

ENGINEERING CHARACTERISTICS OF THE
TAIPEI SILT

Z.C. MOH

Principal, Moh and Associates, R.O.C.

and

C.D. OU

Associate, Moh and Associates, R.O.C.

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Z.C. MOH Principal, Moh and Associates, Taipei, Taiwan, Republic of China
C.D. OU Moh and Associates, Taipei, Taiwan, Republic of China

SYNOPSIS The Taipei Basin was formed some hundreds years ago by a series of sedimentation. The primary subsoils in the Basin are alternative stratum of silt, silty clay and fine sand. The silty and silty clay layers are highly compressible and of low strength. The virgin watertable is very close to the ground surface and presents above the upper silt layer. In recent years due to heavy deep well pumping, the groundwater appears to be separated into two distinct zones, with the upper part appearing to be a perched watertable above the silt stratum and the lower zone dropping into the fine sand stratum below the silt. The piezometric levels in the silt layer become less than the static pore water pressure. This effect has led to problem of serious regional subsidence. This paper presents a discussion on the engineering characteristics of the Taipei Silt in particular reference to its effect on the design and construction of foundations and other geotechnical structures.

INTRODUCTION

The Taipei Basin is situated in the northern part of the Island of Taiwan and bounded by three major rivers. They are Ta-Han River and Hsintien River on the south, Keelung River on the north. In addition, Tam-Hsui River runs through the middle of the Basin. It occupies a total area of approximately 243 sq km with about 224 sq km of land area, which is primarily composed of recent sediments of the four major rivers surrounding the Basin.

In the past decade, due to rapid economic development in the Republic of China, the City of Taipei, capital city of the island which is situated in the middle of the Basin, is facing the challenge of many major construction projects. One of the foremost important aspects of all large scale and/or important construction works, such as tall buildings, underground sewage system, underpasses and freeway system, is how to deal with the subsoils and to solve difficult geotechnical problems. In the past years, due to a lack of understanding and appreciation of the engineering behavior of the subsoils in the Taipei Basin, many projects have experienced serious difficulties during construction. Large sum of money and time have been wasted. In the foreseeable future, many even larger and more difficult construction projects are going to be realized, including underground rapid transit system, storm and sanitary sewer system, elevated railway project and taller buildings, a and more systematic understanding of the engineering characteristics and behavior of the sediments in the Taipei Basin becomes of utmost importance.

In the past, a number of writers, such as HUNG (1966), KUO (1975) and WU et al (1976), has presented results of geotechnical properties of the subsoils in the Taipei Basin. However, due to lack of good quality samples and inadequate information about the site conditions, the value of much of the data becomes quite limited. This paper attempts to present a preliminary systematic analysis of the engineering

characteristics of Taipei Silt on the basis of data collected from a number of good quality undisturbed samples taken from different horizons in the deposit.

GEOLOGY OF THE TAIPEI BASIN

According to the geological history, the Taipei Basin had undergone two cycles of exposed land-lake-land end then reach the present formation. Obviously, the geology of the formation in the Basin is greatly affected by this alternate cycles. The primary subsoil strata in the Basin are sedimentary deposits of recent Quaternary period and the bedrock formation belongs to the Tertiary period. Underlying a thin, about 1 m to 6 m thick, layer of surface deposit, the subsoils in the Basin can be divided into three major strata. Immediately below the surface soil is the Sung-Shan Stratum which extends to a depth of about 60 m below the existing ground surface. This stratum consists mainly of alternative layers of soft and compressible clayey silt, silty clay and sands, and is the so-called "Taipei Silt". Underlying the Taipei Silt is the Lin-Kuo stratum which consists primarily of dense gravels interstratified with thin layers of hard clay. The thickness of this layer reaches over 200 m in deepest places. Below the Lin-Kuo gravel is the tertiary period bedrock formation.

The subsoil stratum which is of prime concern in this paper is the Taipei Silt. In general, the uniformly distributed soil stratum is composed of alternative layers of low plasticity silty clay (ML-CL or ML) and silts (ML), interstratified with fine sand layers containing high silt content. The silt content in the various layers varies from 15% up to 95%. The presence of abundant amount of sea shells and marine insects indicate that the sediments were deposited in or affected by marine or brackish water environment. Because of the oxidation and reduction process, the color of the deposits generally appears to be greyish black or greyish brown.

