City University London

Centrifuge Modelling for Deep Excavations and Tunnels

Professor Neil Taylor
Geotechnical Engineering Research Centre, City University
Secretary General, ISSMGE

Centrifuge modelling

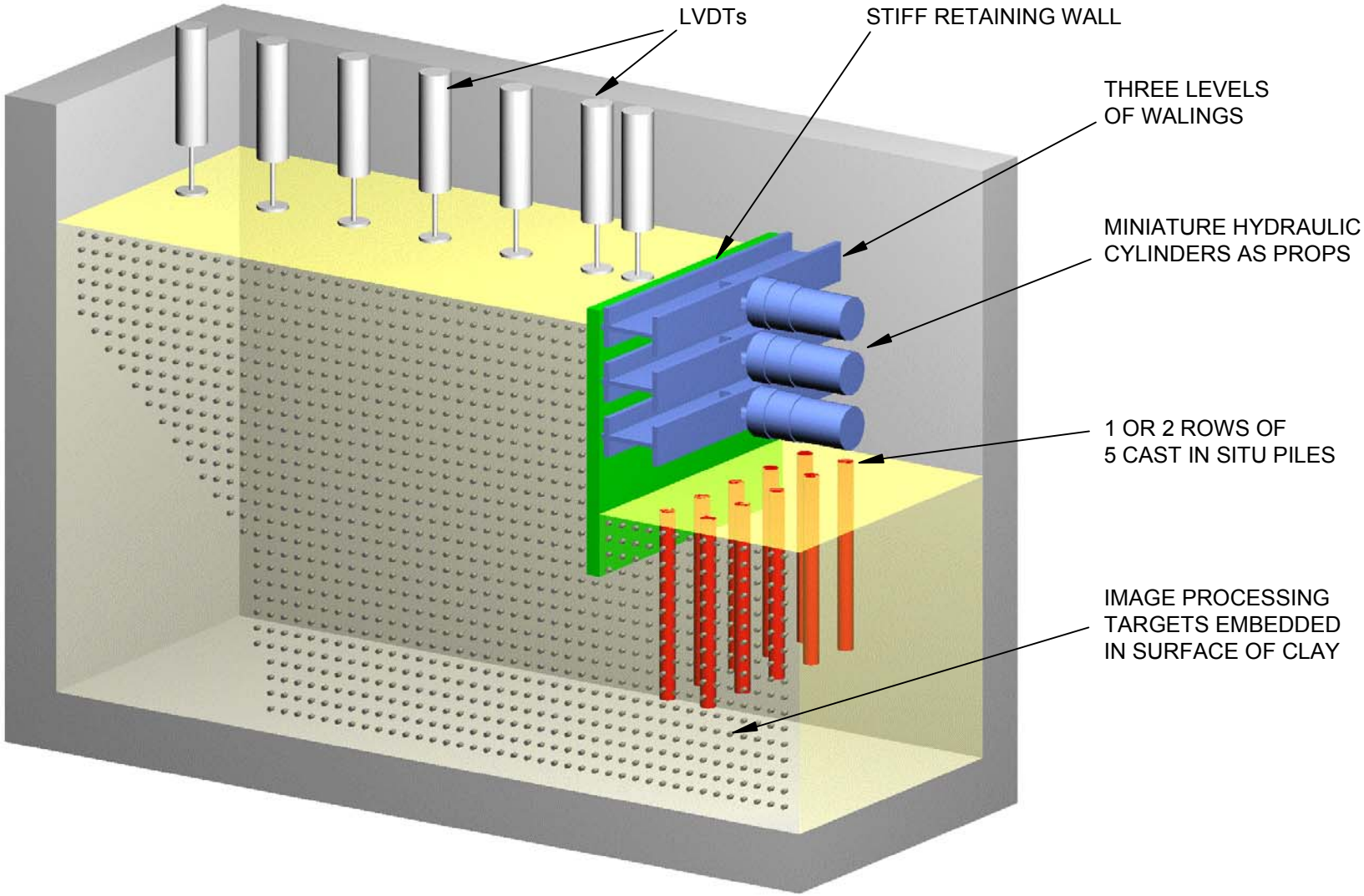
- Use of simple “load frame” to create realistic stress distributions
- Ideal for investigating mechanisms
  - Historically use to visualise mechanisms of collapse
  - Recent work concentrated on mechanisms of deformation
- Requires good visualisation techniques (image analysis)
- Illustrate using examples of excavations and tunnels, with emphasis on introduction of ground reinforcement to control movements

