"SUBSIDENCE OF BANGKOK CLAY DUE TO DEEP WELL PUMPING AND ITS CONTROL THROUGH ARTIFICIAL RECHARGE"

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Abstract

Bangkok is located on a flat deltaic-marine plain 0.5 to 1.5 m above mean sea level. In the past two decades increased pumping of groundwater within the metropolitan area has led to the reduction of pore pressures, compression of soils and surficial deposits, drastic lowering of piezometric levels and ground settlements of more than 0.5 m with a maximum annual rate of 10 cm in some parts of the city. In this paper, the possibility of restoring the piezometric heads in a multiacquifer system through artificial recharge is explored.

Introduction

Bangkok, the capital of Thailand is situated on the Chao Phraya river 28 Km North of the Gulf of Thailand. The present population of the city is 5 million and it was once known as "The Venice of the East". Bangkok is laced by dozens of large canals (Klongs) which drain to the Chao Phraya River. The water table is at or near the surface throughout the city. Consequently, heavy monsoon rains quickly flood the major parts of the urban area during rainy season.

The City is presently sinking at an average rate of 5-10 cm per year and in 23 years has subsided a maximum of 120 cm in some areas. The problem has become so severe now as parts of the city are already below sea level. Land subsidence has created a bowl-shaped depression in the south-eastern metropolitan area and flood water resides there for much longer periods and drainage has become less efficient due to the reduced gradients in canals and storm drains.

More than 30% of the water consumption in the metropolitan area is extracted from acquifers beneath the city. In 1982, ground water use exceeded 1.35 million m^3 per day from more than 11000 wells. In the main acquifers, pumping has resulted in a lowering of the piezometric level from its original position near the surface to more than 50 m below the ground. Wide spread land subsidence is taking place throughout the metropolitan area east of the Chao Phraya River because of this excessive groundwater exploitation.

The first studies of land subsidence in Bangkok were undertaken in late 1960s and 70s (Cox, 1968; Paveenchana, 1970; Brand and Paveenchana, 1971; Brand and Arbhabhirama, 1973; Brand, 1974; Brand and Balasubramaniam, 1976). An extensive study involving field instrumentation at 31 stations has been carried out by the Division of Geotechnical & Transportation Engineering of the Asian Institute of Technology (AIT, 1981 & 1982, Nutalaya and Premchitt, 1981). The objectives of the study were to determine the extent and rate of settling, the effect of pumping on the magnitude and rate of sinking and preventive measures against subsidence.

Geomorphology and Geology

Bangkok occupies an area of about 1540 Km^2 near the southern margin of a low-lying, flat, marine plain termed the lower Central Plain (Fig. 1). The Upper

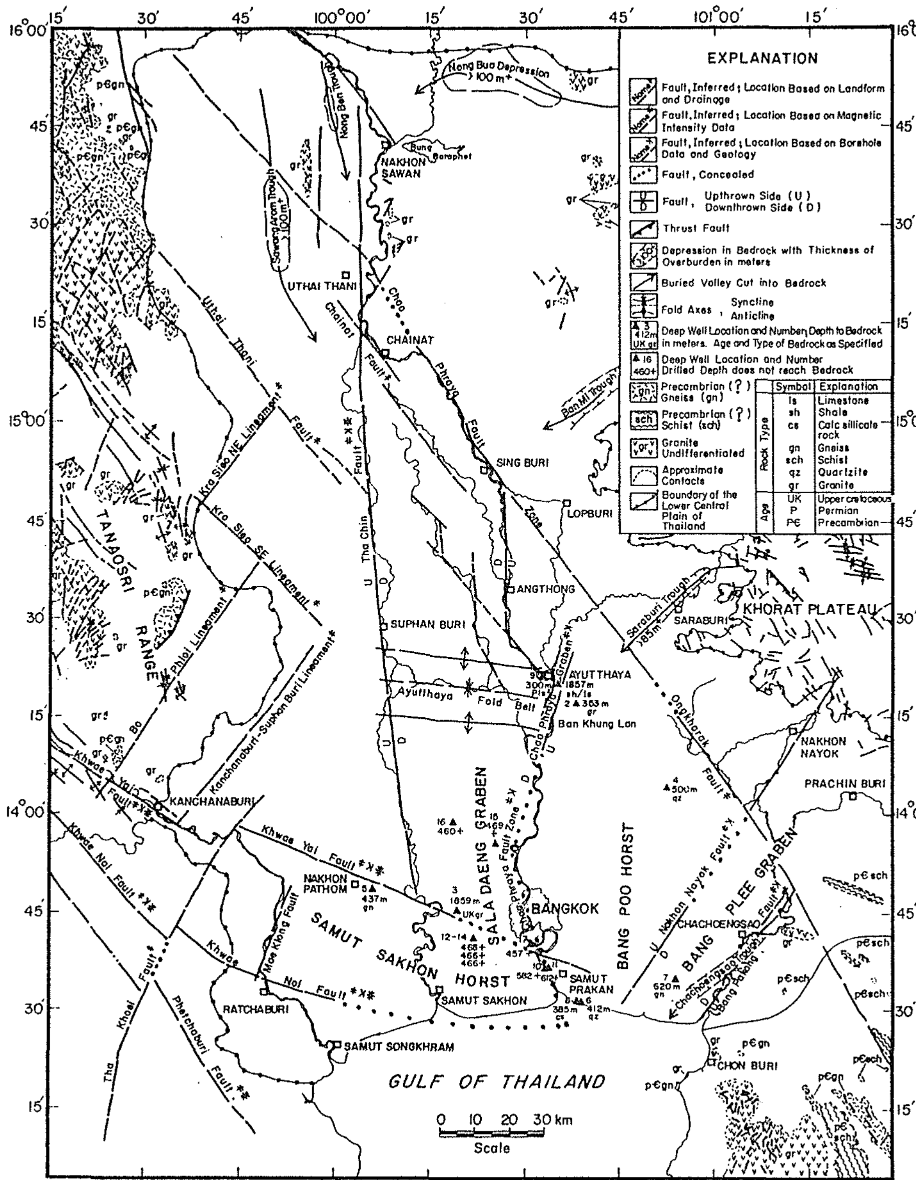


Fig. 1 Structural Framework of the Lower Central Plain of Thailand.

Central Plain begins where four rivers, the Ping, Wang, Yom and Nan, rising in northern Thailand combine to form the Chao Phraya River at Nakhon Sawan 240 Km north of Bangkok. The modern Chao Phraya has developed a meander belt about 10 Km wide down the centre of the Lower Central Plain. Its leeves are low and poorly defined and are not high enough to prevent widespread flooding of areas north of Bangkok, despite attempts made to control the monsoon flows.

