GEOTECHNICAL ENGINEERING MAPPING OF THE TAIPEI CITY

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SUMMARY A major part of the Taipei City is underlain by sedimentary deposits with the top 50 meters composed of loose sandy soils and soft clayey soils. Most of the construction activities in the city have taken place in these subsoil strata and are significantly affected by their geotechnical engineering characteristics. The study, described in this paper, attempts to divide the basin area of the Taipei City into zones according to the depositional characteristics, stratifications and soil properties.

Informations on representative boring logs were collected from major projects within the city. These projects include the N-S Intracity Expressway, the proposed Mass Rapid Transit System, the Taipei Railway Underground Project, the N-S Freeway, and many highrise building projects. In total, information on about seven hundred boring logs were compiled. Results of laboratory testings on samples taken from these boreholes were also reviewed and compiled.

On the basis of their geological origin and sedimentary environment, the subsoils in the Taipei Basin were divided into three major regions. They are: Tamshui River Region, Hsintien River Region and Keelung River Region. From detailed analysis of the composition, thickness of the various strata and engineering properties of the soils, the three major regions were further divided into seven zones. A series of geotechnical engineering maps were produced including geological map, fence diagrams, isopachous maps of the various sublayers, isohyps maps of the various sublayers, and a geotechnical zoning map.

INTRODUCTION

Taipei City, the capital of the Republic of China, is located at the northern part of the Island of Taiwan. A major part of the city is situated on the sedimentary plain of the Taipei Basin. The basin's average elevation is about 5m above mean sea level and the topography is relatively flat.

The upper strata of the Taipei Basin from the ground surface to a depth of about 50 m consist primarily of soft ground, i.e. loose sand and silt, soft silty clay and clayey silt formations. Majority of the underground constructions of major development works, such as the mass rapid transit system, water supply, drainage and sewerage works, foundations for elevated roads and buildings, underground parking garages, etc. are located in this strata of soft ground.

OU et al. (1983) reported that the properties of the subsoils in the Taipei Basin are influenced by the depositional characteristics of three major rivers. They are the Tamshui River, Keelung River, and Hsintien River. Based on the administrative districts, WU (1979) divided the basin area into three regions, i.e. Tamshui River Region, Chungshan- Daan Region and Keelung River Region, to study the properties of soils in the Taipei Basin. MOH and OU (1979) presented the engineering characteristics of the Taipei Silt in the Tamshui River area. This paper describes a study to divide the basin area into different zones on the basis of their depositional characteristics, stratifications, and engineering properties.

GEOLOGY OF THE TAIPEI BASIN

The Taipei Basin is a triangular shaped basin located in the northern part of Taiwan (Fig. 1). The area of the basin below El. 20 m above mean sea level is estimated to be approximately 243 sq. km with a circumference of approximately 70 km long. The Taipei Basin is enclosed by the Tatun Volcanic Group on the north, Linkou Tableland on the west, and a hilly terrain of Tertiary sedimentary rock on the southeast side. There are three major rivers flowing into the basin. They are: Keelung River from the east, Hsintien River from the south, and Tahan River from the southwest. The Tahan River and the Hsintien River converge to form the Tamshui River which flows into the sea at Tamshui.

The Taipei Basin is a structural basin which was formed by the settlement of nappes between thrusts in the foothill range of northern Taiwan during the Pliocene or Pleistocene era. The thrusts generally follow northeast or east-northeast direction. Most of the base of the Taipei Basin is made of Tertiary sedimentary rock except a part of the Peitou area where it is made of volcanic rock of the Tatun Volcanic Group. The surface of the Basin is covered by recent alluvium and Quaternary unconsolidated material. The thickness of the unconsolidated material reaches 250 m in the central part of the Basin. The unconsolidated material of the Basin in the Taipei City can be divided into two formations: the Chingmei Formation and Sungshan Formation in an ascending order. The Chingmei Formation is a very dense coarse sand and gravel layer approximately 90 to 130 m in thickness, whilst the Sungshan Formation is composed of alternate layers of soft and compressible clayey silt, silty clay and fine sand. The Sungshan Formation is immediately below the ground surface and extends to a depth of about 60 m.

