Geotechnical Issues on the Keelung River Reclamation Project

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ABSTRACT

The reclamation project of Keelung River included the planning of material handling and storage, backfilling of the old river channels and ground improvement. Since a significant quantity of materials was needed for the backfilling work, the excavated materials from both the new river channel construction and public construction work in Taipei city were adopted as source materials. Temporary storage areas were developed to accommodate the huge quantity of backfill materials. Since there was about 30m thick soft clay existing below the ground surface, significant consolidation settlement was expected due to the backfill loads. To accelerate such settlement and for the reclaimed lands to be developed as soon as possible, the technique of prefabricated vertical drains (PVDs) with preloading was adopted for this project. A full scale field test was conducted to verify the subsoil parameters and the ground improvement design at the project site. The success of this project is an example of treating soft ground for creating new lands in urban areas and is important for the sustainable development of Taipei city after the year of 2000.

INTRODUCTION

Keelung River is one of the major rivers in the Taipei area. The section of the river between the Chungshang Bridge to Chengmei Bridge was frequently overflowed, resulting in flooding of an area of 555 hectares of low land. Since 1981, the Taipei Municipal Government has commissioned various academic organizations and consulting firms to conduct studies and to propose plans to solve these problems. After more than ten years of study and preparation, a proposal to divert this section was finally approved in 1990. This project not only focused on the treatment of Keelung River, but also on the planning of the use of the reclaimed land in Taipei city, where limited space for its development has been a serious problem. Among the fast growing countries in southeast Asia, similar problems have been faced; this paper presents a successful example of land reclamation within a highly populated urban area.

SUBSOIL CONDITIONS

The project site can be divided into two major sections: Gintai section and Chowchung section (see Figure 1). Their respective subsoil and groundwater conditions are described as follows.

Gintai Section

This section is located near the mountain areas at the northeast boundary of Taipei basin, so the depth of bed rock varies significantly. The river banks in this section have elevations from EL.+3m to EL.+8m. Generally, the subsoil beneath the river bed, from top to bottom, consists (1) 0.4m to 4m of muddy topsoil, (2) 1.5m to 16m of silty sand, (3) 5m to 39m of soft to medium stiff clay, (4) 1m to 22m of alternated silty sand and soft clay, and (5) sandy bed rock with an inclination toward southwest.

The groundwater table ranges from EL.-0.4m to EL.+5.2m and the groundwater distribution is hydrostatic in general.

Chowchung Section

The river bank at this section has elevations from EL.+3m to EL.+7m. The subsoil beneath the river bed of this section, from top to bottom, consists (1) 0.3m to 3.6m of muddy topsoil, (2) 2m to 18m of silty sand, (3) 10m to 30m of soft to medium stiff clay, (4) 5m to 19m of alternated silty sand and soft clay, and (5) gravels.

The groundwater table in this section ranges from EL.-1.5m to EL.+3.2m and the groundwater exhibits underpressure condition below EL.-15m due to the long-term pumping of groundwater from the gravel layer in the past.

In both sections about 30m thick of soft clay was encountered. The possible significant consolidation settlement of this soft clay layer due to surcharge was a great concern for this project.

GEOTECHNICAL ISSUES INVOLVED AND SOLUTION APPROACHES

With the nature of the project and the subsoil conditions encountered, there are three major geotechnical issues involved. They are described below.

(1) Material handling and storage: For backfilling the old river channel, approximately 7 million cubic meters of material was needed. Both the source of suitable materials with such a huge quantity and the locations to temporarily store the materials need thorough study and evaluation.

(2) Backfilling of the old river channel: To backfill the old river channels, geotechnical issues such as the mud treatment at the river bed and the determination of construction sequence need detailed evaluations.

(3) Ground improvement: Since the old river channel area is underlain by a very soft clayey soil layer of about 30 m in thickness, the backfill load at the old river channel area would induce significant consolidation settlement after the backfilling; such type of settlement will take more than ten years to complete naturally. For the reclaimed land to be ready for development as soon as possible, a suitable ground improvement method was necessary to accelerate the consolidation process.

To deal with the three major geotechnical issues mentioned above. Various feasible approaches were evaluated, and the adopted solutions are introduced below.