Deep Excavations (McNamara, 2001)

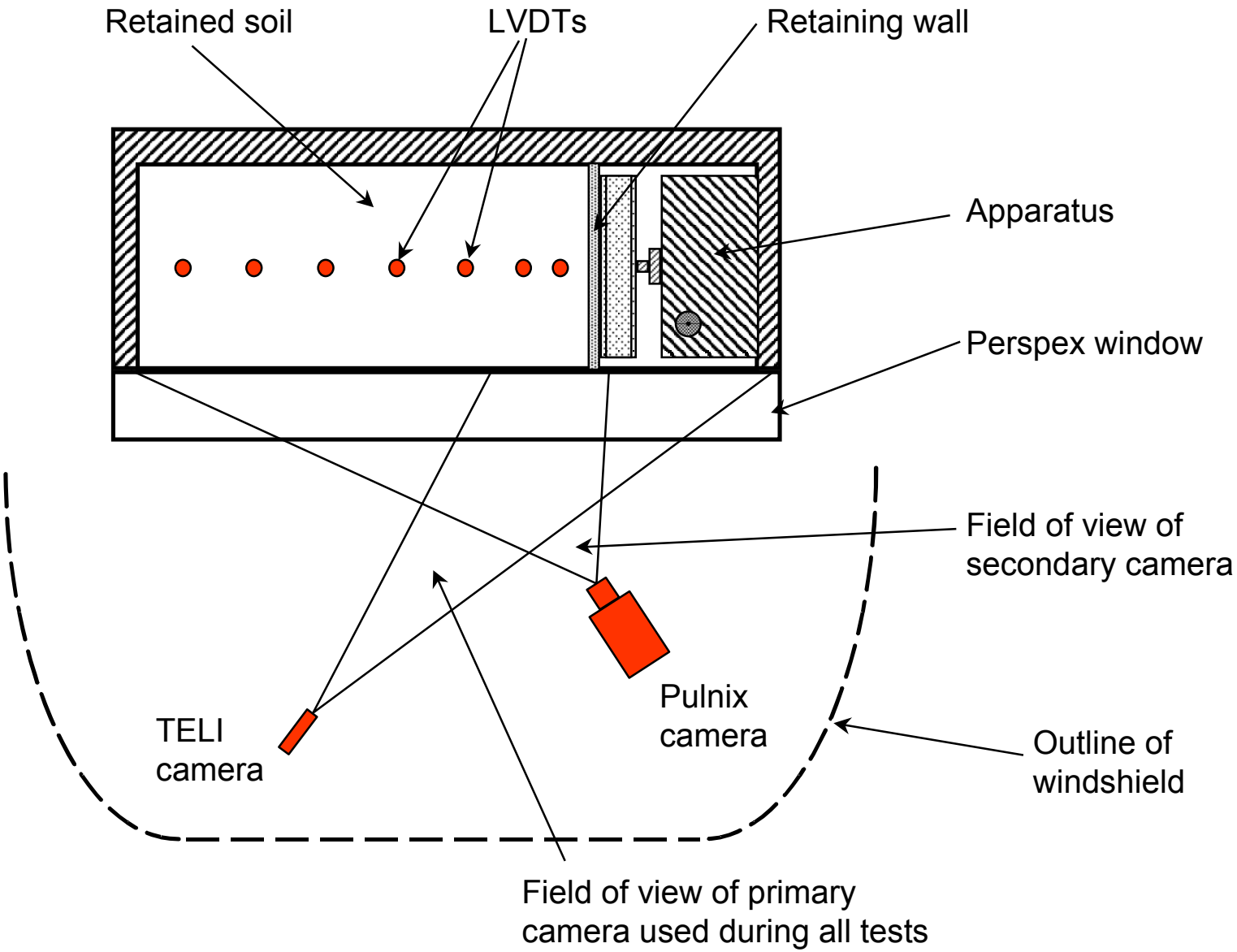
- Investigation of performance of excavation using propped diaphragm walls and with piles placed in excavation formation to reduce heave
- Experiments undertaken at City University and related to Knightsbridge Crown Court development



