SOFT GROUND TUNNELLING IN TAIWAN

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Soft Ground Tunnelling in Taiwan

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ABSTRACT: With the launching of many large scale underground construction projects, soft ground tunnelling has attracted much attention in Taiwan in recent years. Described herein are the various techniques commonly employed in Taiwan and several unique schemes as measures for protecting building along the routes.

1. Introduction

Soft ground tunnelling has a long history in Taiwan. There are several very old large size culverts in cities which may date back to the turn of the century, however, little is known regarding how they were constructed. Conceivably, most of them were constructed by using the cut-and-cover method. More recently, many of the large size utility pipes were installed by pipe-jacking. The laying of the sewerage line running along Mingtsu Road in the City of Taipei is believed to be the first

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application of shield machines in Taiwan. Since then the number of shield machines used increased drastically year by year. About 70 machines have been launched since 1976. It is the purpose of this paper to summarize the applications of various tunnelling techniques adopted in Taiwan. However, due to the limited space available, the cut -and-cover method and pipe-jacking are specifically excluded.

Because of the mountainous terrain of the Taiwan Island, soft ground tunnelling is limited to coastal areas where young sediments are present. In fact, the majority of the projects are carried out in the two largest cities, namely, Taipei and Kaohsiung. Most of the case histories reported herein are located in the Taipei Basin, therefore, a typical soil profile in the T2 Zone of the Taipei Basin is shown in Fig. 1 for reference. The six sublayers, numbered in the sequence of their dates of deposition, in the Sungshan formation are distinct in the central city area. Some of these sublayers thin out towards the rim of the basin, or even totally disappear.

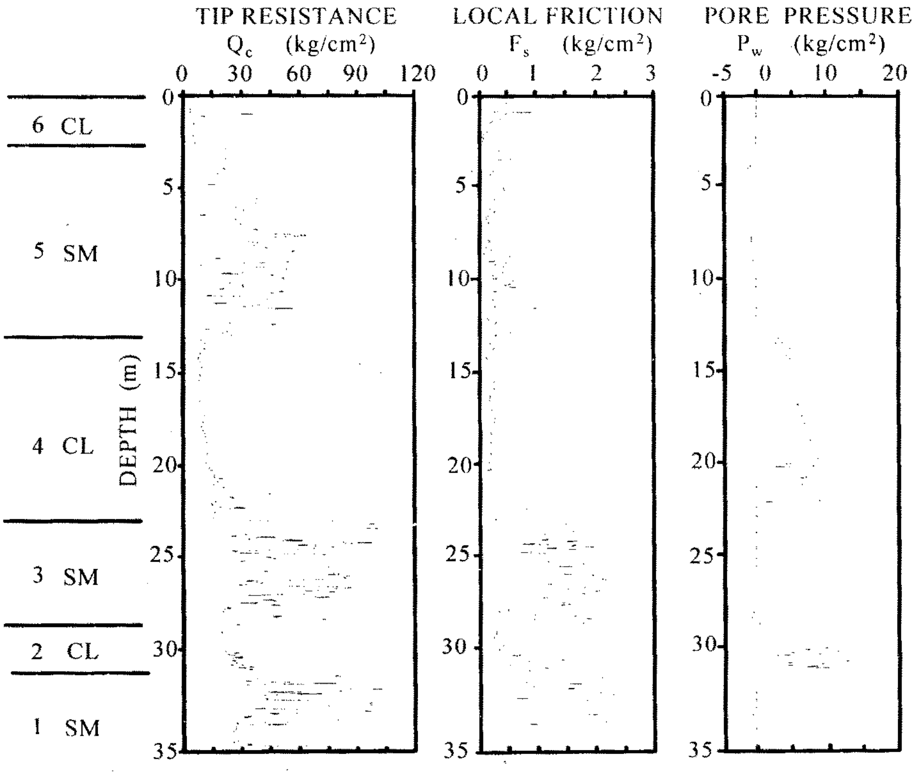

Fig. 1 Soil Profile for T2 Zone of Taipei Basin

2. Tunnelling Techniques

The suitability of various tunnelling techniques to local ground conditions has been extensively studied and reported (Ju, 1984; Tsai, 1988; Ju, 1993). Presented hereinafter are representative case histories in each category.

