Soft Bangkok Clay Zoning

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ABSTRACT: Soft Bangkok Clay is well known as the thick deposit of marine clay on the lower Chao Phraya Flood Plain covering about 15,000 sq.km. and is situated of the capital and economic center of Thailand. The layers of 10 to 20 m. of very soft to soft clay usually create the problems of low bearing strength, high compressibility, slope instability for infrastructures. Generally the thicker soft clay layer is located close to the shore line along gulf of Thailand and gradually decreased the thickness with the distance to the north. This study is aimed to create the zoning for soft clay from more than 4000 boreholes. The data are collected in web-based Geographic Information System(GIS) for efficient management of borehole and geological data. Methods for data screening, error elimination and generalized soil profiles were proposed for the future expansion. The grids of 5x5, 2.5x2.5 and 1.25x1.25 sq. km. were used for GIS interpolation. Physical and engineering properties such as unit weight, water content, strength, consolidation were analyzed for their statistical values and cross correlations. Proposed zoning method based on soft clay thickness, water content, and strength was given for further geotechnical engineering applications. Some case examples of application on pile foundation, highway and embankment designs were given. The system will provide for public services with geological information search function, on-line geological information function, statistical summaries, and administrative functions in the future.

1 INTRODUCTION

Marine deposits of soft clay are spread out over the lowland on the coastal area especially on the river mount. In Southeast Asia, these area usually are the locations of the capitals or major cities such as Jakarta, Bangkok, Ho Chi Minh City, Yangon, Dhaka, Singapore. The economic and political centers of many countries are resting on this geological formation. Figure 1 shows the locations of the soft clay on Southeast Asia.

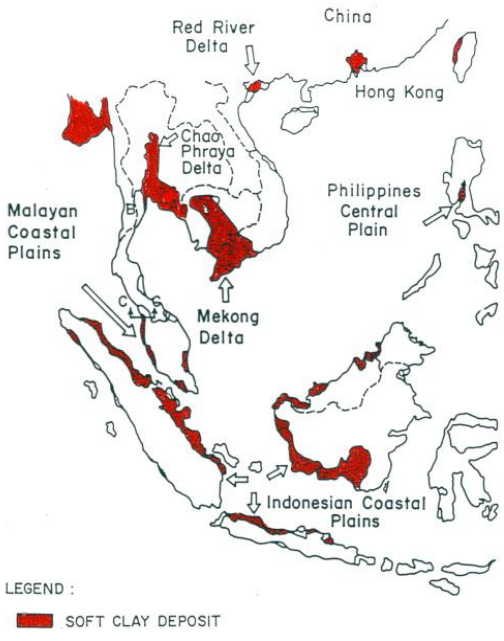
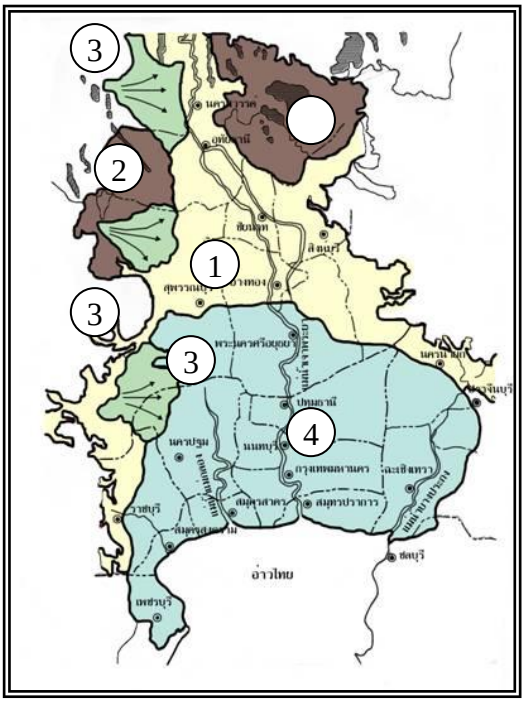


Fig. 1 Soft clay deposits of Southeast Asia (Broms, 1987)

The 1500 sq.m., area of Bangkok Metropolitan is located on the southern of lower Chao Phraya Flood Plain. The plain itself is the large extent of marine clay deposit during the Holocene period when the sea water had raised up to about 5 meter above this present level as shown on Figure 2. The whole flood plain 7000 to 10000 years ago was covered by sea and the sediment from major rivers (Chao Phraya, Ta Chin, Mae Khlong and Bang Pakong) deposit on the area of 14,000sq.km.



① Fluvial deposits
② Terrace deposits
③ Aluvial Fan deposits
④ Soft marine clay deposit

Fig.2 Location of soft marine clay deposit (Visharn, P., 2003)

Soft marine clay deposit present special problems of geotechnical engineering design, construction and serviceability caused by low strength, high compressibility and sensitive properties. In Bangkok and vicinity area, pile foundation failures are common due to miss judgment of pile length, pile capacity and movement or damage of pile during construction. Stability failure of embankments and canals cause by low strength, reduction of strength during construction and excessive movement(creep) during service period. Excessive settlement or differential settlement of building foundation and highway bridge approach are always happened. The global settlement due to ground water pumping in Bangkok area is now extended to soft clay layer by evidence of ground water drawdown in soft clay up to 10-20 meter from original hydrostatic water level.

Fig.3 Problems of slope failure and differential settlement in Soft Bangkok Clay

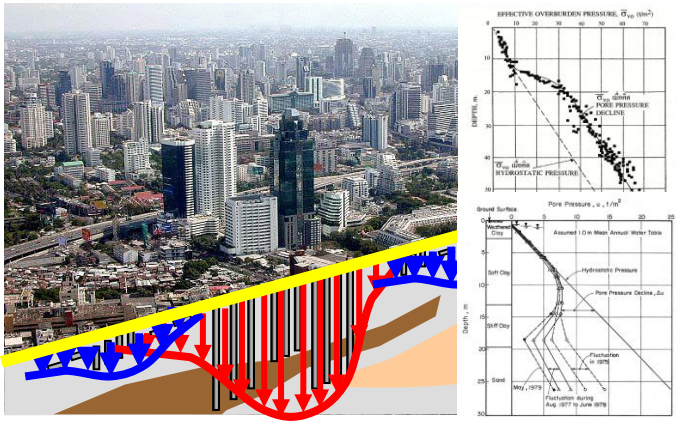


Fig.4 Ground water drawdown and global settlement (AIT, 1978)

Although the authorities concerned such as Public Work and Town Planning Department, Bangkok Metropolitan Authority, Highway Department, Engineering Institute of Thailand, Universities, Engineers are well aware of these problems. They are usually concentrated only on the projects of their own responsibility. Several thousand boreholes were sunk to investigate Soft Bangkok Clay every year. After those data had been used for design, construction supervision and remedial works then they become wasted information. The attempt to reuse the borehole and geotechnical testing as soil database was proposed by Kasetsart University and Engineering Institute of Thailand on 2000. At the present several organizations has started their own database and willing to merge as the national geotechnical information system in the future.