From the engineering view points, the Taipei Silt

TABLE I Properties of Taipei Silt

Layer	Description	Thickness, m	N Value	γ_s , t/m ²	w, %	k, cm/sec	C_u , t/m ²	ψ_u , degree	c'_v , t/m ²	ψ'_v , degree
6	Yellowish grey silty clay	2 - 8	3 - 8	1.93	31.1	$0.3 - 0.75 \times 10^{-7}$	7.1	6.5	6.1	9.6
5	Grey silty sand	2 - 20	2 - 26	2.01	24.3	$0.5 - 6.00 \times 10^{-4}$	-	-	0	31 - 35
4	Silty clay	6 - 29	4 - 14	1.92	30.8	$0.53 - 2.00 \times 10^{-7}$	4.9	14	3.1	26
3	Silty Sand	0 - 19	8 - 36	2.02	22.9	$0.5 - 2.00 \times 10^{-4}$	-	-	0	35
2	Silty Clay	0 - 19	10 - 20	1.98	25.5	$0.33 - 0.75 \times 10^{-7}$	6.4	21	0	34
1	Silty Sand	0 - 15	18 - 48	2.02	19.5	$0.5 - 6.00 \times 10^{-4}$	-	-	0	42

Stratum can be broadly subdivided into six layers as shown in Table I. The thickness and sequence of these layers vary somewhat from area to area. Those shown in the table are mainly that of the Tam-Shui River tributary, whilst in the Keelung River tributary, the silty clay layer becomes the primary one with very little or no sand sublayers. The typical sublayers of the Taipei Silt Stratum are as follows, in accordance with the sequence of deposition:

- (1) Layer 1 - This sublayer lies immediately above the Lin-Kuo Gravel and consists of medium dense to dense gravelly sand. The fine content is usually around 20% or slightly more. The boundary between this sublayer and the Lin-Kuo Gravel is sometime not very distinct. At several locations a thin layer of reddish brown soil is found at the boundary.
- (2) Layer 2 - This layer is a grey silty clay, with silt content varying from 45% to 70%. The soil is of medium to low plasticity and medium dense. The natural moisture content is around 25%. The thickness of this sublayer varies from 0 to 19 m.
- (3) Layer 3 - This layer is a grey non-plastic, medium dense silty fine sand of variable thickness. The silt content is generally above 25%, and the soil contains numerous shells. The natural moisture content is around 20%.
- (4) Layer 4 - This layer is a grey silty clay, 6 to 30 m in thickness, with less than 10% of sand content. The soil contains shells and rotten woods. The natural moisture content of this soil is often near its liquid limit. This sublayer underlies almost the entire Basin at a depth varying from 6 m to about 22 m below the ground surface. This depth is generally the foundation level for most of the major structures. The characteristics and behavior of this sublayer are thus of great concern to the geotechnical engineers.
- (5) Layer 5 - This sublayer is composed of grey silty fine sand. The sand particles are fine and uniform, and the silt content varies from about 30 to 40%. In part of the Basin near Hsintien River, the lower part of this layer frequently contains coarse sand and small gravels. The thickness of the layer is about 10 m.
- (6) Layer 6 - The uppermost layer can be further subdivided into a lower greyish black silt and an upper yellowish brown topsoil. This layer has high moisture content and low strength. The total thickness of this sublayer is about 3 to 8 m.

STRENGTH AND COMPRESSIBILITY CHARACTERISTICS OF TAIPEI SILT

As shown in Fig. 1, the silts and silty clays from Layers 2, 4 and 6 all plot parallel to and near the A line on Casagrande's plasticity chart and indicate that they are of low to medium plasticity. Practically speaking, there is no high plasticity clay soil existing in the Taipei Silt Stratum. The frequency histogram of the grain size distribution in Fig. 2 indicate that even soils in Layers 1, 3 and 5 also contain considerable amount of minus No. 200 sieve fines, generally speaking, between 20 to 40%. A summary of the properties of Taipei Silt, including natural moisture content, unit weight, Standard Penetration Resistance N values, permeability and strength parameters are included in Table 1. It is quite obvious from the data in Table 1 that the silty clay soil in Layer 4 has relatively, high natural moisture content and low strength. The low permeability of this sublayer was found to have significant effect on the distribution of the piezometric head of the groundwater. Furthermore, the low strength of Layer 4 was often found to impose serious problem on excavation work in this soil. The soil layer directly underlying the soft silty clay is a fine sand with rather high permeability. Ground surface settlement around deep excavations were found as result of sand from the Layer 5 flowing into excavations due to inadequate or ineffective construction of retaining structures.

