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Design and installation of special tunnel rings to monitor long term ground loading

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ABSTRACT: In conjunction with a government/industry-sponsored research project to record long term subsurface movements at two locations on the alignment of the Jubilee Line Extension (JLE) running tunnels, it is proposed to install four special tunnel rings to provide additional information on the loadings to the tunnel linings due to both short and long term ground movements.

1 INTRODUCTION

The design, manufacture and installation of instrumented rings on the JLE follows directly from the work carried out by TRL and reported in a paper published in '*Tunnelling 94*' by Barratt *et al (1994)*. The objectives are to relate sub surface movements and changes in pore water pressures with hoop load and relative changes in the stress measured within the tunnel rings. In this way the resulting data may be used to enable designers in the future to adopt more realistic factors of safety in their ring designs.

Four rings have been adapted to measure loads and stresses. Two rings have been installed immediately below the array of instrumentation placed by the research project in St James's Park (Figure 1) and two rings will be installed under Southwark Park where a similar set of sub-surface instrumentation is in place.

The locations were deliberately chosen as greenfield sites to facilitate the monitoring of the instruments and to avoid the complications of interpreting the effects of overlying structures.

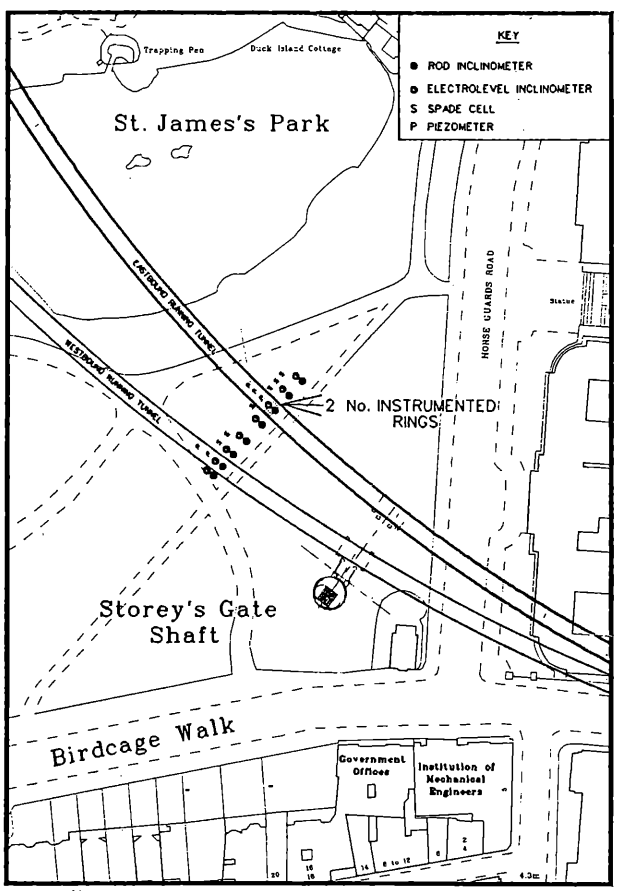

Figure 1 - Location of instrumented rings below St James's Park.

2 THE RINGS

2.1 *St James's Park*

Two rings have been manufactured and installed close to Storey's Gate Shaft, both rings are in the upper, eastbound running tunnel approximately 21 metres below ground level. One ring has four load cells fitted (Figure 2). Note the gaps created in the ring to ensure that the hoop load within the ring is accurately measured. Cells are located at crown and invert as well as at axis level to provide hoop load readings around the circumference of the ring. This will be particularly valuable as the previous work carried out at Regent's Park (Barret *et al* 1994)

