CONSTRUCTION FAILURES OF EXCAVATION IN SOFT CLAY-CASE STUDIES

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Construction Failures of Excavation in Soft Clay-Case Studies

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SYNOPSIS Retaining structures used in excavations are usually designed based on semi-empirical methods which may only pertain to some particular geological environment. This paper describes two case histories in the newly developed area of Taipei City. Experiences which apply to other parts of the city were found not applicable in the very soft sensitive clays encountered. In both cases, the undrained shear strength of the soil was over-estimated. Consequently, the original marginal factors of safety used in the design of temporary structures were greatly reduced. Field monitoring of the retaining system has helped to trace the causes of failure and to arrive at remedial measures.

INTRODUCTION

Due to the rapid growth of Taipei City, the population has increased by many fold. Marginal lands which were usually considered to be unsuitable for development, are gradually being utilized. Project "Sin-Iee" site is such a marginal land being utilized for future development. Important facilities to be constructed in this area are the World Trade Center, the City Hall, the Conference Center, and many high rise buildings.

Project "Sin-Iee" is located in the eastern part of the Metropolitan area of Taipei. The site is the remaining area of the Keelong river flood plain. Originally, the area consisted of many lakes, ponds and swamps. It was later reclaimed and made into rice fields. After decades of agricultural use, the area is now being turned into an important political and financial center for Taipei's Metropolitan district.

However, due to the extreme difficulties of the geotechnical conditions in this area, development of this area has encountered many problems which are unfamiliar in other parts of the city. This paper describes two case histories which illustrate lessons learned from construction failures in the area. In both cases, Moh and Associates were invited to evaluate the problem and to propose remedial measure.

SITE CONDITIONS

Subsoils underlying the two sites can be divided into four sublayers as shown in Fig. 1.

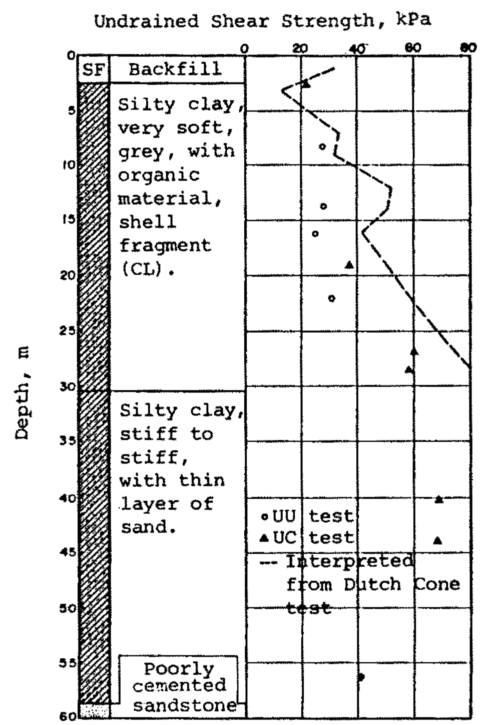

Fig. 1 Subsoil COnditions

Underneath the silty top soil is a layer of very soft, organic, dark grey silty clay with a thickness of approximately 30 meters. The blowcounts of this layer varies from 2 to about 6. The undrained shear strength (s_u) of this layer was determined from laboratory unconsolidated undrained shear strength tests, unconfined compression tests and from field Dutch Cone Penetration tests. Underlying this soft silty clay is a layer of medium stiff silty clay with a thickness of approximately 20 meters. Below the stiff clay layer is a layer of poorly cemented sandstone.

CASE HISTORY I - STORM DRAINS

The planned storm drain through this area is a 6.5 meter width by 3.7 meter height box drain. The drain consists of precasted sections in 1 meter length. The invert of the drain is at 4 to 5 meters below grade. To maintain the stability of the excavation, steel sheet piles and internal strut systems were utilized. The design cross section is presented in Fig. 2 During excavation, excessive heaving at the bottom of the excavation area and severe tilting of the retaining sheet piles occured. A Simplified cross section illustrating the condition of failure is presented in Fig. 3. A field investigation was commissioned to investigate the cause of failure. It was found that although the laboratory and field testing results indicated that the soft clay layer had an undrained shear strength (s_u) of 20 kPa, its remolded strength was only 5 kPa. The subsoil had a sensitivity of about 4. The undrained shear strength of the soil at the failure site, back-calculated from the failure plane, was found to be about 9.5 kPa which was about half of what was determined from laboratory and field tests. The failure could be attributed to reduction of soil strength due to construction which has induced disturbances.

