

# **PORE PRESSURE RESPONSE TO SHIELD TUNNELLING IN SOFT CLAY**

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## **PORE PRESSURE RESPONSE TO SHIELD TUNNELING IN SOFT CLAY**

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**ABSTRACT:** Presented herein are the data obtained for a section of tunnel driven in the K1 Zone of the Taipei Basin with the aim of understanding the porewater pressure response to shield driving. It has been found that tremendously high excess porewater pressures were induced but their distribution is limited to a distance of one diameter from the edge of the tunnel.

### **1. INTRODUCTION**

Although settlement over tunnels during tunneling has been a subject extensively studied by numerous researchers in the past, quantitative prediction still can not be made with confidence. This is because of the fact that there are just too many factors affecting the ground response to tunneling. One of the primary factors is the porewater pressure induced during tunneling leading to consolidation settlements.

### **2. CASE STUDIED**

The instrumented section studied is in Contract CN256 of the Nankang Line. The soil profile at the location of the section is given in Fig. 1. In brief, the site is located in the K1 Zone of the Taipei Basin and the subsoils consist of silty clays with low plasticity (classified as CL). Typical composition of these clays is : sand - 3%, silt - 53% and clay - 44% and typical undrained shear strength is of the order of 30 to 40 kPa (Woo and Moh, 1990). The twin tunnels were driven by using two earth pressure balancing shield machines, 6050 mm in diameter and 7180 mm in length. Each machine is driven by 22 jacks with a capacity of 150 tons each, giving a total thrust of 3300 tons. The tunnels are lined by reinforced concrete segments, 250 mm in

thickness and 1000 mm in length. Both tunnels have a straight and horizontal alignment and therefore copy cutter was not used. The outer diameter of the lined tunnels is 5900 mm, giving a theoretical clearance of 75 mm for the tail void.

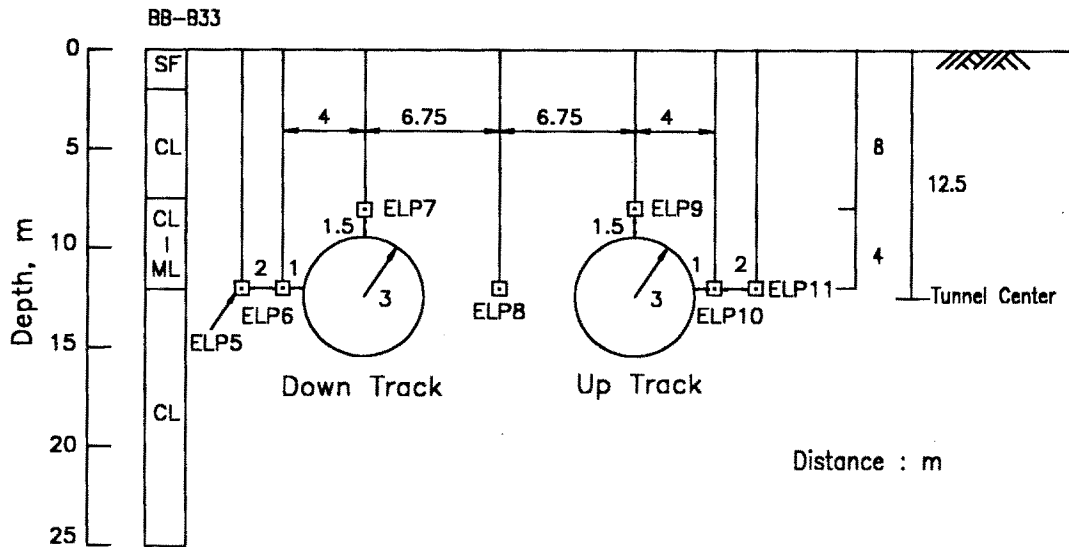


Fig. 1 Soil Profile and Instrument Layout

The Up-Track tunnel was launched first and the shield machine passed this instrumented section on July 3, 1993. For the Down-Track tunnel, the shield machine passed the section on November 16 and 17, 1993. Since more data are collected during the driving of the Down-Track tunnel, the detailed progress of this drive is shown in Fig. 2 for later reference. Field records show a total thrust of 798 tons was applied to the shield and it took 31 minutes to complete the excavation for Ring 90, where the section is located, giving a speed of 33 mm/min. The quantity of the slurry injected into the earth chamber is 1612 liters and a total of 27.03 m<sup>3</sup> of sludge was removed. The total earth pressures in the chamber were monitored by 4 pressure cells and readings indicate an average of 1.73 kg/cm<sup>2</sup> during shoving with a maximum of 2.02 kg/cm<sup>2</sup>.