The Central Plain and the Gulf of Thailand are located within a north-south trending structural depression which was generated by fault block tectonics during the Tertiary time. To the west the depression is bounded by the north-south trending Paleozoic fold belts of the Thai-Malay Peninsula. The eastern boundary of the basin is rimmed by the Khorat Plateau. Khrok Phra Arch at Nakhon Sawan borders the north, and in the south the depression extends southward into the South China Sea. Aeromagnetic data indicated that the Lower Central Plain is floored by basement arches and plutons in association with a diverse assemblage of faults or flexure zones (ACHALABHUTI, 1974). The exact configuration of the basin floor is unknown. A few wells which were drilled down to bedrock revealed several basement rock types at various depths from 1800 m to 350 m in the central part of the plain.

Aeromagnetic and seismic data covering the Gulf area also indicate an irregular basement floored by granite ridges and metasedimentary fold belts of the peninsular trend (KELLEY & RIEB, 1971). On land the aeromagnetic data indicate about 3,300 m of sediments on the coast south of Bangkok. A metamorphic ridge across the narrow part of the Gulf appears to close off partially or completely this basin from the main basin located in the south (CCOP-IOC, 1974).

Subsoil Characteristics

Subsoil profiles for engineering purposes have previously been established by various bodies for specific subsurface design and construction activities in Bangkok. The first attempt to delineate the subsurface strata in Bangkok in a systematic manner seems to have been made by MUKTABHANT et al (1966), in which three profiles within Bangkok city have been established. Expansion of construction activities in Bangkok during 1970-1980 brought further soil investigation over many areas which contributed to better understanding of subsurface conditions in Bangkok. The major projects that have conducted detail soil investigation over long sections (more than 5 km) are such as Bangkok Thonbury Ring Road, Water Transmission Tunnel System and Expressways. These recent results were summarized by POOPATH et al (1978) and typical profiles have been drawn over the Bangkok area. These profiles were restricted to the upper 30 m zone since most of boreholes were drilled upto 30 m only.

As a part of the investigation, two generalized soil profiles cutting through Bangkok area and extending over a great distance were established (Piyasena, 1982). The sections used to establish the profile are shown in Fig. 2. The north-south profile extends from the AIT campus to Pom Phrachul, a distant of about 60 km. The east-west profile covers a distance of about 45 km. from Nong Ngoo Hao in the east to Nong Khaem in the west. These two sections cut across the Bangkok area and cover the vital areas of interest in this investigation.

It can be seen that the soft Bangkok clay has an average thickness of about 14 m beneath the central Bangkok. The thickness increases towards the sea and decreases rapidly with distance to the north of Bangkok. Beneath the soft clay is a stratum of stiff clay which is generally about 5 m thick in central Bangkok, while the thickness decreases gradually with distance to the north and west of central Bangkok.

In the research study carried out at A.I.T. (A.I.T. Research Report No. 91) it was found that among many sand layers, the hydraulic and mechanical pro-

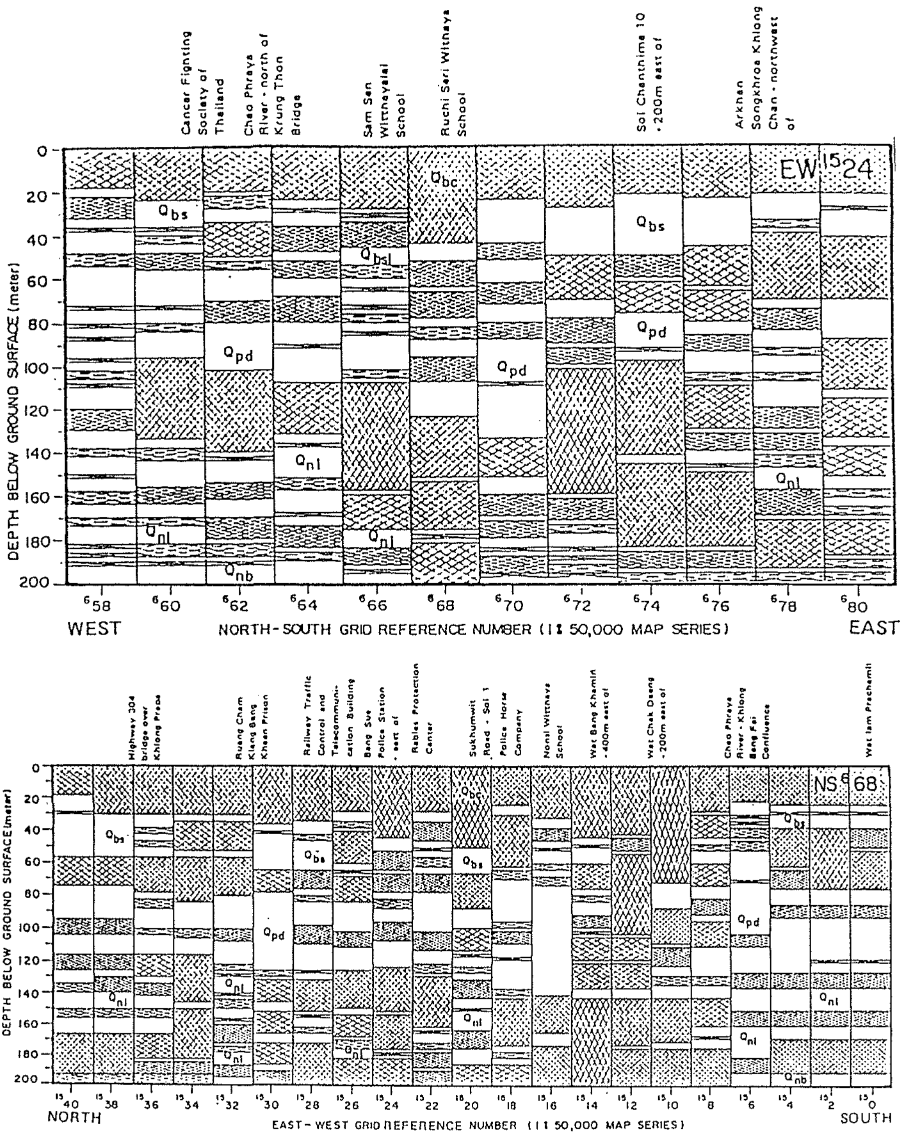


Fig. 2 Profiles of Subsurface Stratification

perties are approximately similar and the same is also true for the properties of different clay layers. To evaluate the hydraulic and compression characteristics of the whole subsurface body, it is not necessary to determine the exact depths and thicknesses of these strata, only the relative abundance of each type within a specified dpeth interval has to be known. The relative abundance of sand layers in 50 m intervals to 200 m depth have been established over the entire basin in this investigation.