Completed centrifuge model



General view of centrifuge model



Plan view showing positions of cameras for image processing

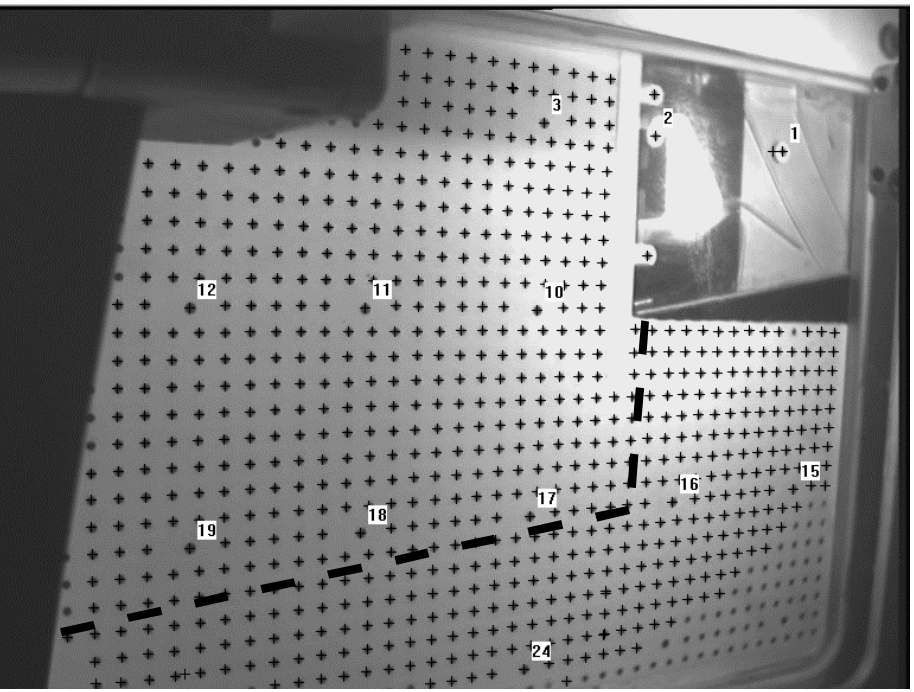


Image from TELI camera