2 QUATERNARY GEOLOGY OF LOWER CHAO PHRAYA FLOOD PLAIN

Soft Bangkok Clay is the results of the deposition of estuarine sediment from 4 major rivers on Lower Chao Phraya Plain namely; Bang Pakong on the east, Chao Phraya on central, Tha Chin and Mae Khlong on the west as shown on Figure 5.(Sin Sinsakul, 2000). The other factors that may influence by the deposit are basement of Tertiary rock, the Quaternary deposit of about 2000 m., the fluctuation of sea level in gulf on Thailand, the Geomorphology and geology structure of the area. Even through the

Soft Bangkok Clay is much more resent deposit as comparing to those factors. However, some reasonable explanation of Soft Bangkok Clay Zoning may come the factors above.

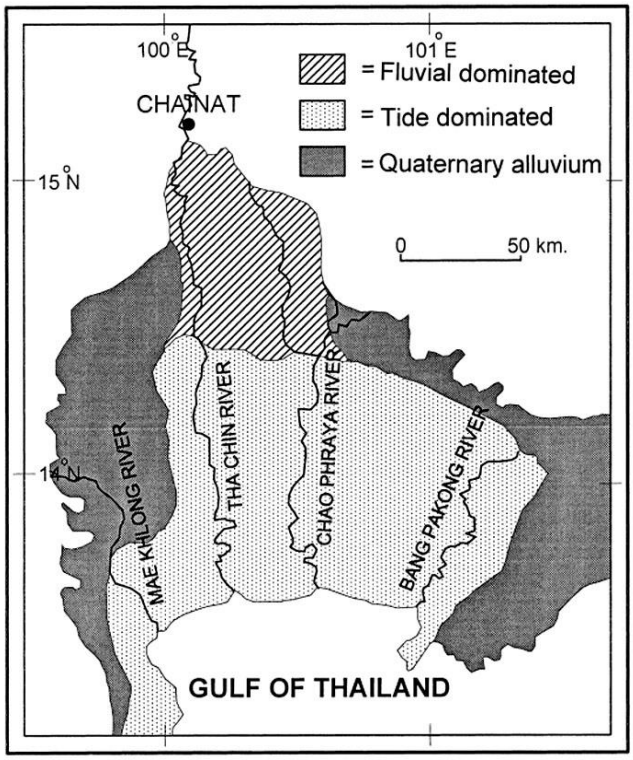


Fig.5 Quanternary Deposits on Lower Chao Phraya Plain (Sin Sinsakul, 2000)

The base rock topography is very irregular, varying from 500 to 2000 m. below the ground surface. Nutalaya and Rau (1984) indicated that bedrocks consists of sedimentary, igneous and metamorphic rocks of Paleozoic to Mesozoic era. While younger tertiary rocks of claystone, siltstone, sandstone and conglomerate found on top as separate basin indicated by the major geologic structures and shown on Figure 6.

Overlaying the rocks are the Quaternary deposit of the complex sequence of alluvial, fluvial and deltaic sediments. Maximum of 2000 m. of deep of Pleistocene and Holocene sediments were deposited in the basin (Nutalaya and Rau, 1984). These layers were formed the ground water aquifers and aquitars of the central plain. The well known aquifers are; Bangkok, Phra Pradang, Nakorn Luang, Nontaburi, Sam Khok, Phaya Thai, Thon Buri and Pak Nam Aquifers. The cross-section of the basin on east-west direction was summarized by JICA (1999) on Figure 7 showing the possible layer of major deposits on bedrock. The uppermost layers are the deposits during the Holocene epoch less than 10,000 years ago. Sea-level rise in this period causes the rapid sedimentary soil layer when flows from major rivers immerging with sea water causing decreasing of flow rate.

Fluvial or fresh water dominated sediments located on the northern part of the plain with sand rich soil. Where on the lower area the effects of river meandering, oxbow lakes, levee and black swarm create the floodplain deposit of fine-grained soil, clay and silt sizes. On the old coastal area or river delta the movement of tidal water and shore line activities result the deposition of riverine and marine environments.

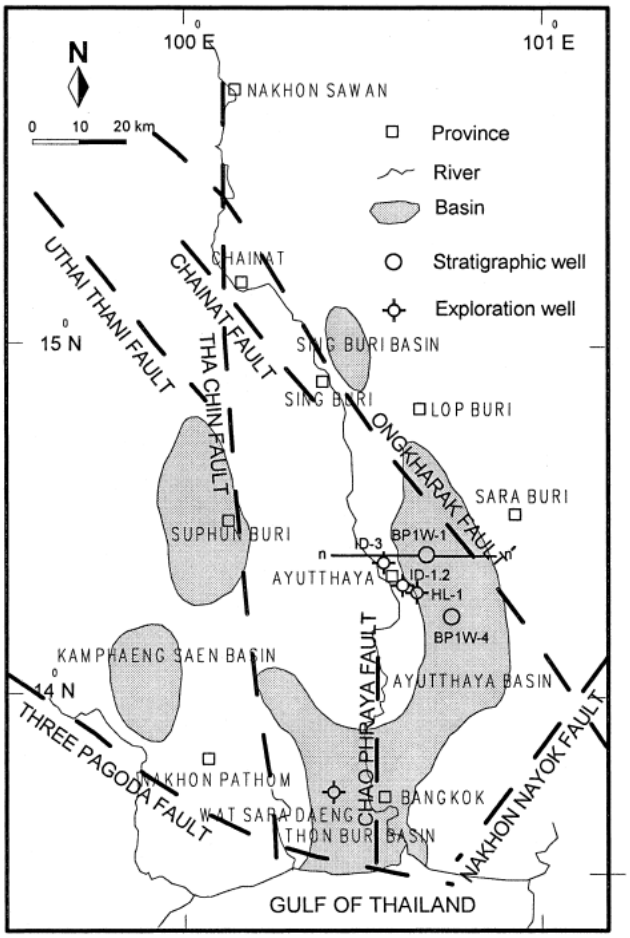


Fig.6 Tertiary Basins and Major Structures (Sin Sinsakul, 2000)