(1) Material handling and storage: Since a huge quantity (approximately 7 million cubic meters) of backfill materials were needed for this project, those excavated during the construction of the new river channel were adopted as material source with first priority. The rest of the needed backfill materials were expected to come from those excavated during various construction works in Taipei city; this can also help solving the problem of limited space for dumping excavated material in the Taipei urban area.

In order to screen and control the supply rate of the materials for backfilling, a material processing and control center was established. The accepted materials were then stored in the pre-assigned temporary storage areas for later use. Besides the source, screening, supply rate control and storage of backfill materials, the route for the material to be transported to the site were carefully planned to ensure minimum impact on traffic from the frequent trucks during the construction.

(2) Backfilling of the old river channel: Prior to the backfill of the old river channels, the Keelung River was diverted first, followed by the construction of drainage canals along the old river channels to serve as their substitutes. The two ends of both Chowchung Section and Gintai Section were then blocked and each of the two blocked sections were divided into a number of working units with access roads. Finally, each unit was pumped out of water separately. Besides, for the treatment of the muddy soil existing on the river bed surface, in-place cementation was adopted.

After the operations described above, the backfilling of the old channel was then ready to commence at each working unit. A construction management program which included access roads, temporary facilities, traffic controls and construction sequences was developed for an effective and economy reclamation process.

Figure 2 shows a typical construction sequence for the backfilling of the old river channel.

(3) Ground improvement: According to the analysis, the consolidation settlements at the old river channel areas due to the backfill load would range from 0.6 m to 1.3 m. To accelerate the significant consolidation settlement due to the backfill loads and the existence of soft clay layer at the site, comprehensive studies of feasible ground techniques were performed. Considering factors such as economy and effectiveness, the ground improvement technique with PVDs was adopted to shorten the consolidation time and to reduce the post construction settlement. With the adopted technique, preload with heights up to 8m and with PVDs about 30m in length and 1.25m, 1.5m and 2m in spacing, were designed. A total of about 8 million meters of PVDs was used. Also, for ensuring the effectiveness of this technique, a proper drainage system which included sand blankets, drain hoses and pumping wells was designed. Figure 3 shows a typical cross section of the ground improvement.

To validate the subsoil parameters and the effectiveness of the adopted ground improvement technique, a full scale field test with a comprehensive monitoring program was conducted at the project site. The details of the full scale field test is introduced in the next section.

A FULL SCALE FIELD TEST AT THE PROJECT SITE

A full scale field test was implemented at the old river channel of the Gintai section, as shown in Figure 1, to monitor the performance of ground improvement. The subsoil conditions, layout, test (monitoring) result and back analysis result are described as follows.

Subsoil Conditions

The subsoil profile at the test site was generally similar to that described in Section 2 for Gintai section. Within EL. -59m four major layers could be divided besides the top muddy soil:(1) silty sand from original river bed to EL. -6m, (2) soft clay from EL. -6m to EL. -20m, (3) soft to medium stiff clay from EL. -20m to EL. -33m, (4) alternated layers of silty sand and clay from EL. -33m to EL. -59m. Figure 4 presents the general physical properties of the subsoil versus depth.

Layout and Cross Section

The full scale field test has a plan dimension of about 100m by 125m, as presented in Figure 5. For the construction of the field test, about 4m thick backfill material was first placed, followed by placing a 0.8m thick sand blanket. PVDs with a length of about 35m and a spacing of 1.25m were then installed in triangular pattern, followed by placing backfill material up to the design elevation of about EL. +8m. Figure 6 presents the cross section of the full scale field test.

A monitoring program which consisted of inclinometers, surface settlement plates, hydraulic piezometers, electrical piezometers, extensometers and settlement points was conducted for the full scale field test. The plan and cross section of the monitoring program are presented in Figure 5 and Figure 6, respectively.

Monitoring Result

Since the major concern for the full scale field test was the surface settlement, the monitoring result from surface settlement plates installed on the river bed is discussed, as presented below.

A typical curve showing the relationship between settlement and time monitored from the settlement plate SP3 is presented in Figure 7. It can be seen from Figure 7 that before the installation of the PVDs the settlement occurred slowly. After the installation of the PVDs and the placement of the second stage backfill material, the settlement accelerated significantly.

From the monitored settlement curve, the final total settlement was predicted with Hyperbolic Regression Method. The predicted total settlement was about 1.2m.