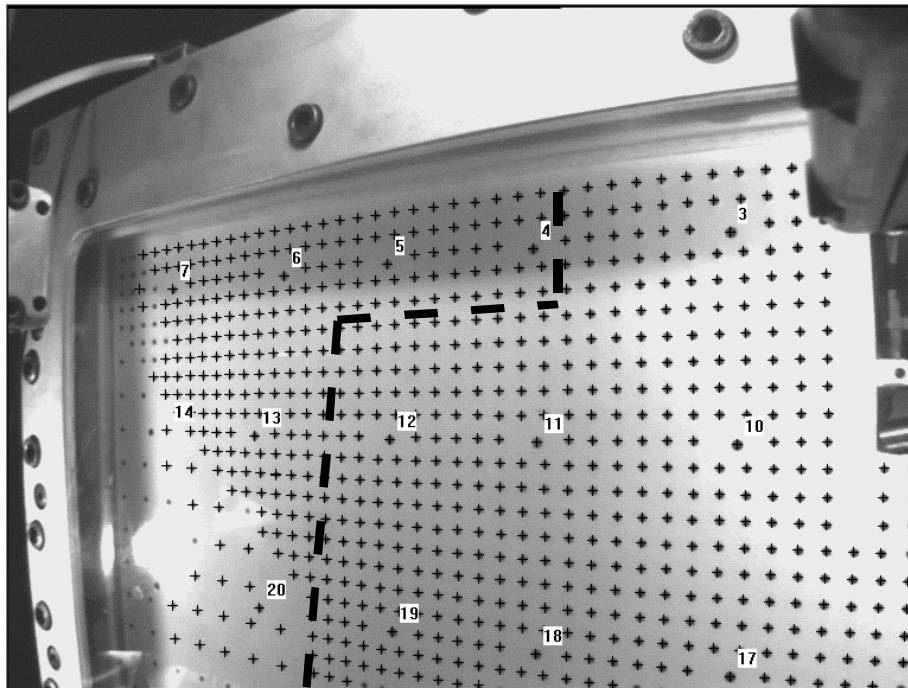
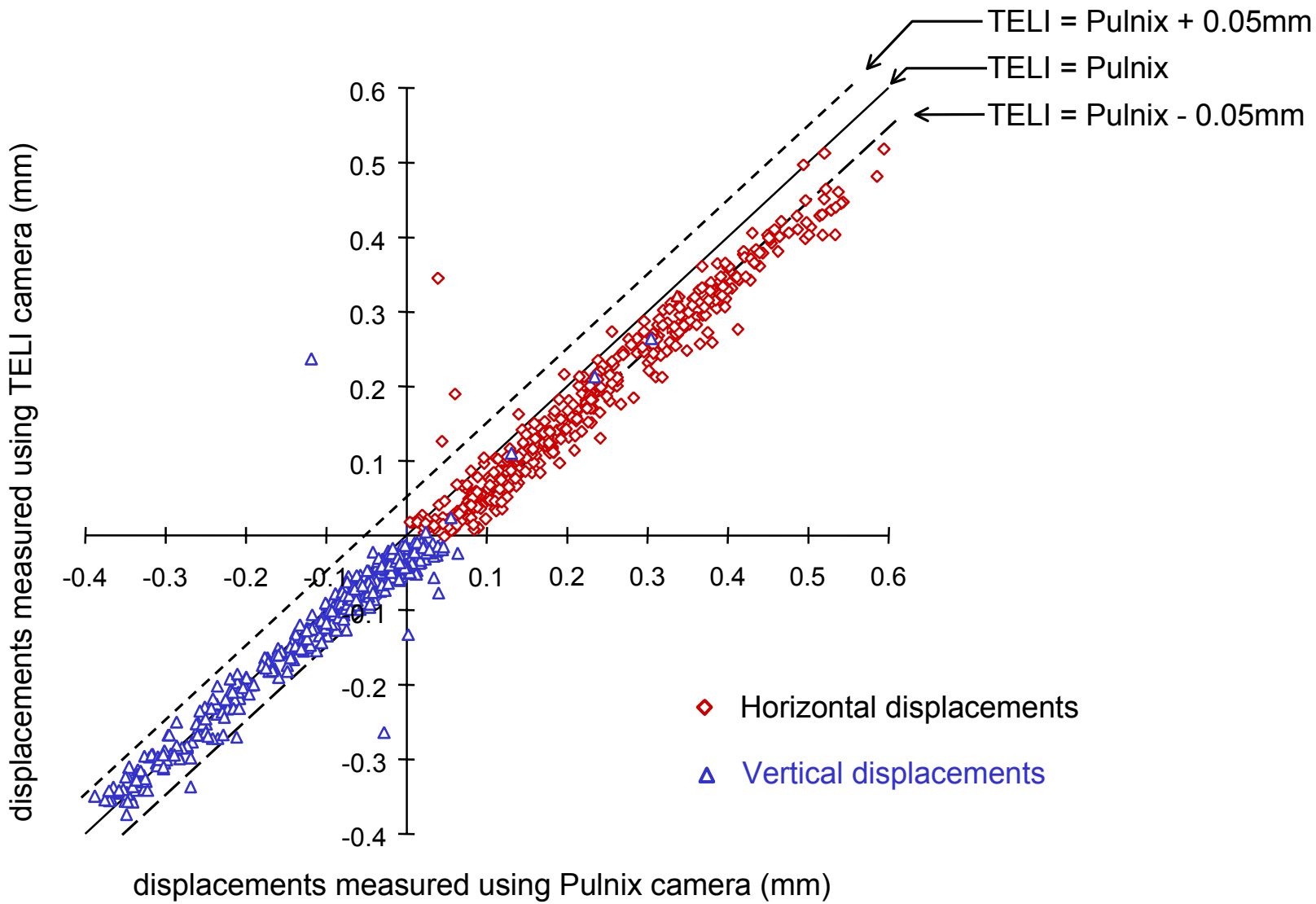
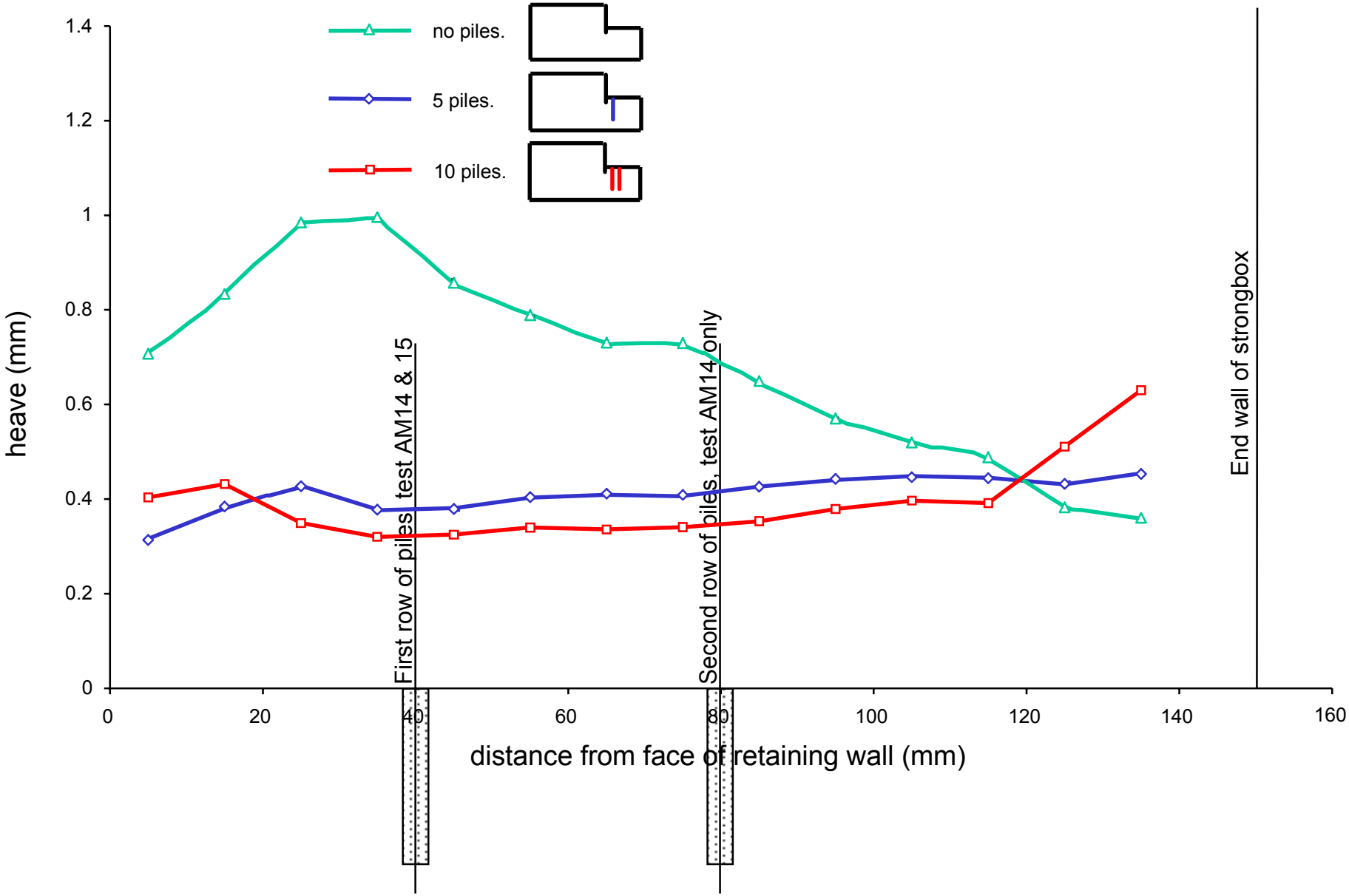


