Ceylon Journal of Science: Physical Sciences, 4(1), 47-59 (1997)

RELATIONSHIP BETWEEN SUBSURFACE GEOLOGY AND GROUND SUBSIDENCE OF BANGKOK METROPOLIS, THAILAND

N.W.A.M.M.K.N. BANDARA*
Asian Institute of Technology, Bangkok, Thailand.

ABSTRACT

Bangkok city, the capital of Thailand which has many engineering and environmental problems due to ground subsidence was selected as the main study object in this research study. The study included data collection, bore hole logging and investigations on some important underground geotechnical parameters to prepare thickness maps, static water level maps, ground elevation and subsidence maps of Bangkok subsoil. Thickness of both fine grained compressible clay layers and that of coarse grained non compressible sand layers are highly varying from place to place and they are highly deformed. Area of eastern Bangkok is affected by the highest ground subsidence and this area is underlain by the thickest portion of both first and second compressible clay layers. The lowest static water levels of upper most aquifers is also overlain by this area. The uppermost two compressible clay layers contribute more percentage for ground subsidence.

1. INTRODUCTION

General Situation

The study area is located within the latitudes 13^0 29' 32" - 13^0 57' 45" and the longitudes 100^0 24'- $100^0$45' Bangkok Metropolis covers an area about 1569 square kilometers. The area is extremely flat and the relief is less than 0.5 m. The elevation is ranging from 0 to 1.5 m while the average elevation is less than 1.0 m above mean sea level (Fig. 1).

The ground subsidence is the most serious threat to the development of Bangkok and its suburbs. Ground water withdrawal from the deep well pumping is the main reason for this. However, the current rate of ground water pumping cannot be reduced by a considerable amount because of the high demand. In addition, the surcharge load of engineering structures, weight of over layers and vibration due to traffic and pile driving are significant. Differential settlement of the ground surface creates engineering, environmental and social problems. However, flooding is the most disastrous result of ground subsidence because of the lower ground elevations and smaller gradient of slopes. There are some places where the ground elevation has gone down beyond the mean sea level.

* Current Address: Department of Geology, University of Peradeniya, Peradeniya.