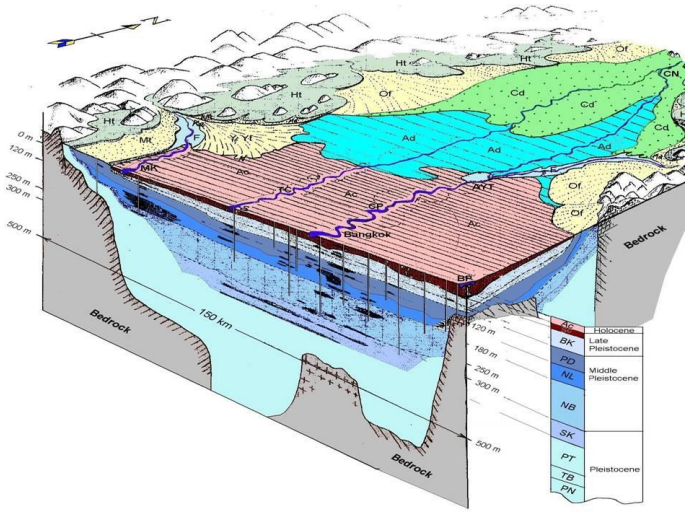


Fig.7 Schematic cross-section of lower Chao Phraya Basin (JICA, 1999)

3 DATABASE OF SOFT BANGKOK CLAY

3.1 *Development of Bangkok Area Soil Database*

Agricultural soil information and mapping had been developed from 1935 by the Department of Land Development according to USDA system. The compilation of soil engineering data in Bangkok area was started in around 1965 and first published by Muthabhant, C. and et.al. (1967). Engineering Institute of Thailand (EIT.) issued a book called " Soil Data on Lower Chao Phraya Flood Plain" in which the profiles along some major roads and canals had presented.

When personal computer are available, many soil databases were created by the researchers and organizations as listed on the Table 1. However, the number of borehole is still limited to 1163 holes mostly in the Bangkok Metropolitan Area.

Table 1 Engineering Soil Database for Bangkok Area

No.	Authers	Years	No. of Bore Hole	Software	Data Format		Plublic Services
					Image	Digital	
1	Kumthorn	1986	416	Hollerith Card		/	-
2	Kaveewong	1987	408	Lotus123		/	-
3	Vichai and et.al.	1992	NA	Lotus123		/	-
4	Chinkulkijniwat	1998	NA	MS-Access		/	-
5	Gangopadhyay et.al.	1999	60	GRASS		/	-
6	Khomgrit	2000	272	MS-Access		/	-
7	Khomsilp	2001	1083	MS-Access		/	-
8	Pranut	2002	1163	GRASS		/	/
9	EIT	2004	1163	GRASS		/	/
10	Prapat and et.al.	2005	70	Notepad	/		-
11	PWA	2005	NA	**	/		/
12	DMR	2005	140	MS-Access		/	/
13	Nuthawuth and et.al.	2006	NA	MS-Access		/	-

3.2 *Bore Hole Locations*

Kasetsart University continue to develop soil data base (ESDS-KU) by upgrading and expanding the scope of soil bore hole from Pranut (2002) to cover the area of 15,000 sq.km. of Chao Phraya Flood Plain. The total numbers of data are consisted of 4,293 bore holes, 305 field vane shear tests and 115 ground water observation wells. The bore hole and test locations are shown on Figure 8.

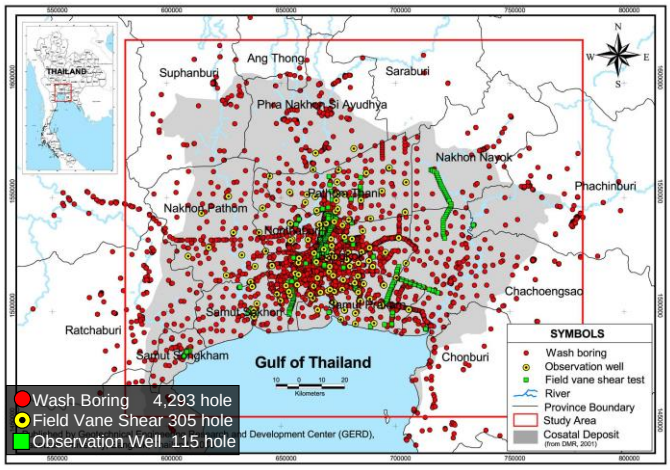


Fig.8 Bore hole locations on the ESDS-KU soil database

3.3 *Database and Data Screening*

The methodology to create ESDS-KU soil database is aimed for the generalized system, then investigation of the existing forms, graphs and reports from soil investigation companies and government organization involved are thoroughly reviewed. Four steps were performed namely; compilation of data, screening data, analysis of soil profile and properties and analysis for engineering application.

The bore hole and testing data came from many sources such as soil investigation contractors, soil exploration section of the government agencies, additional investigation by Kasetsart University etc. Then the discrepancy and error of data need to be checked and screened out from the database. The typical ranges of each parameter and the statistical standard deviation range are applied. The locations of the boreholes are checked with the satellite image to the nearest of 10 m. The screening processes cause about 5 percent of the data out of the database.

3.4 *Extension of Soft Bangkok Clay*

The boundary of the Holocene deposit was originally proposed by the Department of Mineral Resources based on the level of seawater rising about 14,000 sq.km. The present database gives the extension of soft clay 20 – 30 km. north worth as shown on Figure 9. The main reason is to include the soil that may cause the engineering problems as typical Soft Bangkok Clay. This extension may cover the fresh water deposit and fluvial sediment zone.

