance of the structure and therefore adoption of piled raft design concept leads the economical design of the underground structure in MRT Orange Line Project.

Keywords: piled raft; soil structure interaction; diaphragm wall; deep excavation; MRT station

1 INTRODUCTION

The Mass Rapid Transit Authority of Thailand (MRTA) is implementing the MRT Orange Line Project as part of Thailand's government policy to develop a complete mass electric train system network to improve quality of life of people in Bangkok. MRT Orange Line is divided into two sections, East Section (Thailand Cultural Centre – Min Buri) and West Section (Taling Chan - Thailand Cultural Centre). This route is scheduled to be the main mass transit system linking the east and west Bangkok.

The MRTA has awarded an underground civil work to the Ch. Karnchang PLC. and Sino Thai Engineering and Construction PLC. Joint Venture (CKST Joint Venture) for MRT Orange Line (East Section) Project, Contract E1 and E2 which construction started in May 2017. This Project under Contract E1 and E2 involves the construction of about 9.73km, comprises of 7 underground stations, cut-and-cover tunnel, ventilation and intervention shafts, depot accesses and twin bored tunnels. MRT Orange Line (East Section) have already been designed, procured and in the process of construction and expected to complete and open for public in year 2023.

This project involves deep excavation with an aid of diaphragm wall as a retaining structure following the top-down construction method. The foundation system of deep station excavation comprises of the diaphragm walls, base slab and bored piles or barrettes. A design concept of foundation system is very significant to lead the economical design without compromising safety as well as performance of foundation system.

2 GEOLOGICAL CONDITION

Bangkok is situated on the low-lying Chao Phraya plain area. A typical subsoil profile is relatively consistent in different localities in Bangkok. It consists of alternating layers of clay and sand deposits existing to a great depth. The existing ground elevations lie from 0 to 2 m above mean sea level, with the soil layers being marine deposits. The subsoil profile of MRT Orange Line Contract E1 and E2, as shown in Fig.1 and Fig.2, consists of made-ground up to 3 m thick underlain by well-known Bangkok Soft Clay range from 10 to 15 m thick. About 2 to 4 m thick medium stiff clay can be observed between soft clay and underlying stiff clay. Below that, alternating layers of stiff to hard clay and dense to very dense sand is followed.

The piezometric pressure normally considered draw down as a result of pumping in the past (Phienwej et al 2006). Presently, piezometers installed in the project area indicate the piezometric head in the sand layer is approximately at 12 to 13 m below ground surface.

Fig.1 and Fig.2 show subsoil stratigraphy along Contract E1 and E2, respectively. In Contract E1, 3 stations excavation are range about 15 to 26 m deep excavation. The base slab are resting on 1st stiff clay for OR13 and OR14 stations and 1st sand for OR15 station.

While for Contract E2, 23.5 to 34 m deep excavation with base slab resting on 1st sand are involved.

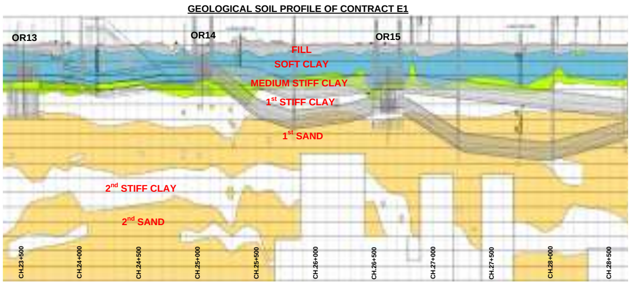

Fig. 1. Geological soil profile along Contract E1.

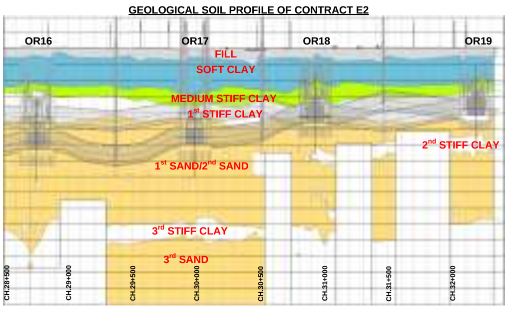

Fig. 2. Geological soil profile along Contract E2.

3 PILED RAFT FOUNDATION CONCEPT

The conventional design of foundations is based on the assumption that the piles are free-standing, and the entire loads are carried by piles. Footing/raft/pile cap are ignored for contribution any portions of loads. This traditional design concept is over-conservative since footing/raft/pile cap are placed directly to the soil. Thus it may carry a significant load portion.

Nowadays, the concept of pile raft foundation has been widely used in the design of high-rise buildings as well as underground structures (Yamashita et al. 1994; Katzenbach et al. 2000; Poulos 2001, Phung 2010 and Amornfa 2012). The design concept is to make use of soil bearing resistance below the raft together with load carrying by pile foundation. To confirm the soil bearing resistance below raft, pile are designed with sufficient lower safety factor than the normal pile design thus the pile settlements are enough to ensure the contact between raft and soil. However, the foundation system must be designed to ensure sufficient stability of the entire system. The serviceability of the structure must be guaranteed for its entire life.