2.1 NATM Tunnelling

The NATM method is being used for constructing a 222m stretch of twin tunnels linking Taipower Building Station (G09) and Kungkuan Station (G07) of the Hsintein Line of the Taipei Rapid Transit Systems (TRTS). A longitudinal section of the tunnels is given in Fig. 2 to illustrate the excavation stages (Chen et al, 1990). The primary lining consists of lagging sheets, wire mesh and a layer of shotcrete of 250mm in thickness. The secondary lining consists of 200mm reinforced concrete. Compressed air, with pressures up to 1.36 bar, is applied for maintaining face stability. The progress was satisfactory for the first 100m and then was hampered by air leakage through drainage culverts and pores in a gravelly layer encountered at the face. The problem was solved by extensive chemical grouting in front of the headings.

The NATM method is planned to be used for constructing the Panchiao Station of the Panchiao Line of the TRTS. The construction is likely to start in 1995. A cross-section of the station is shown in Fig. 3. The work will be a major undertaking for NATM tunnelling in soft ground, particularly in consideration of the high groundwater table at the site, and will certainly be listed among the world construction records for its great

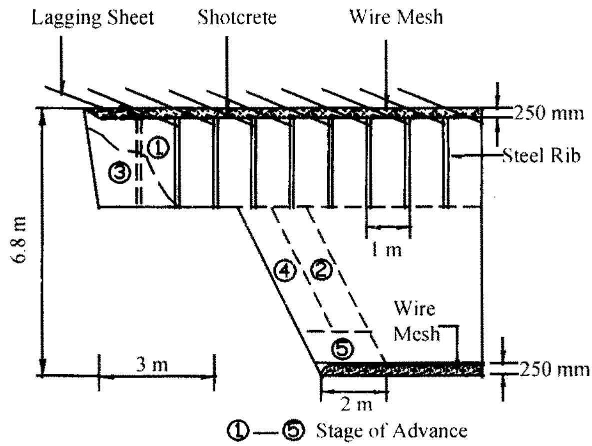

Fig. 2 NATM Tunneling for CH221 of TRTS

height between the roof and the invert. Apart from the running tunnels, it is noted that 47 cross passages, typically 4.5m in diameter, linking the twin tunnels, in the TRTS Priority Network are all to be constructed by using the NATM method (Ju, 1993).

2.2 Shield Tunnelling

In the Taipei Basin alone, 33 km of sewerage tunnels have been constructed since 1976 and 24 km (route length) of TRTS tunnels are scheduled to be excavated by the end of 1995. The diameters range from 2.4m to 4.8m for the sewerage tunnels and are typically 6.1m for the TRTS tunnels. Five types of shield machines have been used and are briefly described as follows:

2.2.1 Use of Open Face Shields

As mentioned previously, the construction of the trunk sewer along Mingtsu Road in Taipei is the first application of shield machines in Taiwan. The tunnel is about 2.6 km in length. Two open-face shield machines of 4,530mm in diameter were launched from the two ends of the tunnel in July, 1977. Earth in front of the face was excavated manually. One of the machines stopped at a distance of 72m and the other at a distance of 33m as a result of excessive inflow of water into the tunnel and sand and leakage of compressed air. Although a series of grouting measures had been implemented, the operation had to be suspended (Ou and Tsai,

