Panel discussion: An overview of the Imperial College-JLEP 'Link' project

Débat de spécialistes: Une vue d'ensemble du projet 'Link' d'Imperial College-JLEP

J. R. Standing, R. J. Nyren & J. B. Burland – *Imperial College, London, UK*
G. Viggiani – *Università di Roma 'Tor Vergata', Italy*

ABSTRACT: This note provides some details of a collaborative research project between Imperial College, industry and the government, aimed at measuring ground and building response to tunnelling. Monitoring has been carried out in parallel with tunnelling and excavation works for the Jubilee Line Extension Project in London. The scope of the project is described and examples from two out of the nearly thirty locations monitored are provided to illustrate the quality of the data.

RESUME: L'article donne des détails d'un projet de recherche commun regroupant Imperial College, l'industrie et le gouvernement. Ce projet a pour but de mesurer l'impact du creusement d'un tunnel sur le terrain et les bâtiments. La surveillance a été effectuée pendant les phases de creusement du tunnel et d'excavation de l'extension de la Jubilee Line à Londres. Le but du projet y est décrit et deux exemples issus des nombreux sites instrumentés sont fournis afin d'illustrer la qualité des données.

1 INTRODUCTION

During the planning stages of the Jubilee Line Extension Project (JLEP) and the subsequent parliamentary hearings, it was recognised that there was a lack of well-documented case studies detailing ground and building response to underground excavation works.

The planned JLEP provided an ideal opportunity to improve knowledge within industry on this key subject that is becoming more relevant with increasing urban development. The tunnels were to pass through different soil strata, beneath a wide range of structures representing a variety of structural forms and foundation types. Additionally, different methods of tunnelling were chosen to suit the ground conditions and protective measures, sometimes novel, were implemented in order to minimise movements in certain areas. A summary of the various aspects of the works carried out along the route of the JLEP are given in a special supplement to World Tunnelling (Wallis, 1994), details are also given along with a description of the ground conditions along the route by Linney and Page (1996).

The Link research project was conceived to capitalise on this opportunity. Its objectives are to provide a series of case studies covering matters such as the subsidence trough, the soil-structure interaction and stiffness in relation to overlying structures, time effects, damage, protective measures and remedial measures. Details of the inception, objectives, funding and management of the Link project are given by Burland et al. (1996).

2 SCOPE OF THE PROJECT

The Link project is funded by the government (EPSRC and DoE) and by various industrial sponsors, the main one being London Underground Limited through JLEP. The research work was carried out from Imperial College and the project managed by CIRIA.

Prior to the main works commencing, a number of buildings along the route were selected for study. The range of structural forms and foundation types is comprehensive, including stone-clad brick masonry buildings, often of historic importance, steel frame and more modern reinforced concrete frame structures and low-rise housing. The range of foundation types was equally varied, with 'shallow' strip and pad footings, rafts and piles.

Protective measures were adopted for a number of these structures, such as permeation grouting, compensation grouting and underpinning. The effectiveness of these measures could therefore be assessed. Those buildings that had no treatment were classed as 'alpha' buildings by the research team. These allowed the response of the structure alone to be monitored, which is important for investigating the effects of factors such as soil-structure interaction and the building stiffness.

Two greenfield control sites were also set up and monitored in parallel with the building monitoring. Although funded independently by EPSRC and LUL, the control sites form an essential integral part of the overall Link project. They act as a reference in terms of how the ground behaves in the absence of overlying structures.

The main intention of the research project is to produce a series of comprehensive documents representing a series of case studies for the different buildings and the construction activities and the protective measures related to them. It should be noted that although another of the primary aims was to record instances of damage and the effectiveness of remedial measures, in the event there has been little reported damage and so involvement with this activity has been minimal.

3 INSTRUMENTATION AND MONITORING

The primary method of building monitoring has been by precise levelling using BRE sockets and procedures set out in BRE Digest 386. In many cases measurements of vertical displacements have been augmented by precise taping measurements carried out using the same points used for levelling, this is considered to be a new development. Horizontal movement between points is therefore also obtained. The accuracy of both of these methods of monitoring is typically ± 0.2 mm.

Three dimensional monitoring of the building facades is another key activity carried out by the team. A total station is used for this monitoring, sights are made from more than one survey station onto a number of retro-reflective prism targets fixed at different levels across the facade. This activity allows horizontal movements both in-plane and out-of-plane as well as vertical displacements to be measured. The accuracy from this method of monitoring is typically ± 1 to 2 mm.

In two of the buildings, sub-surface instrumentation, comprising rod extensometers and electrolevel inclinometers, was installed in boreholes. These allow vertical and horizontal movements to be measured in the ground beneath the structures and around the constructed tunnels. Construction joints and existing and new cracks within the buildings were monitored using a mechanical Demec gauge.

Extensive instrumentation was installed at the two greenfield

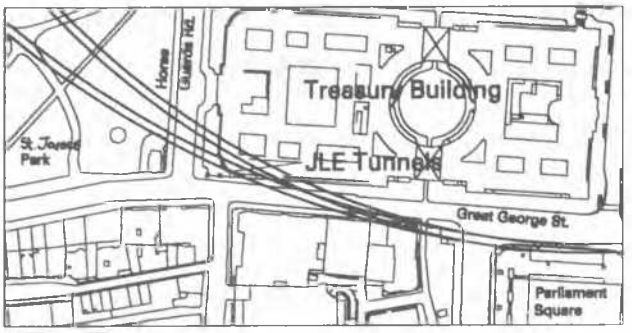

Figure 1 - Plan of the Treasury Building

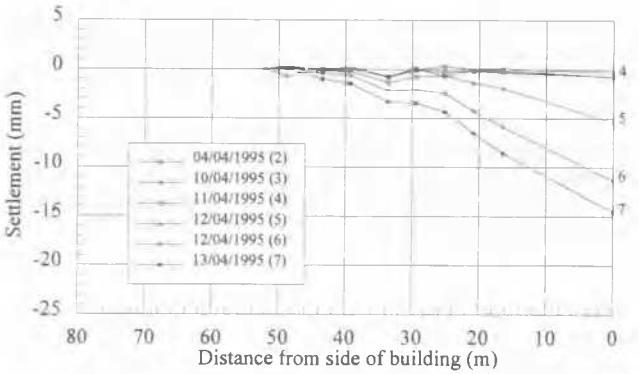

Figure 2 - Vertical displacement profile at the Treasury Building (westbound tunnel - Horse Guards Road side)