Back analysis

In general, soil parameters such as unit weight, moisture content, Atterberg limits, compression index (Cc), volume compressibility (mv), coefficients of consolidation (cv and ch) and hydraulic conductivity (kh and kv) are considered to determine the total settlement as well as rate of settlement during ground improvement. For the ground improvement technique with PVDs, the smear zone induced during PVD installation, the effect of "well resistance", the phenomenon of micro folding and the clogging of PVD jacket will all affect the performance of PVDs.

Since there are many factors associated with the soil parameters and PVD behaviors and many uncertainties are involved, it is difficult to adopt all of them into analysis. As a result, the back analysis was conducted by adjusting critical soil parameters such as volume compressibility (mv), coefficients of consolidation (cv and ch).

With a number of trials by adjusting the above mentioned soil parameters within reasonable range, the evaluated settlement curve were within 20% difference from the monitored curve, as shown in Figure 7.

From the back analysis and monitoring result it was concluded that the adopted ground improvement technique was effective for accelerating the consolidation process.

GROUND IMPROVEMENT VS URBAN DEVELOPMENT IN THE 21ST CENTURY

Up to August 1996, the reclaimed lands had been considered as completed with ground improvement, and a number of construction works were underway. By the end of this century, public facilities, residential buildings and private business buildings will be ready to serve. The Keelung River reclamation project has been one of the major land development projects within the Taipei metropolitan. This project presents a clear idea of generating new lands that are especially needed in a highly developed capital city.

In southeast Asia, major cities such as Bangkok city, Thailand, Saigon city, Vietnam, and Shanghai, China have been encountering bottlenecks in continuing their development due to limited lands available. Recently, areas that were once considered unsuitable for development due to poor subsurface conditions are re-evaluated for possibility of being utilized to satisfy the need of new lands.

Considering the foreseeable future prosperity in southeast Asia, ground improvement methods, such as that used in the Keelung River project, will play a more and more important role in new land development in this region, especially in highly populated urban areas, in the 21st century.

CONCLUSIONS

Three major issues were encountered in the Keelung River reclamation project:(1)material handling and storage, (2)backfilling of the old river channels, and (3)ground improvement. Detailed studies of feasible solutions were conducted and designs were performed with focuses on economy, effectiveness and time efficiency.

To accelerate the consolidation settlement due to backfill load, the ground improvement technique of preloading with PVDs was adopted for ground improvement at the project site.

A full scale field test was conducted to confirm the effectiveness of ground improvement design of preloading with PVDs. Back analyses were performed based on the monitoring data to evaluate the relationship between settlement and time. Several trials were performed until general agreement was found between the monitored and calculated results. The subsoil parameters were then considered representative for the project site. Form the monitoring and analysis results it was concluded that the adopted ground improvement technique was effective in accelerating the process of consolidation settlement.

In southeast Asia, major cities have been encountering bottlenecks in continuing their development due to limited lands available. Considering the foreseeable future prosperity in this region, ground improvement methods will play a more and more important role in new land reclamation, especially in highly populated urban areas, in the 21st century.