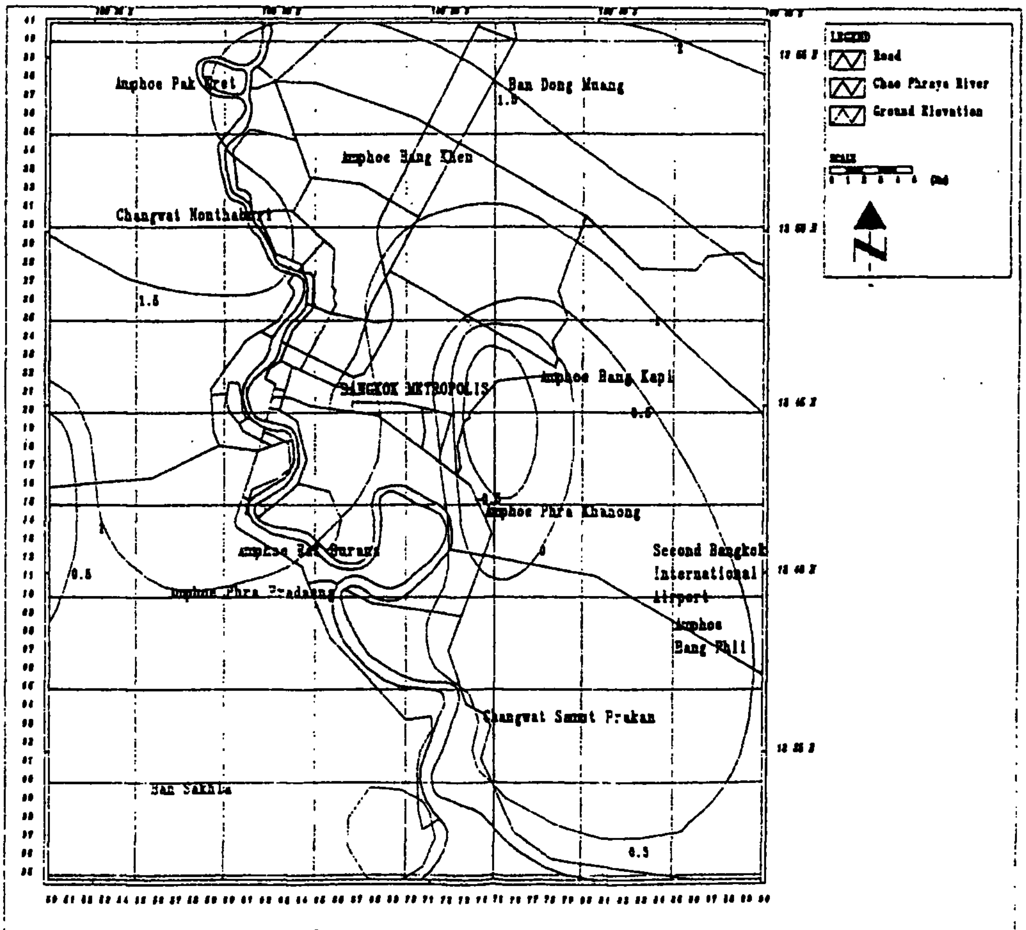

Fig. 1: Ground Elevation above Mean Sea Level

Bangkok and its suburbs are already developed but, the geology of greater Bangkok has been largely ignored in land use planning and development. In addition, a proper land use planning was not used in its development. Unplanned infrastructures and low land reclamation in vulnerable areas are some examples.

The magnitude and the rate of subsidence are directly related to the change in effective stress in the various compacting beds which is a result of piezometric level changes and the thickness and compressibility of soil.

OBJECTIVES

Determination of the relationship between subsurface stratigraphy, ground water withdrawal and ground subsidence.

2. GEOTECHNICAL CONSIDERATION OF GROUND SUBSIDENCE

Geology and Structure

The area is underlain by thick Quaternary and Tertiary deposits consisting of alluvial and deltaic sediments. Subsoil within the uppermost 200 m consists of two types of alternative layers, coarse grained sand with high permeability and low compressibility and fined grained clay with low permeability and high compressibility. According to Brown et al. (1951) and Sodsri (1978), three types of sediments underlain by the Bangkok plain.

I. Unconsolidated silt, sand, clay and gravel in the flood plain, stream channel or terrace.
II. Beach and esturine clay, sand and gravel
III. Residual layers of laterite or creator capping stabilised surfaces.

According to Nutalaya and Rau (1981), Quaternary and Tertiary sediments of the Bangkok delta represent a complex sequence with a thickness of more than 2,000 m but, only the uppermost 200m is explored. In the lower central plain, sedimentation was controlled during the Tertiary and Quaternary times by a combination of tectonic movements both within the plain and in the adjacent mountains. Further, they pointed out that the Bangkok basin had been continuously filled with alternative layers of sand and clay throughout the Quaternary time.

These sediments are underlain by a highly fractured and faulted basement rock consisting of quartzite, gneisses and granitic gneisses. A series of active faults and structural blocks occupied the basement.

Ground Water Consumption

Ground water is extracted from all the sand layers within the uppermost 200 m of Bangkok subsoil. There are number of ground water monitoring stations installed to monitor the ground water level after identifying the critical zones and areas of heavy ground water development in the Bangkok area. It is estimated that, about 1.2 - 1.4 million cubic meters per day of well water is pumped from ground water aquifers in the Bangkok Metropolitan region. Due to the unplanned ground water consumption, a number of environmental problems have arisen such as salt water encroachment, ground subsidence, ground water depletion etc.,.

Flooding

Flooding is one of serious hazards in Bangkok metropolis. The flood season in Bangkok generally begins in September but rainstorms can cause immediate flooding at almost any time between May and October. However, the most severe floods occur in October when river draining from northern Thailand brings water to Bangkok. In the spring tidal period, flooding is more severe as the high water level in the sea retards the river flow, resulting the water level to rise in the flood plains. In addition, hundreds of canals which receive runoff from the large sub urban area also flow in to the river. These canals have with negligible gradients or are concave in some locations. Tidal action sends water back into the canals during high tide periods. Water gates are designed to prevent flood water but when the city is flooded and the river is at its highest state, this measure is not sufficient to prevent flood. Since the gradient is extremely flat, the river flowing across the city called Chao Phraya can not keep the water within its own when a certain gauging height is reached. However, the Chao Phraya river can discharge 1,500 m^3/sec through the city without flooding low lying areas.

Ground Subsidence in Bangkok

As mentioned elsewhere the ground subsidence is a serious problem in Bangkok area. Sodarathit (1989) found that the average ground subsidence in the eastern part of Bangkok metropolitan region was 5 - 10 cm per year and some parts of the area is below the mean sea level. However, it is difficult to determine how much of the annual flood damage is due to the ground subsidence.

Brand and Balasubramaniuum (1976) showed that the consolidation of the soft clay contributes the major part of the subsidence. According to Nutalaya et al. (1989), the ground subsidence of Bangkok area affects more than 4,500 km^2 area.

Effect of Ground Subsidence in Bangkok

According to Nutaliya et al., (1989) differential settlement occurs when structures located at different foundation depth cause cracking and bending of structures, floor slabs, concrete walkways and steps, detachment of septic tanks and sidewalks or steps from buildings. Sinking of benchmarks is another serious problem and hence, the benchmarks of Bangkok area can not be used as reference datum. In addition, as a result of lowering of the piezometric level, saline water replaces fresh water in the aquifers located next to the sea and therefore, the amount of saline water content increases in the ground water. The deterioration of ground water quality is also caused by the penetration of mineralized water from the higher pore pressure area in the clay layers in to the sand layers.

