Compensation grouting at the Docklands Light Railway Lewisham Extension project

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ABSTRACT: As part of the Docklands Light Railway Lewisham Extension project, the construction of nearly 1.1 km of twin 5.88 m diameter running tunnels, passing under the River Thames, was undertaken. The slurry shield method combined with compensation grouting was employed in order to limit surface settlements and to control settlement of the overlying structures. Ground and building movements were carefully monitored and as a result, the compensation grouting technique was successfully implemented. This paper briefly describes the tunnel construction, including the compensation grouting, and the results of the ground movement monitoring.

1 INTRODUCTION

In order to improve access to the south east area of the Docklands in London, a 4.2 km extension to the Docklands Light Railway running from Mudchute Station on the Isle of Dogs to Lewisham Station has been constructed. This project included the construction of around 1.1 km of twin 5.88 m diameter running tunnels, passing under the River Thames, and running from Island Gardens to Greenwich (see Figure 1).

Figure 2 shows a cross section through the tunnels, together with the ground stratigraphy. In this project the slurry shield method, together with the compensation grouting technique during tunnelling, was employed. Ground movements have been carefully monitored. The twin tunnel construction was successfully conducted and the costs of the soil improvement (including compensation grouting) were reduced by 20 percent compared with those expected.

This paper briefly describes the shield tunnel construction and the results of the ground movement monitoring. The implementation of compensation grouting during tunnel construction is also reported.

The contractor for the main works was a joint venture of three companies, Nishihata Construction and Mitsui Products of Japan and John Mowlem Construction of the UK. Compensation grouting was undertaken by a specialist subcontractor, Keller.

2 GROUND CONDITIONS

The ground conditions are summarised in Figure 2. The geotechnical strata from surface level along the route of the bored tunnels comprise varying thicknesses of Made Ground, Terrace Gravel, the Woolwich and Reading Beds (WRB)—now known as the Lambeth Group—and Thanet Sand. The tunnels were mostly driven below the water table through Terrace Gravel, the WRB and

![Figure 1. Route of DLR-LWE tunnel.](image-url)
4 SETTLEMENT PREDICTIONS

Prediction of ground settlement due to tunnelling was made using the method described by O'Reilly and New (1982) and Selly (1988). Assessments of the likely effects of settlement on all structures lying within the settlement trough were also made.

The settlement criteria for the main structures are summarized in Table 1. In making the prior assessment of settlement, it is necessary to estimate a value of 'volume loss', which may be defined as the amount of ground lost in the region close to the tunnel. The volume loss is generally expressed in terms of the volume of the surface settlement trough, expressed as a percentage fraction of the excavated area of the tunnel.

Based on the authors' recent experience of shields in similar ground conditions, a volume loss of 1.0% and a maximum settlement of 15 mm were generally adopted as the project design criteria prior to tunnel construction. This value of volume loss was consistent with those given in the recent report by Mair (1996).

In addition, a maximum angular distortion (see Table 1) of 1 in 1000 was set to minimize the risk of building damage and disruption to sensitive operational equipment. Based on this assumption the settlement at the centre of the trough was estimated to be approximately 30 mm at the location of the Royal Hill Court structure for which data is being presented in this paper. Therefore, the compensation grouting technique was chosen in order to acceptably control settlements, as briefly described below.

5 COMPENSATION GROUTING

The main objective of compensation grouting is to limit the movements of overlying structures within a specified level during tunnel construction. Compensation grouting has tunnel construction with closed-face type recently been introduced to the UK on tunnel construction beneath Waterloo Station and subsequently for the Jubilee Line Extension (Harris et al, 1994; Harris et al, 1996); the principles and applications of compensation grouting are presented by Mair and Hight (1994).

All compensation grouting has been carried out through tubes a manchets (TAMs). The layout of the TAMs is shown in Figure 4. The compensation arrays have been installed from shafts in the case of the Royal Hill Court building or from the ground surface in the case of North River Wall. Compensation grouting was roughly divided into two main stages:

(1) Conditioning grout
Conditioning grouting was injected into the ground below the structures prior to advance of tunnelling. The aim was to stiffen the ground locally so that the subsequent compensation grouting could be effectively conducted.

(2) Compensation grouting
Compensation grouting was carried out to compensate for ground loss and stress relief by tunnel excavation, when it was needed, based on the monitoring results. Controlled quantities of grout were injected to compensate for the volume losses along the route. The compensation grout was mostly injected in the Terrace Gravel at locations where the tunnel was in the Terrace Gravel and likely to adversely affect certain structures.

The compensation grout comprised a bentonite cement mix with various additions such as Pulverised Fuel Ash (PFA) and Silica gel. Generally 30 litres per sleeve were injected at pressures ranging from 5 bar to 7 bar, depending on the TAM positions. Volumes equivalent to...
approximately five times the actual volume losses were injected at any one location.

6. SUMMARY OF MONITORING RESULTS

6.1 Non compensation grouting areas

The surface settlements above the tunnel centre line ($S_{sur}$) are summarized in Table 2. It can be seen that all values of $S_{sur}$ for south bound are less than 15 mm and the volume loss $S$ was satisfactorily controlled to a mean value of 0.7%, and were smaller than 1.0% (the predicted value) at all locations. The sophisticated tunnel excavation control system contributed significantly to achieving these results.

Figure 5 shows a typical example of monitoring results of longitudinal settlement for a non compensation grouting area. Very small settlement above the tunnel face was observed, mainly because the face pressure was carefully and well controlled. The settlement due to the tail void was only about 1.5 mm, which was about 50% of the settlements that occurred during passage of the shield. The pressure on the tail void may be influenced by the stiffness of the houses.

All points D, E and F are consistent with those in Figure 5. The best fit Gaussian distribution curve (Peck, 1969) estimated from the monitoring results is also shown in Fig. 6, and this corresponds to a value of K=0.6 (K being the trough width parameter, Mair and Taylor, 1998). These monitoring points were on a row of two storey mansard houses within basements. The transverse settlement trough based on the monitoring results is reasonably represented by the Gaussian distribution curve. The more detailed discussion on the ground movements in the non compensation grouting areas is described by Sugiyama et al. (1999).

6.2 Compensation grouting areas

Figure 7 shows the development of surface settlement above the centres of the tunnel during the passage of the tunnel machine through the compensation grouting areas beneath the Royal Hill Court. The tunnel was mostly in a theodolite and a tape extensometer. There were no significant displacements associated with the grouting (being generally less than 2.0 mm), nor were there any cracks in the lining. As a result, the effects on the tunnel lining of the compensation grouting were found to be very small. Numerical approaches to this problem have been carried out by Kovacevic et al. (1996) and Lee et al. (1999).

The soil improvement costs (including compensation grouting) for the whole project were reduced by 20% compared with the expected costs.

7 CONCLUDING REMARKS

It has been observed that the volume loss associated with slurry shield tunnelling in the mixed face ground condition, including Terraco Gravel and WBR, could be successfully controlled, being less than 1.0%. The technique of compensation grouting has been proved to be effective in protecting the overlying sensitive structures and in controlling settlements.

The key element of the success in the tunnel construction was the careful control of compensation grouting in response to the detailed observations of the structure movements. In addition, a good synchronisation of harmony between sophisticated slurry shield operations developed in Japan and the compensation grouting technique developed in the UK contributed to the success of this project.

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