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A compensation grouting trial in Singapore marine clay

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ABSTRACT: Tunnelling and excavations in Singapore commonly encounter deep deposits of Singapore marine clay, which is nearly normally consolidated, has high plasticity and a high compression index. It was considered that a potential method of limiting the settlement of buildings and utilities during tunnelling was compensation grouting. It was therefore decided to carry out trials to verify the effectiveness of such grouting. A cement/bentonite/silicate grout was injected into marine clay through sleeved grouting pipes. The heave due to the grouting was measured. A method of predicting the initial pattern of heave was developed. As the excess pore pressures generated by grouting dissipated consolidation settlements were measured. At the end of this period most of the initial heave had been lost due to the consolidation settlements; some points showed an overall settlement during the trial. The grouts, injection sequences, monitoring data and other observations are described.

1 INTRODUCTION

About 25% of the land area of Singapore is underlain by recent deposits of marine and alluvial origin, PWD (1976). The most common of these recent deposits is the Singapore marine clay, which is up to 40m thick. Because of the low strength and high compressibility of this deposit, large settlements have commonly been measured during tunnelling and excavations in it, Shirlaw & Copsey (1987).

In 1995 the Land Transport Authority was preparing tender documents for the design and construction of the North-East line, involving 16 underground stations and linking tunnels. Due to the extensive use of compensation grouting as a building control measure during the construction of the Jubilee line in London, England, it was decided to assess the use of this technique in the Singapore marine clay. The trial was primarily designed to allow the Authority to assess the feasibility of the method, should a contractor propose to use it.

The grouting trial was awarded to L & M Geotechnic Pte Ltd in January 1997.

2 TRIAL

2.1 *Site conditions*

The trial site was a plot of unused state land at the junction of Serangoon Road and Lavender Street. Boreholes drilled prior to the work showed that the site was underlain by 2.5m of fill, and then by 8m of marine clay. A grouting zone 5 to 8m below ground level was selected. At this level the parameters for the marine clay were:

Undrained shear strength: 18 kN/m^2
Plasticity index: 65%
Compression index: 0.9
Permeability: 1 x 10^{-9} m/s

For other details of Singapore marine clay see Ahmad & Peaker (1977) and Buttling, Shirlaw & James (1987).

2.2 *Trial sequence*

Four trials were required under the contract. These involved different patterns of injection pipes and heave monitoring points, as shown in Figure 1. The first three trials were monitored for surface heave only, with the fourth and final trial incorporating piezometers and extensometers as well. The first two trials were to establish the general pattern of heave. The third trial was designed to establish the pattern of heave due to injection from a single pipe, and the fourth trial was designed primarily to obtain further information about the behaviour of any consolidation settlements that could occur after the grouting.

2.3 *Grout mix*

Before the field work started, mix trials were carried out in L & M's laboratory. For grouting in the soft clay it was considered necessary to use:

- A grout with low viscosity, to promote fissuring rather than bulb formation
- A grout with a limited set time, to prevent excessive fissure length
- Sufficient strength to prevent the grout fissures forming a plane of weakness
- Minimum bleeding

The finally selected grout consisted of a mixture of cement, bentonite and silicate. These were prepared as two solutions:

- Solution A:140l sodium silicate, 60l water
- Solution B:59.93kg cement, 179.78l water, 3kg bentonite.

This grout gave a flow consistency (ASTM C939-1993) of 8.58 seconds, a gel time of 72 seconds, and a vane strength of 29kPa after 1 hour.

2.4 *Grout pipes and injection*

The grout pipes were sleeved at 330mm intervals, giving 7 ports in the grouted zone (between 5m and 7m below ground level). All of the pipes were installed vertically. Injection was through a 330mm long double hydraulic packer. The two grouting solutions were mixed independently and only came into contact through a 'Y' piece at the head of the hole. The grouting rate varied from 4 to 12.5l/minute for all of the trials.

3 TRIAL RESULTS

Trials 1 and 2 were used to experiment with different injection patterns. In both trials it was found that heave could readily be achieved, but that, following grouting, there was settlement which reduced the heave.

For trial 3, the extent of the settlement monitoring arrays was spread to cover a wider area than for trials 1 and 2. Initially 2000 litres of grout was injected, all at the bottom port (7m depth). The grout was injected over an 8 hour period, with 250litres being injected each hour. This resulted in a maximum heave of 14mm (Figure 2). During the next nine days, when no grouting was carried out, the maximum heave reduced to 9mm. The sleeved tube was then regrouted with 2100 litres of grout. This time the remaining six sleeved ports (6.67m to 5m depth) were grouted, resulting in a maximum heave (for both the initial and regrouting) of 24mm. In the 17 days following the regrouting this heave reduced to 16mm. Settlement was clearly still continuing at 17 days.