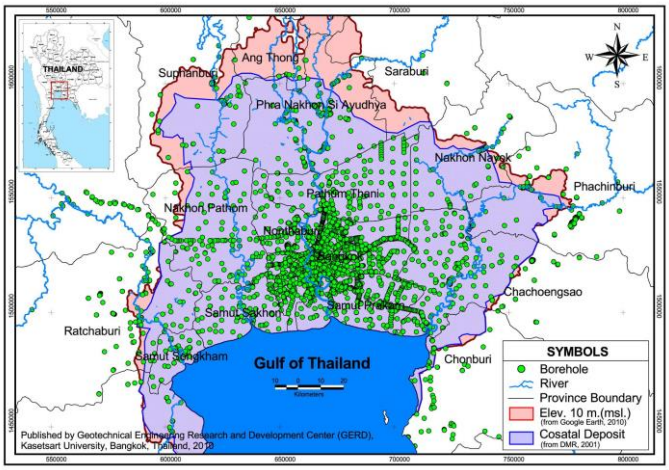


Fig.9 Extension of Soft Bangkok Clay Area

3.5 *Profile Generation*

The ESDS-KU database can interpret the soil profile showing the pertinent layers as client request. This function will assist the engineers and planners to investigate the characteristics of subsoil along the proposed infrastructures such as new highway, tunnel, canal, new development area etc. With this preliminary information, they will foreseen the soil engineering problems involved, roughly perform some of preliminary design, and get information for detailed investigation. The alignment of interested soil profile can be a line or curve according to the structure layout. Some examples of north-south and east-west sections are given on Figure 10 and 11.

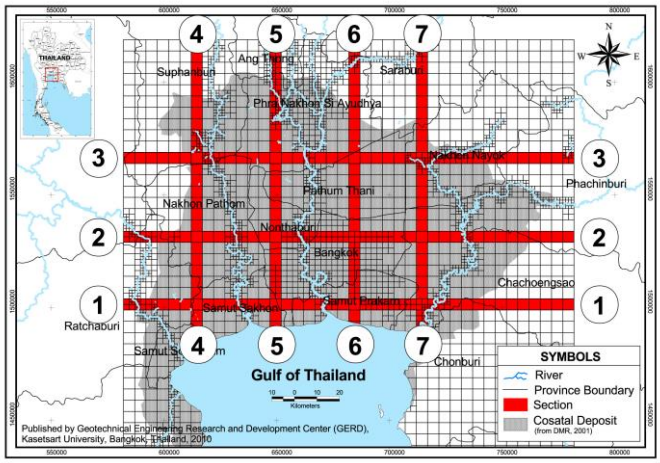


Fig.10 Example of Soil Sections

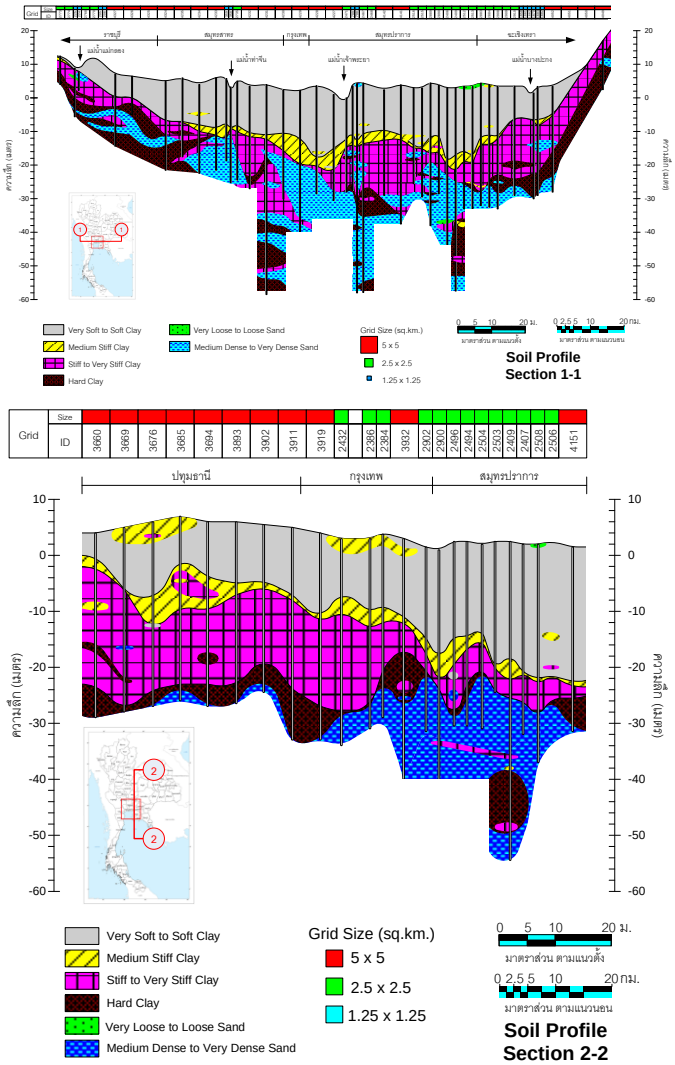
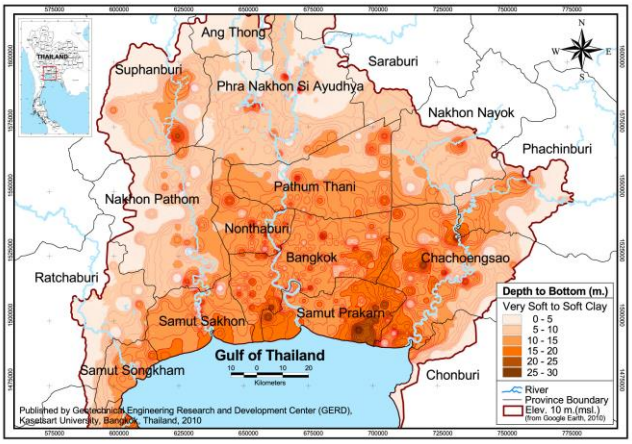


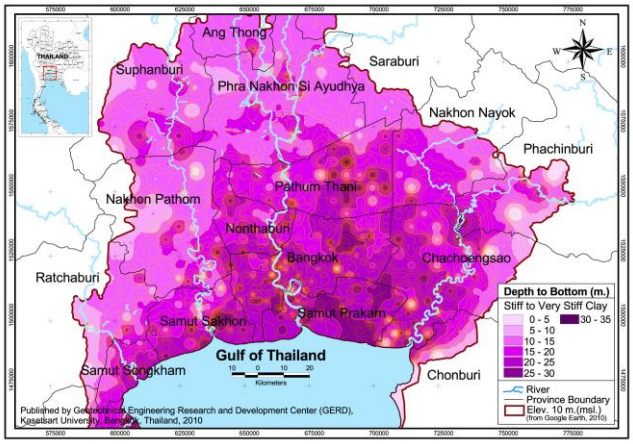
Fig.11 Soil Profiles for East-West and North-South Directions

