LARGE SCALE PUMPING TEST AND HYDRAULIC CHARACTERISTICS OF CHINGMEI GRAVELS

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Reprinted from
Proceedings of Twelfth Southeast Asian Geotechnical Conference and the Fourth International Conference on Tropical Soils
May 6~10, 1996, Kuala Lumpur, Malaysia, Vol. 1, pp.119-124

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Twelfth Southeast Asian Geotechnical Conference
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SYNOPSIS: In the construction of the Taipei Rapid Transit Systems, dewatering scheme was adopted for the excavations of two ventilation shafts to depths exceeding 34m. The site is underlain by a thick layer of Chingmei Gravels which governs the quantity of flow, hence, the cost of the scheme. To determine the hydraulic characteristics of Chingmei Gravels, a large scale pumping test was conducted by using 10 pumps of 100 horsepowers each to provide a total yield of 3,600 cubic meters per hour. The test results and the influence of ground water drawdown are discussed herein.

INTRODUCTION

Excavations for Ventilation Shafts A and B, of which the locations are shown in Fig. 1, of the Panchiao Line of Taipei Rapid Transit Systems (TRTS) are 36.6m and 34m in depth, respectively, and are underlain by a thick layer of Chingmei Gravels which is extremely permeable. It would be quite difficult and expensive for the diaphragm walls to go sufficiently deep into this gravelly layer to provide a total cutoff of seepage flow and blow-in was a serious concern. After a careful evaluation, the designers opted the dewatering scheme to relieve the piezometric pressures for preventing blow-in from happening. The success of this dewatering scheme would highly depend on the permeability of the Chingmei Gravels. Several pumping tests had previously been carried out in the region for evaluating the hydraulic constants of the Chingmei Gravels. However, because of the influence from the tides, the results of the tests could not be interpreted with confidence. A large scale pumping test was then conducted at the location of Shaft B by using 10 pumps of 100 horsepowers (HP) each to provide a total yield of 3,600 cubic meters per hour (cmh) so the drawdowns would be large in comparison with the fluctuations caused by tidal effects.

The test procedures and the analytical method adopted were previously reported by Shau, Wong, Fung and Liu (1995) and will only be briefly mentioned herein. The theme of this paper, rather, is on the influence of dewatering on surface settlements.

GEOLOGY AND GROUNDWATER HYDROLOGY

The test site is located in the T1 zone of Taipei Basin (Huang, et. al., 1987; Woo and Moh, 1990; Moh and Chin, 1991) and is underlain by the so-called Sungshan Formation which consists of six sand-clay alternating sublayers as shown in the soil profile in Fig. 2. Underneath the Sungshan Formation is the Chingmei Gravels which was formed by the deposition of sands and gravels carried downstream by the Hsintien River after the Taipei Basin was formed several thousand years ago. It is postulated that large rocks were deposited near the rim of the basin and smaller rocks were carried by floods further downstream.