Short wooden piles were recommended to alleviate the heaving within the excavated area and to prevent the tilting of retaining sheet piles. Wooden piles of 4 meter long, 15 cm in diameter and spaced at 40 cm were driven below the excavated area. The wooden piles provided downdrag resistance to the soil, which tended to expand and heave due to removal of the overburdens. The wooden piles also provided a firm mat foundation which has significantly reduced settlement of the box drain after backfilling. During the excavation stage, the wooden pile mat could also provide similiar effects as internal struts to the retaining sheet piles. Theoretically, the rotational center of the potential failure plane could be lowered to the tip of the piles. Factor of safety against rotational failure was therefore raised up to as high as 2.07, despite the fact that the undrained shear strength of the soil was lowered to half of what was originally expected due to construction disturbance.

CASE HISTORY II - HOTEL SITE

In the same region, there is a 25-story hotel site. The site is 140 m by 110 m, with excavation to a depth of 13.8 m. Excavation and construction of the basement utilize the "island method", which is carried out by first excavating the central portion of the site to the expected depth

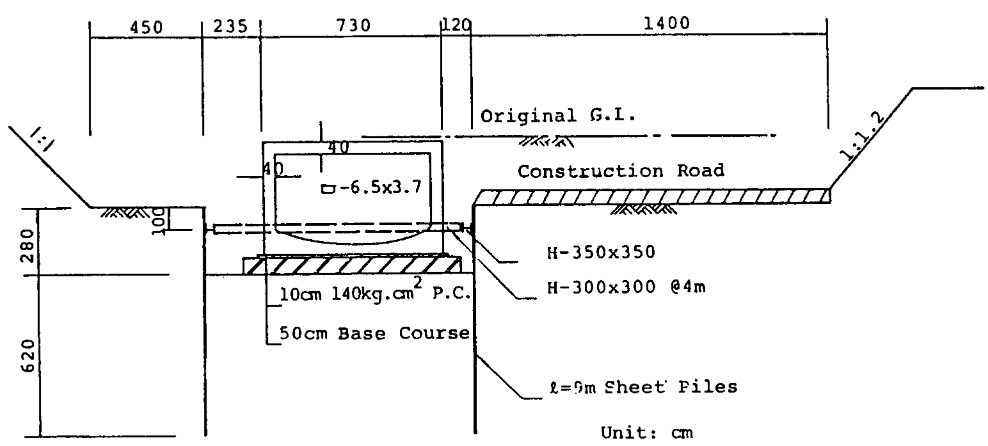

Fig. 2 Design Cross Section

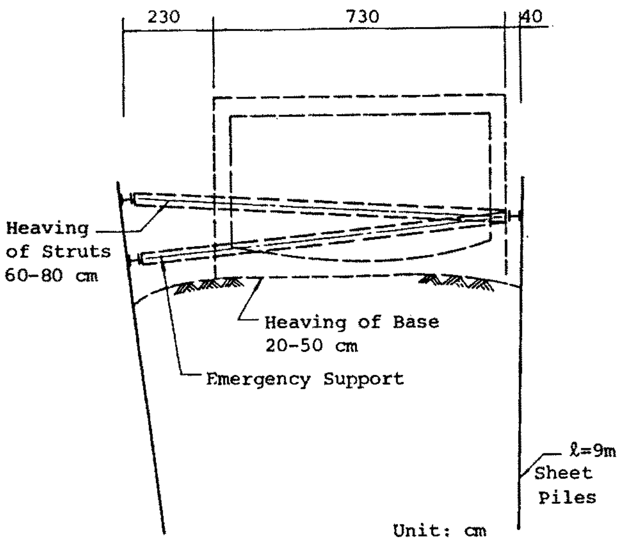

Fig. 3 Conditions at Failure

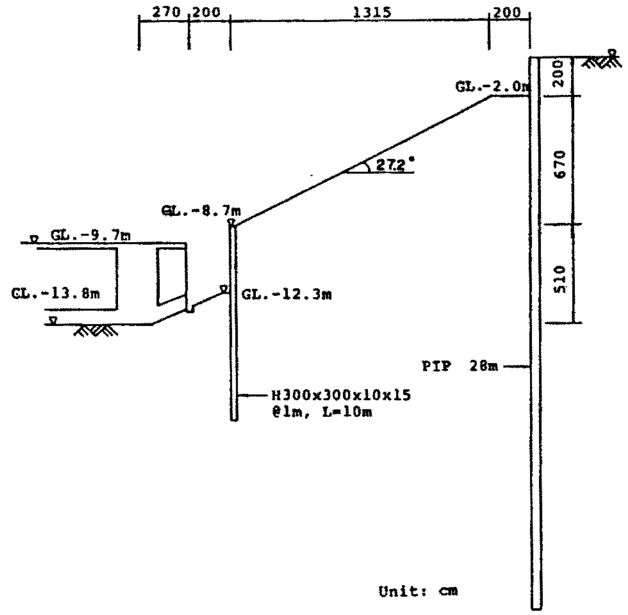

Fig. 4 Retaining Structure during Excavation

and leaving berms along the outer ring of the excavated area. The berms are kept as part of the retaining structure until the central portion of the basement is completed and then kickers using the basement as reactions are installed. After the kickers are installed, the berms can be removed, and the final portion of the basement can be completed.

At the hotel site, the retaining structure utilizes pre-packed motar piles. Fig. 4 illustrates the retaining structures used in constructing the central portion of the basement. In order to allow for more construction space, H-pile with laggings were used to support the toe of the berm. During construction, large movement of the retaining structures, sliding of berms and depression of the surroundings occured. Fig. 5 illustrates the area affected by the excavation of the basement area. From the geometry of the north-east corner slide, one could back-calculate the soil strength to be about 10 kPa. The back-calculated undrained shear strength again was only about half of what was measured from undisturbed samples in the laboratory triaxial testings. The cause of the failure of this slide was therefore attributed to the high senstivity of the soil.

The stability of the H-piles also was reviewed using the disturbed soil strength derived from the failure slide. It was found that the active earth pressure acting on the H-piles was significantly higher than the passive earth pressure which the H-piles could derive from the soil at the toe of the berm. Fig. 6 shows the movement of the top portion of the retaining wall throughout the construction of the basement. It can be found that large movements occured while central portions of the basement were excavated. The forward leaning of the H-piles also triggered the movement of the berm which abutted on the H-piles. The movement of the berm then in turn caused the forward leaning of the retaining sheet piles.