Image from Pulnix camera

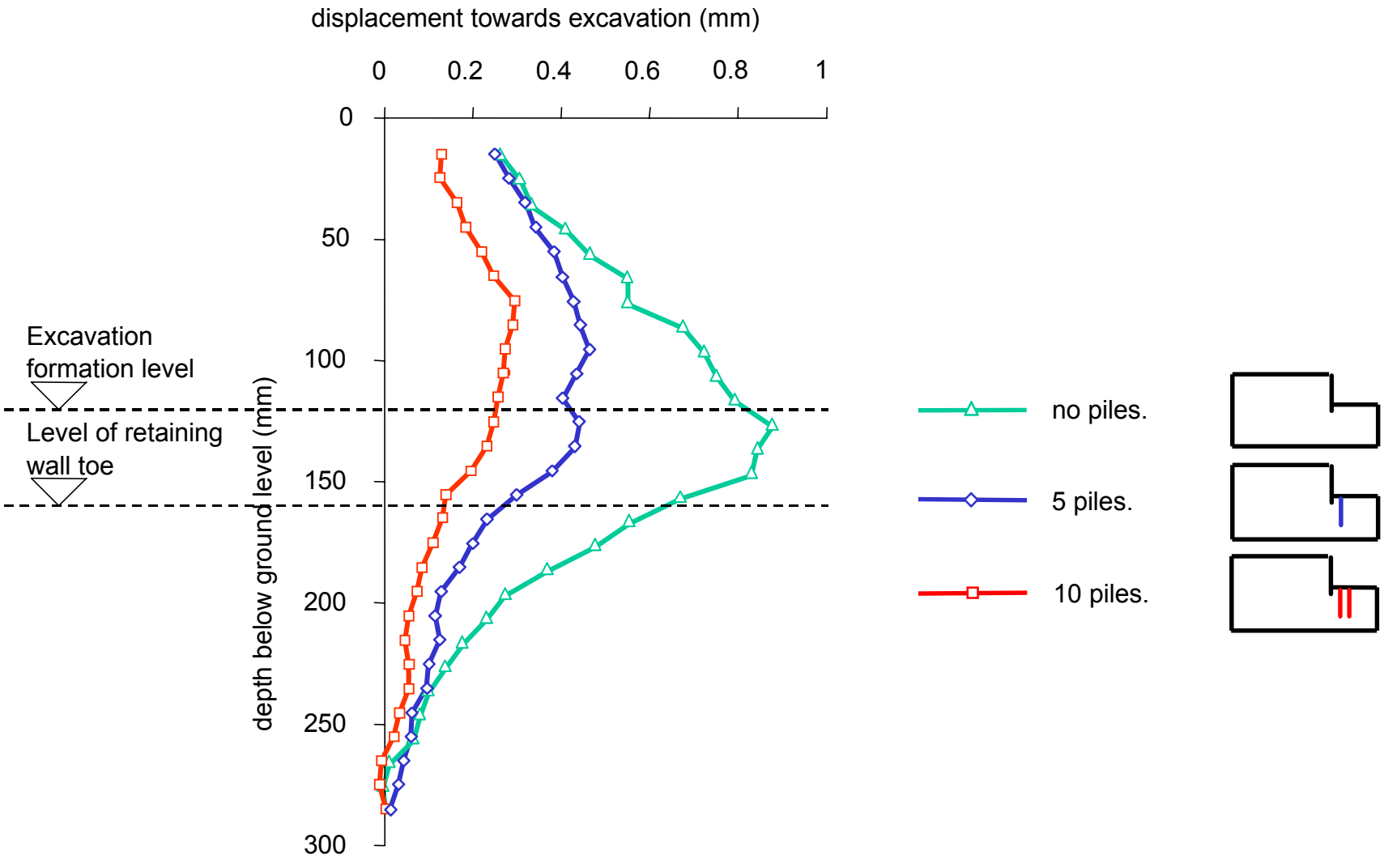
Typical images



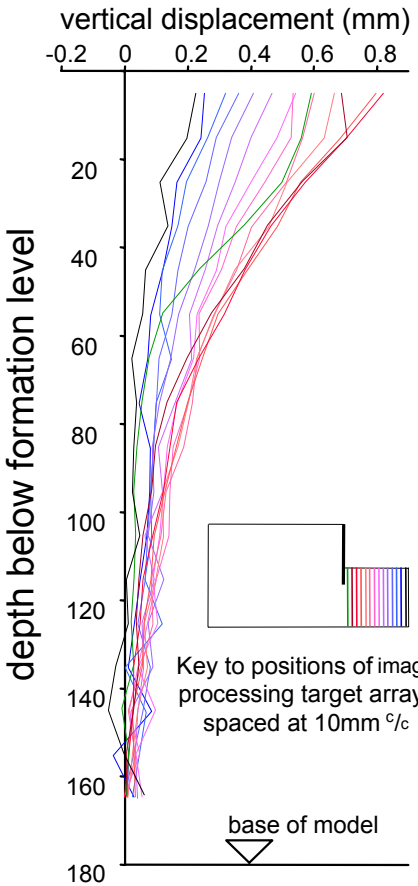
Comparison between displacements measured by TELI and Pulnix cameras



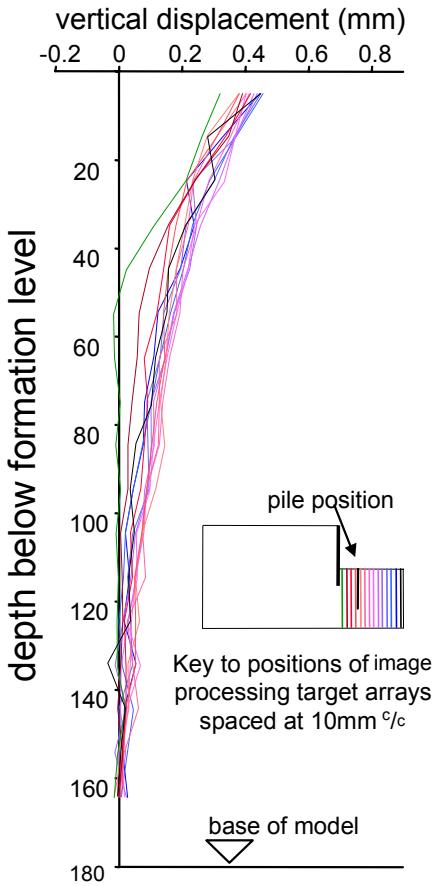