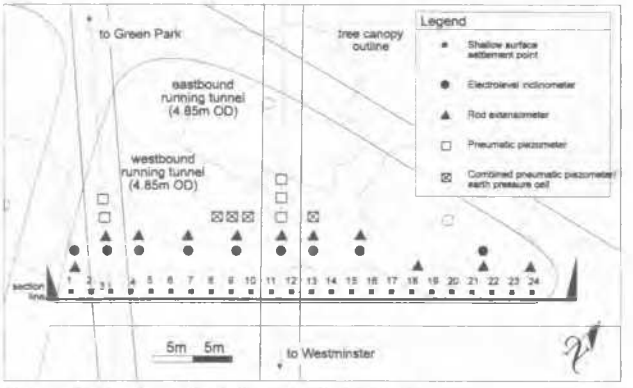

Figure 3 - St. James's Park control site plan

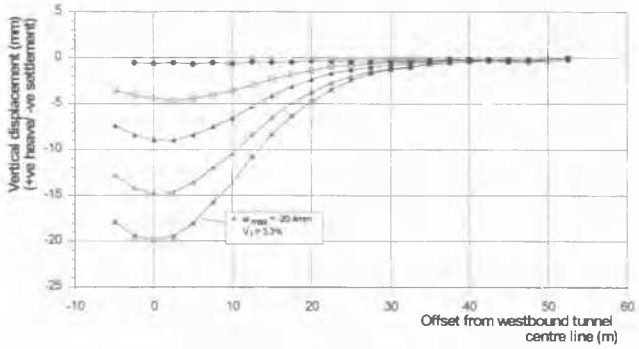

Figure 4 - Vertical displacement profile for westbound tunnel at St. James's Park

control sites mostly in lines transverse to the axis of the tunnels to be constructed. Shallow surface monitoring points enabled three dimensional movements to be established, using precise levelling, micrometer stick measurements and collimation. These measurements were backed-up by total station monitoring to the same points. The subsurface instrumentation comprised rod extensometers and electrolevel inclinometers for determining vertical and horizontal displacements and piezometers and spade cells. The instruments extend from the near surface to below tunnel invert level with their density increased around the tunnels. Details of the instrumentation and monitoring at the control sites is given by Standing et al. (1996).

4 EXAMPLES FROM THE LINK TEAM MONITORING

Two of the sites monitored by the research team are now briefly described and some precise levelling results from the work shown.

The Treasury is a massive stone-clad masonry structure with four storeys above ground and two basement levels. The foundations consist of strips and pads connected by an unreinforced concrete slab founded in the Terrace Gravels which overlie London Clay. The building is shown in plan in Figure 1 with the position of the tunnels marked. Precise levelling and taping were carried out in the sub-basement. The measurements shown in Figure 2 are from the levelling along the Horse Guards Road side of the building (see Figure 1), i.e. roughly transverse to the tunnels, during the passage of the westbound tunnel. No protective measures were implemented at this time, although subsequently TAMs were installed beneath the building and movements corrected both prior to and during the passage of the second eastbound tunnel.

St. James's Park greenfield control site is in the close vicinity of the side of the Treasury discussed above. A plan of the site is shown in Figure 3 with the lines of instrumentation marked. The results shown in Figure 4 are from the precise levelling carried out on the shallow surface settlement points during the passage of the westbound tunnel.

The results from the Treasury and St. James's Park control site can be compared as they are in the close proximity of each other and the westbound tunnel is considered in both. The quality of the monitoring can be assessed from the data sets showing the development of the settlement profiles. The magnitudes of movements at the Treasury are less than those at St. James's Park and the profile is flatter, both aspects reflecting the influence of the building.

Comprehensive documents are now being prepared for each of the buildings that was monitored by the research team. The reports describe the structures and ground conditions, present the results from the monitoring and relate the observed movements with the construction activities that took place.

REFERENCES

Burland, J.B., R.J. Mair, L.F. Linney, F.M. Jardine & J.R. Standing (1996). A collaborative research programme on subsidence damage to buuildings: Prediction, protection and repair. *Proc. Int. Symp. on Geotechnical Aspects of Underground Construction in Soft Ground*:773-778. Rotterdam: Balkema.

Linney, L.F. & D. Page (1996). Site investigation for the tunnels and stations of the Jubilee Line Extension, London. *Proc. Int. Symp. on Geotechnical Aspects of Underground Construction in Soft Ground*:779-784. Rotterdam: Balkema.

Standing, J.R., R.J. Nyren, T.I. Longworth & J.B. Burland (1996). The measurement of ground movements due to tunneling at two control sites along the Jubilee Line Extension. *Proc. Int. Symp. on Geotechnical Aspects of Underground Construction in Soft Ground*:751-756. Rotterdam: Balkema.

Wallis, S. (1994). Jubilee Line Extension: the underground perspective. Supplement to *World Tunnelling*, 42 pp., London: Mining Journal Ltd.