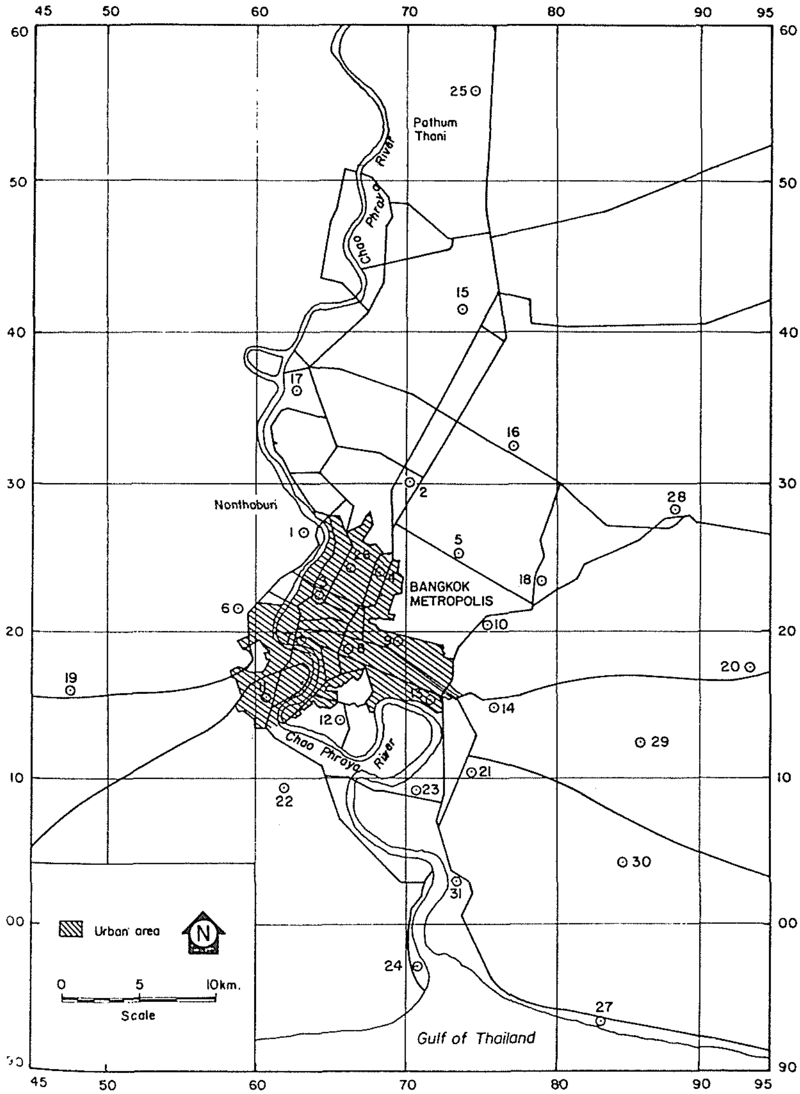


Fig. 3 Location of Subsidence Observation Station

Field Measurement

The observation of subsidence in Bangkok was carried out by installing field instruments at 31 locations as shown in Fig. 3. The monitoring of (i) piezometric levels at various depths and (ii) compression of various soil layers was started as soon as the instruments had been installed. Installation for the upper 50 m range at the first 24 station was completed in 1978 and the addition of deep instruments (upto 400 m) at seven stations was finished in 1982. For the measurements by deep compression indicators it

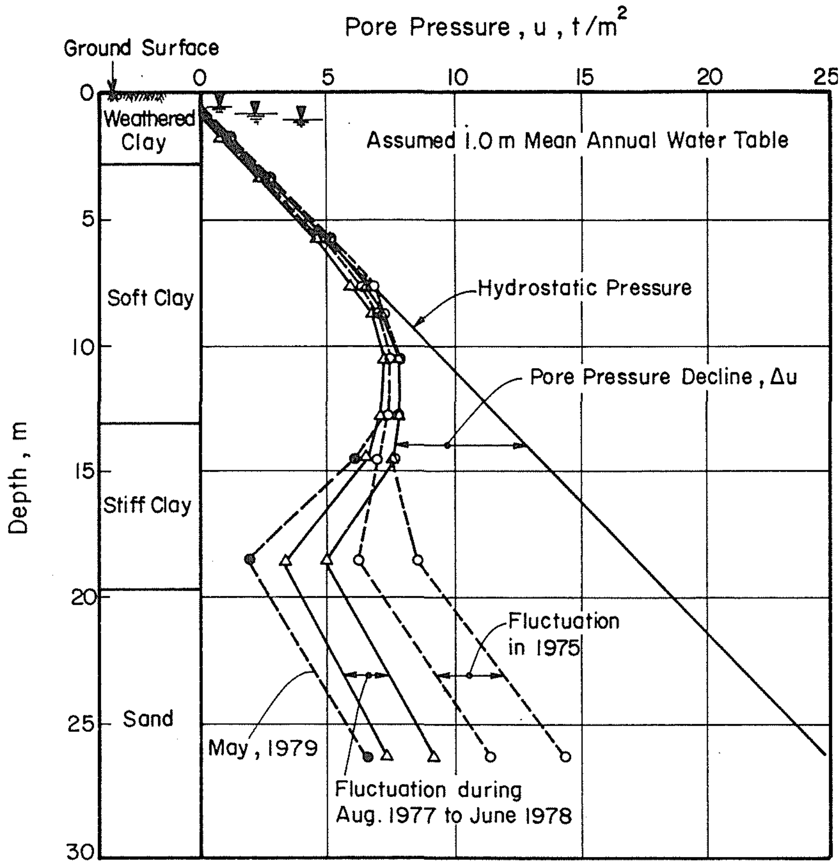


Fig. 4 Typical Variation of Pore Pressure in the Upper Clay Layer in Bangkok (Station No. 8).

was found that the results are almost equal to the surface subsidence obtained by the levelling survey conducted by the RTSD and the measurements can be regarded as absolute subsidence measurements. From the data gathered over the four-year period, the contribution of sub-soil compression to the total surface subsidence can be summarized as follows:

(i) Top 50 m depth range (top clay layer) - 40%, and

(ii) Zone deeper than 50 m - 60%

Figure 4 shows the variation of pore water pressure with depth at different time periods as observed from field piezometers at station 8, Chulalongkorn University. At this particular station the observatio has been conducted by AIT researchers since 1975 (NANEGRUNGSUNK, 1976; THAMMAKUMPEE, 1978). From this long-time observation, it is clearly seen that the pore water pressure in the top 10 m depth zone of the subsurface is within a narrow range and there are no appreciable changes in the pressure over the five year period. On the other hand, the water pressure in the zone deeper than 10 m dropped continuously over the period, with the maximum drop from

1975 to 1979 of about 6 t/m^2 (piezometric level drop of 6 m) at 20 m depth. There exists significant fluctuation of the water pressure with time during a one year period but the general trend is a net annual drop of pore pressure of more than 1 t/m^2. It may be concluded that the pressure in the top 10 m zone is stable and is only subject to small seasonal fluctuations over a one year period without significant influence from groundwater pumping. The water pressure in the deeper zone, however, seems to be influenced by the decline due to groundwater pumping as well as the seasonal fluctuation. The combination of two effects results in the variation of pressure with the time with a net drop in pressure increasing in the zone below 10 m.