Comparison between measured formation displacements



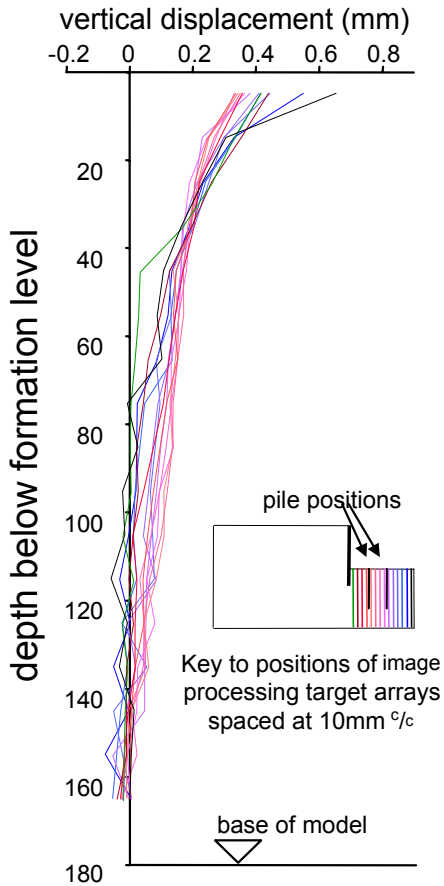
Horizontal displacements behind the retaining wall at completion of the simulated excavation stage of test



no piles.



5 piles.