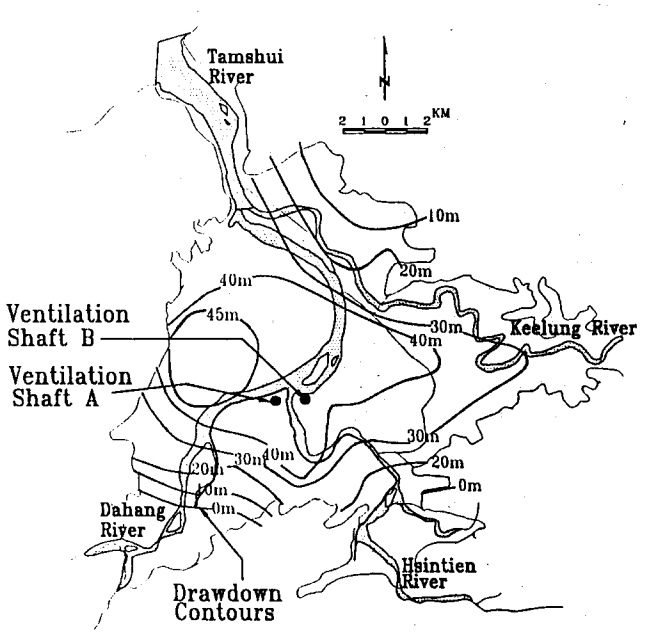

Fig. 1 Drawdowns in Chingmei Gravels and Locations of Ventilation Shafts A and B

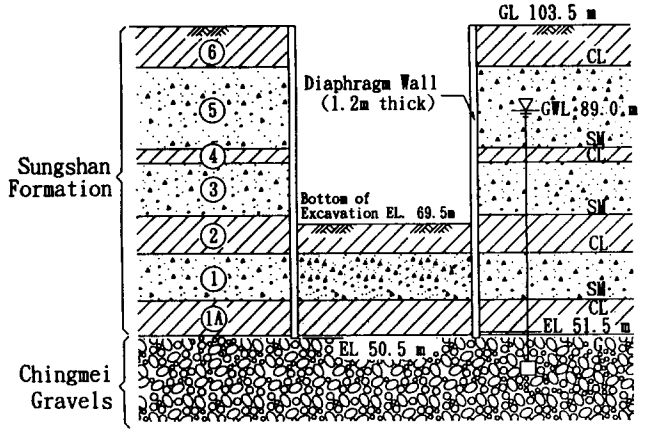

Fig. 2 Soil Profile at Shaft B

downstream. Therefore, it is reasonable to expect that the sizes of rocks decrease with distance from Hsintein.

The piezometric heads in the Chingmei Gravels in the entire Taipei Basin have been closely monitored by Water Resource Planning Commission (WRPC). Because the Taipei Basin is surrounded by high hills in central city area the groundwater in the Chingmei Gravels was once in an artesian condition with a head of 2 to 4m above the ground surface which is roughly at El. 104m with mean sea level at EL. 100m (Wu, 1967; Wu, 1968). Before mid-50's, groundwater was the only source of water supply and the piezometric levels were gradually lowered as the population grew. In 1974, refer to Fig. 1, the piezometric level in the Chingmei Gravels dropped from their original levels by as much as 40m. In 1976, a ban on withdrawal of groundwater was implemented and the piezometric level rose gradually as illustrated in Fig. 3. In mid-80's, the completion of Fe Tsui Reservoir provided the entire Taipei metropolitan with sufficient water reducing the demand for groundwater and the piezometric levels in the Chingmei Gravel rose even more rapidly (Moh and Chin, 1991). Judged from the instant recovery of water levels in wells during pumping tests, the recovery is expected to be much faster than what is shown by the figure. It is postulated that the withdrawal of ground water for various purposes is still substantial. It was reported by WRPC that the annual yield dropped from 430 million tons in 1970 to the current volume of 86 million tons. The recovery slowed down in the 90's presumably because of the vigorous construction activities involving deeper and deeper excavations.

For constructing the subway systems in the metropolitan Taipei city areas, the Department of Rapid Transit Systems (DORTS) has monitored the piezometric levels in the Sungshan Formation since 1985. The data for the central city area are presented in Fig. 3. Sublayer 1 is very thin and is present only locally, therefore, the piezometric level in Sublayer 1 is practically the same as that in the Chingmei Gravels. Sublayer 2 serves as a blanket separating the water regions in Sublayers 3 and the underlying Chingmei Gravels as indicated by the fact that there clearly is a 3m to 5m head differential between the two layers. The clayey Sublayer 4 is also a fairly good blanket separating the water regions and the piezometric levels in Sublayer 5 are unaffected by the fluctuation of piezometric levels in the underlying layers.

The thickness of the Chingmei Gravels at the site is believed to be greater than 140m. However, there are thick clay blankets sandwiched in the Chingmei Gravels and the hydraulic characteristics of Chingmei Gravels are affected by the presence of these clay blankets. Therefore, only transmissibility can be computed from results of pumping tests, not the permeability which requires the knowledge of the thickness of permeable layer.