For trial 4, six sleeved tubes were installed at 2mc/c as shown in Figure 1. The sleeved tubes were grouted in four stages. Each stage involved one day of grouting and two days of monitoring. For each grouting stage 200 litres of grout was injected in each of the six sleeved pipes. The grout was injected at four ports, at 50 litres per port. A total of 4800 litres of grout was injected during the trial.

For trial 4 the instrumentation included 30 levelling points, 2 inclinometers, 2 extensometers and four vibrating wire piezometers. The piezometers were installed just above and below the grouting zone, as shown in Section A-A, Figure 1. The instrumentation was monitored throughout the grouting and for 100 days thereafter.

The maximum heave during trial 4 was recorded on SP16, and was 26mm. All points showed significant settlement, reducing the heave, over the next 100 days. At SP 16 the residual heave after 100 days was 8mm. However, out of the 30 monitoring points 5 showed an absolute settlement and 4 showed zero heave over the full period of the trial (see point SP15 on Figure 3).

The piezometers installed above and below the grouted zone showed that the grouting induced large positive excess pore pressures, as shown in Figure 4. These excess pressures dissipated over the 100 day monitoring period after grouting.

As part of the trial, boreholes were drilled into the grouted zone and a piston sampler used to recover samples of the grout and ground. These samples were opened and inspected for evidence of how the grout had behaved in the ground. The samples were sprayed with Phenol Pthalene to help distinguish the grey grout from the grey marine clay. Samples taken very close to the injection points showed evidence of the grout forming bulbs or thick finger like patterns in the clay. Further from the point of injection, either laterally or vertically, thin (typically 1 to 2mm) grout fractures were found. The orientation of these fractures varied; most were either horizontal or vertical, but some were inclined at approximately 45°.

4 CONCLUSIONS

It has been shown that it is possible to create surface heave by injecting grout into the soft Singapore marine clay. The extent and magnitude of the heave can be predicted as the heave follows the form of the 'error function' curve commonly used for the assessment of settlements over tunnels.

However, the grouting generated large excess pore pressures. After these had dissipated, the pattern of heave was uneven, and in places the final effect was to induce settlement. Grouting in the four cycles used did not appear to reduce this problem