The design of a piled raft foundation requires an understanding of complex soil-structure interaction which effects to the load-settlement behavior (Katzenbach et al. 2000) as shown in Fig. 3.

It is the objective of this study to present the concept design of foundation system for underground structures. The current design practice for underground station foundation system is to apply the concept of piled-raft. Underground MRT station requires a deep excavation range from about 15 to 35 m due to its pass congested area of Rama IX and Ram Khamhaeng Road with stacked platform station. Therefore, base slabs are mainly founded on stiff soil (i.e. stiff clay, dense sand) with good bearing resistance.

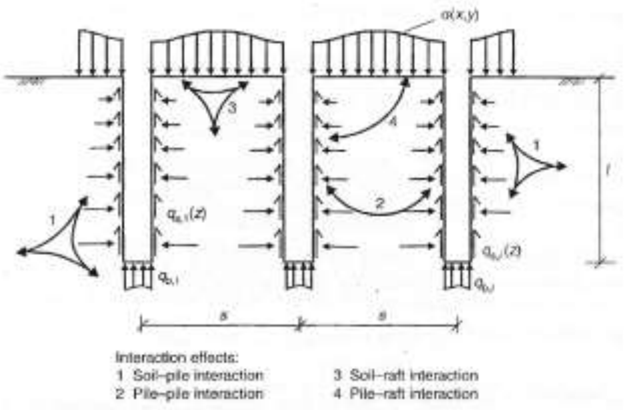

Fig. 3. Soil-structure interaction effexts for piled raft foundation (Katzenbach et al. 2000)

4 APPLICATION OF PILED RAFT FOR MRT ORANGE LINE PROJECT

Deep excavation in soft soil requires an effective retaining structure and therefore diaphragm wall is used practically in Bangkok. The foundation system of deep station excavation in MRT Orange Line Project, comprises of the diaphragm walls, base slab and bored piles or barrettes. Piled raft concepts are applied since base slab of the station is resting on stiff clay or dense sand (typically base slab level is more than 15m depth from ground). Soil underneath the base slab may carry some portion of load and therefore load is taken partly by base slab and partly by diaphragm walls and piles.

4.1 Analysis methods

Structural analysis model based on the beam-on-spring foundation method has been used to model the pile-soil interaction with the spring attached underneath base slab, diaphragm wall and piles. In order to determine the vertical springs attached, a computer program “PRAB” (Piled Raft Analysis with Batter piles) developed by Kitiyodom and Matsumoto (2002, 2003) is employed. The flexible raft is modeled as thin plates and the piles as elastic beams, and the soil is treated as springs, as shown in the Fig. 4. By using PRAB, an analysis has been developed based on a hybrid model. The response of each pile is modelled using the load-transfer method, and the interaction between the piles through the soil, is calculated based on Mindlin’s solutions (Mindlin 1936). Layered soils of Bangkok ground conditions are also considered. PRAB program has a function to input many soil layers with its stiffness parameters and stratum thickness and therefore multi-layered soil condition of Bangkok have been considered. The validity of the proposed method has been verified through comparisons with several existing methods for single piles, pile groups and piled rafts (Kitiyodom 2002, 2003).

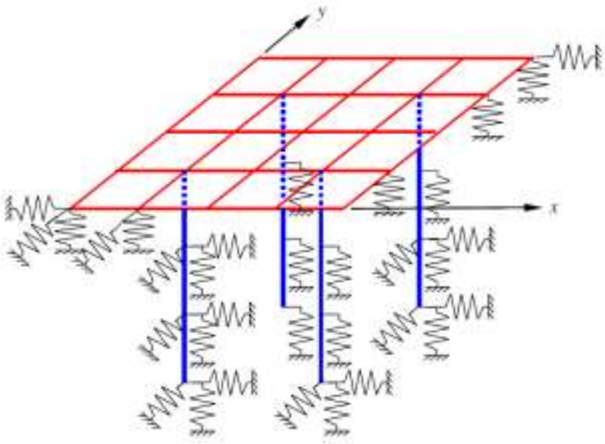

Fig. 4. Plate-beam-spring model of pile raft in PRAB program.

The vertical soil spring of foundation has been analyzed in computer program PRAB from the input soil stratum and soil properties. An equivalent "lumped" soil spring at the toe of the diaphragm wall and pile is determined by load-settlement analysis and covers the combined effect of soil along the pile shaft and below the pile base. This equivalent "lumped" soil spring is incorporated in the structural analysis of the station structure.

The vertical soil spring below base slab has been modeled as a raft foundation founded on layered soils. Load has been applied on top of the raft resulting in soil deformation. Thus, vertical soil spring below the base slab has been calculated by load-settlement analysis. This soil spring is also incorporated in the structural analysis of the station structure as shown in Fig. 5.