TIDAL INFLUENCE

It has been found that the piezometric levels in the Chingmei Gravels are significantly influenced by the tides. To find out its correlation with the tide, the water levels in the Tamshui River, which is practically a tide water, and the piezometric heads in the Chingmei Gravels were monitored using a data logger at 20-minute intervals in the period of February 12 to March 18, 1993 and in the period of June 16 to July 27, 1993. A part of the results are plotted in Fig. 4 (Liu, Hwang and Yang, 1994; Liu, 1993). As can be noted that the peak-to-peak amplitude of the tides is roughly 2m while the amplitude of the fluctuation in the Chingmei Gravels is 0.5m, or about 25% of that of the tides in the river. As depicted in Fig. 1 that Tamshui River has three tributaries, i.e. Dahan, Keelung and Hsintien Rivers, covering the entire Taipei Basin. All these three tributaries are tidal rivers.

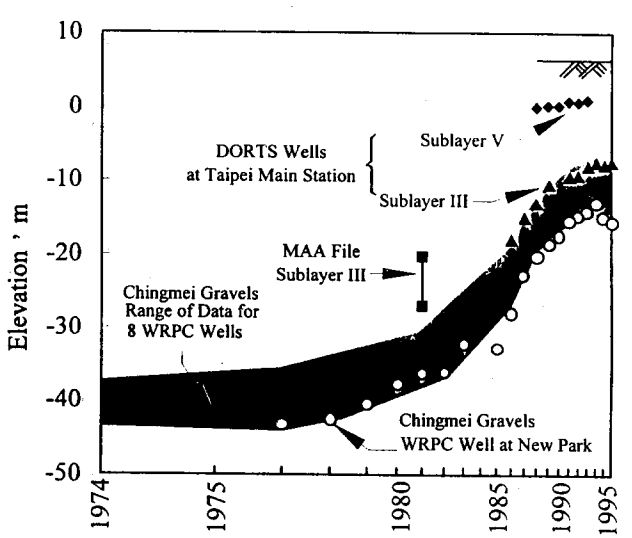

Fig. 3 Recovery of Piezometric Heads

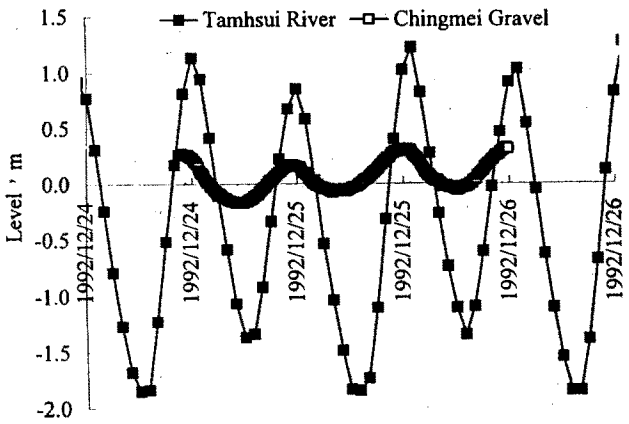

Fig. 4 Tidal Effects on Piezometric Head in Chingmei Gravels

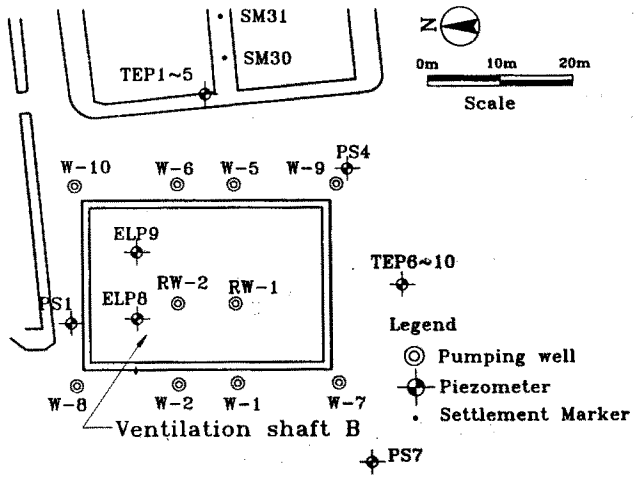

Fig. 5 Locations of Pumping Wells and Instrument Layout

Therefore, the entire Taipei Basin is under the influence of tides. Not only the piezometric heads in the Chingmei Gravels are affected, the piezometric heads in the Sungshan Formation are affected to a certain extend as well. This fact should be recognized when pumping tests are conducted in the future.