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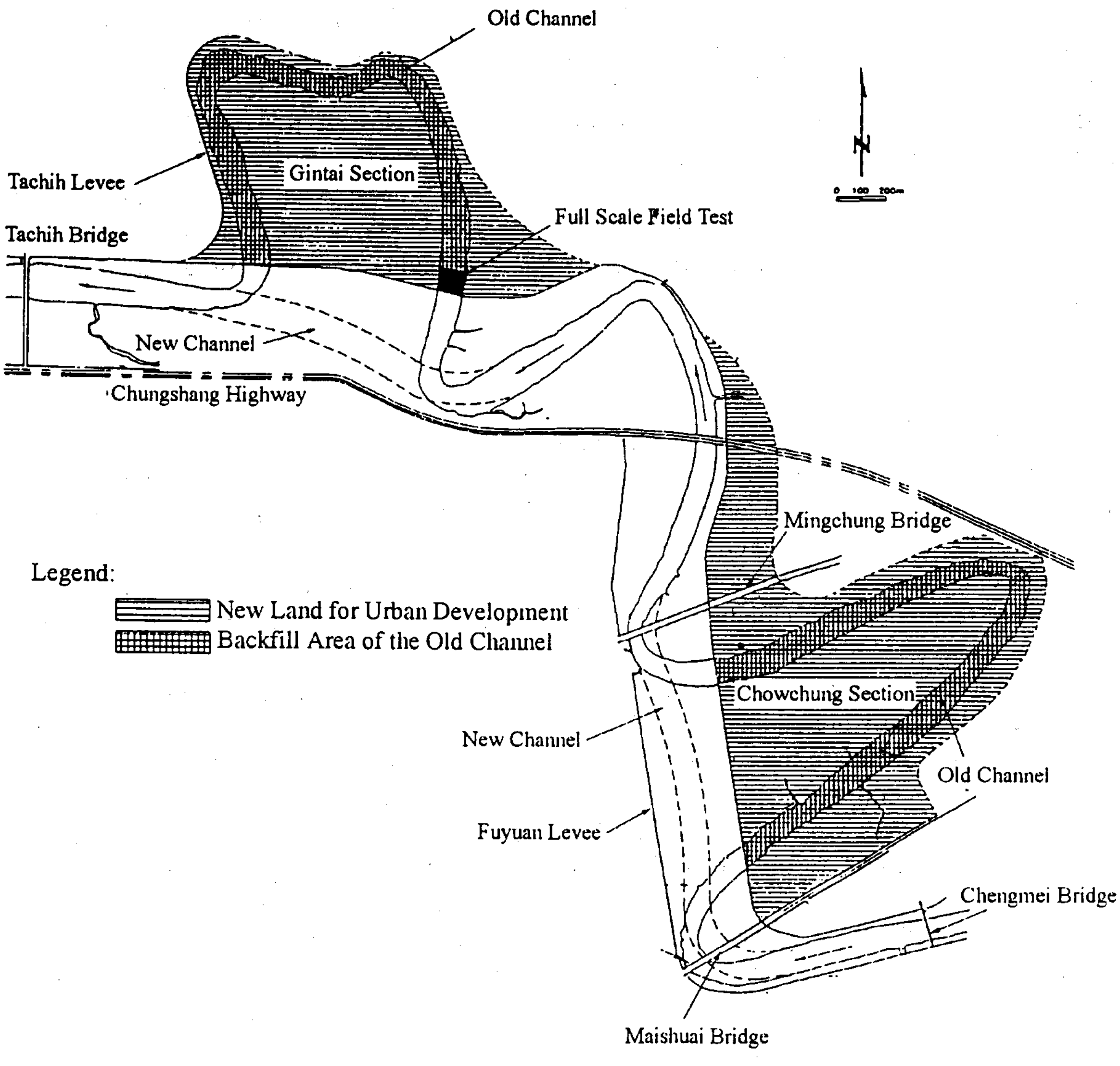

Figure 1 Plan of the Site.