When ground subsidence continues, the gradient of ground surface decreases and therefore, drainage of flood water by gravity flow will be reduced and at the same time, water accumulates in the centre area of subsidence bowl. As a sequence, septic tanks in the flooded area will become water logged and the foul mass of night soils tearing with virulent bacteria and water borne diseases will become a potential health hazard. Therefore, ground water of Bangkok is now highly polluted and not suitable for consumption at all.

3. MECHANICS OF SOIL CONSOLIDATION AND GROUND SUBSIDENCE

The annual rate of subsidence varies greatly in direct response to seasonal pumping. Subsidence at a given location will continue as long as declining water levels continue to cause increased effective stress.

Das (1994), summarized the theoretical expressions related to ground settlement in three ways that is deformation of soil particles, relocation of soil particles and expulsion of water or air from void spaces. In general, the soil settlement caused by load is divided into three categories, i.e. immediate settlement, primary consolidation settlement and secondary Consolidation Settlement. However, primary consolidation settlement of soil is the most relevant type since it is the result of a volume change in saturated cohesive soils due to expulsion of water occupied by the void spaces.

Empirical expression for one dimensional primary consolidation of saturated cohesive soils is as follows,

For normally consolidated soil

$$S = \frac{T}{1+e_0}\left[C_c \log\left(\frac{p_0 + \Delta p}{p_0}\right)\right] \quad (1)$$

Where,

- S = primary consolidation settlement
- C_c = compression index (slope of the *e-log p* plot)
- T = thickness of the Layer
- e_0 = initial void ratio at the initial volume
- p_0 = initial average overburden pressure
- Δp = increase of vertical pressure
- P_c = maximum past pressure

Terzarghi and Peck (1967) described the mechanics of subsidence due to deep well pumping. According to their interpretations subsidence or settlement can result from consolidation of soil deposits due to deep well pumping because of the lowering of ground water level or piezometric pressure. As a result, a descending water flow occurs from compressible clay layers to aquifers. Force generated by this flow will compress the clay and other compressible deposits.

They further introduced a relationship between water level changes and effective stress($\Delta\sigma$) i.e.,

$$\Delta\sigma = \gamma_w(H-h) \quad (2)$$

where,

H = current water table

h = original water table

γ_w = unit weight of water

According to Terzaghi and Peck (1967), if the clay strata are soft and thick, and if the water level is lowered over a considerable distance, the settlement is likely to be occurred over a large area. Further, the general pattern of subsidence can be expected to be characteristics bowl shape, with the greatest subsidence at the centre of the well field.

Declining of piezometric pressure in a water bearing deposit imposes an increase in effective stress in all the soil strata above it and in itself. Increased effective stress causes consolidation and hence ground settlement.

Ground subsidence generally corresponds to the piezometric pressure fall. According to Dowson (1963), in many areas, subsidence is directly proportional to the elevation of the ground water level that is directly related to the quantity of water removed.

4. METHODOLOGY

The ground water well log data and records of ground water monitoring stations in Bangkok were used to identify the subsurface geological charateristics. The thickness of sand and clay layers were individually calculated for each station and transferred them as separate layers based on their depths.

The static water level variation from point to point were estimated by studying the static water level from many stations in the vicinity of Bangkok metropolis.

5. RESULTS AND DISCUSSIONS

Projected Ground Elevation in the Year 2005

From Fig. 2, more than 50% of the study area which is below the latitude $13^0 45'$ N will be submerged by the sea if the current rate of subsidence is allowed to continue. The most important zone of the city is situated within this limit.