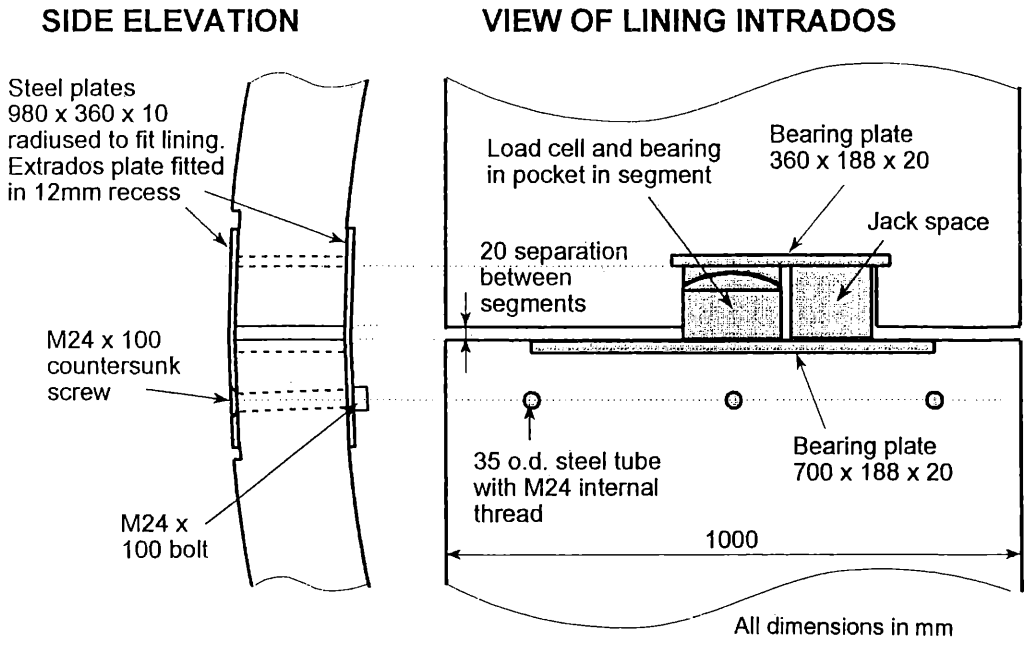

Figure 2 - Details of load cell pocket.

included a cell at invert but this cell failed before any data could be obtained from it. The hoop load is transferred via the load cells onto stainless steel bearing plates (Figure 2). The resultant concentration of load is catered for by locally increasing the reinforcement around the bearing plates to ensure that load is effectively distributed to the full section of each segment. Stainless steel components are used for the radiused stabiliser plates and bolts for durability.

The trackbed will be separated from the lining by a thin membrane to ensure that the loads recorded are due solely to ground loading and also to ensure that the instrumented rings are isolated from adjacent rings. This is important as the load cell ring may have a different stiffness from its neighbours and a shear connection, such as the track slab, could affect subsequent readings. The design also caters for replacement of any load cell in the case of a malfunction. The rings used in the St James's Park area are 4450 diameter, 200 thick expanded linings utilising two wedges at knee to expand the 10 lightly reinforced segments against the London Clay. The general arrangement is detailed as Figure 3. Vibrating wire strain gauges are fitted into the adjacent ring by attaching the gauges to the reinforcement cage of the segments during manufacture (Figure 4). The gauges will record changes in strain within 4 out of the 10 segments making up the ring.

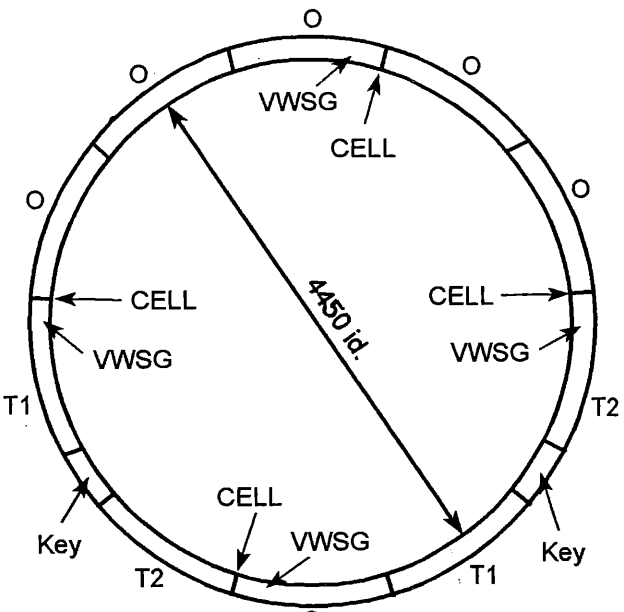

Figure 3 - General arrangement of expanded lining showing load cell positions.