Apart from the measurements carried out in this research, other independent measurements were also conducted by the two companion projects. For the project on "Groundwater Resources in the Bangkok Area: Development and Management Study" a net work of 60 observation wells over the Bangkok area were installed and monitoring has been conducted since completion of the installation and the results were obtained for a period of over four years at some of these observation wells. The project on "Surface Levelling of the Bangkok Area for the Determination of Land Subsidence" has carried out first order levelling over the Bangkok area with the reference elevation originating at a mountain range in Ratburi province. Seven runs of levelling have been conducted at about half-a-year intervals. The repeated levelling runs allow the estimation of the surface subsidence rate over the Bangkok area. These independent measurements were found to confirm the findings in the present investigation.

Attempt has also been made to reconstruct the contour of subsidence rate (Fig. 5) by using the results of last two levellings (1981-1982) and from the automatic subsidence recorders results. Again three zones of subsidence are distinguished. They are (1) above 10 cm/year, (2) between 10-5 cm/year (3) below 5 cm/year. The maximum subsided areas are concentrated in the eastern part of Bangkok, especially in the Phra Khanong and Bangkapi districts.

Analysis and Model Simulation of Subsidence

A mathematical model for land subsidence invariably consists of a hydrologic model, simulating the large aquifer basin with many pumping wells, and a consolidation of compression model, simulating the consolidation of the various sub-soil strata at specified locations. The declines of piezometric levels in the various layers of the hydrologic model are used in the consolidation model as the boundary piezometric heads for the clay layers to estimate compression and surface subsidence at every time step.

In this study, the mathematical model consists of a 'three-dimensional' hydrologic model connected to a one-dimensional consolidation model. A schematic diagram showing the relationship between hydrologic model and consolidation model is given in Fig. 6.

The model was devised to study a time-dependent problem. Normally, model simulation for a system is carried out to estimate and predict the future performance of the system. The parameters employed in the simulation were obtained from small scale field tests or laboratory tests on samples.

(a) Hydrologic model - For the mathematical simulation of a real multi-aquifer system, the model should take into account the inhomogeneity and anisotropy of the material properties. In the general case, the governing equation for the piezometric head in an aquifer in a multi-aquifer system can be expressed as:

$$\frac{\partial}{\partial x} T_x \frac{\partial h_i}{\partial y} + \frac{\partial}{\partial y} T_y \frac{\partial h_i}{\partial y} = S_i \frac{\partial h_i}{\partial t} + Q_i + W_i \qquad \ldots\ldots (1)$$

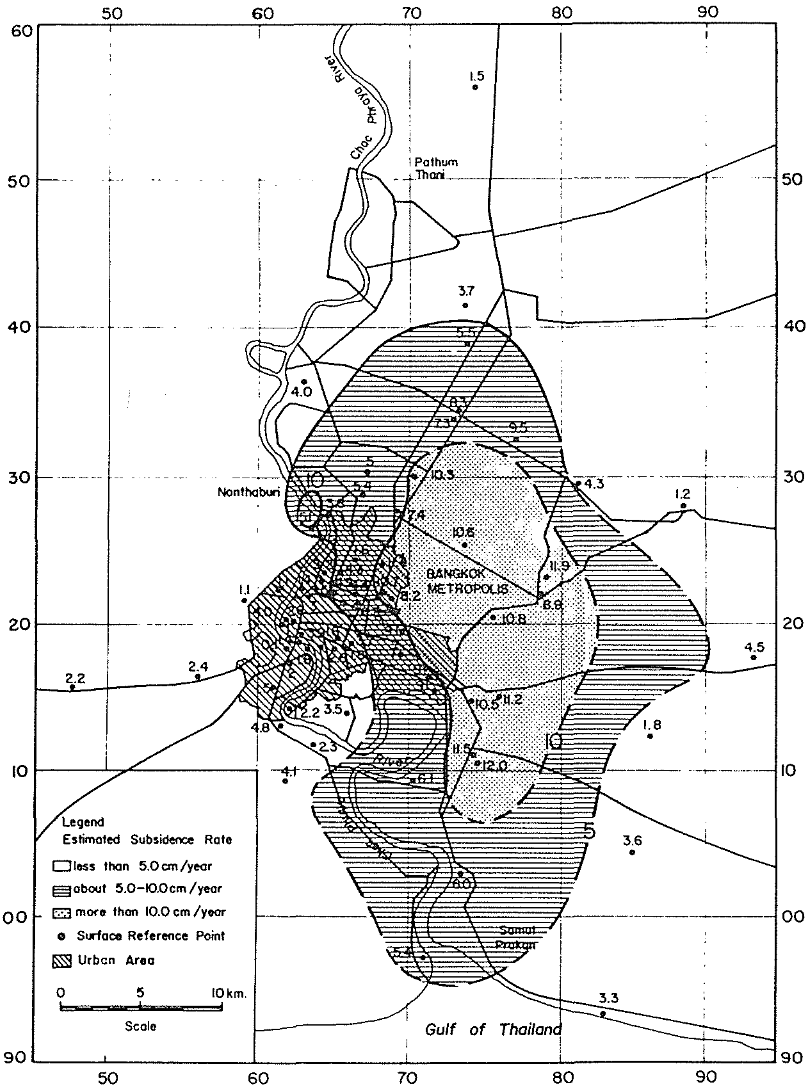


Fig. 5 Subsidence rate in Bangkok (cm/year)

where, i is the number assigned to the aquifer under consideration
h_i is the piezometric head in the aquifer
T_x, T_y denotes directional transmissibility of the aquifer
S_i denotes the storage coefficient
Q_i is the rate of ground water extraction out of the domain

The term W_i corresponds to the rate of ground water flow to the upper and lower aquifer in the domain, which includes (i) the direct seepage between