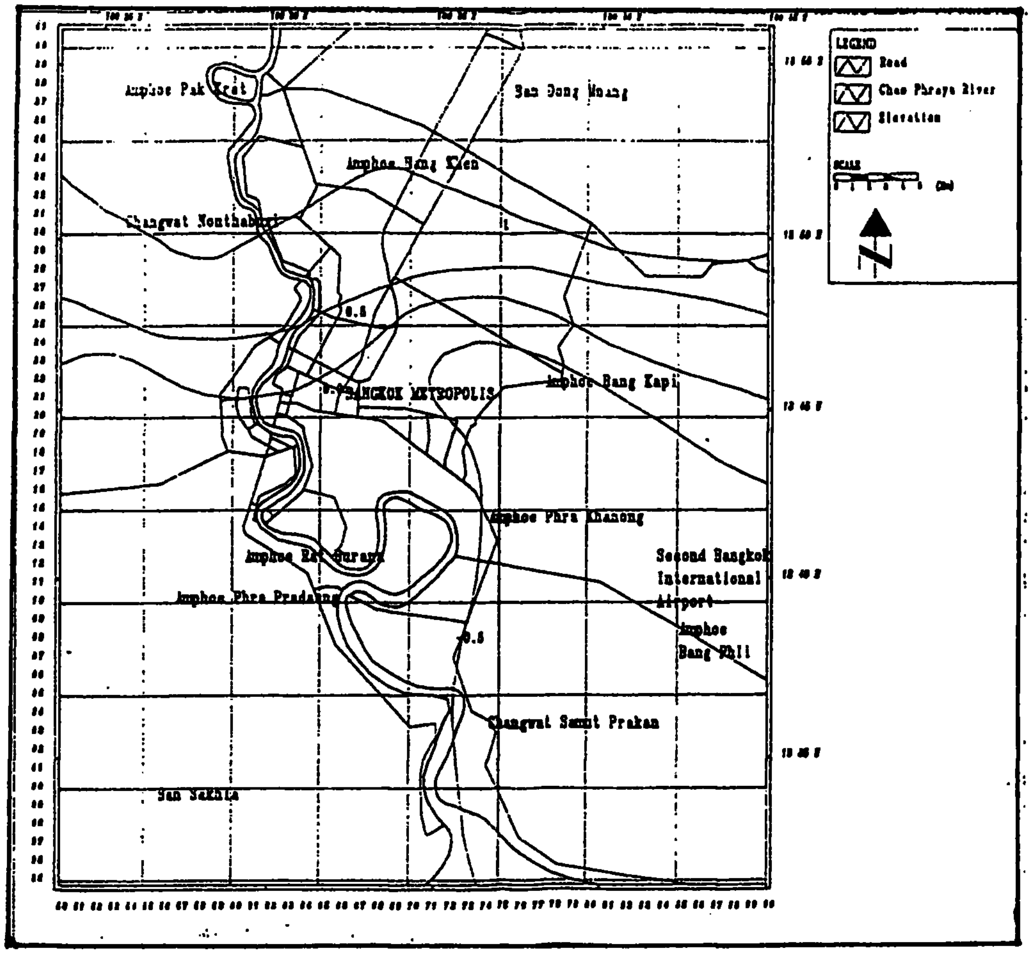

Fig. 2: Projected Ground Elevation AMSL (m) in the Year 2005

Stratigraphy of the Study Area

The *Chao Phraya* basin comprises alternative layers of sand and clay. However, during this study, these alternative layers were examined only up to 200 m depth from the ground surface because of two reasons. First one is the depth of bore holes since most of them penetrated up to the depth around 200 m while the other one is geotechnical importance of uppermost subsoil within this range.

Five sand layers and another five clay layers could be identified within this limit and the variation of subsoil characteristics of these strata and their depth range is shown in Table 1 and a N-S cross section over the study area is shown in Fig. 3.

From the Fig. 4, the rate of ground subsidence is varying from place to place. According to the maps produced in this study, the highest ground subsidence rate takes place in the area south to the Bangkok Metropolis where the first compressible clay layer has its thickest section (Fig.5). This layer has the highest compressibility when compared to the other lower lying compressible layers. In addition, as mentioned above, the static water levels of top most two aquifers (*Pra Phradaeng* and *Nonthaburi*) are at their lowest level beneath the same area (Fig. 6 and 7).

Furthermore, the rate of subsidence varies from place to place making depressions. In addition to that, the rate increases towards the centre of each depression. Six major depressions can be seen over the study area.

With the increasing of ground water withdrawal from sand layers, water contained in compressible layers drains off from both top and bottom in to the overlaying and underlying sand layers resulting a heavior. This is because of the hydraulic gradient developed due to the ground water withdrawal.

Table 1: Description and the Depth Ranges of Soil Strata within the Upper-Most 200 m of Bangkok Sub Soil

Name of the Strata	Soil Description	Depth Range (m)		Thickness (m)	
		Top of Layer	Bottom of Layer	Range	Average
Bangkok Soft Clay	Gray colored soft clay with shell fragments	0	11-19	11-19	15
First Clay Layer	Stiff to medium clay with shell fragments	11-19	13-65	1-45	13
First Sand Layer	Fine to coarse sand in association with clay patches,shell fragments	13-65	25-75	5-45	12
Second Clay Layer	Clay with shell fragments	25-75	35-82	5-20	14
Second Sand Layer	Fine to coarse sand with clay layers	35-82	44-90	5-30	16
Third Clay Layer	Silty clay with shell fragments	44-90	60-102	5-40	17
Third Sand Layer	Sand, fine to coarse with clay layers and gravel	60-102	85-123	6-40	25
Fourth Clay Layer	Hard clay with inter beds of sand, shell fragments	85-123	98-157	5-25	19
Fourth Sand Layer	Silt sand with shell fragments	98-157	118-185	5-36	15
Fifth Clay Layer	Clay, sandy with shell fragments	118-185	124-210	5-68	14
Fifth Sand Layer	Fine to coarse sand with thin clay layers	124-210	-	-	-