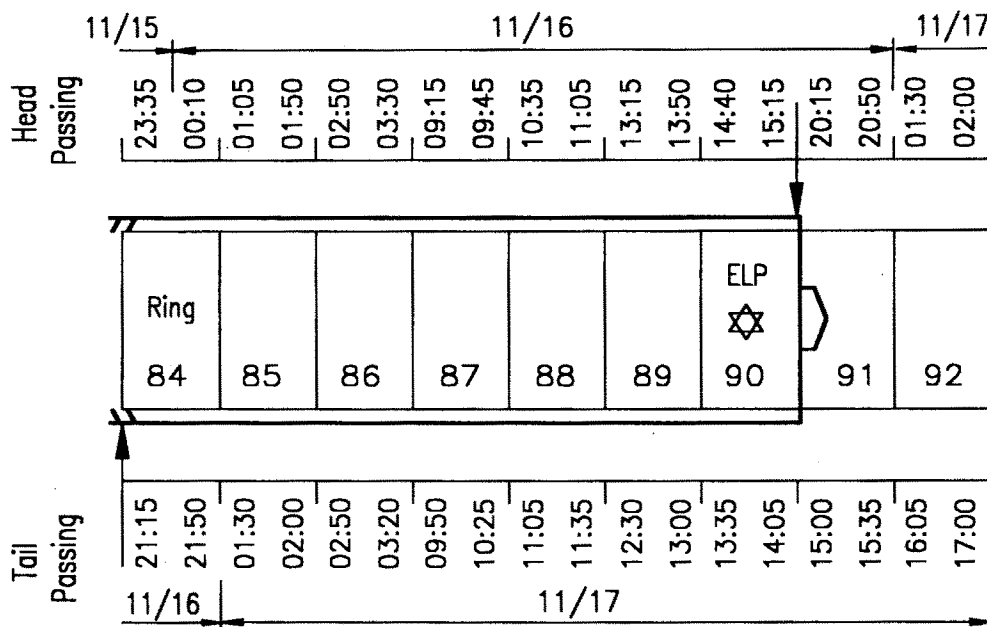


Fig. 2 Progress of Tunneling

### 3. POREWATER PRESSURE RESPONSE

Porewater pressures were monitored by using electrical type piezometers (ELP) and the positions of these piezometers are depicted in Fig. 1. The readings taken are shown in Fig. 3. As can be noted, significant positive excess porewater pressures were recorded as the shield machines approached and passed the section.