3.6 *Depth and Thickness of Soil Layers*

The typical soil profile Bangkok Clay Area from surface consist of 1) Top Crust of 1-3 m. 2) Very Soft to Soft Clay of 10-20 m. 3) Medium Clay of 2-6 m. 4) Stiff to Very Stiff Clay of 2-6 m. 5) Medium Dense Sand of 2-6 m. 6) Dense to Very Dense Sand of 0-6 m. The depths and thickness of each soil layer above can be generated by the database to show the distribution over the study area. The depth to the bottom of Very Soft to Soft Clay is shown on Figure 12 a. The thickness is larger on the area close to the Gulf of Thailand with maximum depth to 25 m. at Samut Prakarn Province between Chao Phraya and Bang Prakong River. This information will indicate the potential of stability and settlement problems on the area. The depth to bottom of Stiff to Very Stiff Clay that overlays the Dense Sand layer is shown on Figure 12 b. This depth indicate the length of pile for the foundation of typical medium size building in the area. Depth and thickness of soil layers can also use for Bangkok Clay Zoning and future study for sedimentation and Holocene geology.

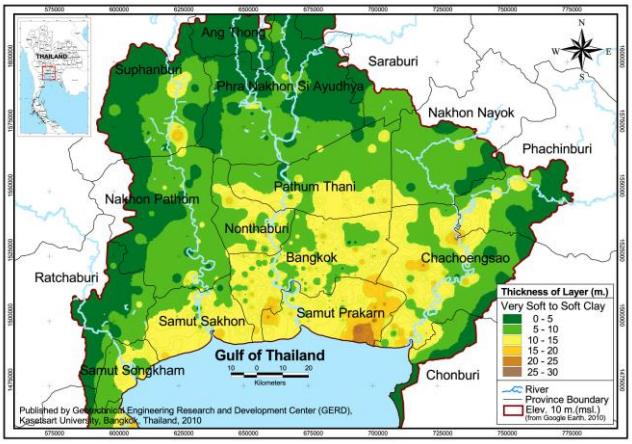


a) Very soft to soft clay

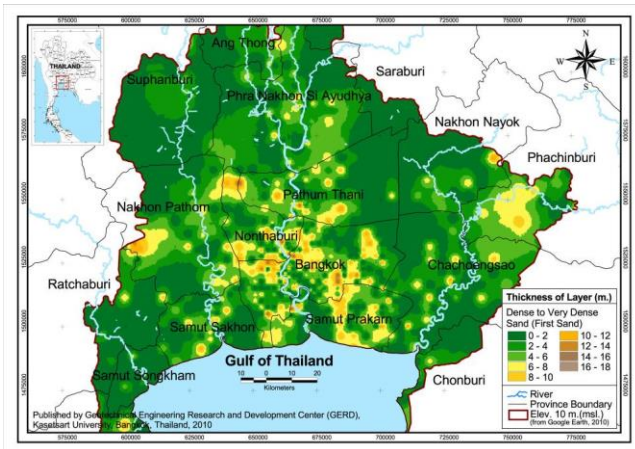


b) Stiff to very stiff clay

Fig.12 Depths to the bottom of soil layers



c) Very soft to soft clay



d) Dense to very dense sand

Fig.13 Thickness of soil layers

3.7 *Zoning of Soft Bangkok Clay*

Failures of building and bridge foundations, slope failure and excessive settlement in Bangkok Clay are often caused by not understanding of the soil variation and un-awareness of critical area. Many engineers assign the typical pile length of 20-24 m. to the foundation constructed any place in Bangkok Clay Area. They also use typical highway or canal sections for the critical area of very low strength, thick and highly compressible clay. When the authorities concerned such as Bangkok Metropolitan Authority, PWA and Highway Department do not has enough soil information to issue the regulation and law. The mis-understanding of engineers on Bangkok Clay will continue. The zoning of Bangkok Clay can help to solve the problems and give more information to the engineers. Attempt of the zoning can not possible without good soil database.

Zoning of Bangkok Clay is done by identified the causal factors such as thickness of very soft clay and soft clay layer, natural water content, Atterberg limits, and Unit Weight of soil at each location as shown on Figure 14. The points can assign for the ranges of each factor as on Table 2. These points were multiplied to the different weight based on how important each factor related to the engineering problems. When the total scores are summed up for each grid in the area, then the zones can assign to that grid.