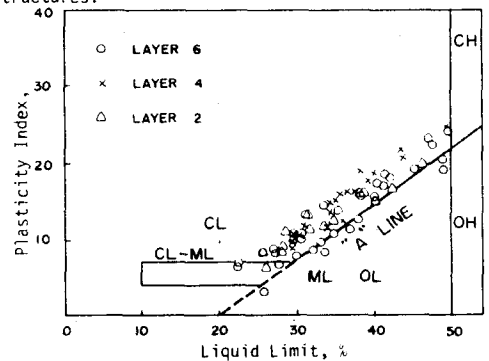


Fig. 1 Plasticity Chart

The compression and swelling characteristics of the Taipei Silt are also of importance to engineering design and construction. The compression curve shown in Fig. 3 illustrates the typical volume change characteristics of the Layer 4. Table II presents the over-consolidation ratio (OCR) of the Layers 2 and 4

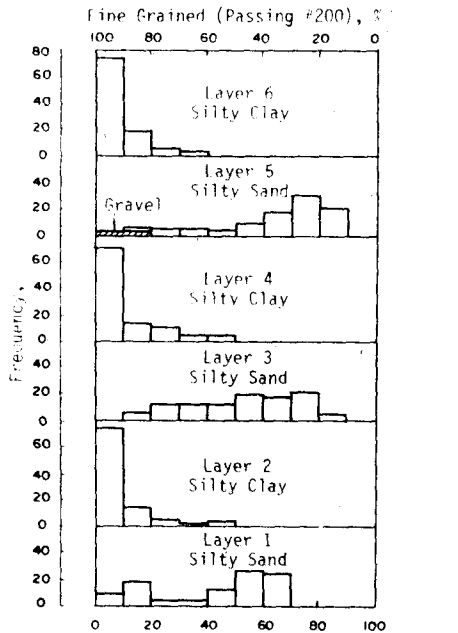


Fig. 2 Grain Size Distribution of Taipei Silt

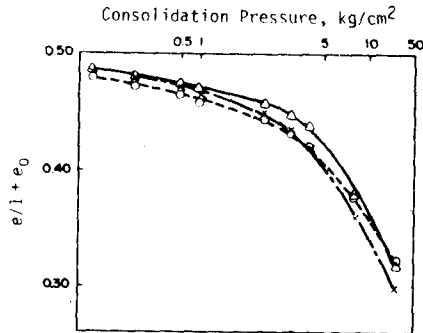


Fig. 3 Compression Curve of Silty Clay in Layer 4

TABLE 11 Maximum Past Pressure and OCR of Silty Clay and Clay Layers

Layer No.	Depth, m	$\bar{\sigma}_{cm}$	Static u		Measured u	
			$\bar{\sigma}_{v0}$	OCR	$\bar{\sigma}_{v0}$	OCR
4	17.65 - 17.70	4.4	1.8	2.4	2.3	1.9
	18.85 - 18.90	3.7	2.0	1.9	3.3	1.1
	19.52 - 19.57	3.2	2.1	1.5	3.4	0.94
2	31.40 - 31.45	4.1	3.2	1.3	5.6	0.73
	32.08 - 32.13	3.4	3.2	1.1	6.1	0.56

Note: all stresses in kg/cm²

as calculated from the maximum past pressure ($\bar{\sigma}_{v0}$). It is clear from the table, Layer 4 would be in a normally consolidated state if the groundwater is a

static condition. However, based on recent measurements of subsurface pore pressures, both Layers 2 and 4 are under-consolidated, other words, these two sub-layers are still consolidating.

VARIAION OF SUBSURFACE PIEZOMETRIC PRESSURE AND REGIONAL SUBSIDENCE

Overall speaking, the Taipei Silt Stratum is a good reservoir for free water due to the relatively high permeability and water content of the deposit. However, due to the presence of the silty clays with low permeability, the groundwater in the sand layers sometimes appears to be under pressure.

The free water surface or the perched watertable fluctuates with a number of factors, such as season, climate, runoff, and usage. Past records show that the perched watertable generally fluctuates between 1 to 6 m below the ground surface with an average of about 4 m.

Since 1946, due to development of the metropolis, deep well pumping is used to augment water supply. The subsurface water level was found to decrease rapidly. Most significant drop occurred since 1957 due to rapid development of industries in the area. The subsurface water storage gradually becomes inadequate to supply the large number of deep wells. Due to deep well pumping, the water level in the waterbearing layers appears to be non-static and separated into two zones. The piezometric level of the lower zone drops 2 to 3 m per year with some of the deep wells completely depleted. The watertable of the upper zone appears to float above the silty clay of Layer 4. Figure 4 shows a typical distribution of the piezometric pressures in the Taipei Silt Stratum.

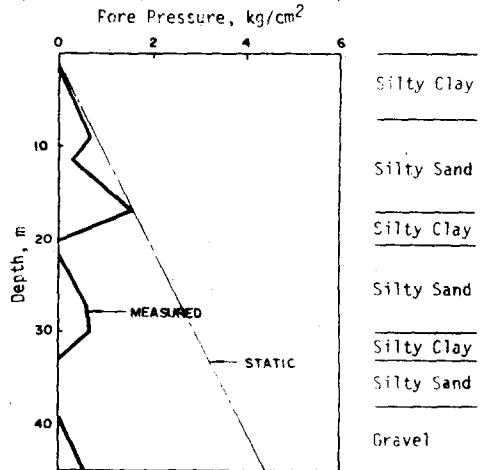


Fig. 4 Variation of Piezometer Level with Depth

As a consequence of the drop in the subsurface piezometric level, serious regional subsidence occurs in the Basin. Figure 5 shows the total subsidence in the Basin within a 21 year period from 1955 to 1976. There are 2.98 sq km of area with subsidence exceeding 2 m, and 50.68 sq km with settlement more than 1.5 m, which is almost 21% of the total land area in the Basin.