Based on geological history and general soil properties, the Sungshan Formation can be subdivided into six sublayers as shown below:

Sublayer	Description
Top Soil	Yellowish Brown Clay (CL, CL-ML)
Sublayer VI	Grayish Black Silt (ML)
Sublayer V	Gray Silty Fine Sand (SM)
Sublayer IV	Gray Silty Clay (CL-ML)
Sublayer III	Gray Medium Dense Silty Fine Sand (SM)
Sublayer II	Gray Silty Clay (CL-ML)
Sublayer I	Medium Dense to Dense Gravelly Sand (SM)

The Sublayers VI, IV and II are general clayey soils and the Sublayers V, III and I are general sandy soils.

ESTABLISHMENT OF DATA BANK

Fig. 2 shows the approach adopted in the study for establishing the data bank of soil information. The main sources of information are governmental institutions, academic institutions and private organizations. The data source covers public works, such as bridges, river dikes, sewerage, public buildings, the North-South Freeway, the Mass Rapid Transit System, etc., and many private highrise buildings.

The data were initially sorted into one of sixteen index files according to their location. The borehole locations were also plotted on the base map with a scale of 1:25,000 to show their distribution.

The principles of data management are as follows:

(1) The data are handled on the basis of the concept of six sublayers for the Taipei Silt Stratum (Sungshan Formation).

(2) The data of stratigraphy is stored in the Stratigraphy File for the correlation of stratigraphy. The informations in the Stratigraphy File consist of the elevation of the borehole and the thickness of each sublayer.

(3) The data of tests are separated into a Physical Properties File and an Engineering Properties File. The informations in the Physical Properties File include dry unit weight, water content, specific gravity, liquid limit, plasticity index and grain size distribution. The Engineering Properties File consists of the test results of one-dimensional consolidation tests, unconfined compression tests, direct shear tests, triaxial unconsolidated undrained shear tests, triaxial consolidated undrained tests and triaxial permeability tests.

The Physical Properties File and the Engineering Properties

File are connected to facilitate statistical correlation analysis. The data bank containing the Stratigraphy File, the Physical Properties File and the Engineering Properties File in a tree structure was then established to proceed with the geotechnical engineering zoning and statistical analysis of soil properties.

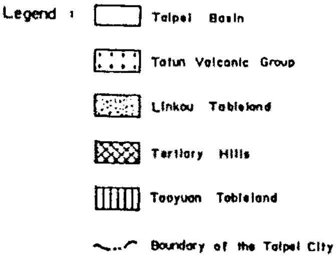
GEOTECHNICAL ENGINEERING ZONING

The approach of the geotechnical engineering zoning is shown in Fig. 3. Before the preliminary zoning, maps of fence diagrams, soil profiles, isopachous maps and isohyps maps of each sublayer and the rock surface were shown in a scale of 1:25,000, and the geological map of the Taipei Basin area was shown in a scale of 1:50,000. These were plotted to realize the transformation of the subsoils.

The fence diagram is a drawing in perspective of several geologic sections with their inter-relationships to each other. It is used to demonstrate changes in thickness and other stratigraphic conditions occuring between boreholes. Fig. 4 shows a part of a fence diagram of subsoil distribution of the Sungshan Formation. Soil profiles are drawn along the north-south direction and the east-west direction in the Taipei City. The horizontal scale of the soil profile is the same as that of the base map and the vertical scale is exaggerated to 1:800. Besides the sequence of the different sublayers, the standard penetration test N values and the streets map are also plotted. Fig. 5 shows a part of the soil profile I-I which is one of the eight soil profiles evaluated in the study. The isopachous map gives the isopachs which are lines of equal thickness of each sublayer. A total of six isopachous maps were prepared for the six sublayers. The isopachs are given for equidistances of 2 m for Sublayers VI, V and IV, and equidistances of 5 m for the rest sublayers. The isopachous maps provide a very clear idea about the variation of the thickness of each sublayer. In addition to the isopachous maps, isohyps maps of each sublayer were also prepared. The isohyps maps show the isohypses which are lines of equal altitude of the top of each sublayer. Since the elevation of the top of each sublayer can be obtained from the corresponding isohyps map, the drawing of a geological cross section along any direction can be made fairly easily. The geological map shows the distribution of rock formation and geological structure of the hilly area outside the Taipei Basin. Combining the isohyps map of the rock surface and the geologic map, the ancient topographic landform can be deduced. Since the extent of majority of the boreholes usually stopped at only few meters into the gravel layer and does not reach the underlying rock surface, the isohypses of the rock surface were inferred from information obtained from drilling and geophysical investigation.

