PORE PRESSURE INDUCED IN SOFT GROUND DUE TO TUNNELLING

by

R. N. Hwang, Z. C. Moh and M. Chen

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Pore pressure induced in soft ground due to tunnelling

Hwang, Richard Nanhuei
Moh and Associates, Inc., Taipei, Taiwan
Moh, Za-Chieh
Moh and Associates, Inc., Taipei, Taiwan
Chen, Michael
Chief Engineer, CDPO, Dept. of Rapid Transit Systems, TMG, Taipei, Taiwan

ABSTRACT: Dissipation of excess pore pressure has been known to cause long-term consolidation settlement of ground. Pore pressures were closely monitored during the driving of two tunnels, one in silty sands and the other in silty clays, in an attempt to reveal the responses of pore pressures to tunnelling. It has been found that backfilling grouting was responsible for the excess pore pressures induced and the responses in sands and in clays have totally different patterns.

1 INTRODUCTION

Excess pore pressure induced during tunnelling is a potential source of long-term consolidation settlements and deserves studies. However, because of its complexity, the problem of pore pressure response to tunnelling is not fully understood. Piezometers were installed and pore pressures were closely monitored during the passing of shields at a few sections of Taipei Rapid Transit Systems. The results of two of the cases, one with the tunnel driven in sand and the other with the tunnel driven in clay, are presented herein.

2 CASES STUDIED

2.1 Sandy Ground

The instrument layout and soil stratigraphy for Section T2 of Contract CP261 of the Panchiao Line are shown in Fig. 1. The centers of the twin tunnels are at a depth of 27.1m below surface. An earthpressure balancing shield machine, with an outer diameter of 6250mm and a length of 6920mm, was used for driving these two tunnels. Reinforced concrete lining segments are 250mm in thickness and 1000mm in length. The outer diameter of the segments is 6100mm.

The site is located at the border between T1 and T2 Zones in the Taipei Basin (Chin, Crooks and Moh, 1994; Woo and Moh, 1990). At the tunnel depth, the sand belongs to Sublayer 3 of the Sungshan Formation with an average N-value of 12 and an effective friction angle of 33 degrees. The sand is quite silty with an average fine content of about 40%. The representative coefficient of permeability of the sand is of an order of 1×10^{-6} m/sec. The clay above the tunnel crown belongs to Sublayer 4 of the Sungshan Formation with N-values varying from 6 to 10. Typical properties of this sublayer are summarized in Table 1.

Table 1 Properties of Sublayer 4

Natural water content, %	32
Liquid limit, %	34
Plastic limit, %	22
Plasticity index	12
Sensitivity	3.5 to 4
Su, kN/m2	50
Cc	0.3-0.4
Cv, m2/year	20

Also shown in Fig. 1 are the pore pressure responses recorded by piezometers ELP38 and ELP39, located in the same plane as Ring No. 166, during the driving of the Up-track tunnel. As can be noted that a maximum excess pore pressure of an order of 40 kPa was recorded by ELP38.