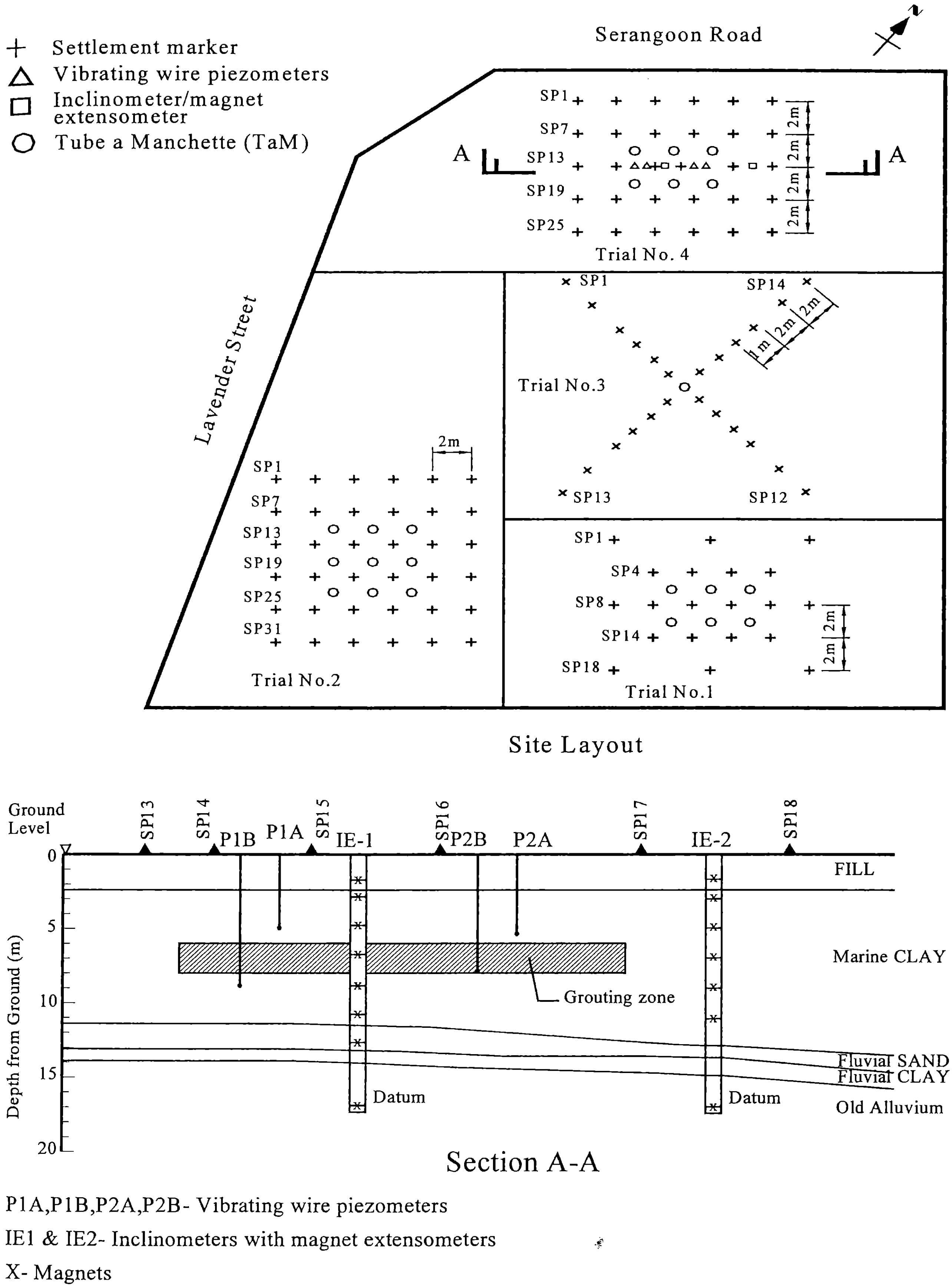

Figure 1. Trial and instrument layout.