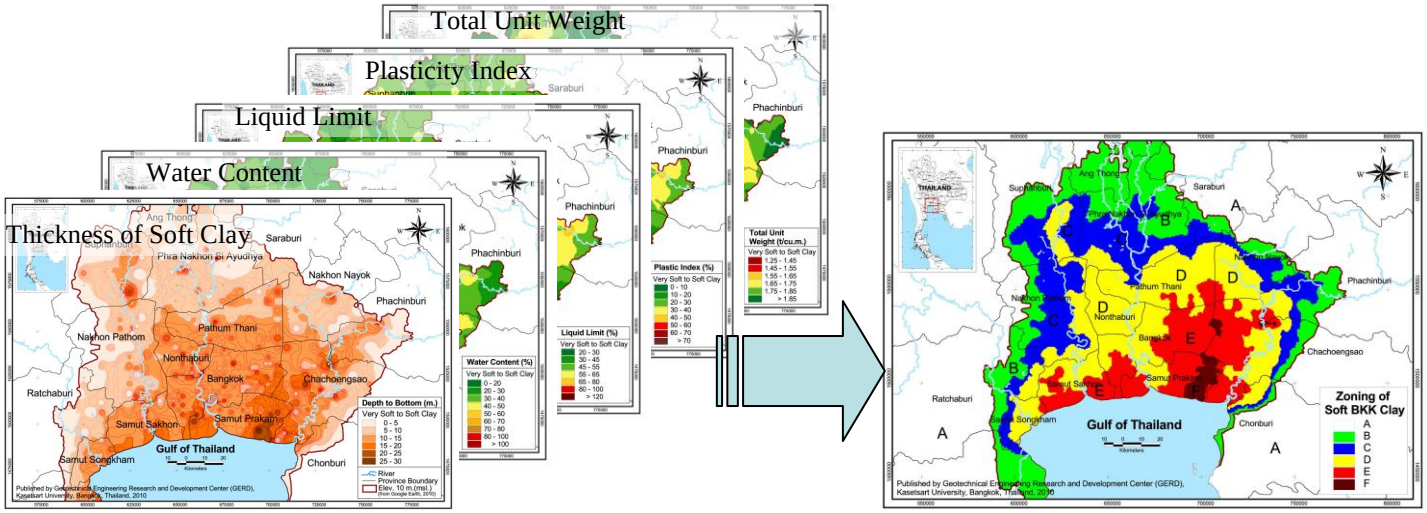
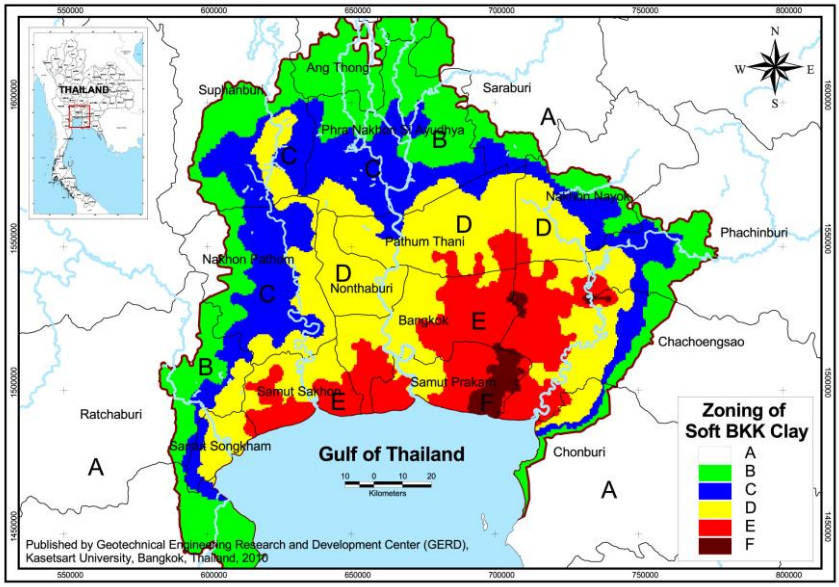


Fig.14 Causal Factors for Zoning

Table 2 Score, Weight and Zoning Criteria

Factors	Soft Clay (m.)	Water Content (%)	Liquid Limit (%)	Plasticity Index (%)	Total Unit Weight (t/m^3)		Zoning Criteria	
Weight / Point	0.4	0.3	0.1	0.1	0.1		Score Range	Zoning
1	0 - 3	< 20	< 20	< 10	> 1.85		0 – 1.2	A
2	3 - 6	20 – 40	20 – 40	10 – 20	1.75 – 1.85		1.2 – 2.5	B
3	6 - 10	40 – 60	40 – 60	20 – 30	1.65 – 1.75		2.5 – 3.3	C
4	10 - 14	60 – 80	60 – 80	30 – 50	1.55 – 1.65		3.3 – 4.2	D
5	14 – 18	80 – 100	80 – 100	50 – 60	1.45 – 1.55		4.2 – 5.0	E
6	> 18	> 100	> 100	> 60	< 1.45		5.0 – 6.0	F

The results of zoning is ranged from best to worst properties (A to F) presented on Figure 15. On the area of zone "F", the most critical, soil has the layer of soft clay thicker than 18 m., natural water content and L.L. more than 100 %, P.I. more than 60% and total unit weight of less than 1.45 ton/cu.m. This soil can be interpreted as very soft clay, low strength, highly compressible and sensitive. The location on Zone "F" is in between Bang Pakong and Chao Phraya River in Samut Prakarn Province and extend north to Chachoengsao Province.



soft clay > 18 m.
Wn > 100 %
LL > 100 %
PI > 60 %
γ_t < 1.45 t/m^3
F

soft clay 14-18 m.
Wn 80-100 %
LL 80-100 %
PI 50-60 %
γ_t 1.45-1.55 t/m^3
E

soft clay 10-14 m.
Wn 60-80 %
LL 60-80 %
PI 30-50 %
γ_t 1.55-1.65 t/m^3
D

soft clay 0-3 m.
Wn 0-20 %
LL 0-20 %
PI 5-10 %
γ_t 1.85-2.15 t/m^3
A

soft clay 3-6 m.
Wn 20-40 %
LL 20-40 %
PI 10-20 %
γ_t 1.75-1.85 t/m^3
B

soft clay 6-10 m.
Wn 40-60 %
LL 40-60 %
PI 20-30 %
γ_t 1.65-1.75 t/m^3
C

Fig.15 Zoning of Soft Bangkok Clay

The soil properties of each zone can be evaluated for future application as the average values of natural water content, liquid limit, plasticity index, total unit weight, undrained shear strength and standard penetration value as shown on Figure 15.