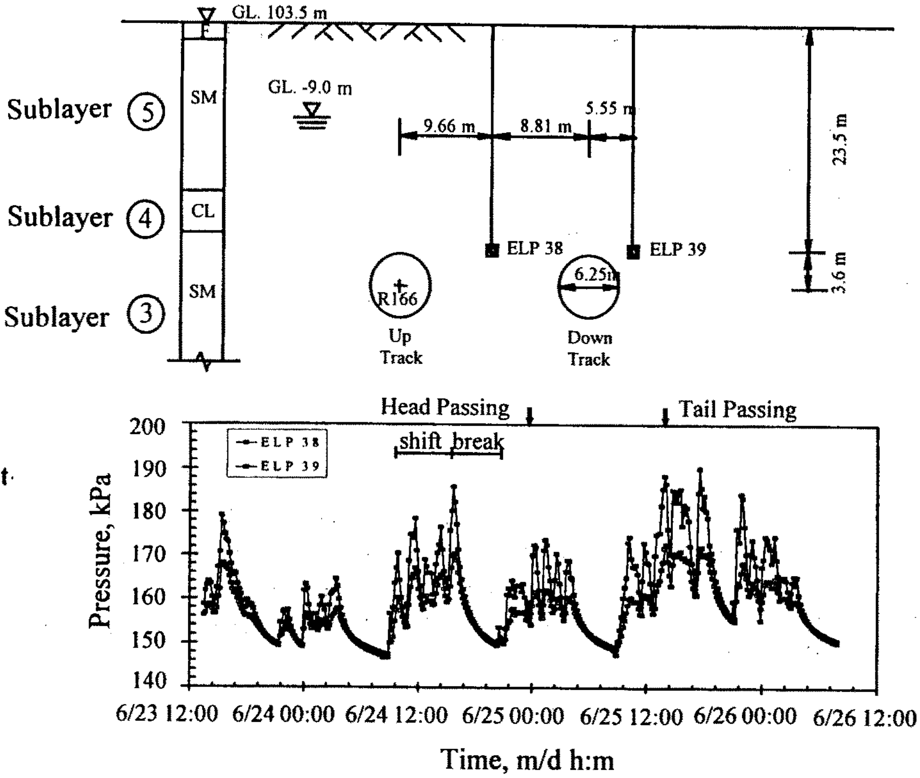

Fig. 1
Soil Profile, Instrument Layout and Piezometer Readings at Section 261T2

2.2 Clayey Ground

Figure 2 shows the instrument layout at Section T1 of Contract CN257 of the Nankang Line. The clay in which the twin tunnels are buried belongs to Sublayer 4 of the Sungshan Formation with properties given in Table 1.

The twin tunnels with centers at a depth of 12.4m below surface were also driven by using an earthpressure balancing shield machine. The outer diameter of the shield is 6040mm and that of the segments is 5900mm. The shield itself is 7000mm in length.

Also shown in Fig. 2 are the readings obtained by the two piezometers, PP62 and PP63 which were located in the same plane as Ring No. 238, during the driving of the Down-track tunnel. As can be noted that a maximum excess pore pressure of an order of 90 kPa was recorded by PP63.

3 PORE PRESSURE RESPONSES

3.1 Sandy Ground

In the case of CP261, pore water pressure responses recorded by both piezometers, refer to Fig. 1, were already significant as monitoring started on June 23 when the head of the shield was 12m, or twice of the tunnel diameter, away from the piezometers. They remained to be significant at the end of monitoring on June 30 when the tail of the shield was already 27m away. Piezometer ELP39 was at a transverse distance of 21m from the edge of the tunnel. From these facts, it is concluded that the influence of tunnelling stretched beyond a distance of 25m. The ground water table was at a depth of 9m below surface in Sublayer 3 as indicated by piezometer readings. The earth pressures in the chamber ranged from 2.5 to 4 bars during shoving and such pressures corresponded to a coefficient of earth pressure of 0.6 at most for a depth of 27.1m to the center of tunnel. It is thus highly unlikely that the excess pore pressures picked up by the two piezometers were a result of the advancement of the shield.

Because of the high permeability of the sands, pressures dissipated rapidly and the time histories show a zigzag pattern. In any case, three phases can be identified in Fig. 3. Before the arrival of the head, i.e., in Phase I, pressure induced exceeded the pressure dissipated, resulting in a net increase of pressure, during the advancement of each ring. The pressures accumulated and the envelope of readings rose to its peak till the head passed this instrumented