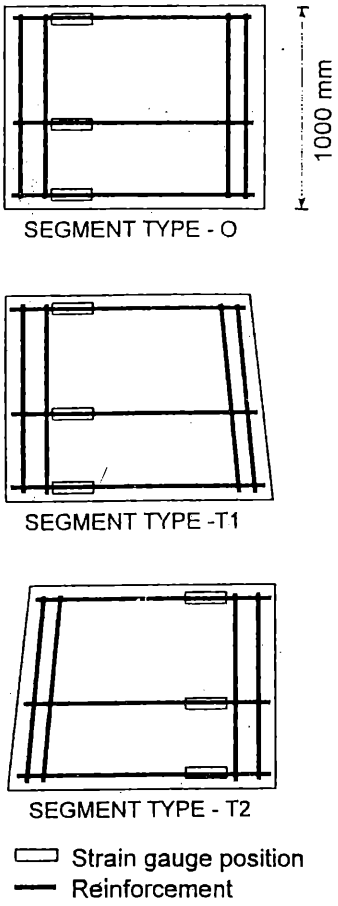

Figure 4 - Arrangement of vibrating wire strain gauges.

2.2 *Southwark Park*

Two rings will be installed in this case, one in each of the two running tunnels again straddling the location of the LINK instrumentation. As for the St James's Park site, the results of the sub-surface monitoring will be combined with the changes in the lining stresses to provide a complete picture of how the linings behave due to long term ground movements and pressure changes. It is not possible to break the tunnel rings and introduce load cells as for the St James's Park location as the ground conditions at Southwark Park are not appropriate being of low cohesion, water bearing, clayey sands. Each ring will therefore have four segments containing a set of four vibrating wire strain gauges fixed to the reinforcement cage. Due to the nature of the surrounding ground, and the fact that a heavy, closed-face shield machine is used to drive the tunnel, the tunnel rings at this location are heavier than those at St James's Park. They are 250mm thick and heavily reinforced, 5 segments and a key bolted together forming the ring. Also, as for St James's Park, the monitoring of the tunnel rings can be carried out from a nearby shaft, in this case Culling Road shaft, to enable daytime readings to be taken.

3 INSTRUMENTATION

The main requirements for the instrumentation were durability for the installation process and throughout the design life of the tunnel, long term stability and adequate capacity to measure the expected loads.

Triple vibrating wire load cells were specified for the St James's Park site because previous experience showed these instruments to be generally robust and reliable. The cells were rated to be capable of precisely recording loads up to 150% of the calculated overburden. This was to ensure that in the event of any asymmetrical loading the instruments were unlikely to go off scale.

Vibrating wire concrete embedment strain gauges are more problematic instruments to interpret because they provide an indirect indication of load. Additionally in longer term applications they may be susceptible to creep effects. However, as described above, the ground conditions on the eastern section of the Jubilee Line Extension precluded the use of the stress cell system and strain gauges were selected. The decision to install a strain gauged ring adjacent to the stress cell ring at Storey's Gate was made to allow comparison of the data from stress cells and strain gauges in similar conditions and thus aid interpretation of the data from other strain gauged sections.

4 ERECTION PROCEDURE

4.1 *St James's Park*

At each instrumentation location it was intended to minimise any disruption to the normal erection procedure and thus achieve as typical a section of lining as possible. In the case of the strain gauge ring this did not present particular difficulties. The segments were similar to standard segments with the exception of a number of cables which emerged from the inside faces of some segments. These cables were cut short to minimise the risk of their being damaged during handling. The ring was thus built in the normal sequence without undue delay with the only special work being the taking of initial readings prior to the next build. For logistical reasons permanent wiring from the instruments to a readout