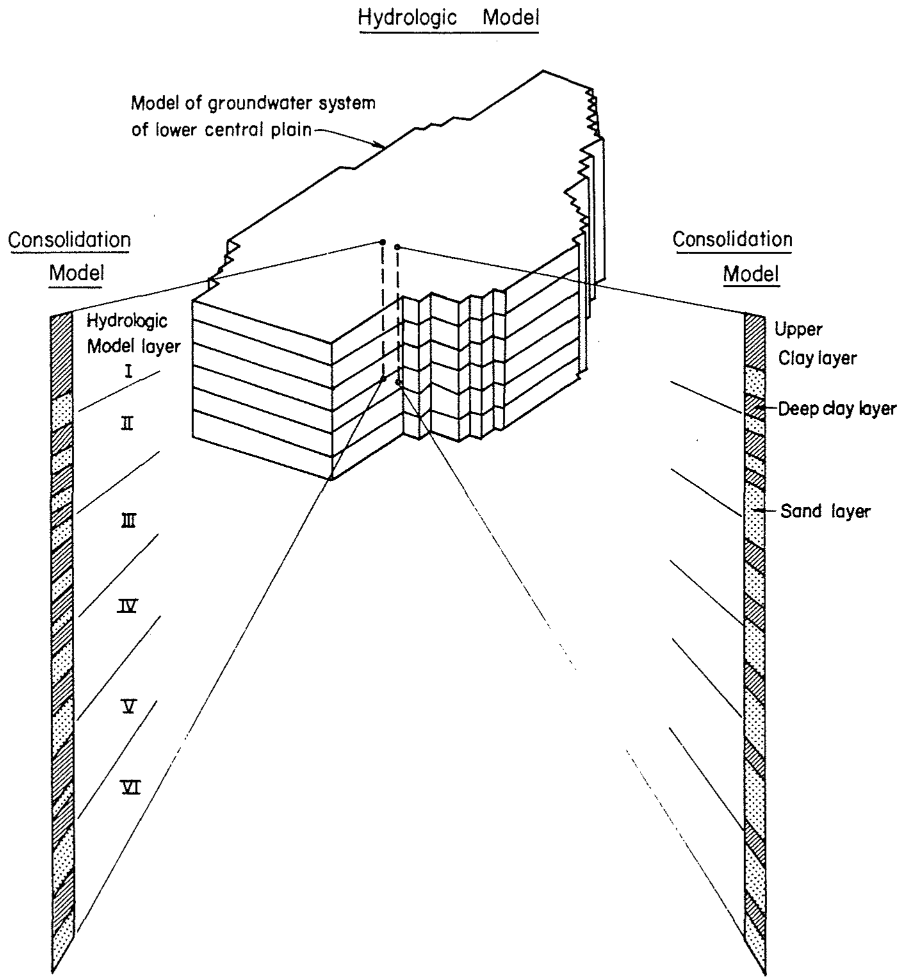


Fig. 6 Schematic Diagram of Coupled Model for Simulation of Land Subsidence Caused by Groundwater Withdrawal.

aquifers, and (ii) the water yielded from storage in the clay layers. The general expression for the term W_i can be given as:

$$W_i = \Sigma \frac{k}{\ell} \int_o^t M\ (t-\tau)\ \frac{\partial h'}{\partial \tau}\ d\tau \qquad \ldots\ldots (2)$$

where k and ℓ are the permeability and thickness of the intervening aquitard respectively, M is a flow rate function involving a time rate factor c_v/H^2, h' is a function of piezometric levels in the given aquifer and two adjacent aquitards and t is the time since the start of simulation.

In a simplified case where the effect of time-delayed yield of the aquitard is neglected, the term W_i is given by,

$$W_i = \frac{k_{i-1}}{\ell_{i-1}} (h_i - h_{i-1}) + \frac{k_i}{\ell_i} (h_i - h_{i+1}) \quad \text{..... (3)}$$

(b) Consolidation model - The Consolidation Model was developed to find (i) the detailed piezometric head distribution throughout the clay layer, and (ii) the magnitude of the compression of each slice, Δz, of the clay layer (due to the drop in piezometric head) and to sum these to represent the layer compression.

The governing equation for the piezometric head in a clay layer which takes account of the inhomogeneity of the clay, is:

$$\frac{\partial}{\partial z} k_z \frac{\partial h_c}{\partial z} = S_{sv} \frac{\partial h_c}{\partial t} \quad \text{..... (4)}$$

which is equivalent to,

$$\frac{\partial}{\partial z} c_v \frac{\partial h_c}{\partial z} = \frac{\partial h_c}{\partial t} \quad \text{..... (5)}$$

The piezometric heads in the aquifers derived from the Hydrologic Model are used as the boundary piezometric heads for the Consolidation Model for an individual clay layer at any location. The compression of each slice, Δz, caused by the piezometric head drop, $-\Delta h_c$, can be found from the e-log $\bar{p}$ relationship as follows:

$$\Delta\varepsilon = \frac{C_c}{1+e_o} . \log \{1 + \frac{\Delta\bar{\sigma}}{\bar{\sigma}_o}\} \quad \text{..... (6)}$$

or alternatively:

$$\Delta\varepsilon = CR . \log \{1 - \frac{\Delta h_c \gamma_w}{\bar{\sigma}_o}\} \quad \text{..... (7)}$$

where $\Delta\bar{\sigma}$ is the effective stress increment which in subsidence study can be taken as: $- \Delta u = \Delta h_c \gamma_w$; $\bar{\sigma}_o$ is the effective overburden stress and $\Delta\varepsilon$ is the incremental strain for a soil slice of thickness Δz.

The calculation can be simplified by using the following relationship:

$$\Delta\varepsilon = -S_{sv} . \Delta h_c \quad \text{..... (8)}$$

where S_{sv} (clay storage or clay compressibility) can be approximated without significant error as:

$$S_{sv} = 0.435 \frac{CR \gamma_w}{\bar{\sigma}_o} \quad \text{..... (9)}$$

In the situation where piezometric head is rising instead of declining, the swelling (or recompression) parameters have to be used in place of C_c, CR and S_{sv}, due to the characteristic two moduli of compression of the soil. This is also the case where the effective stress at the moment is less than the maximum effective stress that the soil has experienced in the past. The change of parameter is also applied to c_v (k/S_{sv}) where the coefficient of consolidation should be changed to the coefficient of swelling, c_s.

The compression of sand layers occurs immediately when a pore pressure drop takes place due to groundwater pumping. The compression can be found directly from the pressure drop, the layer compressibility and the layer thickness. Summation of the compressions of all clay and sand layers through the depth constitutes surface subsidence at the location.

The parametric study was carried out by setting up a group of parameters to represent the 'normal' condition. Individual parameters were then varied