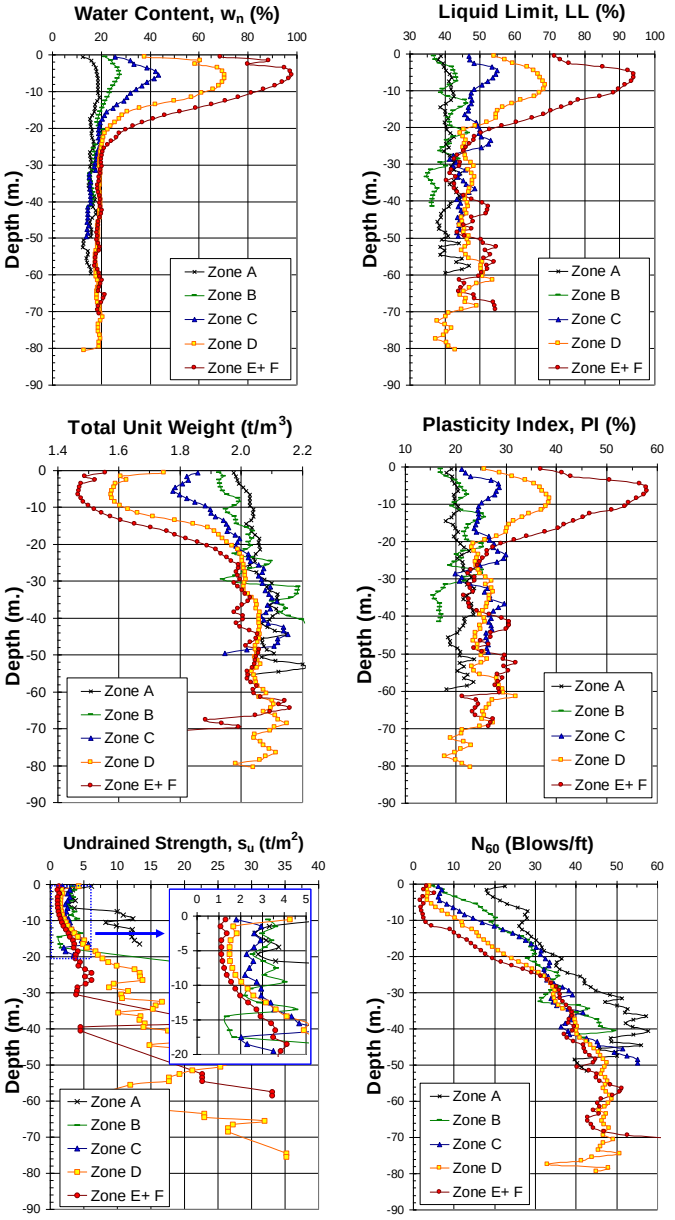


Fig.15 Soil Properties for Each Zoning

Statistical correlation between soil properties can be performed for cross checking of possible ranges or estimation of engineering properties from physical properties as the example shown on Figure 16 and 17. These data may relevant for the comparison with other soft clay properties on other region and for brief description of Soft Bangkok Clay.

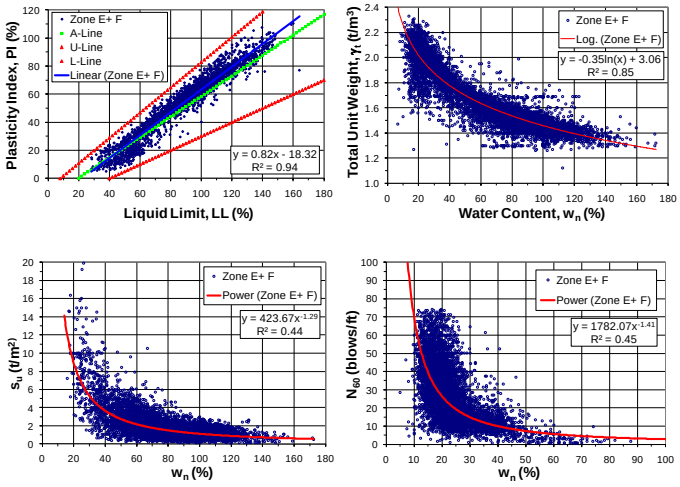


Fig.16 Relationships between soil properties

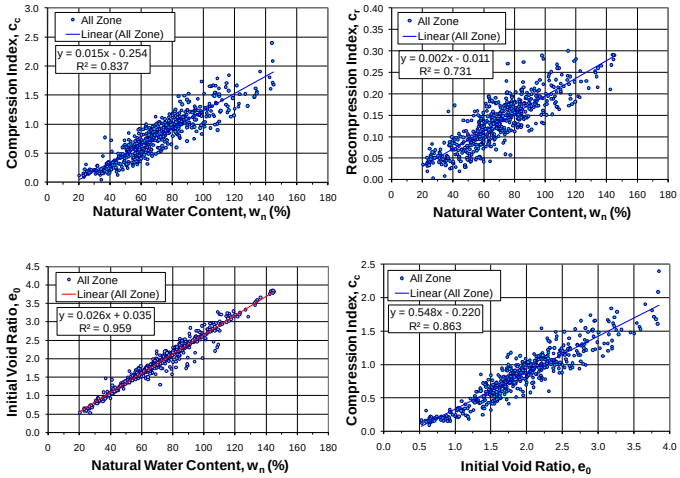


Fig.17 Relationships of Natural Water Contents with C_c,C_r, e_0 and e_0 with C_c

4 ENGINEERING APPLICATIONS AND INFORMATION SERVICES

The engineering applications from the ESDS-KU can be wide varieties depending on the researcher or engineer such as foundation engineering, geo-environmental engineering, earthquake engineering, engineering geology etc. Some examples of engineering applications are attempted as follows.

4.1 *Evaluation of pile tip elevation.*

One of the methods to find the pile tip elevation is to look for the N-values from STP. Figure 17 shows the elevation of several N-values on GIS maps that may suitable for medium capacity piles.

4.2 *Stability and settlement of highway embankment.*

Thousands kilometers of local road need to be designed every year in Bangkok Clay region. The planners and engineering can get the benefit from

ESDS-KU database by preliminary analyzing the stability and settlement for the typical highway embankment as shown on Figure 18. From this plot, engineer shall be able to spot the critical zones of unstable embankment slope and large settlement on the route planned.