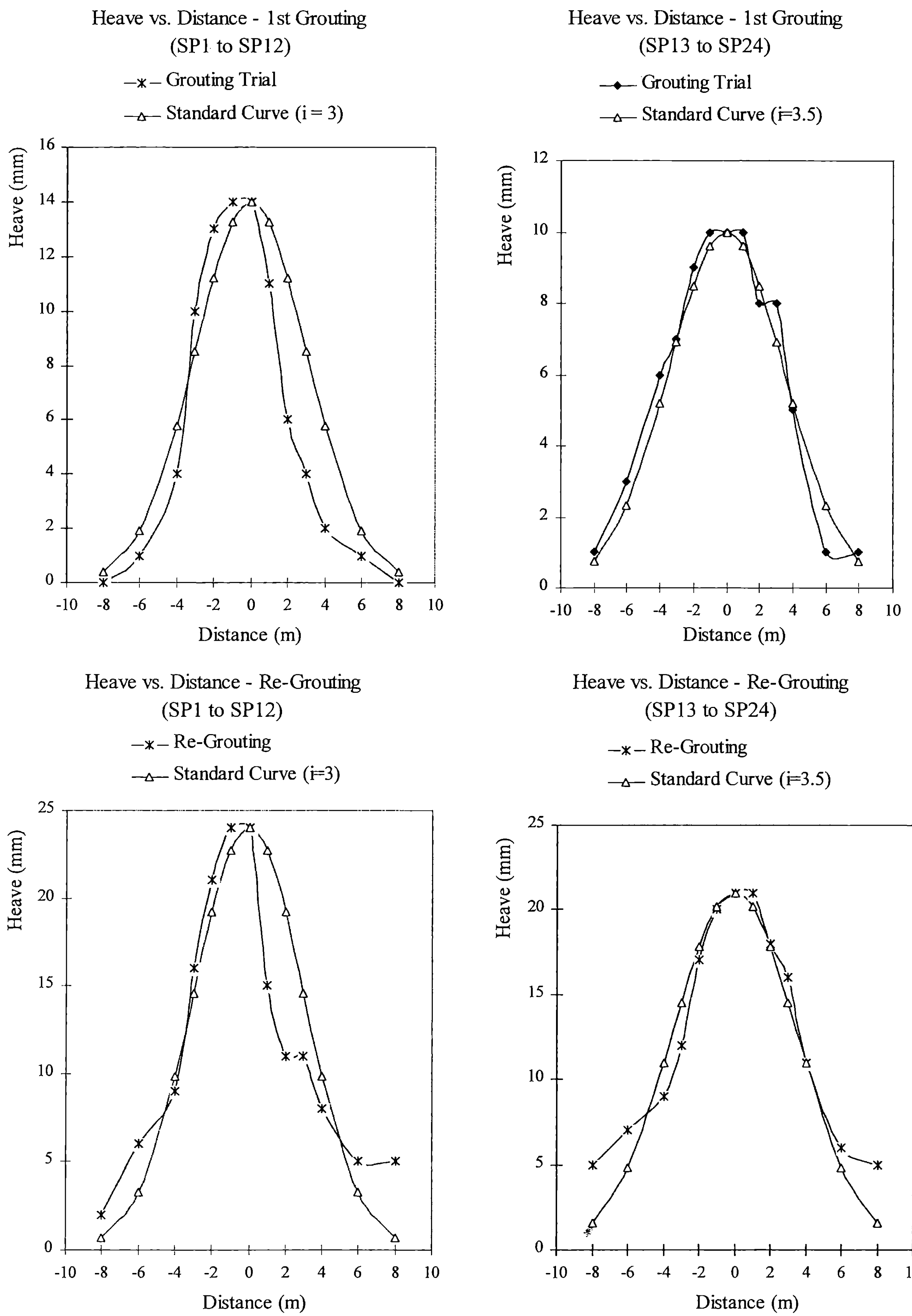

Figure 2. Heave at Trial no. 3.

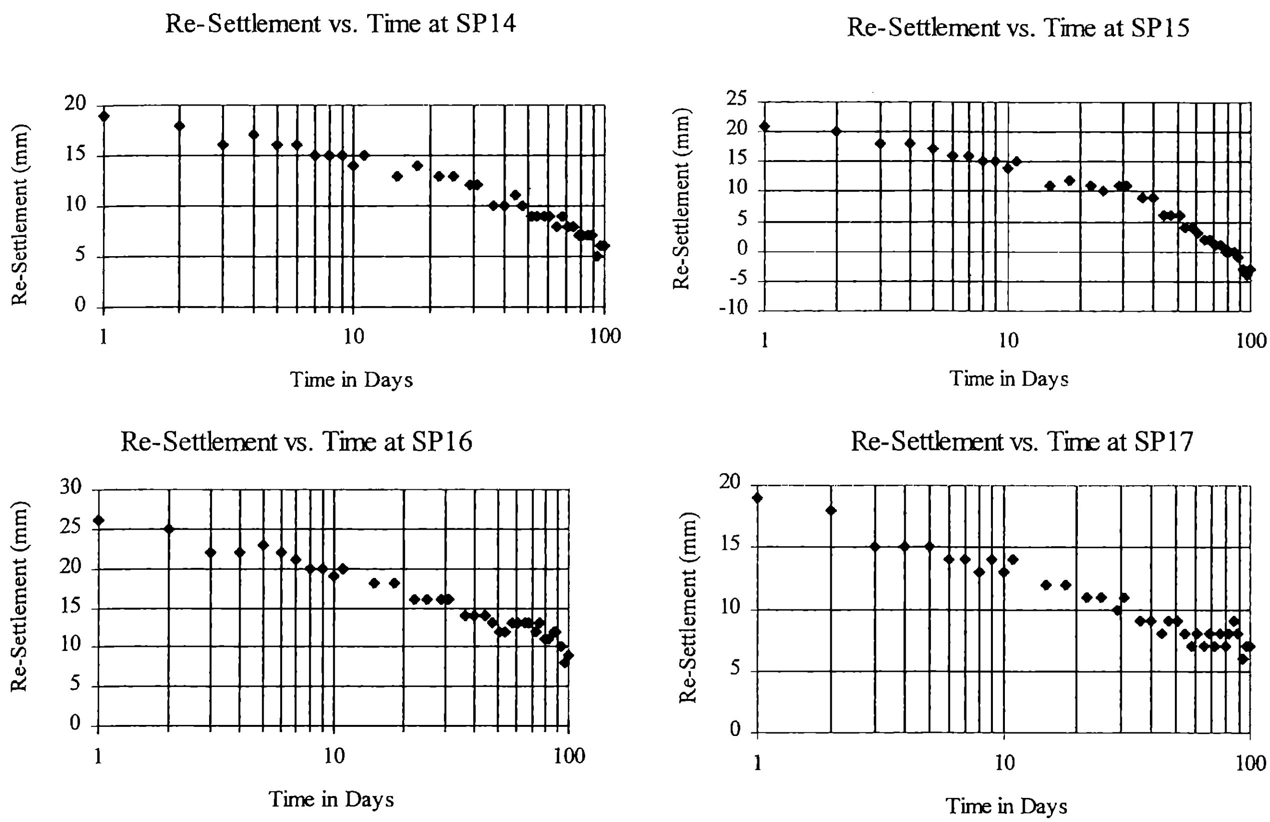

Figure 3. Heave and re-settlement at trial no. 4.

