

Widespread urbanisation of communities has led to a need for increased urban infrastructure. Surface space constraints in urban areas have resulted in new infrastructure being increasingly moved underground. Significant tunnel construction, using various tunnelling techniques, has been undertaken in a number of major cities in recent years. The ground is subjected to stress relief during tunnelling; this propagates through the soil to the foundations of buildings and infrastructure close to and above the tunnel. The interaction between these movements and the foundations is important for assessing movements and any subsequent damage to the overlying structures. Research has historically focussed on shallow foundations, with deep, or piled foundations, receiving less attention. Investigations into the effects of tunnelling on piled foundations have, in the past, concentrated on tunnelling adjacent to piles and the effect on pile bending. Where work has been undertaken for tunnelling directly beneath piles, this has been directed at driven piles. As pile driving is less desirable in urban areas, owing to noise and vibrations, bored piling is becoming increasingly prevalent. As a result, the focus of this research has been the effect of tunnelling beneath bored piles in clay.

Centrifuge modelling was used to investigate the effects of tunnelling on bored piles in clay. A new centrifuge package, including an innovative new pile, was designed to simulate tunnelling on bored piles in clay and used in the test series. Particle Image Velocimetry (PIV) was used to monitor the soil and pile movements when tunnelling volume losses were simulated. Internal pile loads were inferred from strain gauges embedded in the piles, allowing measurement of the change in load due to the soil-pile interaction. Combining this with the PIV measured movements, the load-transfer mechanism between the pile and soil was analysed. The effects of pile-soil relative stiffness, the pile factor of safety and the positioning of the piles relative to the tunnel were all investigated as part of the test series. The effect of pile factor of safety was seen to be significant in determining the pile head settlement when subjected to tunnelling movements. Pile positioning was also shown to be important, as were the effects of pile-soil stiffening and interaction effects between piles.

Two case studies, from the Crossrail project in London, are presented for tunnelling on piled structure in clay. The case study at 4-18 Bishops Bridge Road (BBR) showed the effects of earth pressure balance (EPB) tunnel boring machine (TBM) tunnelling on an overlying piled building. The other case study at Kempton Court showed the effects of sprayed concrete lining (SCL) tunnelling on an overlying piled building. Both of the buildings exhibited displacements which followed the 'greenfield' surface settlements, which was unexpected when compared with the centrifuge data. Further analysis showed that the effects of pile caps/ground beams and reduced actual loads, as opposed to design loads, were significant in limiting the building displacements.

A number of analytical models were compared with the centrifuge results, with most able to predict aspects of the data. The need for plasticity within the analytical models was highlighted. The importance of correctly modelling the pile base was also shown as could lead to unconservative analyses if ignored.

Keywords: pile, tunnel, clay, bored, centrifuge, soil-pile, interaction