The zoning guidelines are as follows:

(1) The drainage basins of the Tamshui River, the Keelung River and the Hsintien River are the main regions of zoning.



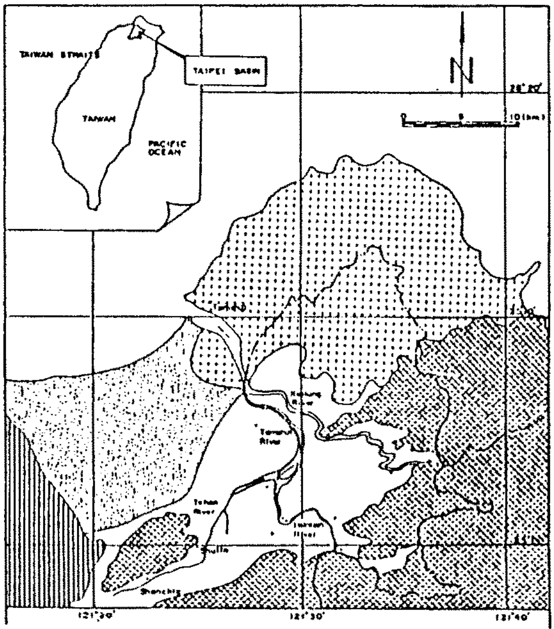


Fig. 1 Taipei Basin and Geology of Its Surrounding Area

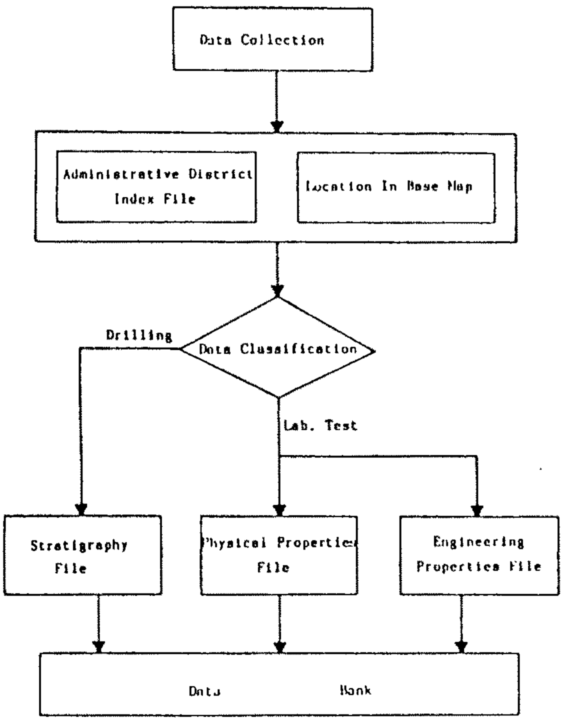


Fig. 2 Approach of Establishing the Data Bank

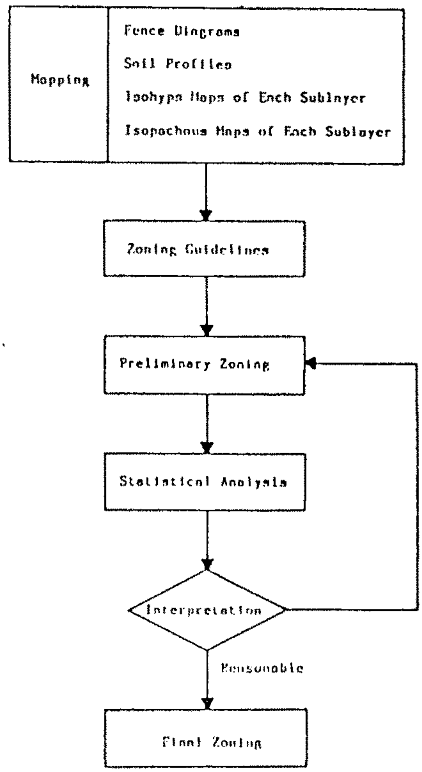


Fig. 3 Approach of Geotechnical Engineering Zoning

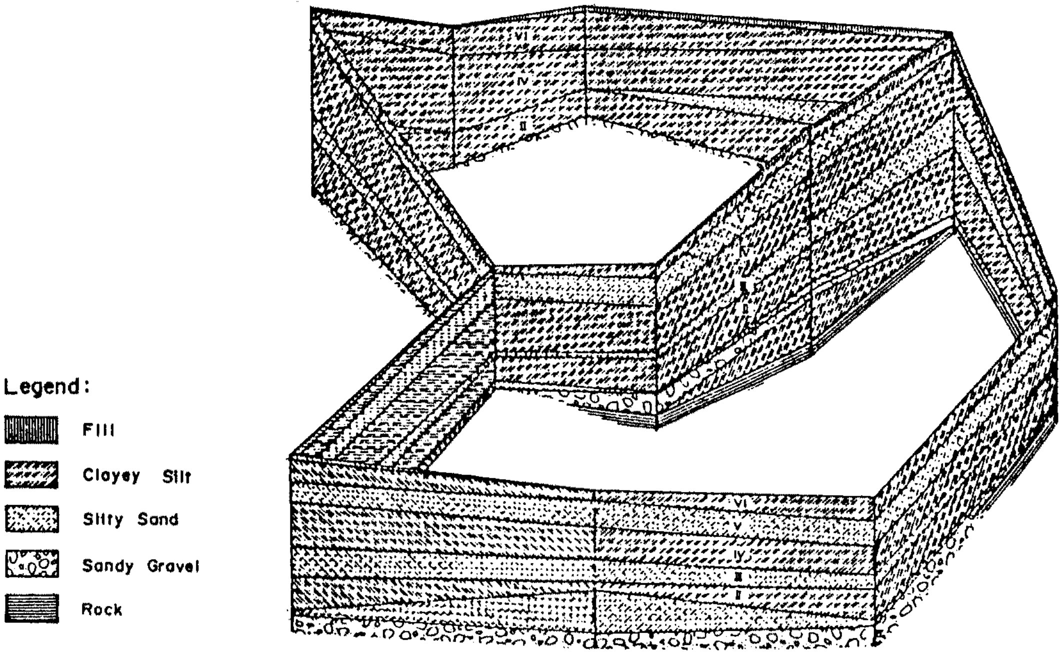


Fig. 4 Illustration of Fence Diagram of Subsoil Stratification

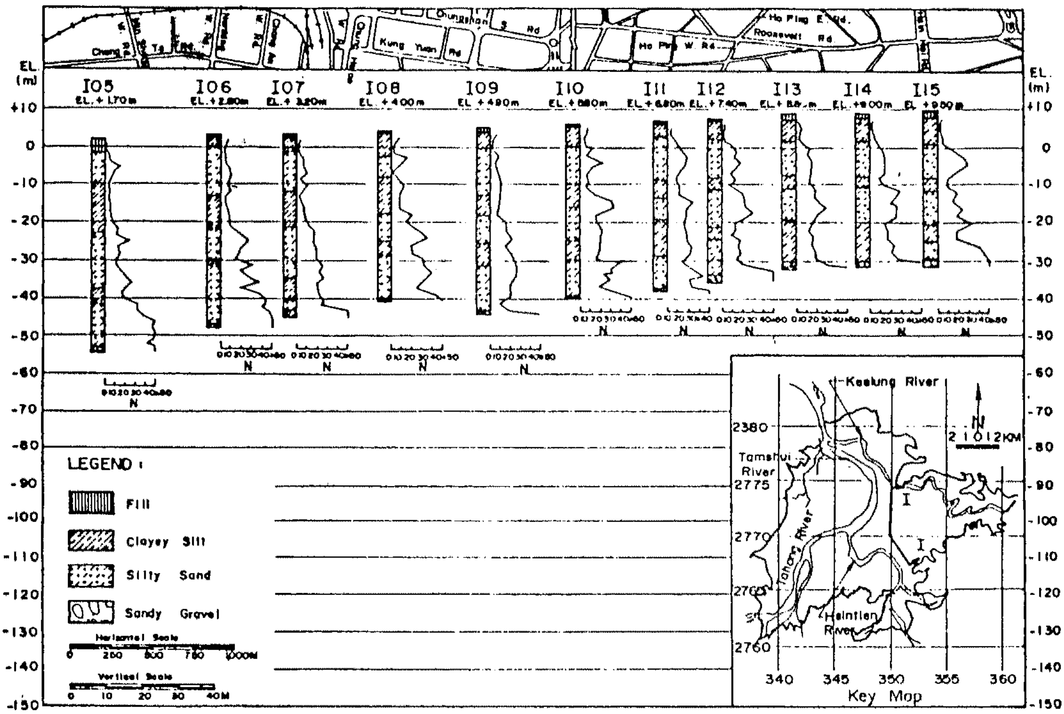


Fig. 5 Illustration of A Soil Profile

(2) The zones in each specific drainage basin is further divided according to the distribution of the sublayers and the depositional environment.

The geotechnical zones were preliminarily delineated following these guidelines. Statistical analysis of the physical properties and the engineering properties of the soils in each zone were then carried out. After the statistical