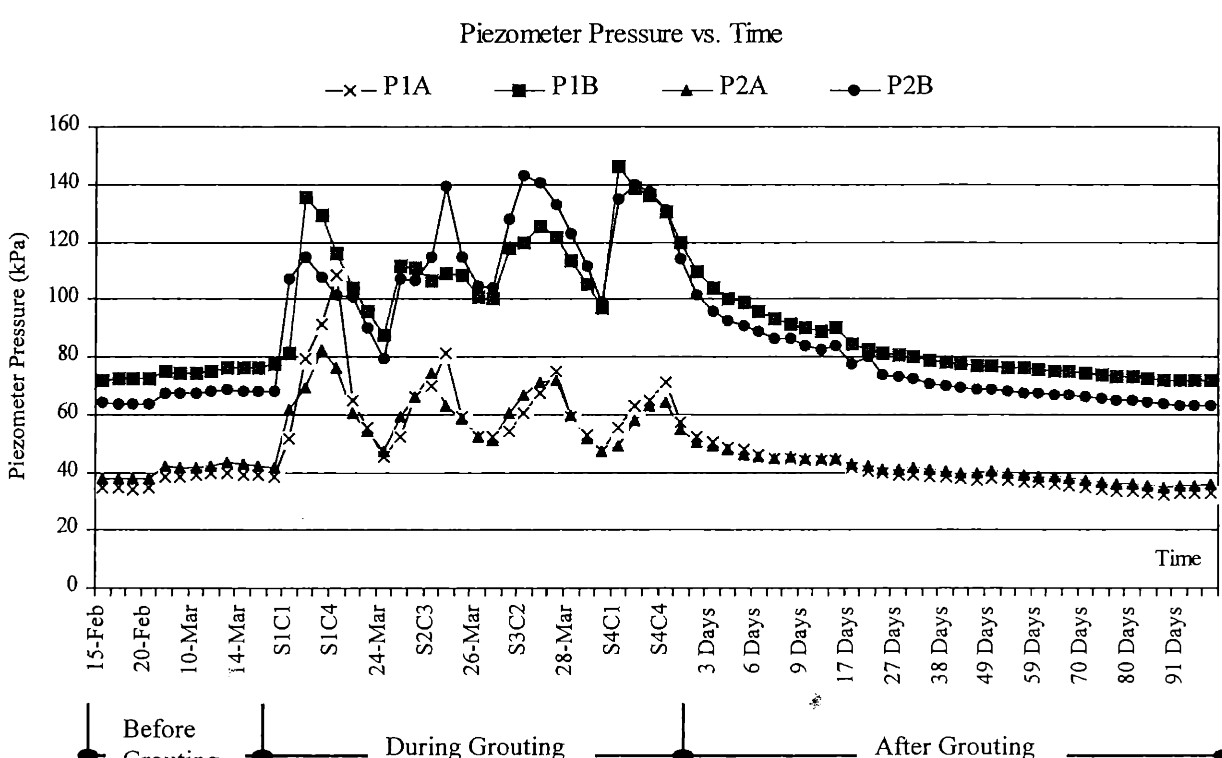

Figure 4. Piezometer readings at trial no. 4.

with excess pore pressures. It was concluded that the use of compensation grouting as a building protection measure within the Singapore marine clay was unlikely to be successful.

The trial provided confirmation of previously observed effects relating to settlement over tunnels in Singapore. As recorded by Shirlaw, Busbridge and Yi (1994), tail void grouting carried out after the marine clay had closed onto tunnel lining rings resulted in a temporary reduction in the settlement due to tunnelling. However, after dissipation of the excess pore pressures that were generated, the total settlement was almost the same as if no grouting had been carried out at all.

REFERENCES

Ahmad, S. A. & Peaker, K. R. (1977) Geotechnical properties of soft marine Singapore clay, *Int. Symp. On Soft Clay,* Bangkok, Thailand, 5-6 July 1977

Buttling, S, Shirlaw, J. N. & James, J (1987) The shear strength of Singapore marine clay, *Proc. 5th Int. Geotech. Seminar "Case Histories in Soft Clay"*, NTI, Singapore 2-4 Dec. 1987.

PWD (1976) *Geology of the Republic of Singapore*, Public Works Department, Singapore

Shirlaw, J. N. & Copsey, J. P. (1987) Settlement over tunnels in *Singapore* marine clay, *Proc. 5th Int. Geotech. Seminar "Case Histories in Soft Clay"*, NTI, Singapore 2-4 Dec. 1987.

Shirlaw, J. N., Busbridge, J. R. & Yi, X. (1994) Consolidation settlement over tunnels: A Review, *Canadian Tunnelling*, 1994