PUMPING TESTS

A previous pumping test was carried out by using a pump with a power of 75 HP and a capacity of 100 cmh. Observation wells located only 5m away from the pumping well showed drawdowns of 0.4m which was of a similar order as the fluctuation of the piezometric heads in the Chingmei Gravels caused by tidal effects. For the excavation to be carried out safely, it was estimated that the flow would be of a magnitude of 4600 cmh for lowering the piezometric heads in the Chingmei Gravels by 10.5m. A full-size pumping test was then carried out soon after the commencement of the contract to allow for time to add pumping wells if the desired drawdown was not achieved. Figure 5 shows the layout of pumping wells and the locations of observation wells. A total of 10 pumps were adopted. Eight of them, i.e., W1, W2, W5 to W10, were outside the Shaft and were installed to a depth of 82m below the surface. The remaining two wells, i.e., RW-1 and RW-2, were inside the Shaft and were installed to a depth of 72m. Many piezometers were available for monitoring drawdowns in the Sungshan Formation and Chingmei Gravels. The drawdowns obtained at ELP8, which was located inside the Shaft as depicted in Fig. 5, are compared with computed drawdowns in Fig. 6 and the drawdowns at VaO, which is located near Shaft A on the other side of the Tamshui River as shown in Fig. 1 with a distance of 1.1 km from Shaft B, are shown in Fig. 7.