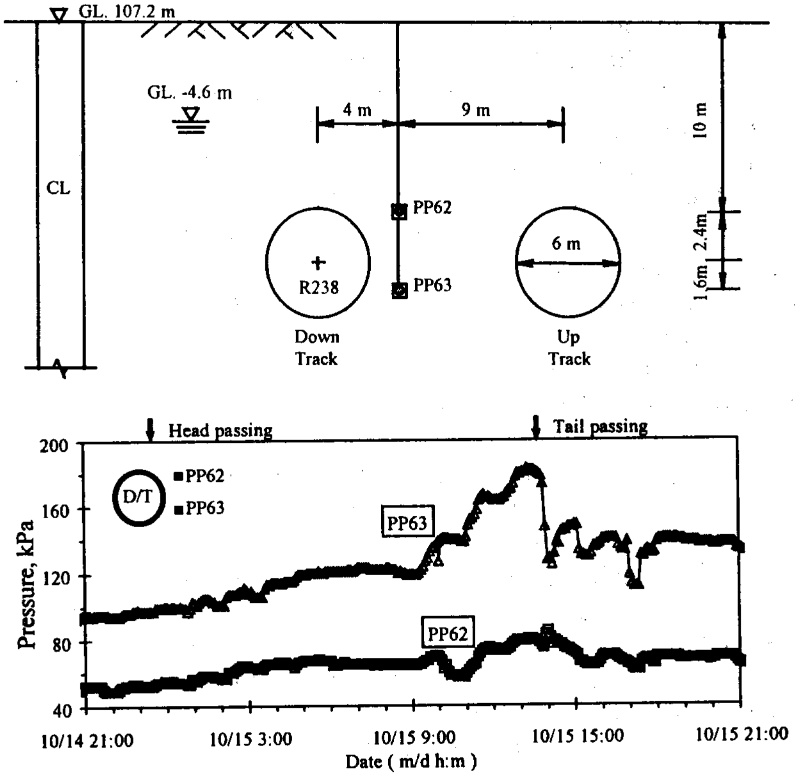

Fig. 2
Soil Profile, Instrument Layout
and Piezometer Readings
at Section 267T1

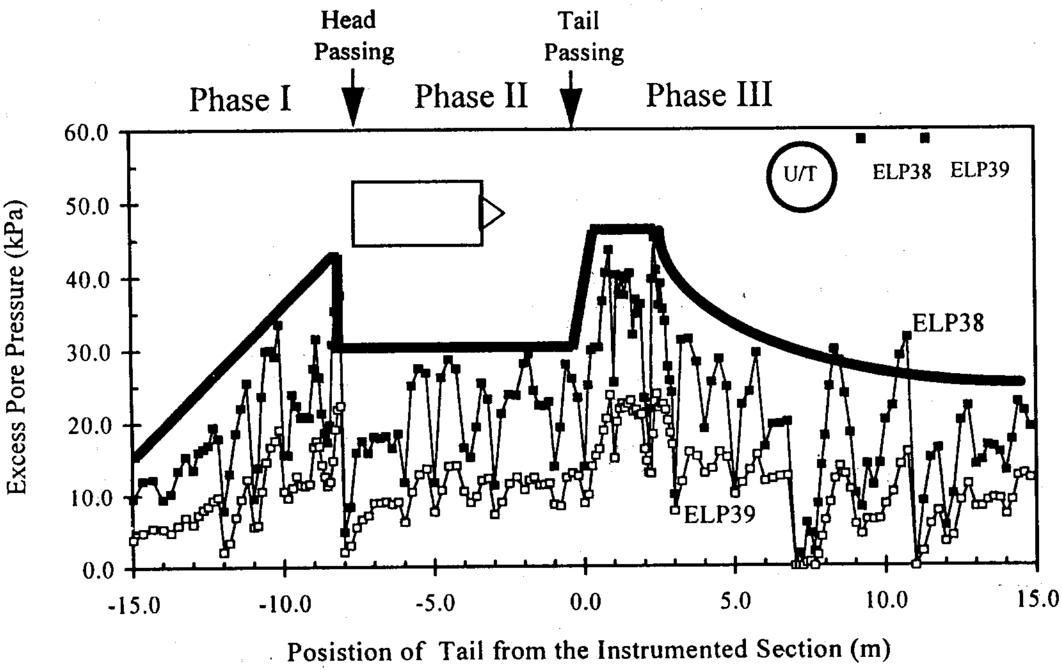

Fig. 3 Excess Pore Pressures versus Position of Tail at Section 261T2

section. As the head passed, i.e., at the beginning of Phase II, the pressures immediately dropped, presumably, in response to the creation of a gap between the shield and the surrounding soil. The pressures were relatively steady in Phase II. During the passing of the tail, i.e., at the beginning of Phase III, the pressures suddenly increased and the envelope jumped to a new high which sustained for a couple of rings. Subsequently, pressure dissipated exceeded the pressure induced resulting in a net reduction of pressure during the advancement of each ring and the envelope tailed off gradually.

Figure 4 shows a close-up of the readings together with the tunnelling activities. Excavation for each ring took about 40 minutes. In the meanwhile, back grouting for filling the tail void was carried out three rings behind the one being excavated. That means, for example, after Ring 168 was erected, excavation was carried out for Ring No. 169 and backfilling grouting was carried out at Ring 166. After the completion of excavation, the shield stopped for 40 to 50 minutes for installing Ring No. 169.