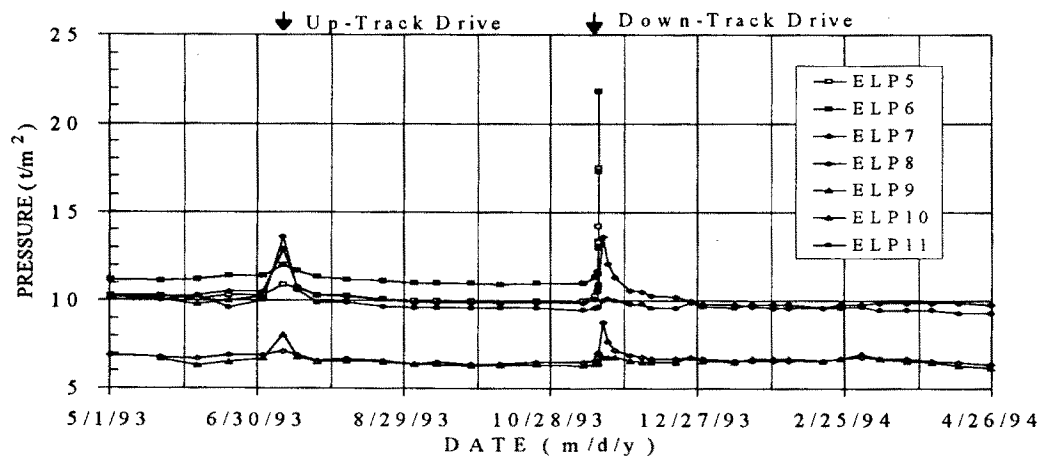
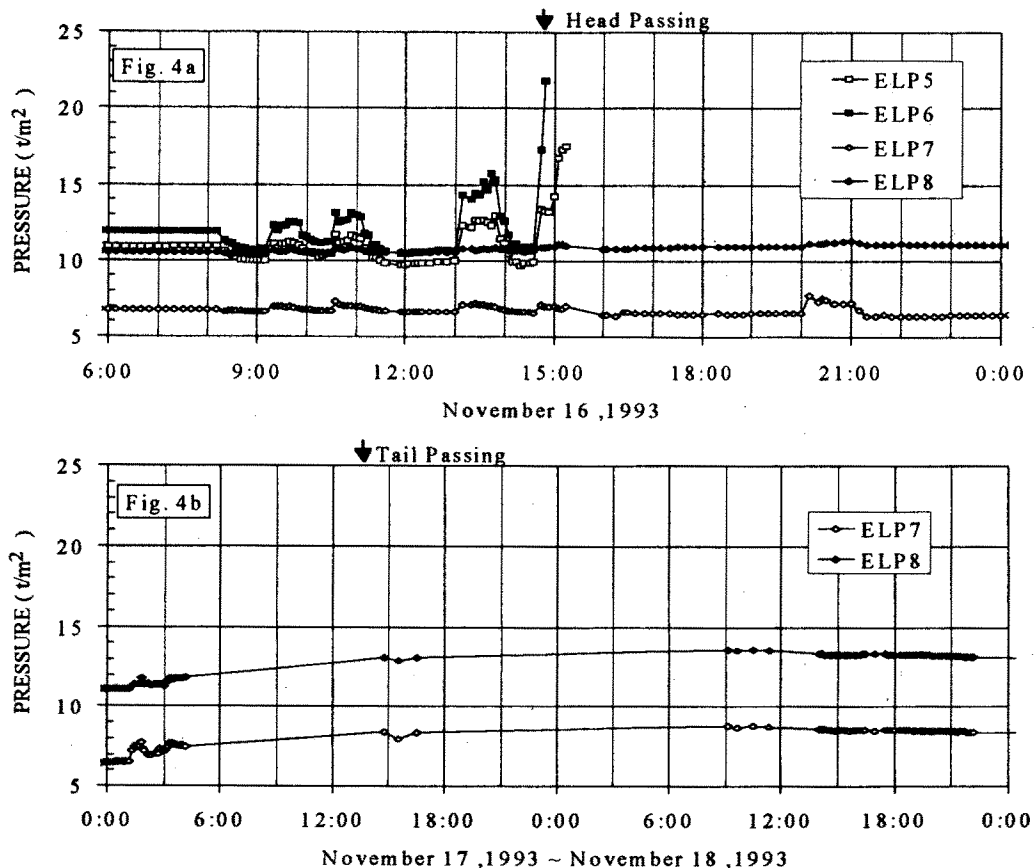


Fig. 3 Pore Pressure Readings

The final readings indicate a slight drawdown of the groundwater table. This was frequently observed for other tunnel drives and the reason for this to happen is unclear at this moment. It might have something to do with seepage flow into the tunnels as a result of leakage which is extremely difficult to totally prevent. In any case, the magnitude of the drawdown is too small to worry about.

A close-up of the readings taken in the 2-day period in which the shield machine in the Down-Track tunnel passed the section is given in Fig. 4. For simplicity, only the readings taken by those piezometers close to the tunnel are presented. The data shall be read in conjunction with the dates given in Fig. 2 for correlation with the progress of tunneling. Porewater pressure response was perfectly in phase with the movements of the shield. For example, on November 16, the day-shift started at 8:15 with the erection of Ring 82 after a long pause overnight. Piezometers indicated minute, but evident, reductions in porewater pressures. The reductions could be a result of disturbance to the ground due to the operation of the segment erector. Excavation for Ring 87, which is 3m ahead of the section of interest, started at 9:15 and ended at 9:45, and piezometers responded to the event faithfully.