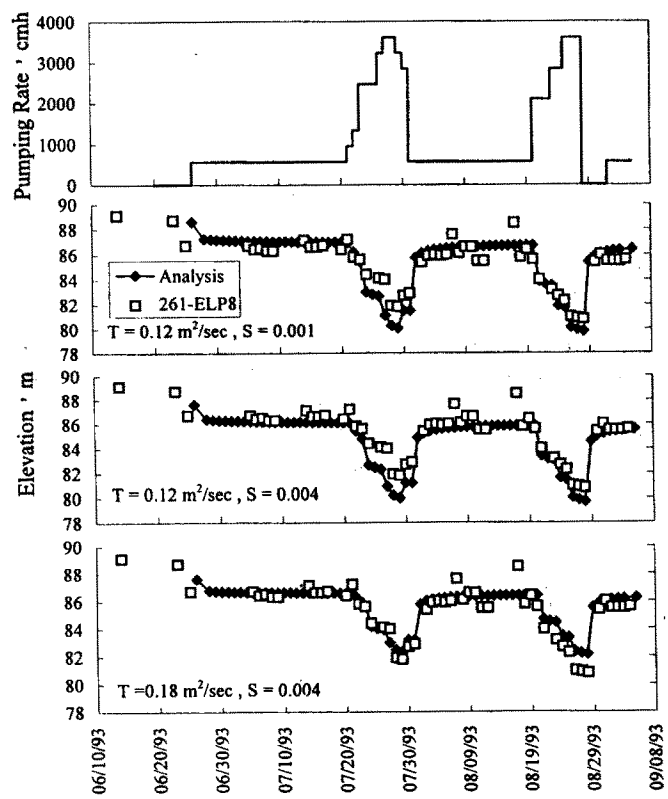

Fig. 6 Comparison of Observed and Computed Drawdowns at ELP8

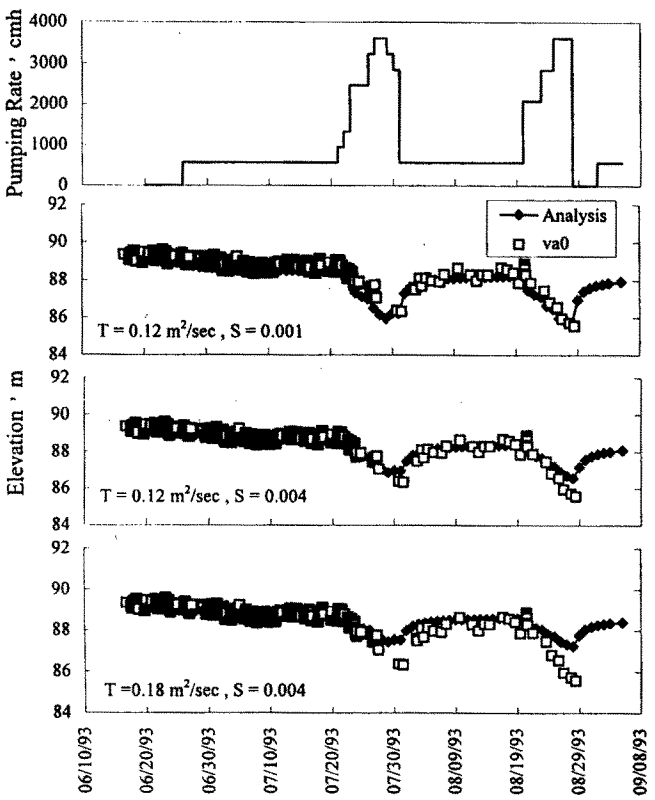

Fig. 7 Comparison of Observed and Computed Drawdowns at Va0 (at Shaft A, see Fig. 1 for Location)

Since the test was carried out for only several days and during the test period the flow was not steady with pumps on-an-off from time to time, steady-state solutions are inadequate for the back analyses. Theoretical drawdowns were thus calculated by using the Theis Non-equilibrium Equation (Theis, 1935) as follows:

$$s = \frac{1}{4}\frac{Q}{T}w(u) \qquad \text{Eq. 1}$$

$$w(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \cdots \qquad \text{Eq. 2}$$

$$u = \frac{r^2 S}{4Tt} \qquad \text{Eq. 3}$$

in which s = drawdown, Q = flow rate, T = transmissibility, S = coefficient of storage, r = distance to well, t = elapse time. The total drawdown from multi-wells is obtained by superposing the drawdowns due to all the single wells. A curve-fitting process was adopted to find the most appropriate combination of T and S values. Calculations indicate that, depending on location, S vary from 0.001 to 0.004 and T vary from 0.12 to 0.18 m²/sec. Although the Chingmei Gravels are apparently uniform, its hydraulic characteristics are governed by the clay seams. It is therefore difficult to compute the coefficient of permeability, k, of the Chingmei Gravels without knowing the stratigraphy. In any case, such computation is redundant because, after all, only S and T, not k, are required in computing drawdowns.

RADIUS OF INFLUENCE

As illustrated in Fig. 8, within a radius of at least 2 km the piezometric levels in the Chingmei Gravels were affected during the test. Also shown in the figure are the theoretical drawdown curves for pumping from a single well located at the center of Shaft for t = 1 day and 10 days obtained by using Eq. 1 with two sets of parameters, i.e., (a) T = 0.18 m²/sec and S = 0.001 and (b) T = 0.12 m²/sec and S = 0.004. Both sets are judged to provide results in a reasonable agreement with the observations for distances greater than 100m. Within 100m the simulation of multi-wells by a single well may not be valid. The

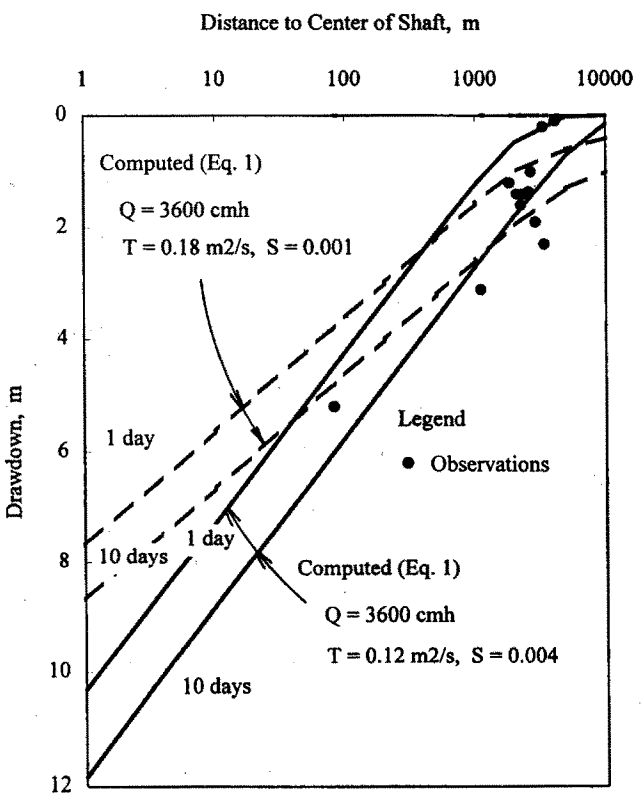

Fig. 8 Estimation of Radius of Influence

characteristics of the Chingmei Gravels are likely to vary from place to place and it is therefore expected that both T and S are site dependent.