The design of deep station excavation have been conducted by using Plaxis 2D, finite element code for soil and rock analyses, to take into account an effect of earth pressure. Then the design has been followed by structural analysis software (i.e. SAP2000, Midas-Gen). Vertical spring stiffness below base slab and foundation system are incorporated in the design. Comparison of the design with and without raft resistance has been performed.

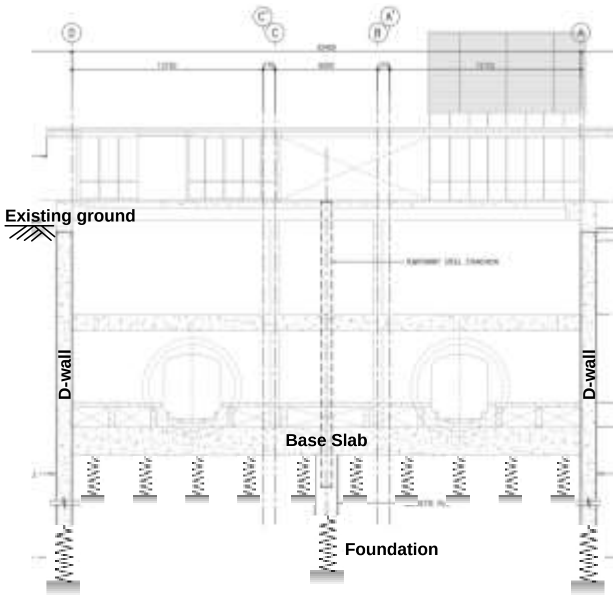

Fig. 5. Model of pile raft foundation with spring supported for MRT station.

4.2 Results

Based on the results of structural analysis after piled-raft concept is adopted, Fig. 6 shows load sharing between pile and raft for the case of cut-and-cover tunnel with base slab resting on stiff clay. The red line shows the load shared on diaphragm wall and bored pile only in case of vertical raft spring is neglected. The other blue line indicates the load distribution to an entire piled raft system. Total load is shared to the diaphragm wall and bored pile partly, and distributed to soil underneath base slab.

The analysis indicated load sharing ratio on soil underneath base slab of 40% approximately and the rest is supported by diaphragm walls and piles. Unit end bearing of raft is limited against total overburden pressure as well as settlement at base slab is checked within tolerable limit. Diaphragm wall and pile lengths can be reduced economically within the safety limit. The overall stability of the structures has also been checked.

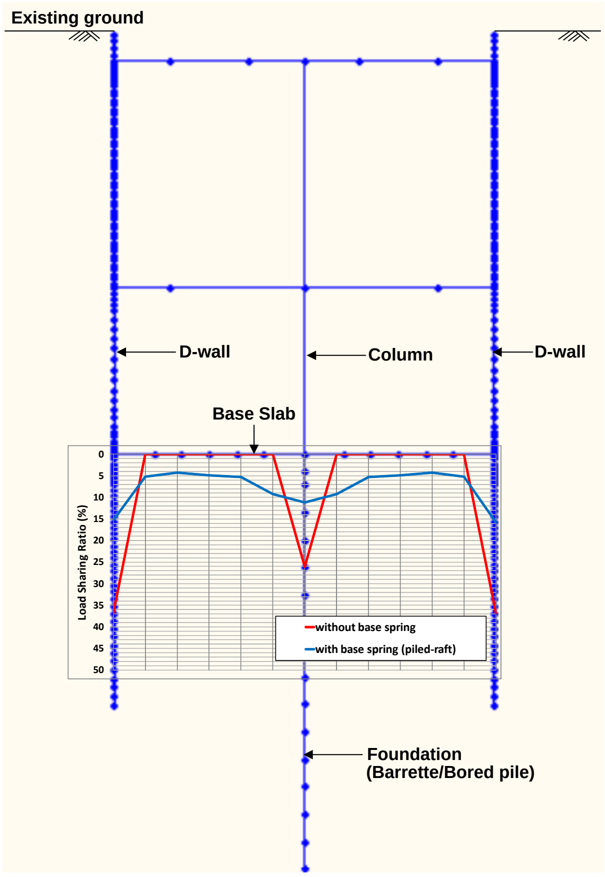

Fig. 6. Comparison of predicted load sharing in case of with and without base slab spring.

5 CONCLUSION

As the application of piled-raft concept being adopted for MRT Orange Line Project, the stiff ground with good-bearing resistance underneath base slab (raft) is utilized in piled-raft application. The analysis indicated load sharing partially by raft and partially by diaphragm wall and pile which will lead economical design of foundation system. However, the ground bearing capacity and settlement have also been checked to ensure the stability of the entire system. In conclusion, adoption of piled raft design concept leads the economical design of the underground structures in MRT Orange Line Project.

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