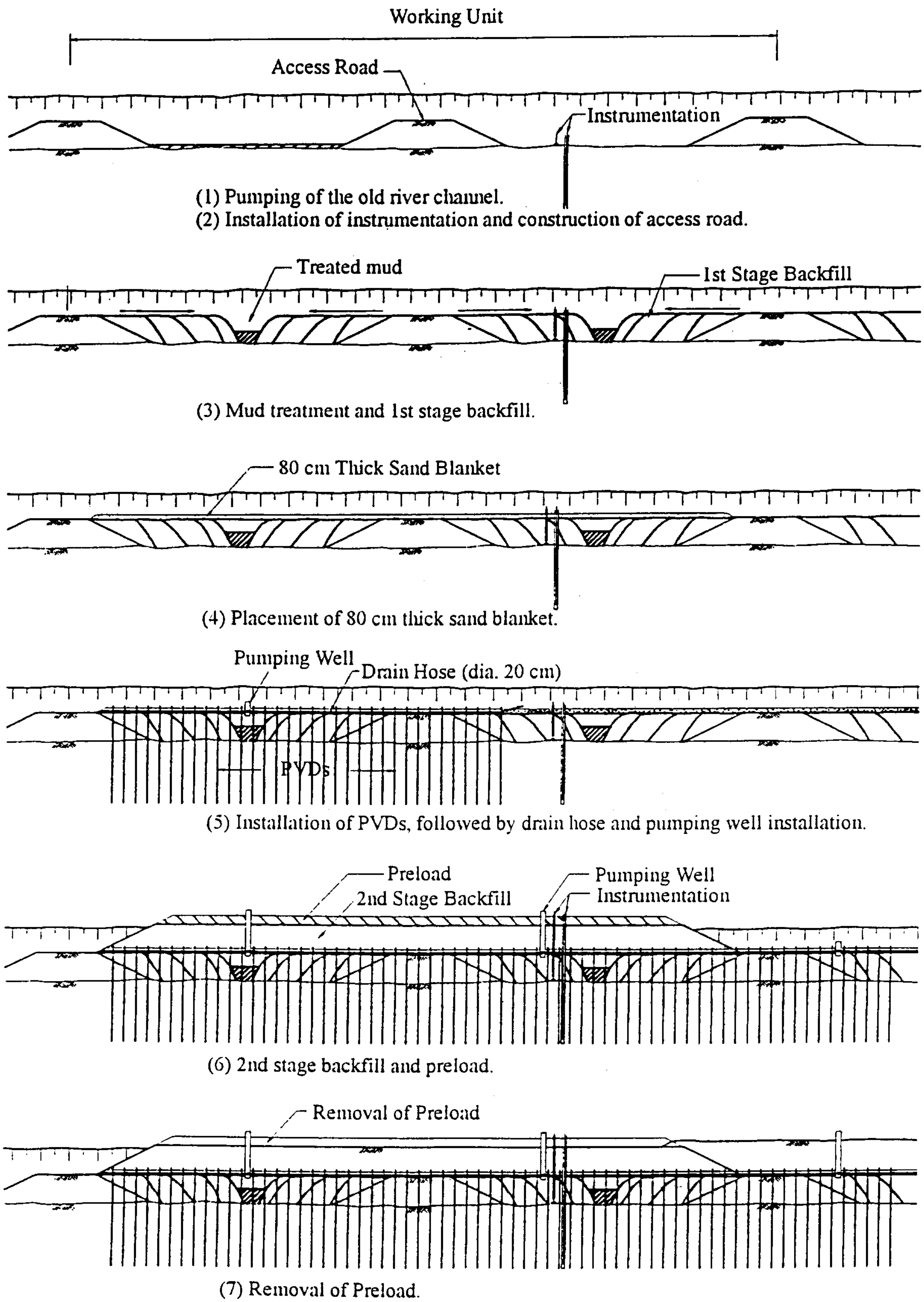

Figure 2 Typical Construction Sequence for the Backfilling of the Old River Bed.