It should be noted that it is improper to use empirical relationships suggested in textbooks, such as $R = 3s\sqrt{k}$ (Sichart and Kyrieleis, 1930), to compute the radius of influence R. The results could be seriously misleading because R is a function of T, S and t, and has little to do with k. Any agreement with observations using such relationships is purely coincidental. Under a steady-state condition, the radius of influence can be estimated as follows:

$$R = \sqrt{\frac{2.25Tt}{S}} \qquad \text{Eq. 4}$$

In fact, the radii of influence can be obtained by simply extending the straight portions of the drawdown curves in Fig. 8 and estimating the distances for zero drawdowns. As can be noted that the actual radii of influence are greater than the theoretical ones.

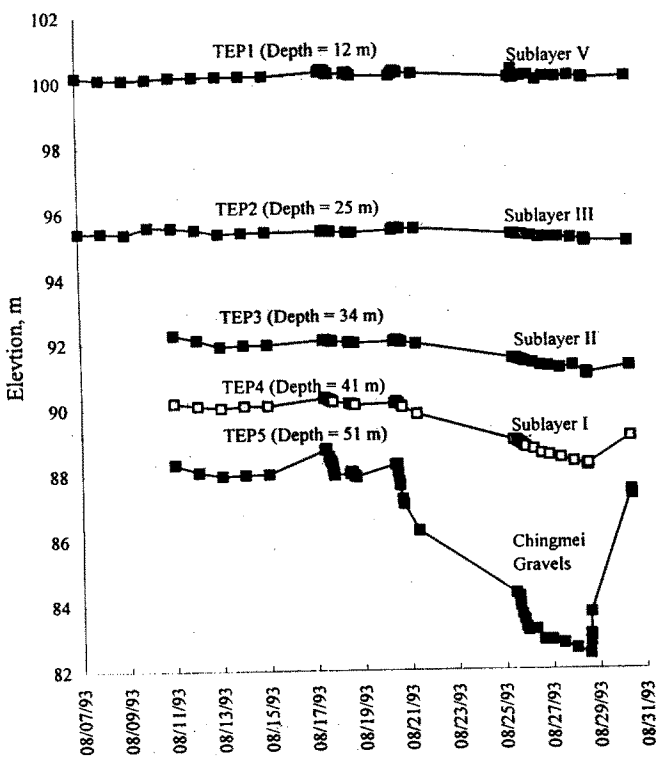

Fig. 9 Effects of Drawdowns in Chingmei Gravels on the Piezometric Heads in Sungshan Formation

GROUND SETTLEMENTS

In consideration of the extreme difficulty in extending diaphragm walls to a sufficient depth for providing cutoff effects, it is obvious that dewatering is an economical way for deep excavations in or near gravelly layers. However, in many projects lowering of ground water table is restricted to a small amount, usually 1m only, because of the worry that much drawdown may lead to ground settlement which may be detrimental to adjacent structures. As depicted in Figs. 1 and 3, the piezometric levels in the Chingmei Gravels were one time as much as 40m below their present levels and the piezometric levels in Sublayer 3 were one time as much as 20m below their present levels. Therefore, it is reasoned that all the sublayers below Sublayer 5 in the Sungshan Formation have been consolidated to much greater effective pressures than the present overburden pressures and ground settlement resulted from drawdown in the Chingmei Gravels would not be serious.

The drawdowns in the Sungshan Formation at TEP1-5, located at a distance of roughly 15m away from pumping wells W-5 and W-6 are shown in Fig. 9 and the nearby ground settlements throughout the entire construction period were practically nil as shown in Fig. 10. Based on the observations made throughout the 5-year construction period of TRTS project, it can be generalized that a 10m drawdown in the Chingmei Gravels will, at the most, lead to 3m drawdown in Sublayer 3 and 1 m drawdown in Sublayer 5 and in the central city area, where the Sungshan Formation has been previously consolidated, the ultimate surface settlement will definitely not exceed 5mm. This magnitude of settlement is hardly consequential. Furthermore, as depicted in Fig. 8, the drawdown curve is fairly flat and the ground settlements are thus expected to be rather uniform.