Grouting was conducted at pressures up to a maximum of 2.8 bars and the quantity of grout was roughly 3,000 liters per ring. The theoretical volume of the tail void is only 1,455 liters (over-cut was minimal and is ignored). It is therefore expected that much grout did permeate into pores in the surrounding soil mass. In addition, secondary injection was carried out outside the upper half of the tunnel to form a hood with a thickness of 2.5m for reducing settlements and roughly 1,200 liters of grout was injected at each ring. Injection was carried out at pressures varying from 1 to 4 bars and at distances varying from two to eight rings behind the one being grouted.

The fact that the pore water pressure response was the most drastic when grouting was carried out at Ring No. 166, where the two piezometers were located, and the two subsequent rings leads to the belief that the most possible source of the excess pore pressure sensed by the two piezometers was the grouting for filling up voids behind the tail of the shield.

3.2 Clayey Ground

In the case of CN257, the story is quite different. The ground water table was at a depth of 4.6m below surface as indicated by piezometer readings. The earth pressures in the chamber ranged from 1.5 to 1.8 bars and corresponded to a coefficient of earthpressure of about 0.6 at most for a depth of 12.4m to the center of tunnel. Such a pressure would not be able to induce much excess pressures. This is evident in Fig. 2 that excess pore pressures were nil as the head of the shield passed. The pressure responses versus the position of the shield are shown in Fig. 5 and the responses versus tunnelling activities are shown in Fig. 6. It is even more clear in this case than the case of CP261 that excess pore pressures were induced as a result of backfilling grouting, not a result of "pushing" of the ground by the shield machine. However, this time, peak response occurred during grouting at Ring No.

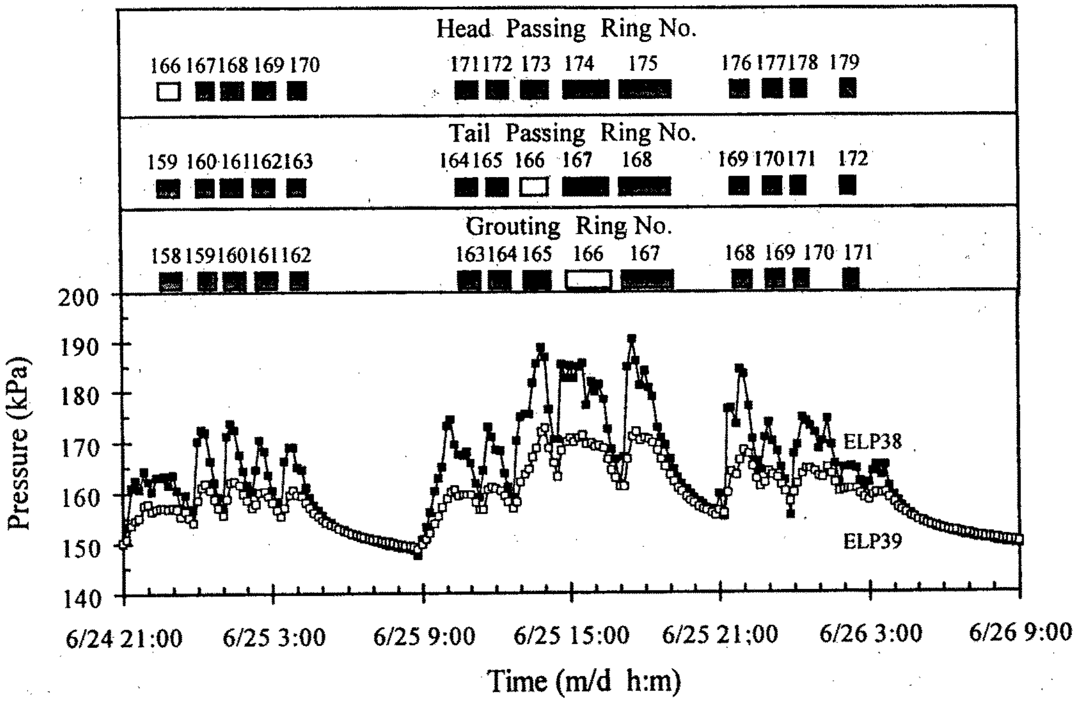

Fig. 4 Piezometer Readings versus Activities at Section 261T2

236 which is a ring two rings before Ring No. 238 where piezometers were located.