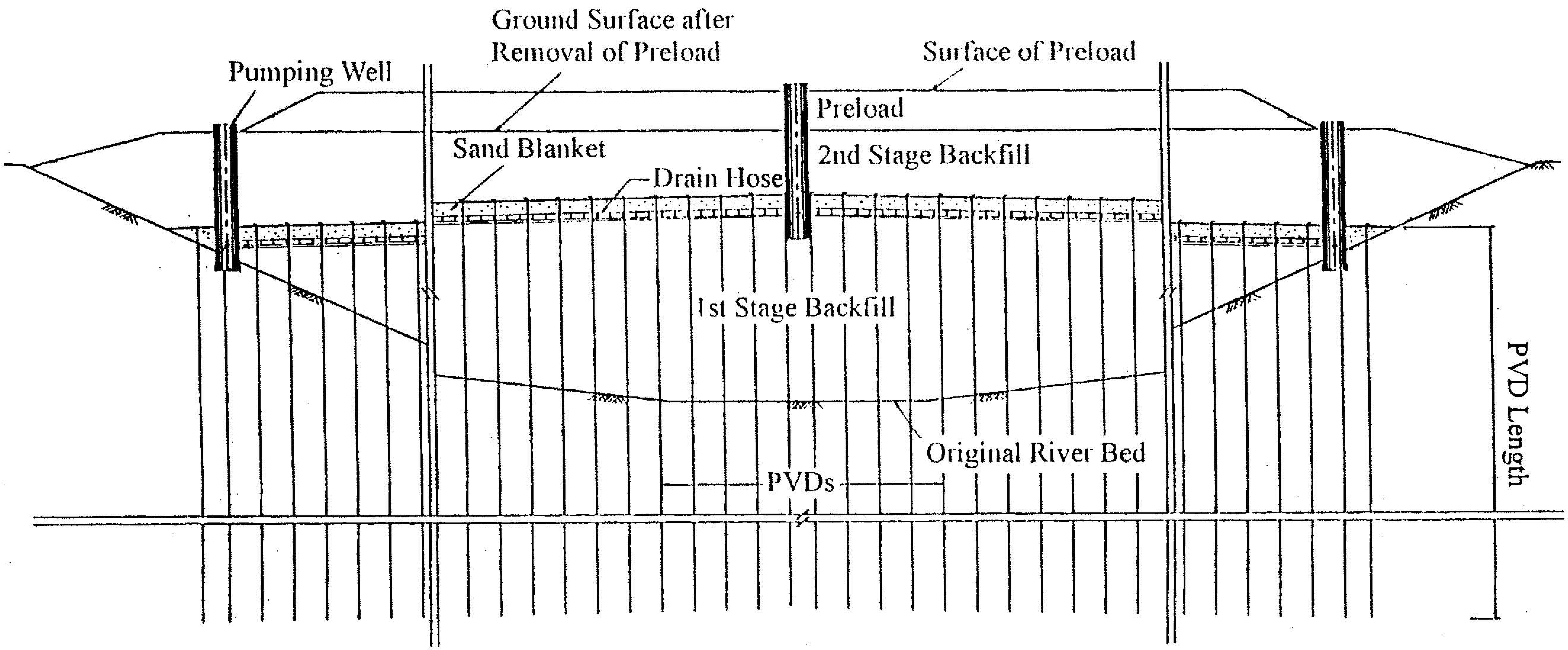

Figure 3 Typical Cross Section of Ground Improvement.

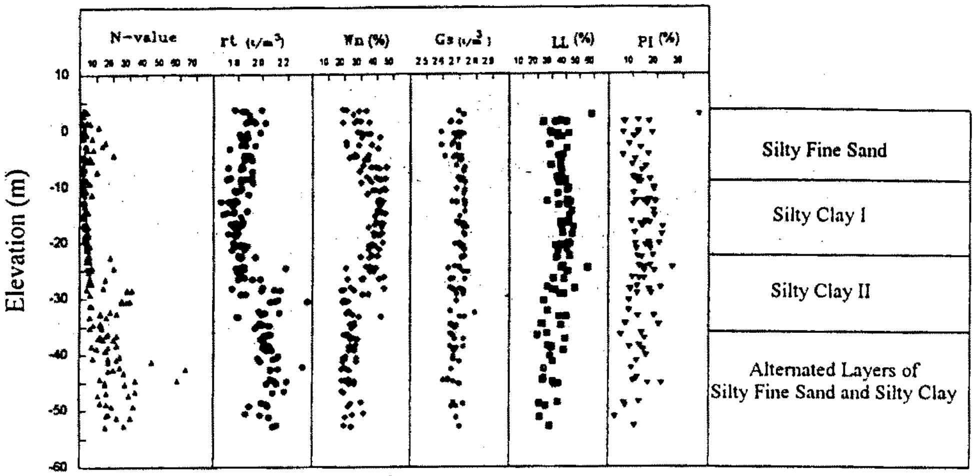

Figure 4 Soil Properties.