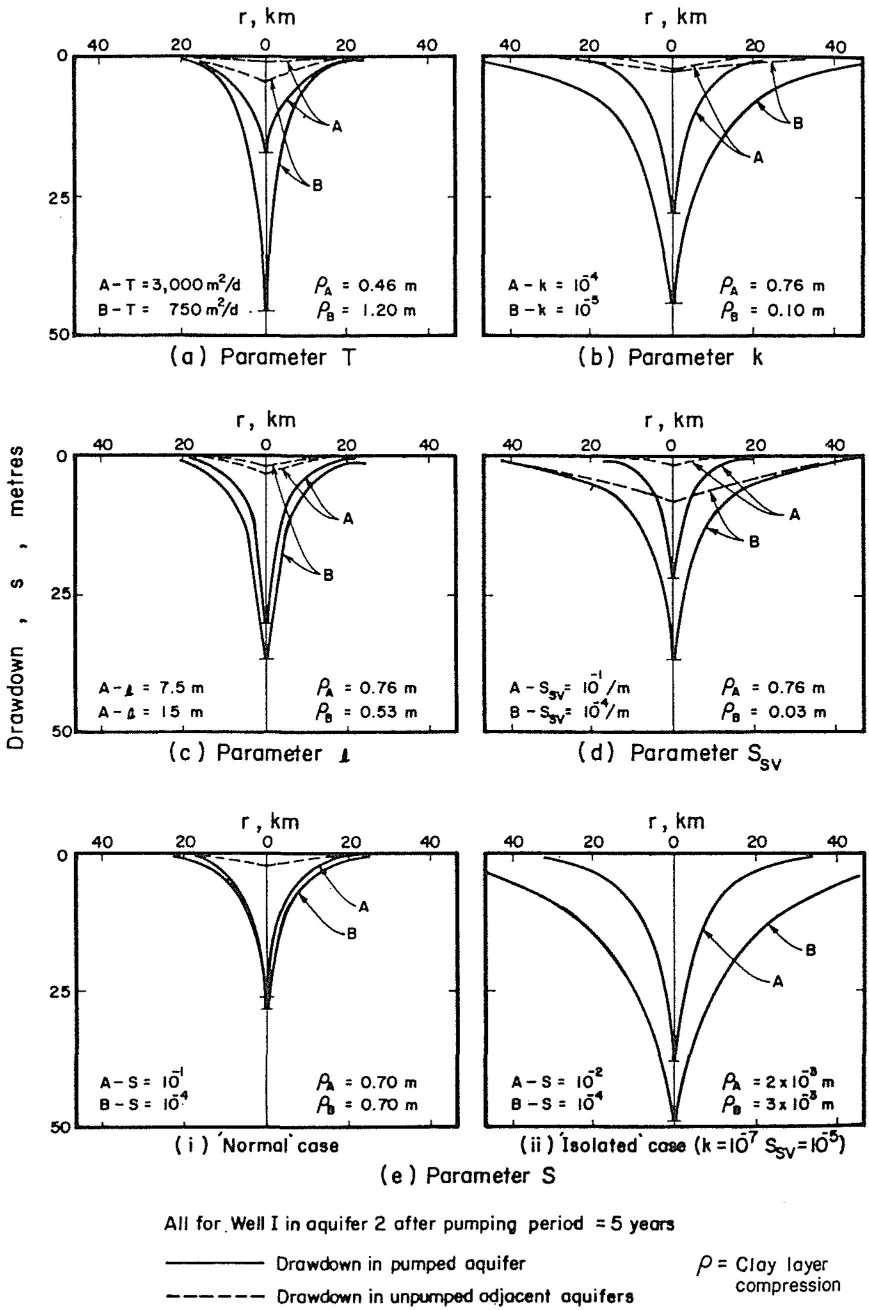


Fig. 7 Effect of Various Parameters on Regional Drawdown Distribution (Normal Case at 5 years)

to observe the changes in the solutions for the drawdowns in the aquifers and the magnitudes of clay layer compressions as compared to the solutions for the 'normal' condition. The parameters that were adopted for the 'normal' condition (these are approximately the parameters for the Lower Central Plain of Thailand) were:

i) transmissibility of the aquifers, $T = 1{,}500\ m^2/day$,
ii) storage coefficient of the aquifers, $S = 10^{-4}$,
iii) thickness of the clay layers, $\ell = 15$ m,
iv) permeability of the clay layers, $k = 10^{-4}$ m/day, and
v) compressibility of the clay layers, $S_{SV} = 10^{-2}$ /m.

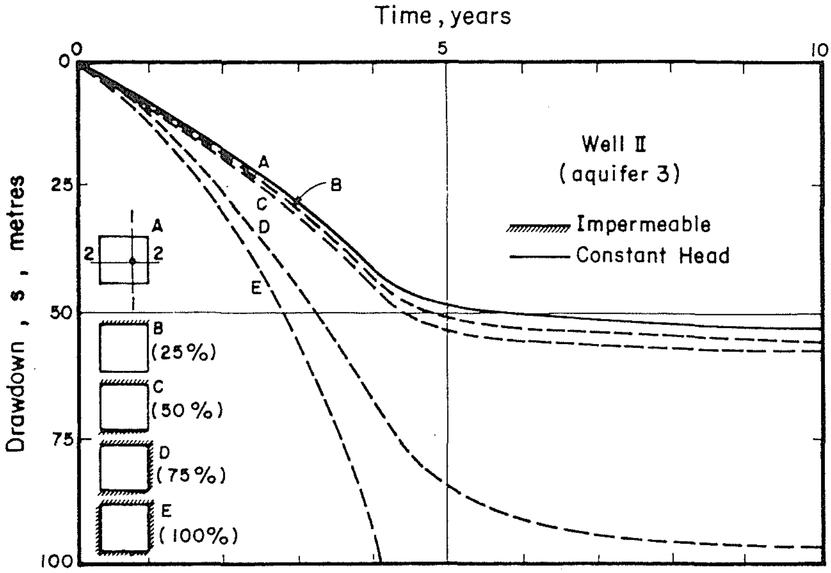
To assess the simulation in a rigorous way, full expression in integral terms was used for the term W_i in this parametric study. The technique in solving the resulting integrodifferential equation may be found from PREMCHITT (1981).

A summary of the effects of variation of the various model parameters in this assessment is presented in Fig. 7. The results are given for a time of 5 years after pumping started. The variation of the parameters affects both the magnitude and the pattern of piezometrical level drawdown over the domain. The compression of the clay layer adjacent to the concerned aquifer is also given in the figure. In the study of the parameter S, the variation within three orders of magnitudes (10^{-1} to 10^{-4}) did not produce significant changes in the solutions. However, when each aquifer is isolated and the yields from adjacent clay layers are reduced to insifnificant values ($k = 10^{-7}$ m/day, $S_{SV} = 10^{-5}$/m), considerable changes in the drawdown solution were observed (Fig. 7 (e)).

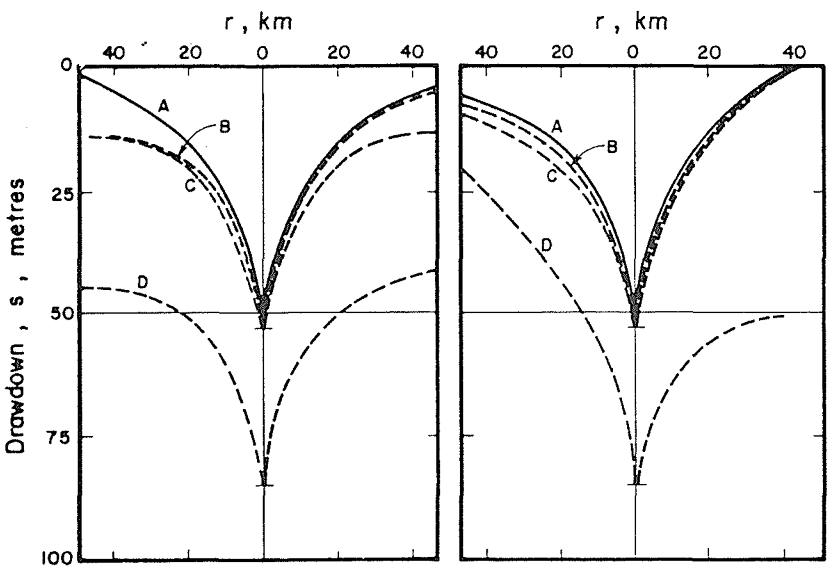
Influences of boundary conditions on the model responses were also assessed in this parametric study. Figure no. 8 shows the influence of an impermeable boundary on the maximum drawdown at Well II and on the regional drawdown distribution for the 'isolated' condition ($k = 10^{-7}$m/day, $S_{SV} = 10^{-5}$/m). The square domain was examined for the five conditions in which 100, 75, 50, 25 & 0% respectively of the periphery was in impermeable boundary, the remainder of the periphery was assigned to be a constant head boundary. It can be seen that the drawdowns are much greater for the cases where 100% and 75% of the boundary are impermeable than for the other three situations, in which the drawdowns are equal.