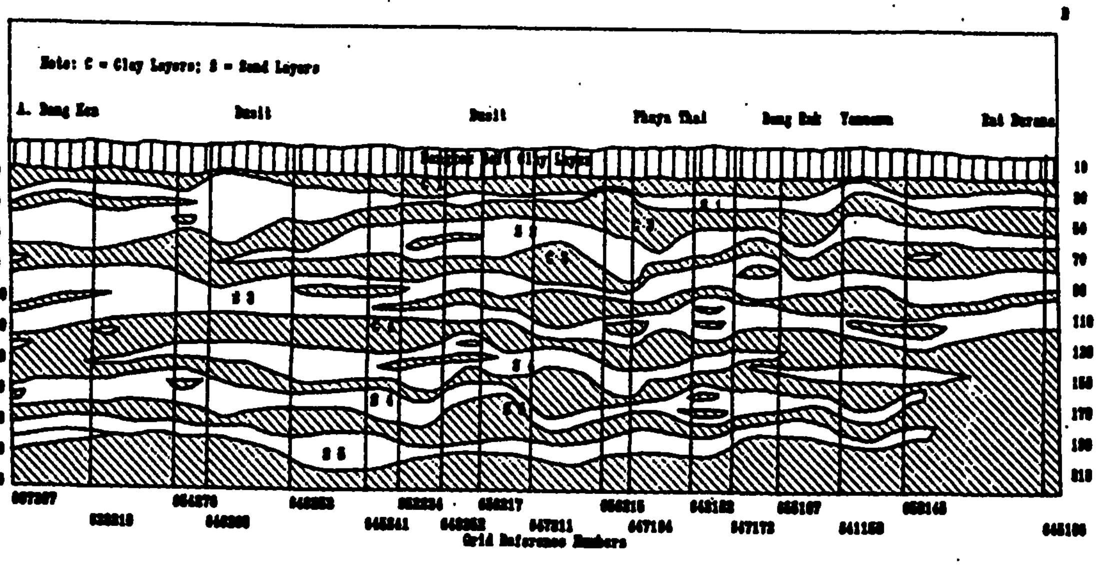

Fig.3: North-South Vertical Cross Section of Bangkok Metropolis

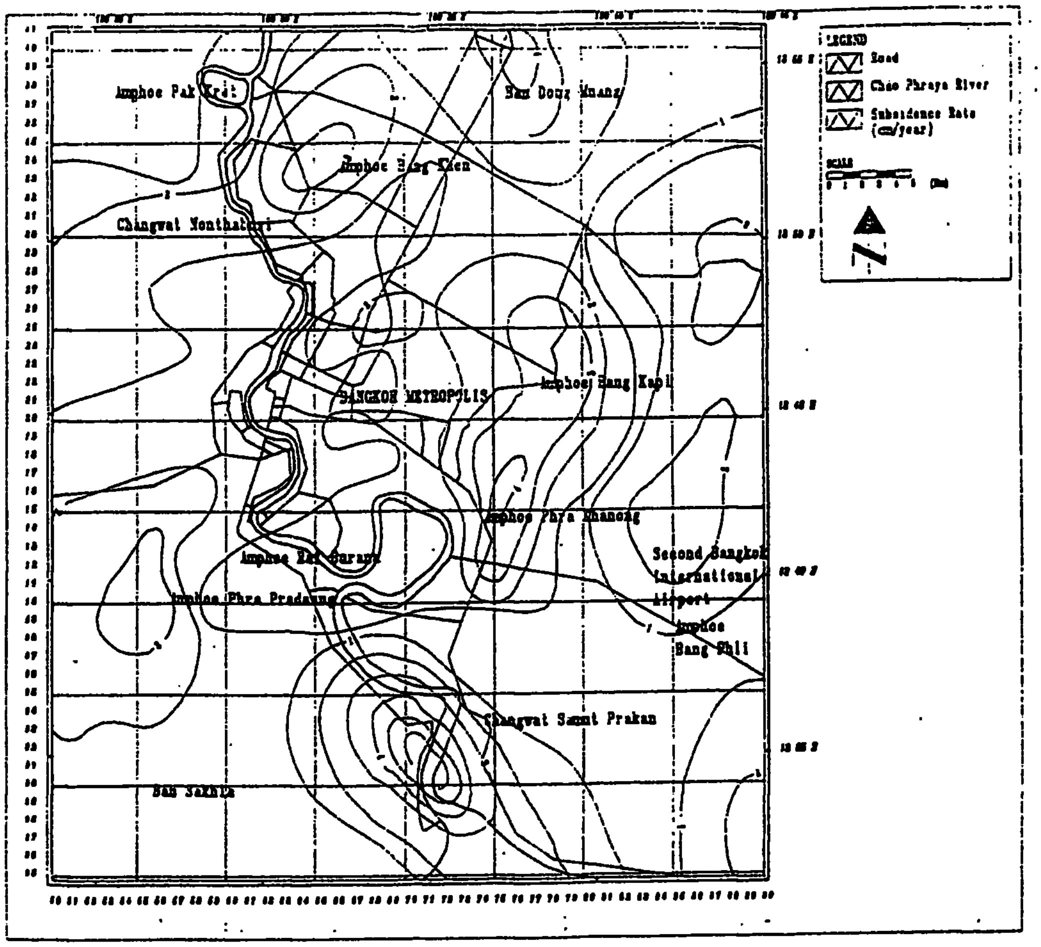

Fig.4: Rate of Ground Subsidence in the Year 1996 (cm/year)