study, the results were inspected to detect zones with unreasonably high variances. If the unreasonably high variance in one particular zone were due to data from the boundaries, the zoning boundaries were adjusted. This zoning and statistical study process were iterated until reasonable agreement was arrived.

The results of zoning are shown in Fig. 6. The Taipei Silt Stratum in the Taipei City can generally be classified into three main regions of drainage basin. Due to differences in the location or the depositional environment within the same drainage basin, each main region can be further divided. A total of seven zones was divided. The relationship between the various zones and the main drainage basins is shown below:

Drainage Basin	Geotechnical Engineering Zone
Tamshui River	T1
	T2
	T3
Keelung River	K1
	K2
Hsintien River	H1
	H2

The drainage basin of the Tamshui River mainly covers the area of Hsuangyuan District, Guting District, Longashan District, Chengchung District, Yanping District, Chiencheng District, Datung District, Daan District, the western part of the Chungshan District and the southwestern part of the Shilin District. The extent and the characteristics of the strata in Zone T1, Zone T2 and Zone T3 are briefly described.

(1) Zone T1 - Zone T1 covers the Hsuangyuan District and the area of the Guting District near the Hsintien River. Due to possible influence of shift of the river course, the variation between the sublayers is very complex. Sublayer VI is not distinct in most part of this Zone and Sublayer V is about 15 m thick.

(2) Zone T2 - Zone T2 covers the Datung District, the Yanping District, the Chiencheng District, the Longashan District, the Chengchung District, the Guting District, the northeastern part of the Hsuangyuan District, the southwestern part of the Chungshan District and the western part of the Daan District. The stratification characteristics of the six sublayers of the Taipei Silt Stratum in this Zone is most distinct. Generally