CONCLUSIONS

The foregoing discussions lead to the following conclusions:

1. In pumping tests for determining the hydraulic characteristics of the Chingmei Gravels, because of the influence of tides, the pumps must have sufficient capacities to produce sufficient drawdowns for meaningful results to be obtained.

2. It is expected that the entire Taipei Basin is under the tidal influence, therefore, the above recommendation is not limited to those areas in the vicinity of rivers.

3. Based on results of this pumping test, it is found that the transmissibility of the Chingmei Gravels at the site varies from 0.12 m^2/sec to 0.18 m^2/sec and the coefficient of storage varies from 0.001 to 0.004.

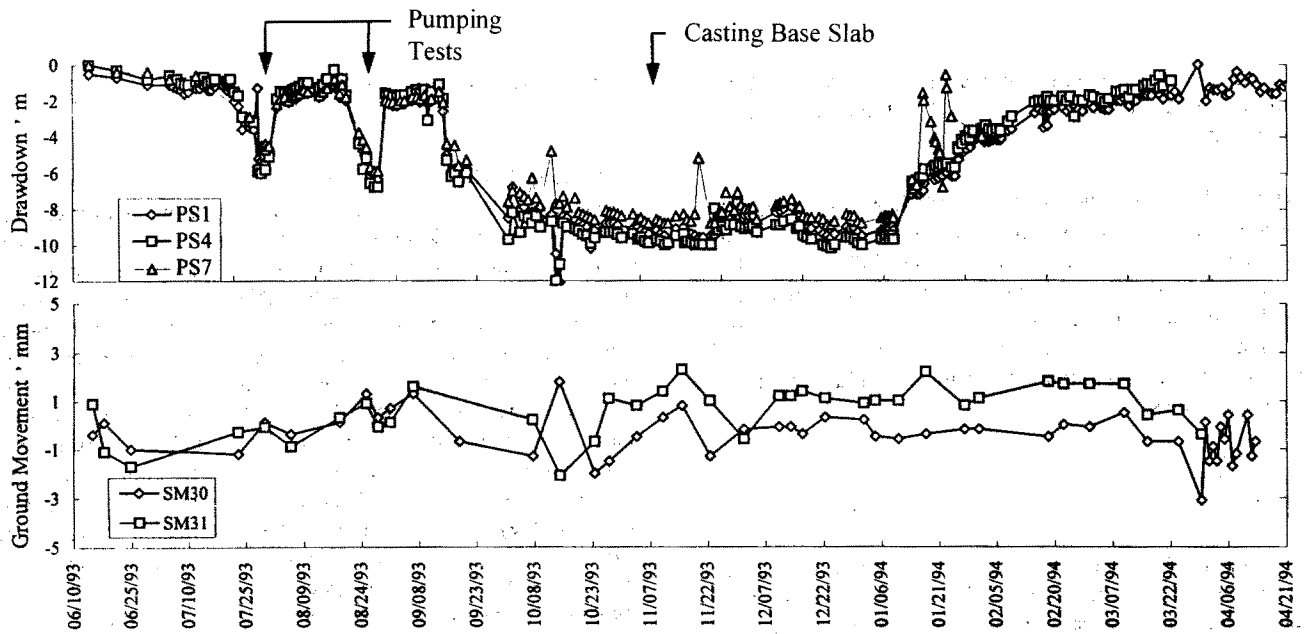

Fig. 10 Effects of Drawdowns in Chingmei Gravels on Ground Settlements

4. Lowering of piezometric level in the Chingmei Gravels is unlikely to cause much ground settlements in the central city areas and ground settlement, if any, is expected to be uniform.

ACKNOWLEDGMENT

The authors wish to express their sincere gratitude to the Department of Rapid Transit Systems for granting the permission of publishing the data presented herein. They are also grateful to Continental Engineering, the Contractor of this construction contract, for providing the detailed information.

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