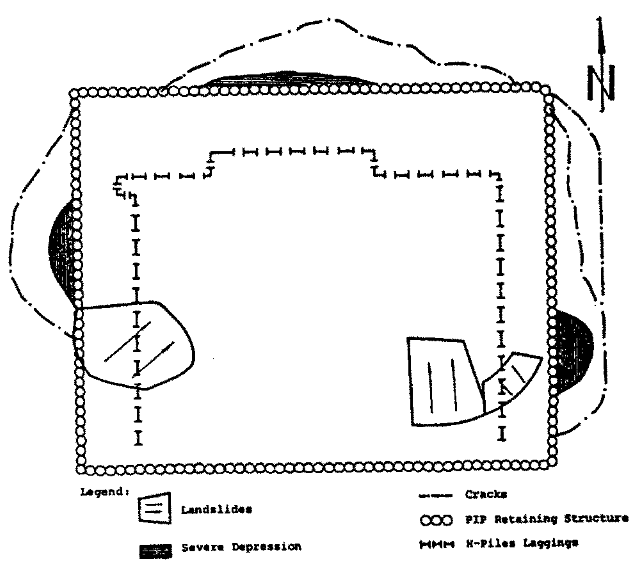

Fig. 5 Failure along Excavated Area

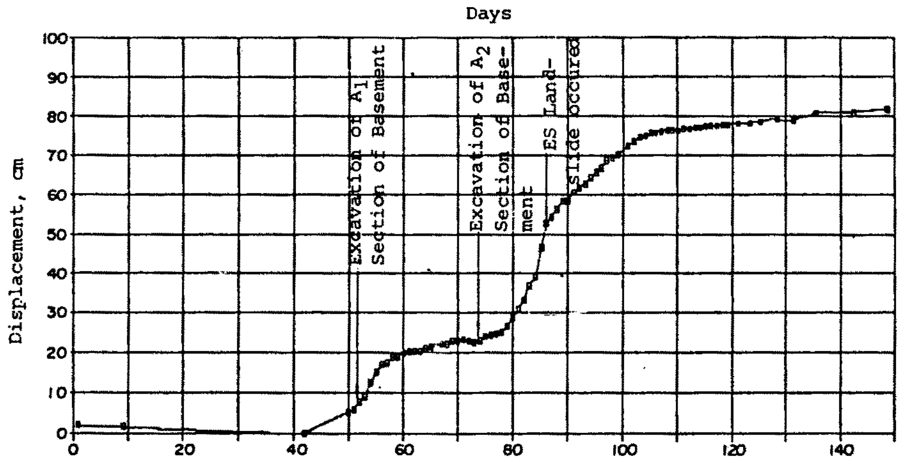

Fig. 6 Displacement at Top of Retaining Structure

Fig. 7 is a summary of the movement of the retaining sheet piles. The forward leaning failure phenomenon is remarkably different from the backward leaning failure observed in the previous case history. Fig. 7 also indicates that significant movement had occurred while soils in front of the H-piles were removed. Finally, the give-in of the sheet piles had induced depression outside the excavated area. The movement of the H-piles therefore triggered a sequence of failures of the retaining structure.

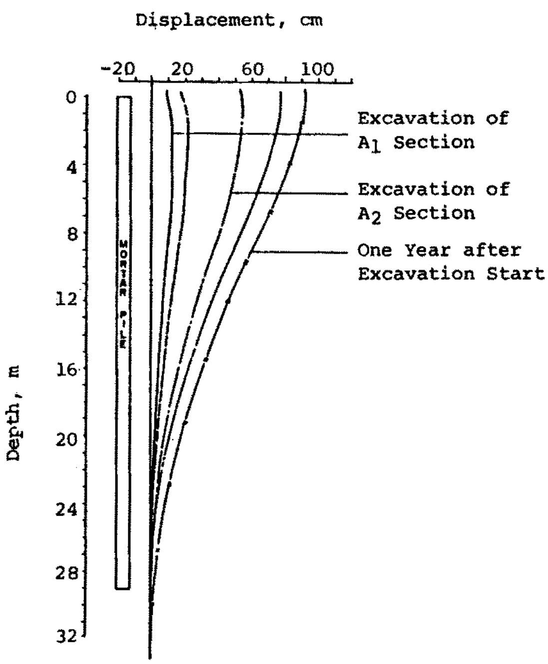

Fig. 7 Deflection of East Side Retaining Structure

LESSONS LEARNED

Generally, the design practice for retaining structure is semi-empirical. And, since it is a temporary structure, a marginal factor of safety is used. In the two case histories presented, it was found that empirical experiences obtained from other areas in the city failed at this unfamiliar site and the marginal factors of safety adopted in the designs were greatly reduced by over estimating the real soil strength after excavation.

Short wooden piles prove to be effective in preventing heaving of excavated area and in providing an internal structing effect to the retaining structure.

If sequential measures of retaining structures are used, failure of any measure may trigger a Domino failure mechanism as described in the Hotel Site case history.