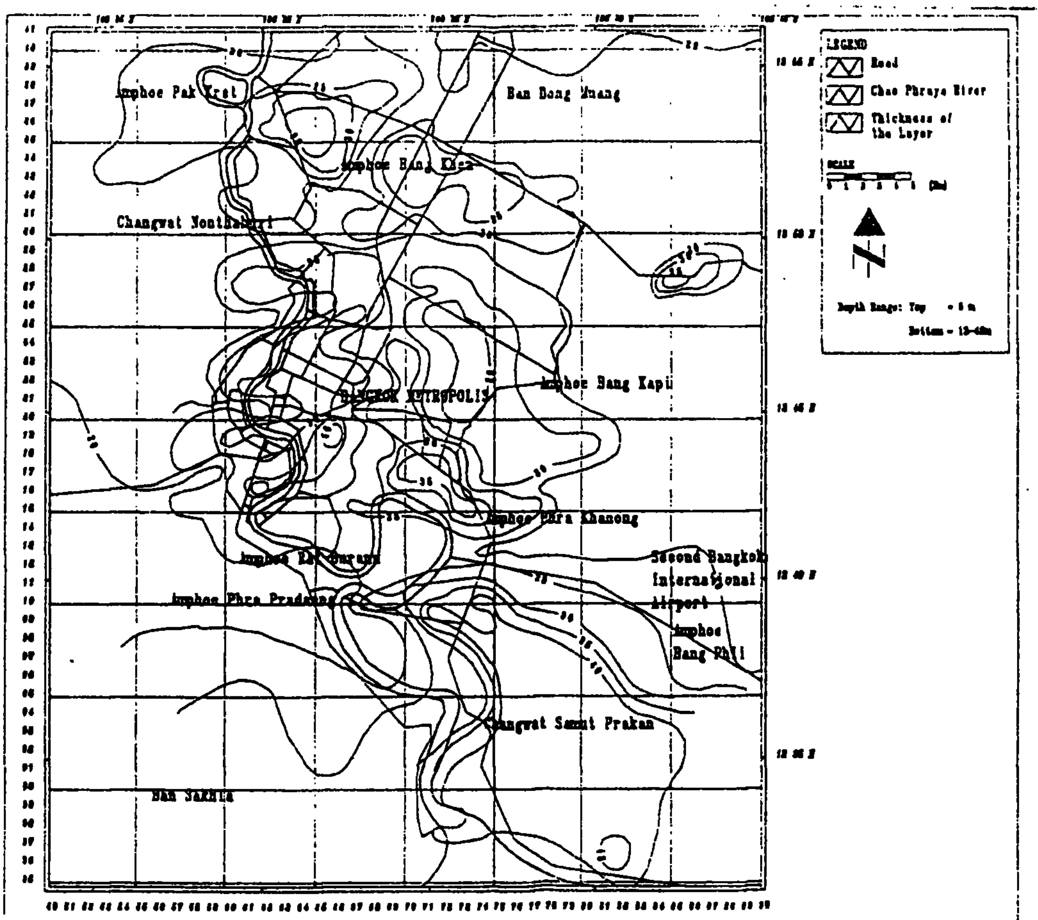

Fig.5: Thickness of the Uppermost Clay Layer (m)