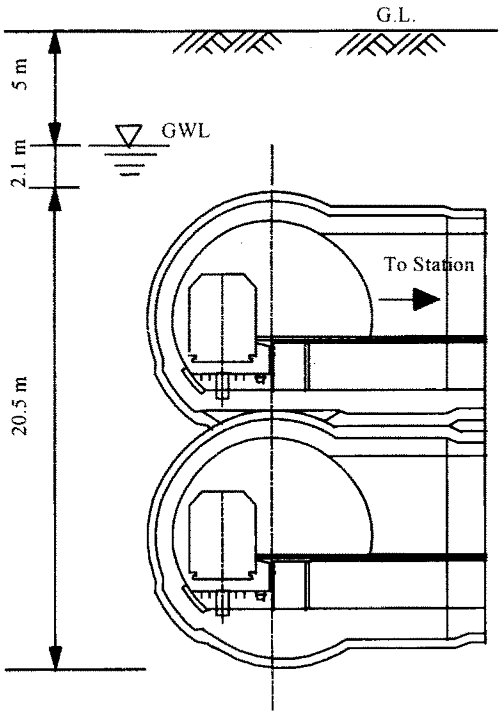

Fig. 3 NATM Tunnelling for Panchiao Station

1988). Open-face shields have not been used since then because of this poor experience.

2.2.2 Use of Mechanical Shields

The Project was resumed in July, 1980 by using two mechanical shield machines equipped with disc cutters (Tsai, 1988). The tunnel was finally completed in May, 1984. However, mechanical shields lost the market to earthpressure balancing shields and slurry shields, and were seldom, if ever, used since then.

2.2.3 Use of Earth Pressure Balancing Shields

Earthpressure balancing shields appear to be the most popular type of shields in Taiwan nowadays. They are used in all but one of the 22 civil contracts, which involve shield tunnelling, in the Priority Network of the TRTS. For the sewerage systems in Taipei, between 1979 and 1992, a total length of 31 km of sewerage lines were driven by using earthpressure balancing shield machines, while only 5 km were driven by using slurry shield machines. For the construction of Kaohsiung sewerage systems, presumably, because the subsoils are sandier, earthpressure balancing shield machines and slurry shield machines compete closely, with a total length of 5 km for the former and 5.6 km for the latter.

2.2.4 Use of Slurry Shields

Two slurry machines were used for the four tunnel drives in Contract CH221 of TRTS. This is the only application of slurry machines in TRTS. The Sungshan formation in the T2 Zone of Taipei Basin in which most of tunnel drives are located, refer to Fig. 1, contains both sands and clays of equal amounts. Therefore, from a technical point of view, slurry shields and earthpressure balancing shields are comparable. In fact, most of the earthpressure balancing shields are equipped with facility of adding slurry or some kinds of lubricants to improve the workability. The major reason for slurry shields to be outnumbered is the lack of space to house the slurry treatment plant.

2.2.5 Use of Blind Shields

Blind shields were successfully used for constructing a 1,170m section of sewerage line along Fuyuan Street in Taipei City. The shields were 3,730mm in diameter and the outer diameter of the lined tunnel was 2,800mm. The earth cover over the crown was 7 to 9m. The average daily product was 5 rings per day, with a length of 900mm each ring, and 17 rings maximum (Tsai, 1988; Fang, Pan and Lin, 1992).

3. Protection Measures

3.1 Ground Treatment

High pressure jet grouting is the most common type of ground treatment for various purposes. It is used, with few exceptions, at: (a) the back of tunnel mirrors before the breakout of retaining wall for maintaining the face stability and for stopping seepage flow, and (b) at crosspassages to solidify the ground for hand mining. High pressure grouting is frequently used when two tunnels are in a close proximity, particularly in a staggered or a stacked configuration, for minimizing disturbance to the tunnel(s) which have been completed during the driving of the subsequent tunnel(s). It also serves the purpose of minimizing ground settlements due to tunnelling. For example, Fig. 4 shows the grouting scheme adopted for protecting North