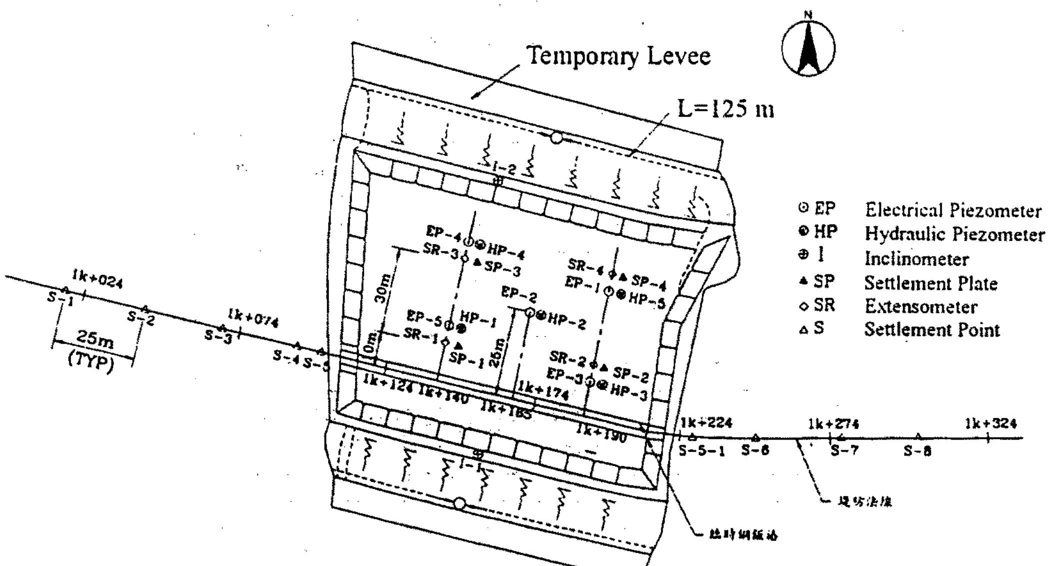

Figure 5 Instrumentation Layout.

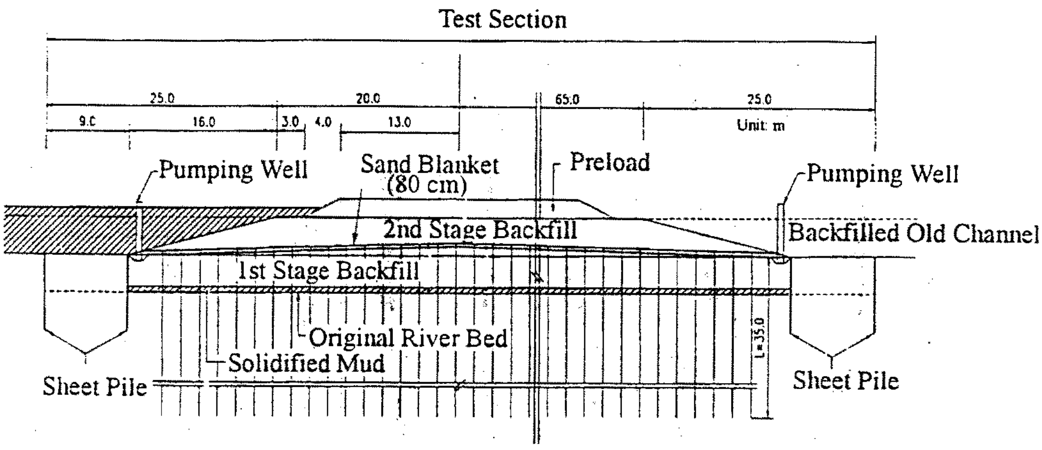

Figure 6 Cross Section of Full Scale Field Test.

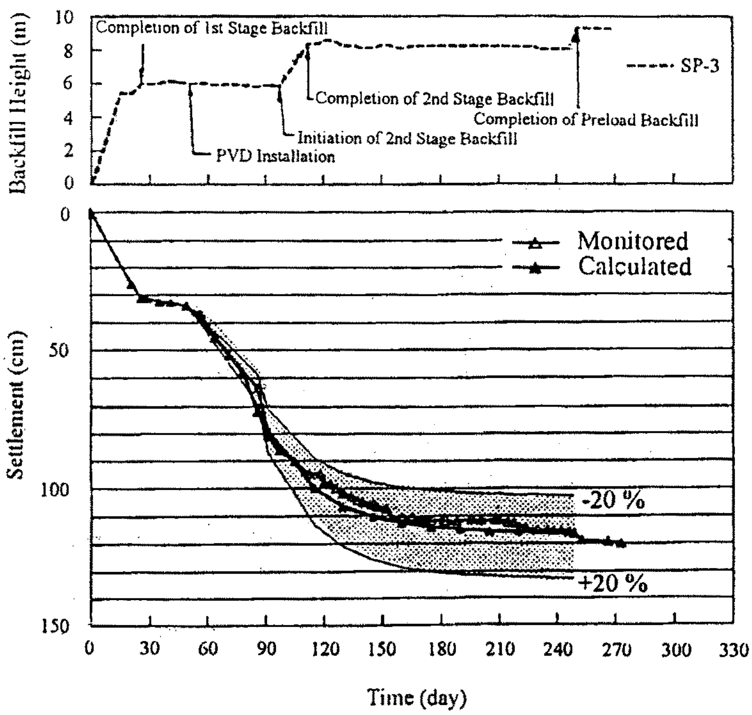

Figure 7 Monitored and Calculated Settlements.