As soon as Ring No. 238 "moved" out of the tail, pressures dropped immediately, presumable, in response to the creation of void. Before that, as can be observed in Figs. 5 and 6, the excess pore pressures accumulated, i.e., more pressures were induced than dissipated for each ring; Subsequently, more pressures dissipated than induced for each ring resulting in reductions of pressures with progress.

Grouting was carried out at four rings, instead of three rings as in the case of CP261, behind the ring being excavated. The theoretical volume of tail void is 1312 litres (overcut is minimal and is ignored).

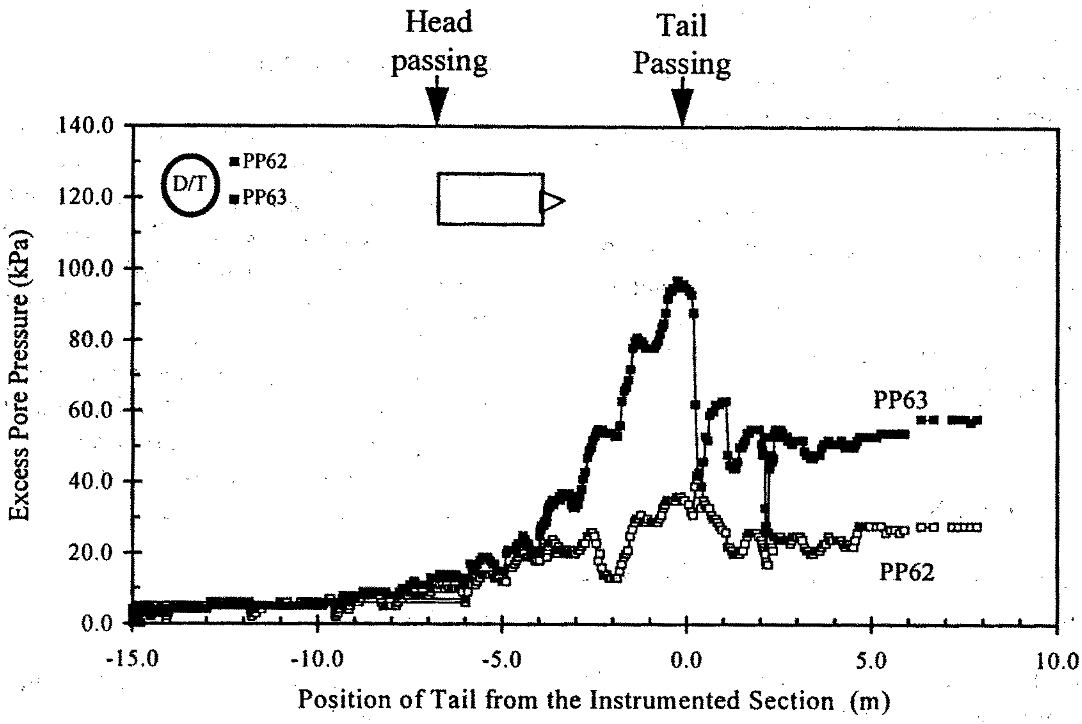

Fig. 5 Excess Pore Pressures versus Position of Tail at Section 257T1

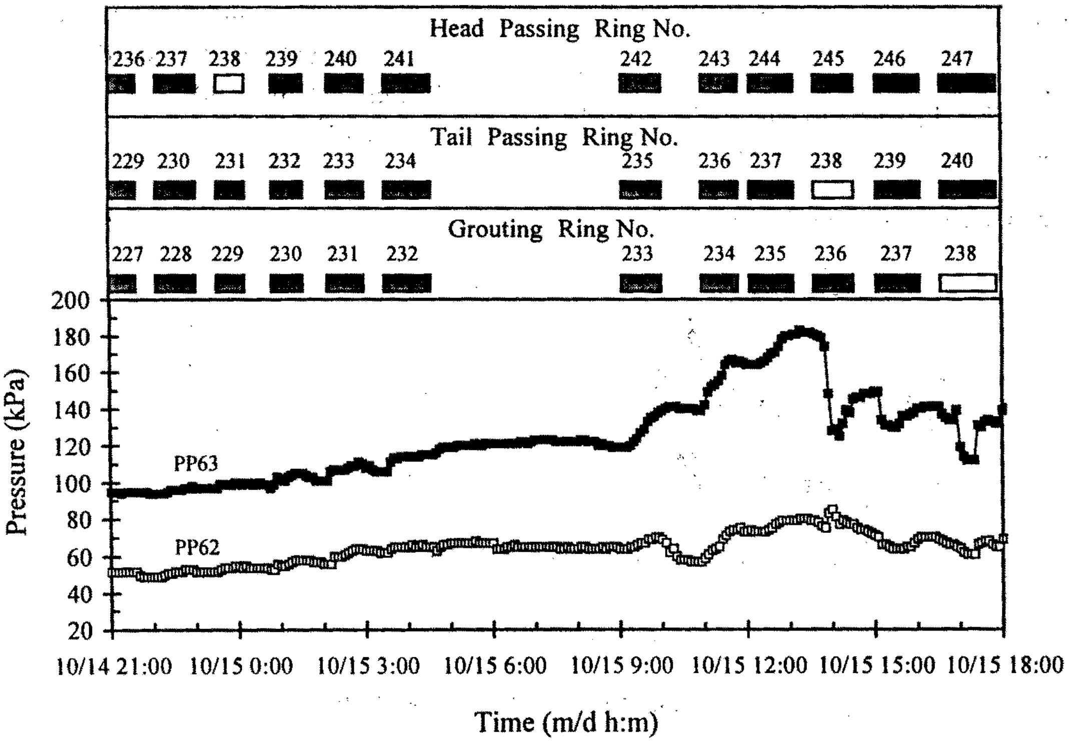

Fig. 6 Piezometer Readings versus Activities at Section 257T1

The average grout take was 1791 liters per ring and is 120% of the theoretical volume of the void.

As can be noted from Fig. 5, the excess pore pressures were virtually nil when the tail was 5m away from the piezometer. At that time grouting was carried out at 6m away. The same can also be noted from Fig. 6 that the response was small when Ring 232 was grouted. This together with the fact that during the driving of the Up-track tunnel of which the edge is 6m away from the piezometers, very little excess pore pressures were recorded indicates that the pore pressure response to grouting is limited to 6m or so.