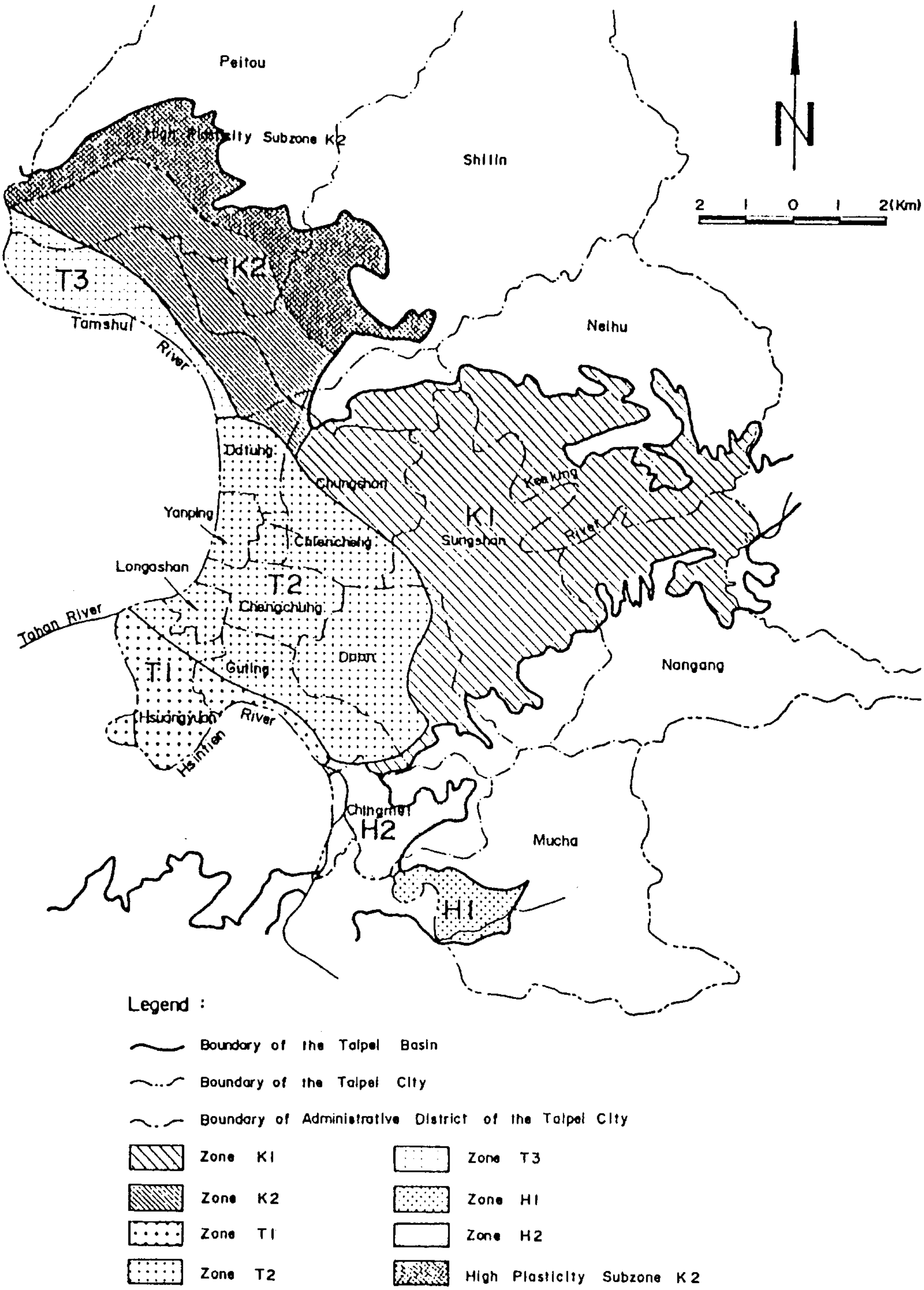


Fig. 6 Geotechnical Engineering Zones of the Taipei City

speaking, the clayey soil is relatively thin and the thickness of Sublayer IV is about 5-10 m. The sandy soil is relatively thick and the thickness of both Sublayer V and III is about 15-20 m. The sandy soil becomes thicker and the clayey soil becomes thinner as it comes closer to the Tamshui River.

(3) Zone T3 - Zone T3 covers the southwestern part of the Shilin District near the Tamshui River and the southwestern part of the Peitou District. The special characteristics of this Zone are the relatively thick sandy soil and the thinning out of the Sublayer VI.

The relatively thick layers of clayey soil and the relatively thin or thinned-out sandy soil strata are the characteristics of the drainage basin of the Keelung River. The distribution of the Taipei Silt Stratum is highly influenced by the elevation of the underlying rock formation. The drainage basin of the Keelung River can be generally divided into two zones: Zone K1 and Zone K2.

(1) Zone K1 - Zone K1 covers the Sungshan District, the northern part of the Nangang District, the southern part of the Neihu District, the western part of the Daan District, and the central part of the Chungshan District. In the areas of the Sungshan Municipal Airport and the proposed Hsinyi Project Township, Sublayer V is found to be in absence. The Sublayer III in these areas is also very thin or non-existing. Consequently, the standard six sublayers of the Taipei Silt Stratum is not distinct in this zone. The clayey soils from Sublayers II, IV and VI become almost continuous and relatively thick.

(2) Zone K2 - Zone K2 covers the northeastern part of the Datung District, the southwestern part of the Shilin District and the southern part of the Peitou District. Like in Zone K1, Zone K2 has a thick layer of clayey soil and lacks the standard six sublayer stratification. The average clay size particles content of the Sublayer VI and IV in Zone K2 is about 15% and 10%, respectively, higher than those in Zone K1. The average liquid limit and plastic index of the Sublayer VI and IV are about 3 to 5% higher in Zone K2 as compared to those of Zone K1. As shown in Fig. 6, there is a high plasticity subzone in Zone K2. The average liquid limit of Sublayer VI of this subzone reaches 67%, with average plasticity index about 35%, and natural water content around 60%.