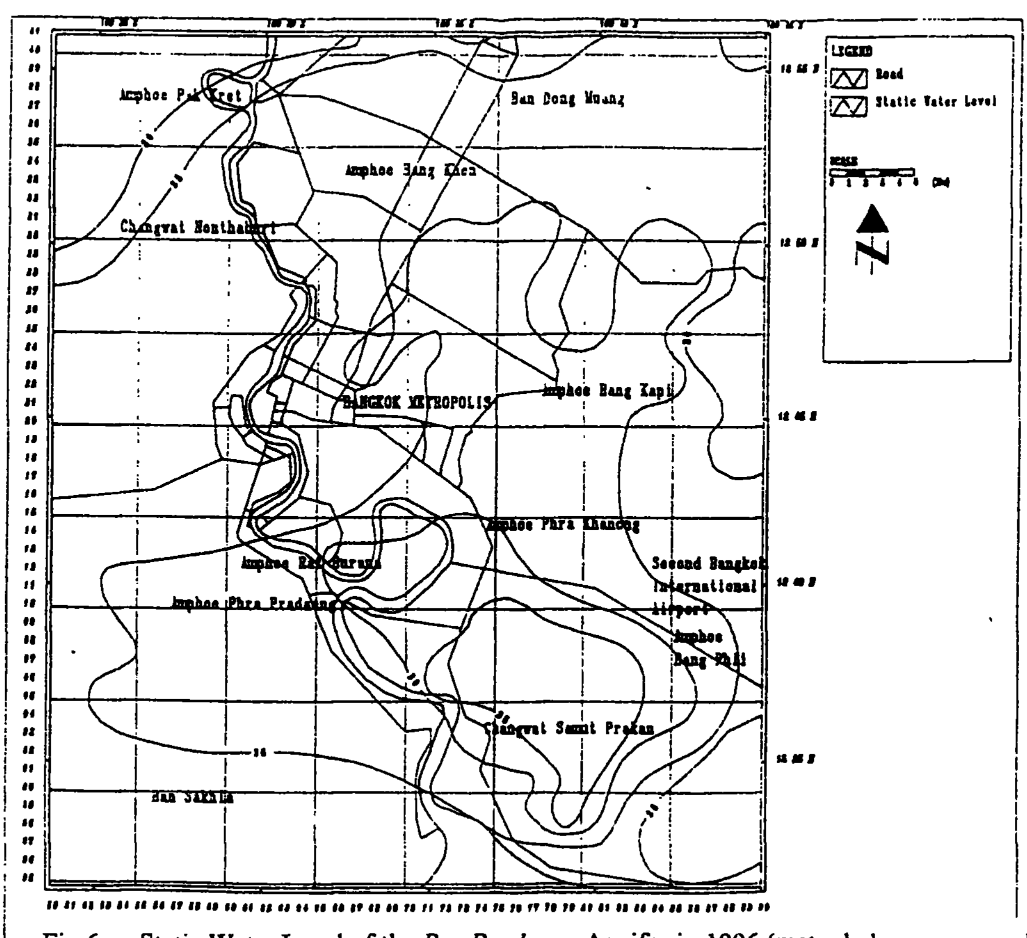

Fig.6: Static Water Level of the *Pra Pradeang* Aquifer in 1996 (meter below mean sea level)