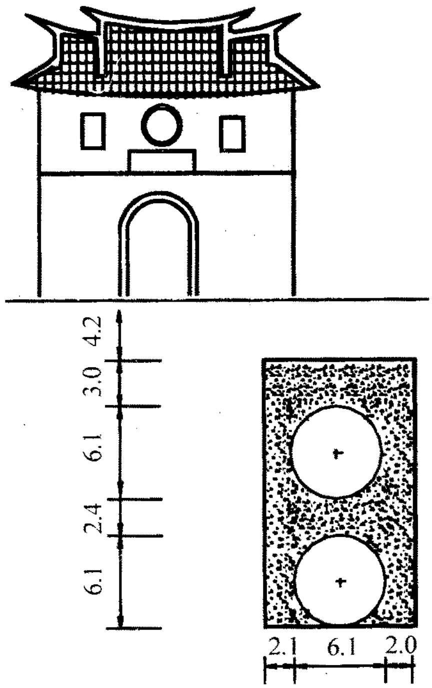

Fig. 4 Jet Grouting for Protecting the North Gate

Gate, a Class A historical monument, of the Taipei City. HDD (Horizontal Directional Drilling) injection method is adopted by the contractor of CC277 of the Chungho Line of TRTS for protecting houses on top of tunnels, refer to Figs. 5 and 6 (Bilfinger, et. al, 1994). There will be 18 grouted tubes, 1.5m in diameter, to form an annulus around each tunnel for the purpose of reducing ground settlements, hence, potential to building damages.

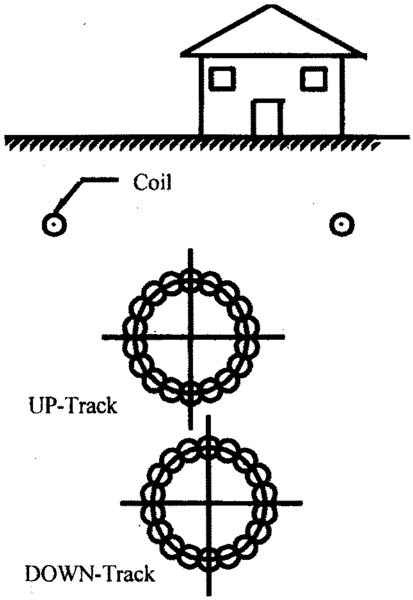

Fig. 5 HDD Grouting for Building Protection along Chungho Line

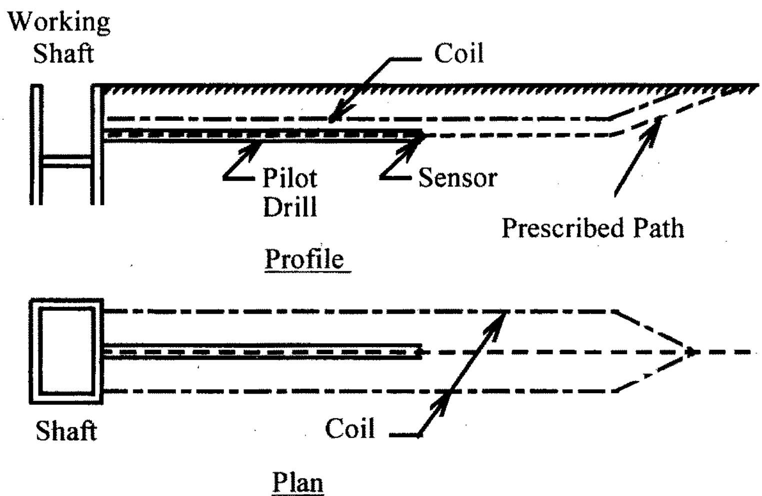

Fig. 6 Locationing and Steering of HDD Grouting

Firstly, pilot drills will be made by using a self-guided drilling bit equipped with a sensing unit which receives signals from the two coils buried at shallow depths below the ground surface. The signals are transmitted back to a Gyro navigation system which continuously monitors the position of the drilling bit. This Gyro navigation system is of the same type as the one used in the oil and gas industry for oil/gas explorations and in the aeronautic industry for guiding missiles and other types of kinematics objects. With the position of the drilling bit continuously monitored, a True Tracer system will steer the bit to follow a prescribed path. The deviations from the prescribed path are claimed to be within 300 mm.

The hole is supported by slurry for stability. Once the drilling bit reaches its final destination, it will be replaced by a reamer for the enlargement of the hole. This reamer will be rotated and pulled by the rig until the reamer is back to the starting point. A larger reamer is then attached and the string is pulled from the other end to enlarge the hole for the second time. This procedure is repeated till the desired diameter of the hole is achieved. The hole is then filled with cement grout. The work is to be completed by the summer of 1995 and the results are anxiously awaited.