The readings are replotted in a semi-log scale in Fig. 7 and it can be noted that it took 60 days for excess pore water pressures to fully dissipate. Although consolidation dragged on for so long, data indicate small long-term consolidation settlements which are still being investigated.

4 CONCLUSIONS

The foregoing discussions lead to the following conclusions:

(a) For shield tunnelling using earthpressure balancing machines, so long as the chamber pressures are near the at-rest earth pressures, the predominant source of excess pore pressures induced in the ground is the grouting for filling the tail void.

(b) In sands, the effects of grouting on pore pressure may reach a distance of 25m or even greater. In clays, the influence is limited to a distance of, say, 6m or so.

(c) In sands, excess pore pressures dissipated in hours after grouting.

(d) In clays, the closure of tail void, as the tail passed the instrumented section, leading to reduction of pore pressures can clearly be noted from time histories.

(e) In clays, the excess pore pressures may take months to fully dissipate.

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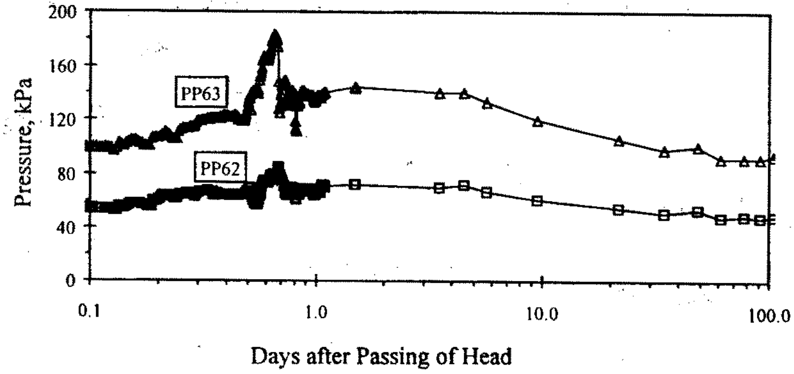

Fig. 7 Dissipation of Pore Pressures, Section 257T1