The influence of an impermeable boundary for the 'normal' condition is shown in Fig. 9 for the two extreme cases of an all-round impermeable boundary and an all-round constant head boundary. Surprisingly, there is almost no difference at all in the solutions obtained from the two schemes. This can be explained by the fact that the pumped groundwater comes mainly from direct seepage from the ground surface through the layers, together with yield from clay storage, rather than from recharge at the periphery for this 'normal' condition: it should be mentioned that the piezometric head in the upper clay layer was kept constant, which implies a continuous recharge from the surface. For the 'normal' case, the values of the parameter k (associated with the amount of vertical seepage through the clay layer) and the parameter S_{SV} (associated with the yield from clay storage) are a thousand-fold higher than for the 'isolated' case.

Of the parameters necessary for the mathematical simulation of natural subsurface strata for and subsidence predictions, some are commonly not accurately determined, some are determined by conventional tests which might not be representative of actual field behaviour and some either cannot be or have not been determined. It is important, therefore, to assess the relative significance of the various parameters involved in the model simulation. The parameters which have greatest influence should be carefully selected



(a) Drawdown – Time Relationships



(b) Cones of Depression for Section 1-1 (5 years)

(c) Cones of Depression for Section 2-2 (5 years)

Fig. 8 Effect of Impermeable Boundary for 'Isolated' Case ($K = 10^{-7}$ m/d, $S_{sv} = 10^{-5}$/m)

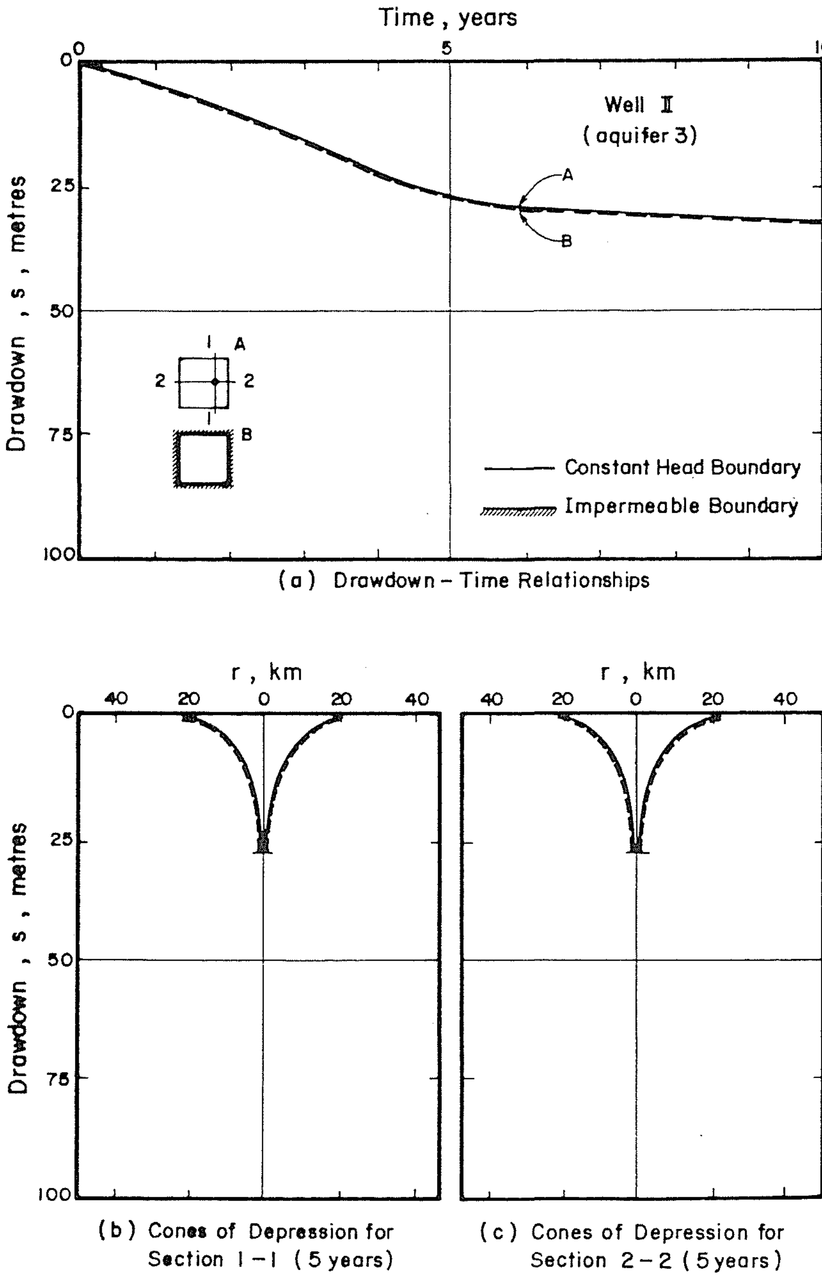


Fig. 9 Effect of Impermeable Boundary for 'Normal' Case ($k = 10^{-4}$ m/d, $S_{sv} = 10^{-2}$/m)

and require more attention than the other ones. The significance of each parameter in the Hydrologic Model can be observed from the changes in the solutions for drawdowns obtained from the model when each parameter is doubled or halved from the value under normal conditions. The relative significance of the parameters can be described on this basis as:

First order parameter - T (40%)
Second order parameter - k (15%), ℓ (12%)
Third order parameter - S_{SV} (4%), S (very small)

The value in the parenthesis is the change in the drawdown derived from the model when the 'normal' value of the parameter is doubled or halved.

Remedial Measures - Artificial Recharge

In order to increase the amount of water in the aquifers and to maintain the present piezometric levels, clean water must be recharged to the acquifers. If the amount recharged is greater than the amount withdrawn, the subsidence will stop and original piezometric levels eventually recovered.

Groundwater recharge by injection wells is relatively common and the technical problems relating to its application in Bangkok can be briefly outlined. Construction techniques are similar to those of pumping wells. To utilize the advantage of the method, the recharge well should penetrate to the heavy drawdown depth zone, i.e. from 100-200 m. It is expected that the recharge capacity of the well would be much smaller than the capacity of an equivalent pumping well (SUTER & HARMESON, 1960; BLAIR, 1970). Apart from pretreatment and mechanical cleaning to prevent clogging, the method of alternate pumping and recharging with a longer recharge period can also reduce the problems of clogging.