Excavation for Ring 90, where all the piezometers are located, started at 14:40 of November 16 and porewater pressures immediately shot up. Excavation halted for a while because of a mechanical problem and the readings of ELP-5 taken during the pause (at 14:45, 14:50 and 14:55) appear to be steady. ELP-6, which is at a distance of, supposedly, only 1m from the edge of the shield at springline, was working at 14:45 and 14:50 but failed to give readings at 14:55. A similar event occurred previously to ELP-10, which has a similar position in relation to the tunnel as ELP-6, during the passing of the shield machine in the Up-Track tunnel. Therefore these two events can't be accidental. However, it is quite puzzling why and how this could have happened. Piezometers are quite durable and these piezometers used are supposed to be adequate for pressures up to 150 psi (10.5 kg/cm<sup>2</sup>). Ground displacements are not expected to be large enough to dislocate cable connection.

A set of readings were taken at 15:15, when the excavation for Ring 90 was completed. ELP-5 could no longer be read at 16:00. Since ELP-5 is even farther away from the tunnel (3m instead of 1m), ground displacements are expected to be even smaller. Furthermore, the three readings taken before the incident are steady and are well within the working range of the piezometer. Therefore, the cause for ELP-5 to become inoperative is even more puzzling.

The tail of the shield passed the section between 13:35 and 14:05 of November 17. Back grouting on Ring 90 was carried out between 15:00 and 15:35. A total of 1868 liters of grout was injected at pressures varying from 2.1 to 3.5 kg/cm<sup>2</sup>. Only three sets of readings were taken in this afternoon and they were taken at 14:45, 15:30 and 16:30. Therefore, pitifully, the effects of creation of the void at the tail were not picked up. As the tail void was created, one would expect the porewater pressures to drop because soils tend to close in leading to dilation of soil mass.

#### 4. DISCUSSION

The excess porewater pressures induced are plotted against the positions of the head in Fig. 5. The trend of increasing pressure as the shield approached and passed the section is readily apparent. The all-time highs of the excess porewater pressures for the two drives are shown in Fig. 6 and Fig. 7. For the Up-Track drive, the head passed the section between 15:05 and 15:45 of July 3 and the tail passed the section between 11:20 and 11:49 of July 4. Readings were not taken in the period between July 2, and July 10, therefore, peak response could have been missed. This explains the fact that less excess porewater pressures were recorded during the driving of the Up-Track tunnel. ELP-10 became inoperative on July 10. It is unsure

exactly when it was damaged. For the Down-Track tunnel drive, since reading of ELP-5 was steady, it is unsure whether the uprising reading taken by ELP-6 at 14:50 can be trusted.

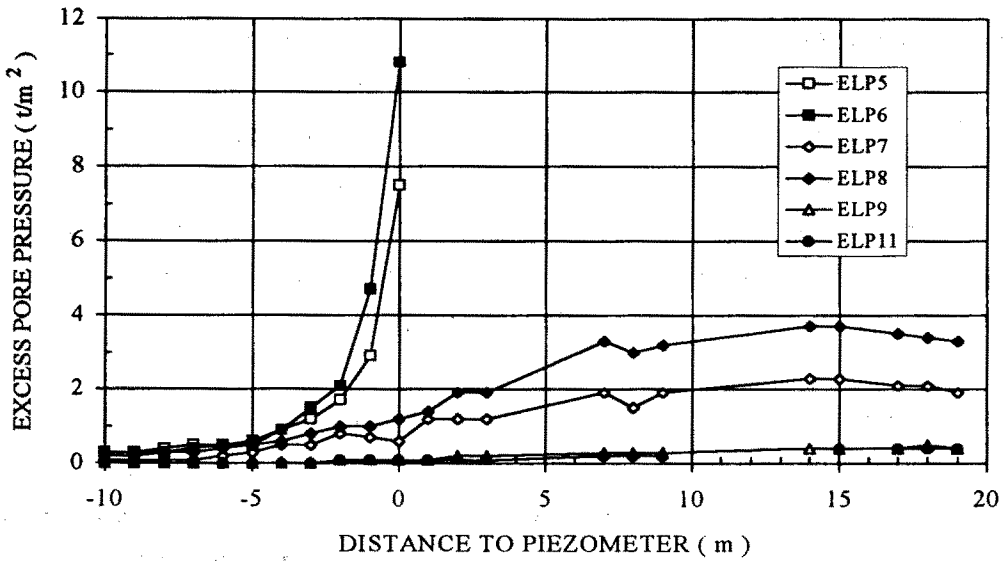


Fig. 5 Excess Pore Pressures Versus Distance ( Down Track )