3.2 Compaction Grouting

A trial was carried out by the contractors of CT201A of the Tamshui Line of TRTS for evaluating the effectiveness of compaction grouting as a building protection measures. A mixture of pea gravels, sand, cement and water was injected into ten holes at depths of 8m and 7m below the ground surface immediately after the passing of the shield. The average intake was 0.9 cubic meter per hole. The layout of the grout holes and the locations of the grout bulbs in relation to the tunnel are shown in Fig. 7. Data indicate that the settlements in the grouted zone (SM-50 and SSI-18) were essentially the same as those in the ungrouted zone (SSI-22 and -23). In fact, the former are even larger than the latter by 2 to 3mm. It is thus doubtful that compaction grouting will be effective in soft ground.

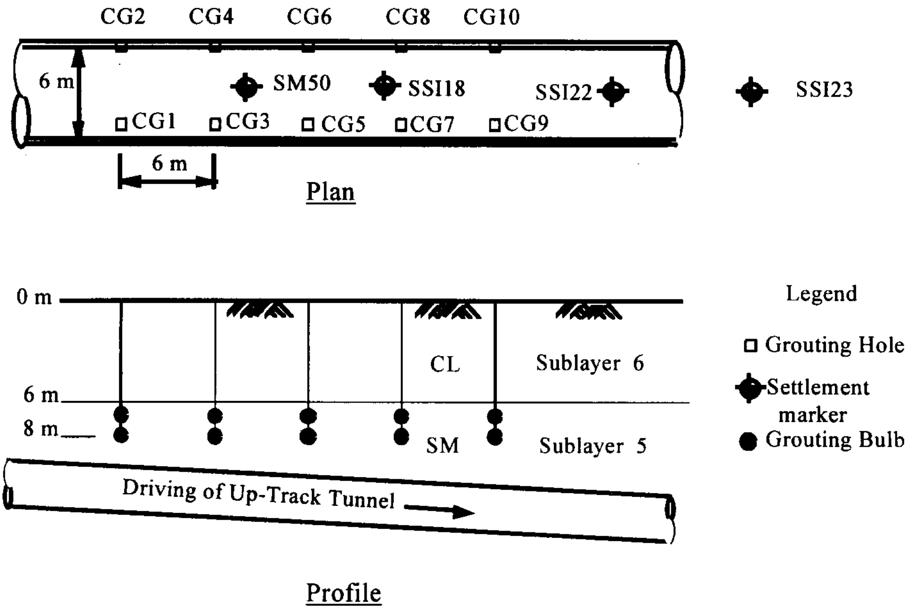

Fig. 7 Compaction Grouting for Reducing Ground Settlements over Tunnels

3.3 Secondary Chemical Injection

On the other hand, unpublished data indicate that the application of secondary chemical injection, as illustrated in Fig. 8, reduces ground settlements by a half. There are quite many sections of tunnels in which secondary chemical injection was carried out. The data are being compiled and will be published soon.

4. Ground Settlements

Ground settlements due to tunnelling have been extensively studied (Fang and Chen, 1990; Fang, Lin and Su, 1994). Excellent records, refer to Fig. 9, were obtained for Section B-1 of Contract CH218 of TRTS and the three phases of ground settlements can clearly be