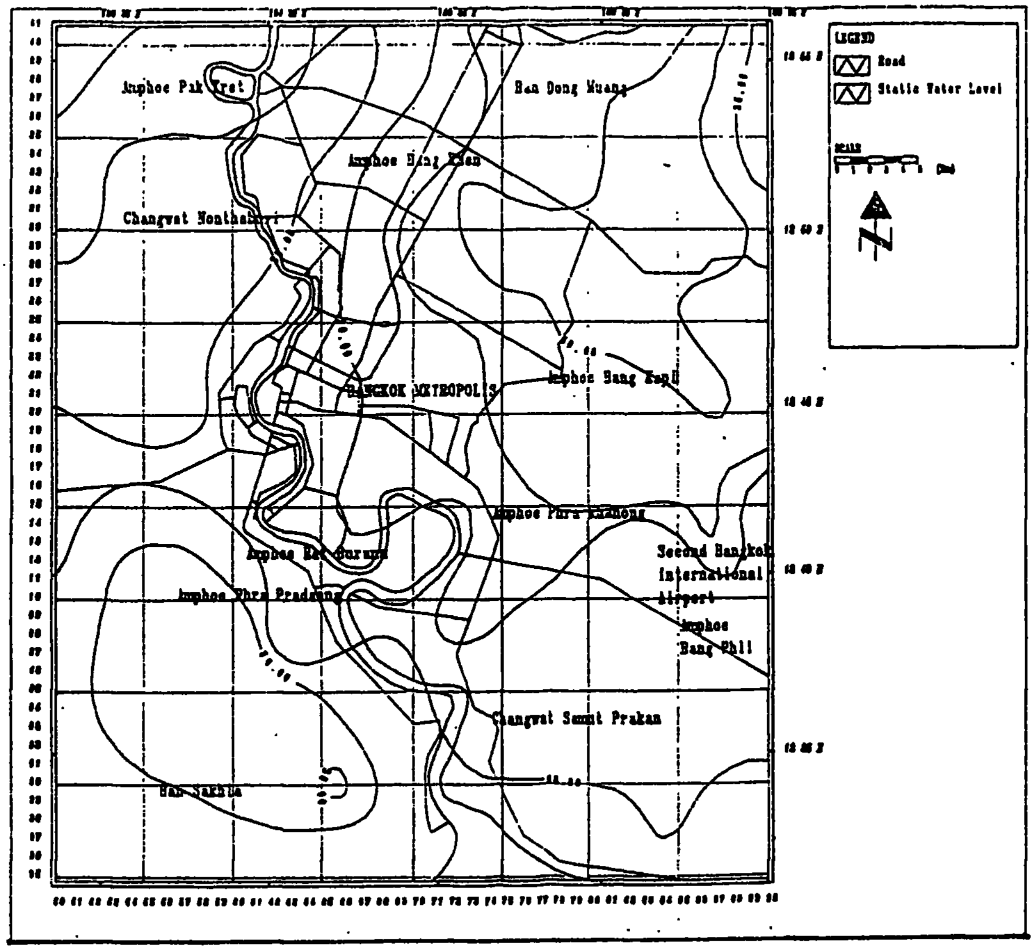

Fig.7: Static Water Level of the *Nontha Buri* Aquifer in 1996 (meter below mean sea level)

6. CONCLUSIONS

1. Six compressible and five non-compressible layers were identified in the strata within uppermost 200m depth (table 1). Basically, Bangkok metropolis consist of five sand layers. The five sand layers are found at an approximate distance of 30m, 60m, 90m, 135m and 170m depth from the surface. Although these values will give some idea of the sand layer locations, there can be high variations to the above figures depending on the locality due to the presence of synclines, anticlines, connections of layers etc. In some instances, sand lenses are found at various depth levels in the Bangkok area. The first sand layer which is situated at a level of 20-40m takes almost a planner and horizontal profile throughout the study area.

   The Bangkok soft clay layer with an approximate thickness of 10-20m is the top most layer. Other five layers are interbeded with sand layers.

2. The present highest subsidence rate takes place in the area of eastern Bangkok where both the two top most compressible clay layers have their thickest sections.

3. The static water levels of all the top most aquifers are at their lowest, where the rate of subsidence is highest.

4. Ground subsidence makes depressions throughout the area.

ACKNOWLEDGEMENTS

The author first expresses his profound gratitude and sincere appreciation to his advisor Professor Prinya Nutalaya, for his persistent guidance, invaluable suggestions, generous help and friendly discussions, all of which enabled the author to accomplish this study.

Author also wishes to extend his sincere appreciation to Professor A.S.Balasubramanium and Dr. Noppadol Phein Wej for their valuable guidance, suggestions.

A very special word of thanks goes to Dr. Vachi Ramnarong, Director of the Mitigation of Ground Water Crisis and Land Subsidence in Bangkok Project (MGL), Department of Mineral Resources, Thailand for providing valuable data related to this study work.

REFERENCES

1. Research Report, Division of Geotechnical and Transportation Engineering, AIT, Bangkok, Thailand, Vol. 2 (1978b).
2. Research Report no 82, Division of Geotechnical and Transportation Engineering and Division of Water Resources Engineering, AIT, Bangkok, Thailand (1978 c).
3. Research Report No.91, Vol. 2, AIT, Bangkok, Thailand (1981).
4. A Report submitted to the Japan International Co-operation Agency by School of Civil Engineering, AIT, Bangkok, Thailand (1993).
5. Brand, E. W. and Balasubramanium, A. S., *Proceedings of the Second International Symposium on Land Subsidence,* Anaheim, California, pp. 365 - 374 (1976).

6. Das, B. M., *Principles of Geotechnical Engineering*, Third Edition, Ch. 8, pp. 253- 315 (1994).
7. Dawson, R.F., *J. Surveying and Mapping Division*, ASCE, V.89, No.SU2, pp 1-12 (1963).
8. Department of Mineral Resources and Ministry of Industry (DMR), 1992, Ministry of Industry, *Records of Groundwater Monitoring Wells in Bangkok and Adjacent Provinces,* Report No. 1, Bangkok, Thailand (1992).
9. Heley and Aldrich, *Report of Haley and Aldrich, Inc.* (1969)
10. Metcalf and Eddy Inc., *Report on Ground Water Monitoring, Well construction and future programs,* The Metropolitan Water Work Authority, Bangkok, Thailand (1972).
11. Nutalaya, P. and Rau, J.L., *Episodes,* Vol. 4, pp. 3-8 (1981).
12. Nutalaya, P., Yong, R.N., Chumnankit, T. and Buapeng, S., *The Report Presented at the Workshop on Bangkok Land Subsidence,* 22-23 June (1989).
13. Rau, J. L., *The Geology of Bangkok Metropolis and Adjacent Areas,* AIT, Bangkok, Thailand (1981).
14. Terzaghi, K., and Peck, R. B., *Soil Mechanics in Engineering Practices,* Wiley, New York (1967).
15. Worayingyong, K., Preliminary Predictions of Subsidence in the Bangkok Area, *M.Eng. Thesis*, AIT,Bangkok,Thailand (1975).
16. Nutalaya, P., *Proc. of the Conference on the Geology of Thailand*, Department of Geological Sciences, Chiangmai University, Thailand (1973).