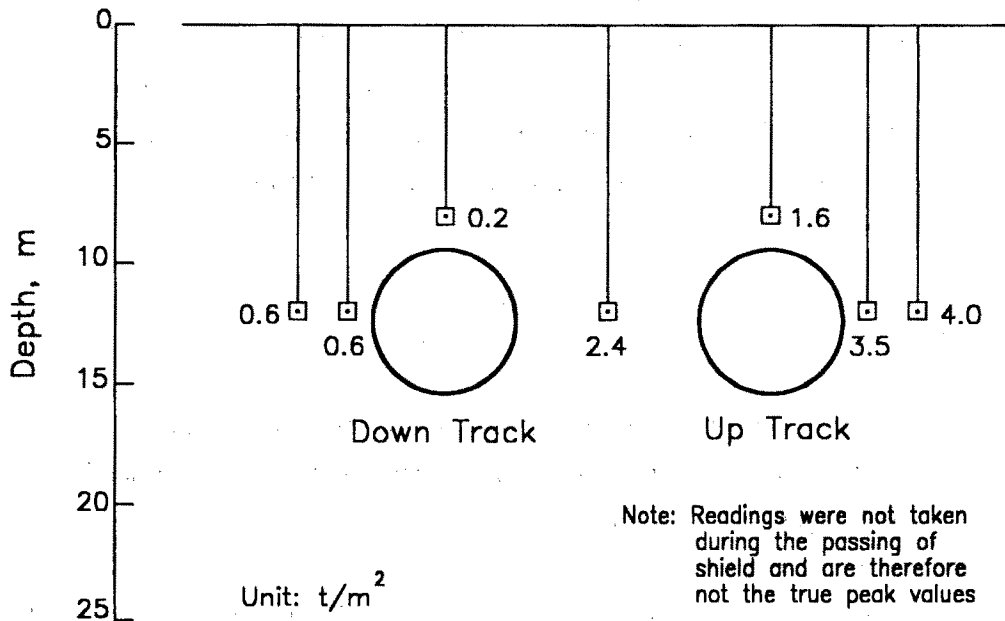


Fig. 6 Maximum Excess Pore Pressures due to Driving of Up-Track Tunnel

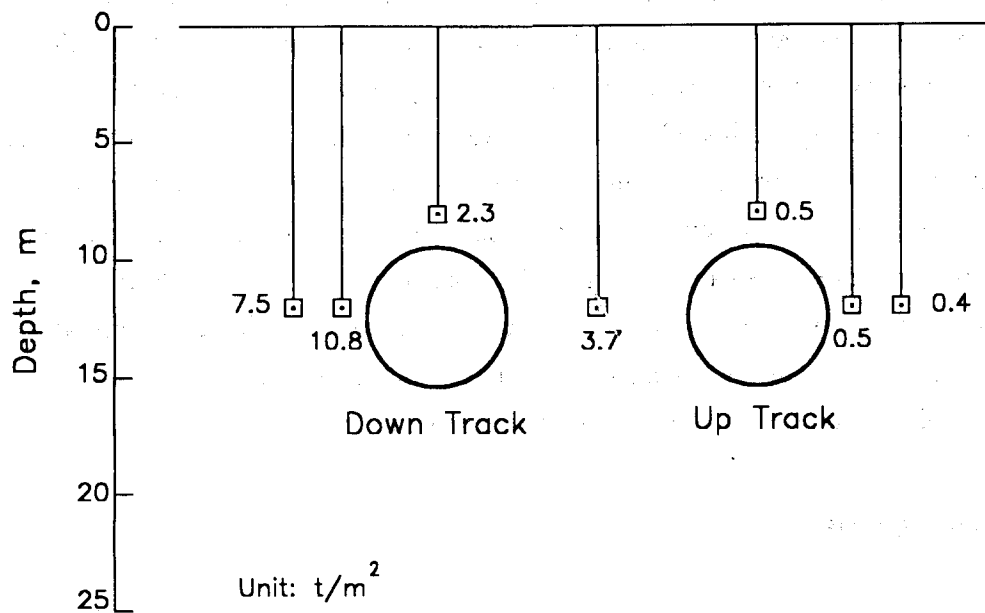


Fig. 7 Maximum Excess Pore Pressures due to Driving of Down-Track Tunnel

Naturally, the piezometers closer to the tunnels give greater excess porewater pressures. This will be clear from Fig. 8 which shows the variation of excess porewater pressures with distance. If a threshold of  $1 t/m^2$  is adopted, the porewater pressure response is found to be limited to 6m, or one diameter from the edge of the tunnel.

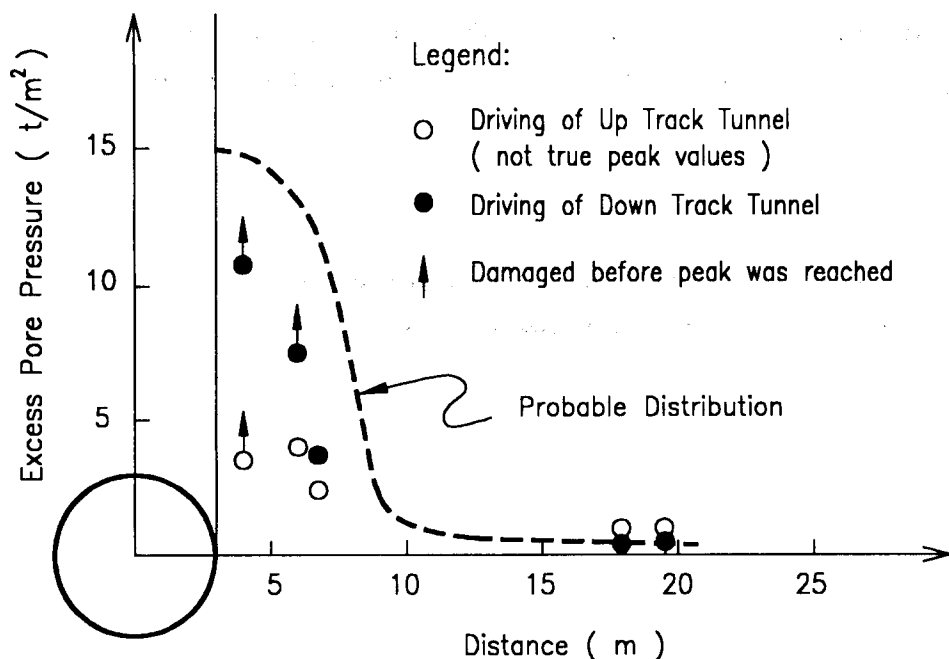


Fig. 8 Excess Pressures at Springline Level

It is noted that the pore pressures induced before the passing of the head dissipated rather quickly but the pore pressures induced after the passing of the tail dissipated rather slowly. The former phenomenon was due to the decrease in earth pressure in the chamber as the shield stopped moving. The magnitudes of excess porewater pressures induced as a result of shield driving are affected by ground condition and the way the shield is shoved. Greater excess porewater pressures will be induced in clays than sands because of the low permeability of the clays. As these pressures dissipate, ground will consolidate and settle. Settlements of this nature may drag on for months. In sands, porewater pressures dissipate quickly and there is little chance for them to build up. Therefore, ground settlements mainly come from the closure of tail void and will be completed in a very short time, say, in days.

## **5. CONCLUSIONS**

In the case studied, generation of excess porewater pressures is found to be limited to a distance of one diameter from the edge of the tunnel. The excess pore pressure induced as the head of the shield passed dissipated rather quickly while it took a month or even more for the pore pressure induced as a result of back grouting to fully dissipate.

## **ACKNOWLEDGMENTS**

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## **REFERENCES**

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