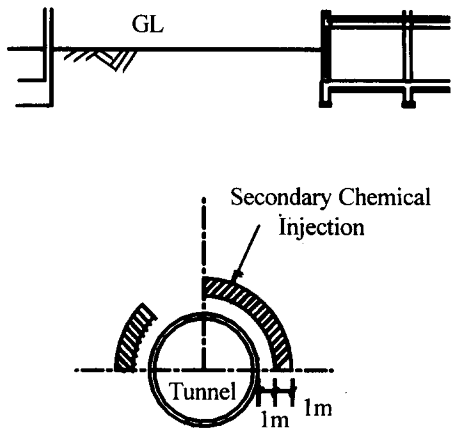

Fig. 8 Secondary Chemical Injection

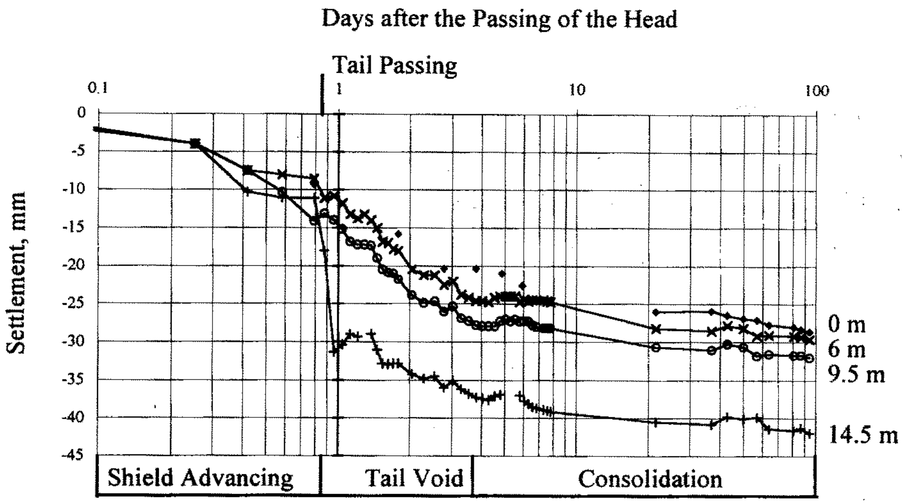

Fig. 9 Settlements at Center, Section B-1, CH221

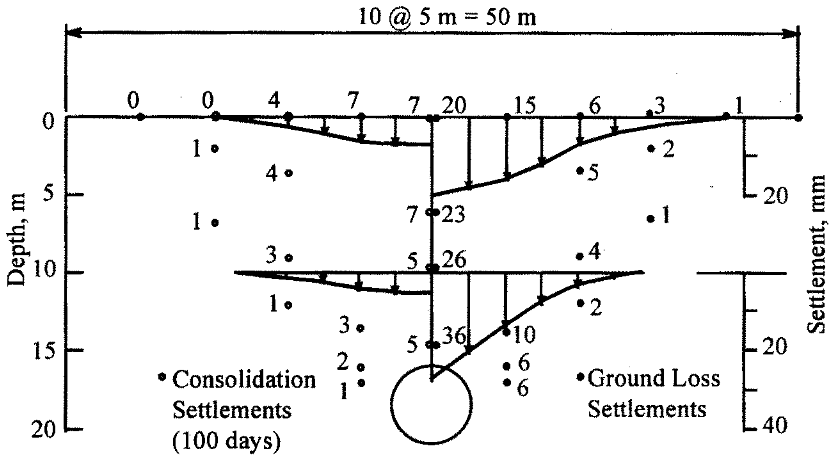

Fig. 10 Ground Loss/Consolidation Settlements and Settlement Troughs at Surface and at a Depth of 10m

distinguished (Hwang, Wu and Lee, 1995). The ground loss settlements and consolidation settlements are plotted side by side in Fig. 10. Also plotted in the same figure are the settlement troughs at surface and at a depth of 10m. Since ground loss settlements and consolidation settlements have different mechanisms and are affected by different factors, it is important to study them separately. The ground loss (with consolidation settlements excluded) for different geological zones in the Taipei Basin are plotted in Fig. 11. Data can be classified into five categories as follows:

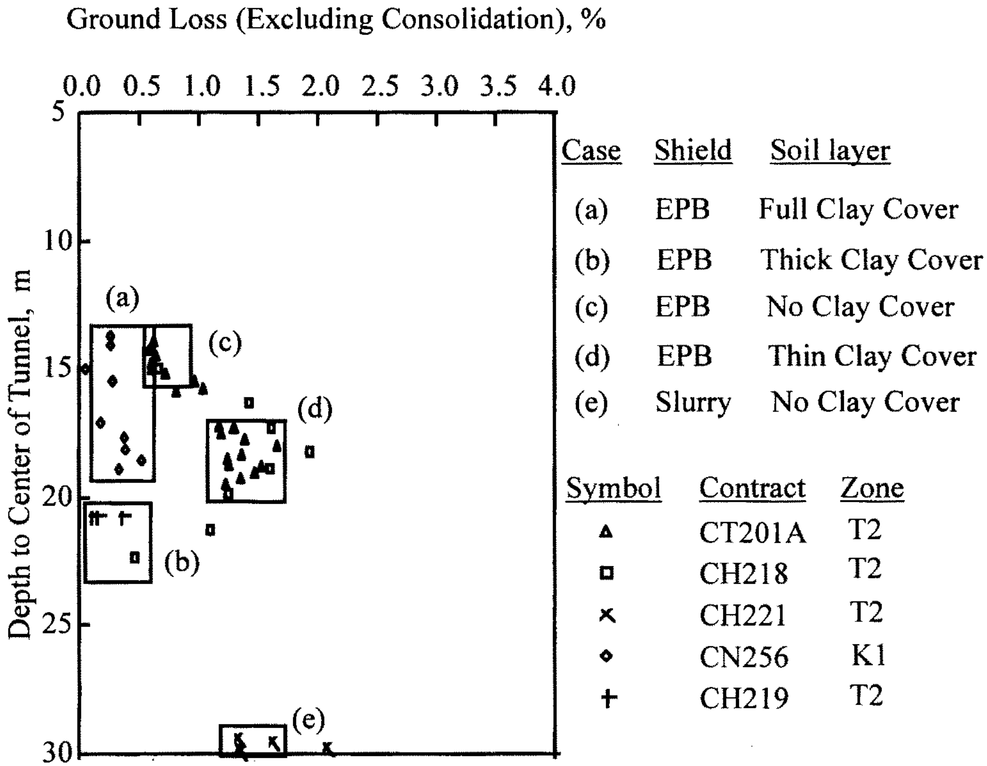

Fig. 11 Ground Loss for TRTS Tunnels

(a) The ground loss is the smallest in K1 Zone in which the sandy sublayers in the Sungshan formation, namely, Sublayers 3 and 5, are absent and clay dominates.

(b) In the T2 Zone, where the clayey cover above the tunnel crown is thick (say, 3m or more) ground loss is the same as that in the K1 Zone, i.e., Case (a).

(c) Where the clayey cover is totally absent, the ground loss is slightly higher than those for Cases (a) and (b).

(d) Ground loss is the highest where a thin clay layer, say, a couple of meters or less, is present above the crown.

(e) Slurry shield machines were used on the CH221 tunnel drives with both horizontal and vertical curves.

In Cases (a) and (b), it is conceived the clay in Sublayer 4 has sufficient standup time to hold up the tail void. In Case (c), presumably the sand in the Sublayer 5 has a high