The Hsintien River Drainage Basin covers the Chingmei District and the Mucha District. According to the depostional environment, the Hsintien River Drainage Basin can be divided into two zones: Zone H1 and Zone H2.

(1) Zone H1 - Zone H1 covers the western part of the Mucha District. It is located on the alluvial valley plain which is deposited by the Chingmei Creek, a tributary of the Hsintien River. The subsoil is mainly composed of clayey soil of about 20 to 30 m in thickness directly overlying rock formation. In areas along the Chingmei Creek, the subsoils are more variable and composed of interlayers of silty sand and silty clay.

Within the silty sand stratum, gravel particles are sometimes found.

(2) Zone H2 - Zone H2 covers the Chingmei District. The subsoils are mainly composed of sandy soil and gravel. The thickness of the clayey soil tends to increase from the Hsintien River eastwards.

REGIONAL VARIANCES

Representative results of the statistical analysis of the engineering properties of the clayey soils and the sandy soils in three largest zones, i.e. T2, K1 and K2 are presented in Tables I and II. Among the three clayey sublayers, Sublayer IV has the highest compressibility whilst Sublayer VI is the least compressible. Comparing the compressibility in the three zones, Zone K2 is the highest and Zone T2 is the lowest. On the other hand, the shear strength of Zone T2 is the highest and Zone K2 is the lowest. The unconfined compressive strength value of Sublayer VI and Sublayer IV of Zone K2 is about 1.5 times that of Zone K2. Comparing the effective angle of shear resistance of the sandy soils, Table II, Sublayer I is the highest and the Sublayer V is the lowest. The effective angle of shear resistance of Sublayer V appears to be about the same in all these three zones.

CONCLUSIONS

On the basis of depositional characteristics, stratifications and engineering properties, the subsoils in the Taipei City can be divided into three regions which can be further divided into seven major zones. It was found that the geotechnical engineering characteristics vary continuously from one zone to another, the boundary lines between any two zones were therefore established somewhat artificially. However, through repeatitive iteration process, it was possible to obtain the most representative physical and engineering properties of each sublayer of the subsoil strata. It must be emphasized that the geotechnical zoning of the Taipei City area described in this paper was a first attempt. Furthermore refinements and modifications are anticipated when more data become available. The average engineering properties of the subsoils reported herein should be used for reference and preliminary planning only. Special cautions must be exercised to extend the use to engineering design.

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Table I Average Engineering Properties of Clayey Soils in Zones T2, K1 and K2

Sub-layer	Zone	N	e_o	C_c	q_u, t/m^2	s_u, t/m^2	$\bar{c}$, t/m^2	$\bar{\phi}$, deg.	k_v, cm/sec.
VI	T2	5	0.87	0.29	6.3	4.4	0	33.6	4.4×10^{-7}
	K1	3	0.92	0.28	5.5	2.7	0	33.9	2.1×10^{-7}
	K2	3	1.03	0.34	4.2	3.1	0	34.5	-
IV	T2	8	0.94	0.39	9.6	5.3	0	32.3	1.4×10^{-7}
	K1	4	1.06	0.46	7.3	4.0	0	31.3	2.7×10^{-7}
	K2	3	1.18	0.50	6.4	3.4	0	30.9	3.1×10^{-7}
II	T2	19	0.84	0.33	17.4	5.3	0	35.5	-
	K1	14	0.88	0.38	14.6	5.5	0	31.6	-
	K2	14	1.04	0.50	13.9	-	0	30.6	-

Table II Average Engineering Properties of Sandy Soils in Zones T2, K1 and K2

Sub-layer	Zone	N	$\bar{c}$, t/m^2	$\bar{\phi}$, deg.	k_v, cm/sec.
V	T2	10	0	32.5	2.6×10^{-4}
	K1	12	0	32.3	1.8×10^{-4}
	K2	5	0	32.4	-
III	T2	21	0	33.3	1.7×10^{-4}
	K1	16	0	32.4	-
	K2	20	0	35.3	-
I	T2	31	0	34.2	-
	K1	31	-	-	-
	K2	19	-	-	-

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