Large part of the ground elevation of the Taipei Basin

is less than about 6 m above mean sea level. Regional subsidence has caused many acres of useful lands to be inundated by sea water. Furthermore, subsidence has caused serious problem to the drainage system and damages to structures in the metropolis. The effect of subsidence on design and construction of foundations and other underground structures cannot be over-emphasized.

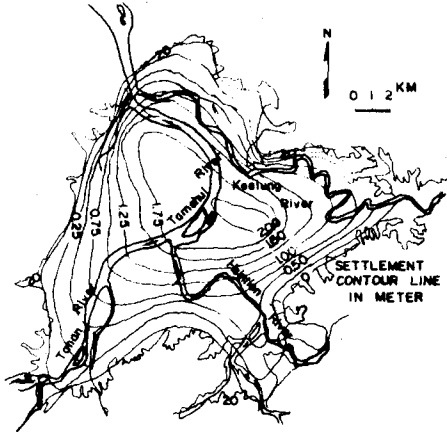


Fig. 5 Ground Subsidence of Taipei Basin (1955 to 1976)
GENERAL DISCUSSION ON GEOTECHNICAL ENGINEERING
PROBLEMS IN TAIPEI SILT

For any type of structure, the major geotechnical engineering problems are: (i) selection of foundation type, (ii) design of retaining scheme for excavation, (iii) selection of construction method, and (iv) dewatering. On the basis of the characteristics of the Taipei Silt Stratum as discussed in the above sections, some special problems can be delineated.

For tall buildings in Taipei area, the two most commonly used foundation types are large diameter bored piles founded on the gravel layer underlying the Taipei Silt and the other is compensated floating foundation. For the bored pile foundation, quality control and the effect of down-drag (or negative skin friction) due to subsidence have been the major problems. A number of buildings has developed considerable differential settlement. The most serious problem in design and construction of floating foundation is safety during deep excavation. In Taipei, it is common to place a mat foundation at a depth of more than 10 m below the ground surface. Due to the soft nature of the Taipei Silt, the large volume change characteristics of the Layer 4 and movement of the fine sand in Layer 5, damages to adjacent structures due to excavation are common phenomenon. Design of the retaining scheme and proper control during excavation are problems of major concern.

As discussed in previous section, the perched groundwater level in Taipei Silt is very high, only a few meters below the ground surface, dewatering is a necessity during excavation. However, due to the compressible nature of the Taipei Silt formation, extensive dewatering without proper control often causes surface settlement of adjacent areas. Figure 6 illustrates the extensive effect of dewatering at one project in Taipei. A more detailed discussion on foundation problems in Taipei is being presented in an ac-

companying paper for the Forum on Foundation Practices.

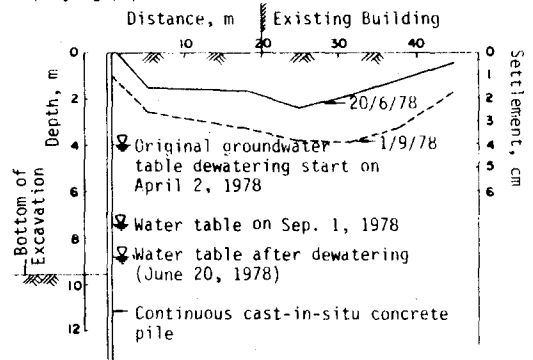


Fig. 6 Settlement of Ground due to Dewatering during Construction
CONCLUSIONS

In the foreseeable future, there are many major construction works going to take place in the Taipei Basin. Problems relating to geotechnical engineering will be numerous. With the present state of knowledge, there appears to be only few unsurmountable problems. However, many of the solutions and methods commonly used are semi-empirical and based on actual observations of foundation performance. In view of the characteristic of the Taipei Silt Stratum and the peculiar distribution of the subsurface piezometric pressures, information obtained from in situ monitoring and performance observations of geotechnical structures will be invaluable in improving the accuracies of analysis and prediction of foundation behavior.

Some of the special problems about the Taipei Silt which need further systematic study includes strength changes due to excavation and reloading, lateral earth pressures on retaining structures for deep excavation, and effect of regional subsidence on foundation design and construction.

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