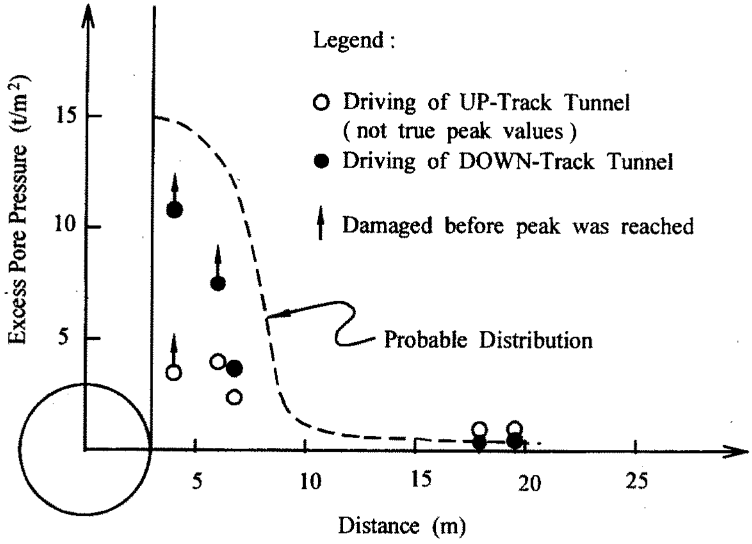

Fig. 12 Excess Pressures at Springline Level

permeability to allow water to ingress into the tail void fast enough to equalize the water pressure, meanwhile, it has an optimum silt content to avoid internal erosion of particles. Therefore, the closure of tail void is minor. In Case (d), water isunable to get into the void freely because of the low permeability of the clay, on the other hand, the clay blanket is too thin to fully withstand the differential pressures on the two sides. Therefore, the potential for the void tends to close in is greater than the above cases. Case (e) can not be compared with other cases fairly because: (1) different type shield machines were used, (2) the drives have both horizontal and vertical curves, and (3) the depths are much greater.

5. Porewater Pressure Response

For confirming the above hypothesis and to study the mechanism of consolidation settlements, pore pressure response to tunnelling was closely monitored at several sections. Figure 12 shows the results obtained by Hwang, Wu and Lee (1995) for a 6m diameter tunnel of the TRTS. As can be noted that a maximum excess pore pressure of an order of 10 to 15 t/m² was recorded and the distribution appears to be

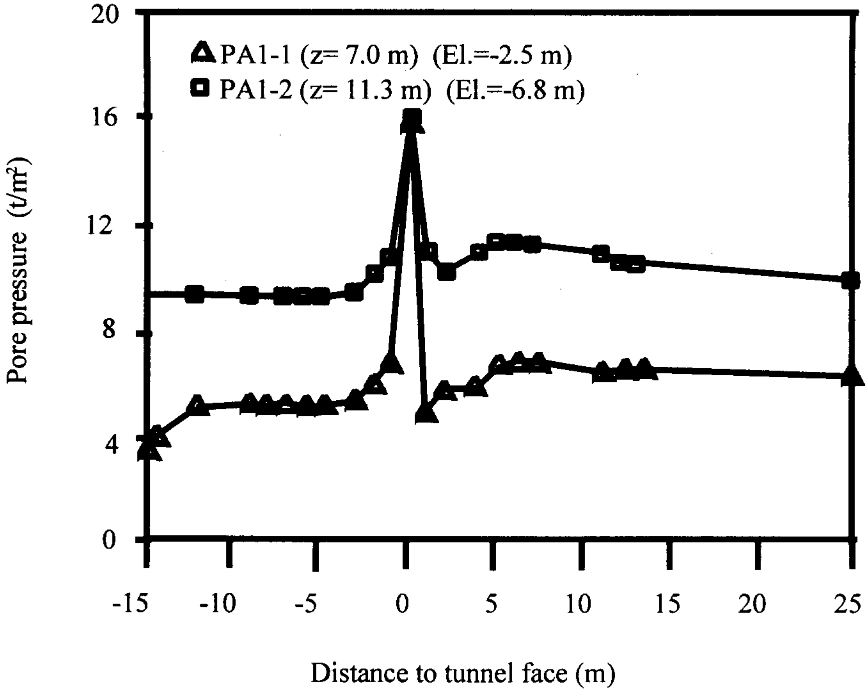

Fig. 13 Variation of pore-water pressure during construction (After Fang and Chen, 1990)

limited to one diameter from the edge of the tunnel. A similar study was conducted by Fang and Chen (1990) for a 3.8m diameter sewerage main and Fig. 13 shows the results obtained. In both cases, earthpressure balancing shields were used. So far data are insufficient for detailed studies. There are many instrument sections along the TRTS routes to be passed, and in a year or so, there will be sufficient data for drawing conclusions.

6. Summary

With the launching of the Six-Year National Development Plan, many major underground works are being carried out in Taiwan and much progress has been achieved in soft ground tunnelling. As the technology advances, the performance of recent tunnel drives, in terms of both productivity and safety records, is by far better than what was experienced before.

Acknowledgments

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