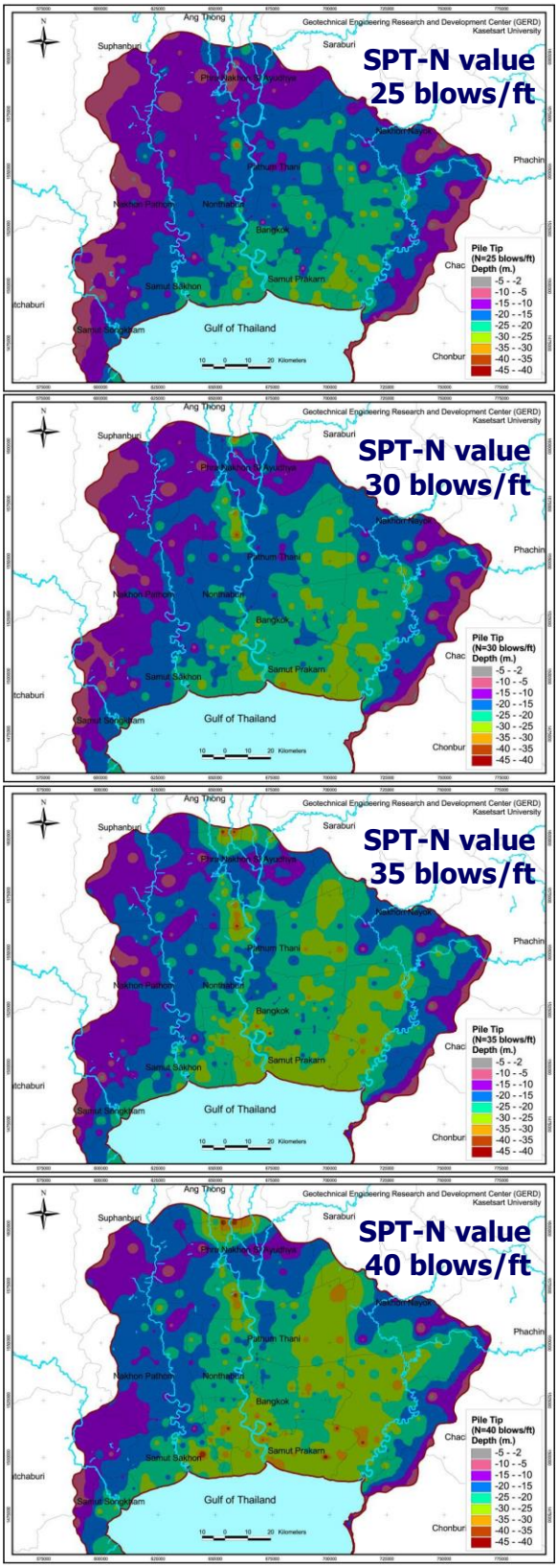


Fig.17 Contour maps of STP- N values for selection of pile tip elevations

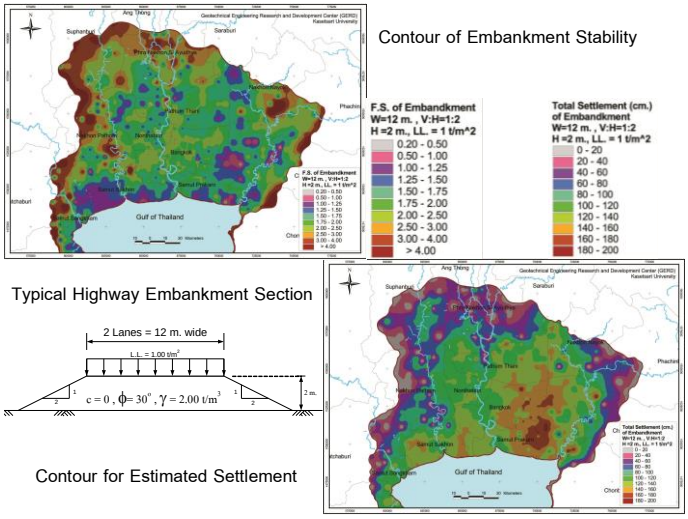


Fig.18 Contour of typical highway slope stability and settlement

4.3 *Soil information services*

Soil database (ESDS-KU) is aimed for cooperative data updated and service to public via internet. Then the users are classified into 3 security levels namely;

(1) Administrator – person who look after the system.

(2) High Level Users – researchers, cooperative organization personals.

(3) Ordinary Users – engineers, contractors, planners.

Those users have different right in using the database as shown on Figure 19.

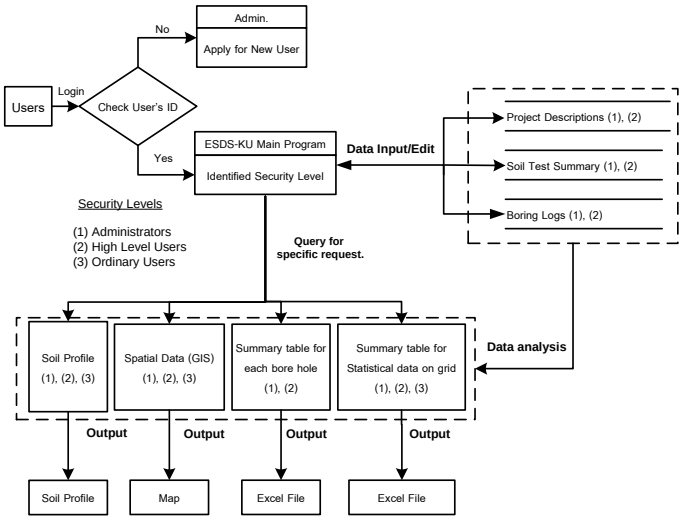


Fig.19 Schematic diagram for ESDS-KU service structure

In case of ordinary users, they can request for grid summary statistical data(5x5 sq.km.), a plot of average request data and the average soil profile on specified lines. They can not access to any individual bore hole data or test results and project data in the grid. Thus the information that ordinary users get

will serve as guide line for planning, preliminary design or further detailed investigation. The database do not intend for ordinary users to use the soil information for detailed design or to replace the necessary soil investigation they must do.

5 CONCLUSION

Bangkok Clay was formed by the deposit of alluvial clay from 4 major rivers on Lower Chao Phraya Flood Plain covering about 15,000 sq. km. During the Holocene period (4000 to 10000 years ago) the sea level was rising to 5 m. higher than the present and sea water emerged more than 100 km. in land. The sedimentation formed in the marine environment results of soft and sensitive clay layer. The thick soft clay from 10 to 20 m. creates a several geotechnical engineering such as low bearing capacity, unstable slope, large settlement etc.

Engineering soil database (ESDS-KU) was created to compile more than 4000 bore holes and laboratory tests data. It is aimed for cooperative data compiling from soil investigation subcontractors and government agencies. Data screening by the possible ranges of soil properties and statistical ranges were applied to improve the data quality. Grid of 5x5, 2.5x2.5 and 1.25x1.25 sq.km. are used to analyzed the data in GIS based program.

The soil profiles on the specific lines can be created both from each bore hole properties or grid averaged properties. The depths and thickness of soil layers can be generated over the study area. The statistical properties of the general and engineering properties can be calculated and mapped as contour. Also the correlation among the soil properties are given for screening and for properties estimation.

The relevant properties such as thickness of soft clay, natural water content, liquid limit, plasticity index and total unit weight are used to analyzed for zoning of soft clay area. The zoning divided area into 6 zones as A to F. Zone “F” represents the poorest soil properties of soft clay thicker than 18 m., water content more than 100%, high plasticity and total density less than 1.45 t./sq.m. This zone is consider to be the critical area where a number of geotechnical problems arised. This first attempt for zoning of engineering soil is expected to give some informations for awareness on geotechnical design and construction. More over, the geotechnical engineering applications from the soil database such as variation of pile length, settlement contour, stability map can be created by the researcher’s interests.

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