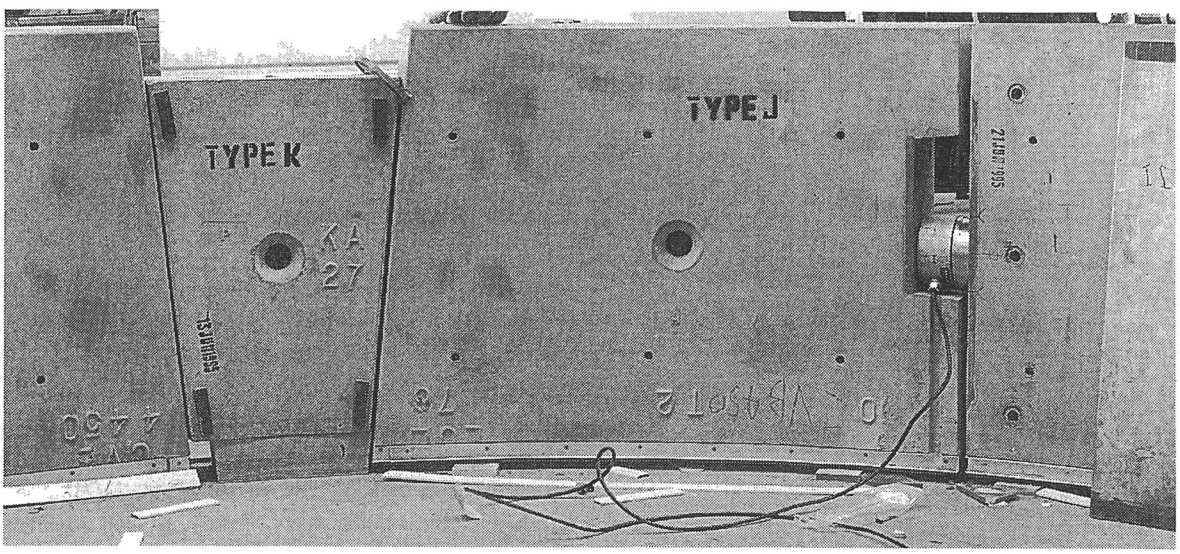

Figure 5 - Trial build of expanded ring showing load cell recess.

box in the Storey's Gate shaft will be arranged after construction of the section has been completed. Erection of the stress cell ring presented greater problems because the modified shape of several segments had the potential to alter the stability of the expanded ring. Specifically the replacement of the normal concrete to concrete line contact at four joints with a steel on steel single point contact was of concern. Given that stability of the whole ring depends on transmission of hoop loads through these joints any slippage of the cells would be unacceptable. To overcome this potential difficulty a system of steel retaining plates was devised (Figure 2). At each cell location one such plate was bolted to the extrados of the first segment to be erected such that it overlapped the cell and the end of the next segment. The cell was then placed in position and the next segment erected. Once the next segment was in position, and while it was still supported by the erector system, another retaining plate was bolted to the inside of the first segment covering the intrados face of the cell pocket and overlapping the next segment. Together the two plates prevented any lateral slippage of either segment and thus secured the joint. This sequence was repeated at each cell location.

After erection of the ring was completed readings of each cell were taken and the ring was expanded by shoving the key rams. Particular care was taken during the following full shoves of the shield to ensure that all rams were applied evenly to reduce the risk of any disruptions to the instrumented ring.

A major advance in the design of the present ring over that installed at Regent's Park was the facility to replace a defective cell either during erection or at any point in the life of the tunnel. This procedure would involve removal (after appropriate propping of the ring) of the internal retaining plate and insertion of a hydraulic jack in the space beside the cell. The jack would then be used to temporarily take the load during substitution of the cell.

4.2 *Southwark Park*

As at St James's Park it is planned that the strain gauged rings at Southwark Park will be installed in a near standard build. Because of the expected wet conditions in the Woolwich and Reading Beds the gauges have been cast into the segments with extended cables already attached. This will ensure that no electrical connections need be made near the invert of the tunnel where wiring may become immersed. The only special operations will be careful handling to avoid cable damage, and the necessary readings and cabling work after the segments are all placed. In the case of the closed face machines in use at Southwark Park the latter operations can in fact be undertaken during the next excavation cycle without disruption to normal working.

5. PROGRAMME

The instrumented rings for the St James's Park site were successfully installed into the eastbound running tunnel on 10 January 1996.

The first of the two rings at Southwark Park will be erected late January 1996 into the westbound tunnel between Bermondsey and Canada Water stations. The second ring in the eastbound tunnel is programmed for installation in August 1996.

The permanent monitoring consoles located at the Storey's Gate and Culling Road shafts will be set up mid 1997 following the installation of the permanent running track and during the cable-laying works.

6. CONCLUSION

Due to the recent installation of the instrumented rings, no data is available for publication at this time however this will be reported at a later date. It is hoped that the data in conjunction with that from the ground instrumentation will provide information on how the load on rings is built up relative to surrounding ground changes.

7 ACKNOWLEDGEMENT

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8 REFERENCE

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