Another attractive recharge technique for the Bangkok area is the recharge through the base of some structures. Since these structures have to penetrate through the 15-25 m thick layer of soft and stiff Bangkok clay, the design and construction techniques in the Bangkok area, unlike the recharge well, have to be closely studied. The unsupported open-excavation is not feasible in the Bangkok area. The excavation with support structure to resist lateral earth pressure is possible but the shape and size of such a structure have to be selected in such a way that the amount of support structure is minimized and the construction technique is simple. The cylindrical pit seems to be the optimum choice, since there would be only the tangential compressive force on the members of the structure. Apart from this consideration, the site for the construction of the recharge structure should be selected in such a way that the recharge will be most effective in raising the ground-water level and that surface water is available in sufficient quantity. At the same time the amount of excavation should also be minimized by selection of an area where the top clay layer is thin.

A preliminary study on the feasibility of groundwater recharge in the Bangkok area has been carried out. Regarding the recharge pit, many sites in the area seem to suit the requirements. Three of these sites are selected for study. With the low groundwater level in the top aquifer prevailing in the area, the hydraulic head difference for the gravity flow of water from the pit is in the order of 15 to 20 m. For a pit diameter of about 10 m and the given head difference, theoretical estimation gives a flow rate through the recharge pit in the order of 5,000 to 20,000 m^3/day. Confirmation of this theoretical estimation can be made by an appropriate pilot test scheme. The pit of smaller size will require less excavation effort but the recharge rate will be reduced accordingly.

The construction of a cylindrical pit of 10 to 20 m in diameter which penetrates to 25 m depth is not a simple task, but it was found to be feasi-

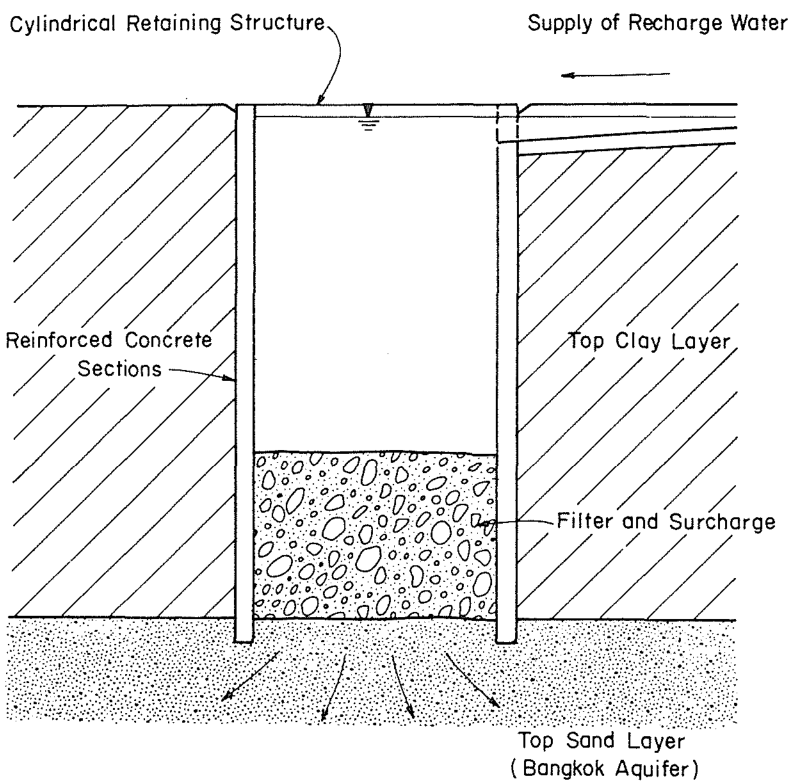


Fig. 10 Schematic Diagram of Recharge Pit

ble. Past experiences showed that construction of such a pit in the Bangkok area with the presently available techniques would take only 10 to 20 days. A schematic diagram of the proposed cylindrical pit is given in Fig. 10.

Quality of the recharge water is also an important factor in the recharge scheme. Recharge water of high turbidity may eventually clog the recharge structure and the aquifer. This will result in a significant reduction of the recharge rate. Some types of filter are necessary to reduce the amount of suspended solid particles and turbidity of recharge water before it will enter the aquifer. In the case of a cylindrical recharge pit, the filter can be placed in the pit or in the adjacent area or both. Regular cleaning of the used filter is also necessary. Other aspects of water quality also need attention since poor quality recharge water may pollute the existing groundwater system. The contents of such constituents as, dissolved oxygen, ammonia, bacteria and certain minerals are indications of undersirable water.

The performance of recharge schemes can also be assessed theoretically by mathematical model simulation. A detailed analysis will give a comprehensive picture of various aspects of recharge schemes. Research and development of the model in this regard has been initiated.

The actual implementation of recharge schemes including recharge pit and injection well recharge needs further extensive study and analysis. The only way to fully assess the potential of recharge schemes is to conduct a pilot test in the Bangkok area. Sufficient instrumentation to monitor field performance is necessary and it has to be carried out over at least a complete one-year period in order to assess the long term performance and the effects of seasonal variation.

Recommendations

The fact that Bangkok is sinking at a rapid rate must be realized and remedial measures should be taken at once. No time is left for indecision when 10 cm of ground surface is continuously subsided each year. Within the next 3-5 years, several square kimometer areas in Bangkok will be below mean sea level. The problem is not only complex but it is big also causing millions of Baht of loss annually. Since the ground water pumping will continue to increase and the city will continue to grow, the land subsidence problem will continue to grow unless we find a solution. In the light of this, the following recommendations are made:

1. An agency should be assigned to solve the problem and it must be given full authority to execute the approved plan.

2. The plan for the control of the land subsidence of Bangkok, Nonthaburi, Pathum Thani and Samut Prakan must be set such that the subsidence in these areas will be arrested within 5 years.

3. Details of these measures should cover the following:

   3.1 The subsiding areas must be demarcated into zones according to the rate of subsidence. The critical zone of highest subsidence will require immediate remedial action.

   3.2 Pumping of groundwater must be controlled, at the same time clean water should be recharged to the aquifers to prevent further drop of groundwater level and eventually to raise the groundwater level up to the original level.

   3.3 Full support should be given to the MWWA Bangkok Water Improvement Program such that the full implementation of the program is on schedule.

   3.4 Raw surface water in the equivalent amount of the present groundwater pumped to replace or replenish the groundwater must be allocated.

   3.5 In planning the land use, the subsiding areas with its restrictions and problems must be taken into consideration.

   3.6 Fees should be levied to the usage of groundwater at a comparable rate to the public water supply rate.

   3.7 Monitoring and evaluations of results of the remedial measures must be done periodically so that modification of the plan to meet the objectives can be carried out.

   3.8 The people who live in the subsiding area must be made aware of the subsidence problem due to groundwater withdrawal and they should actively participate/cooperate in the development of the remedial plan and action.

4. Adequate funds should be allocated by the government to solve this problem. Eventually this money will be recompensed through the groundwater pumping fees.

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