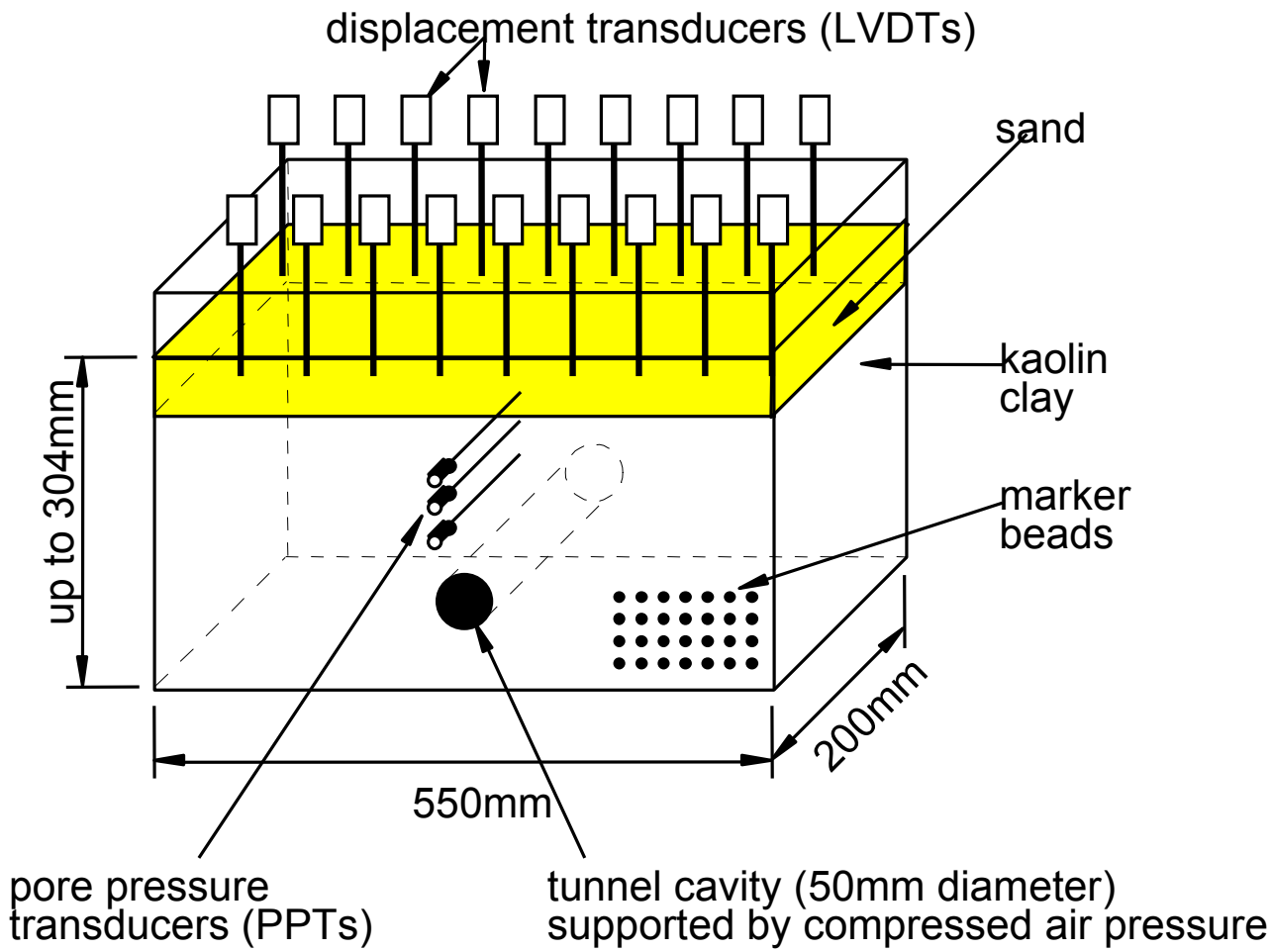
10 piles.

Vertical displacements below excavation formation level on completion of the simulated excavation

Tunnels

- Investigation of subsurface ground movements towards a tunnel excavation
- Influence of spile reinforcing introduced at a tunnel heading
- Use of soil nailing to control ground movements

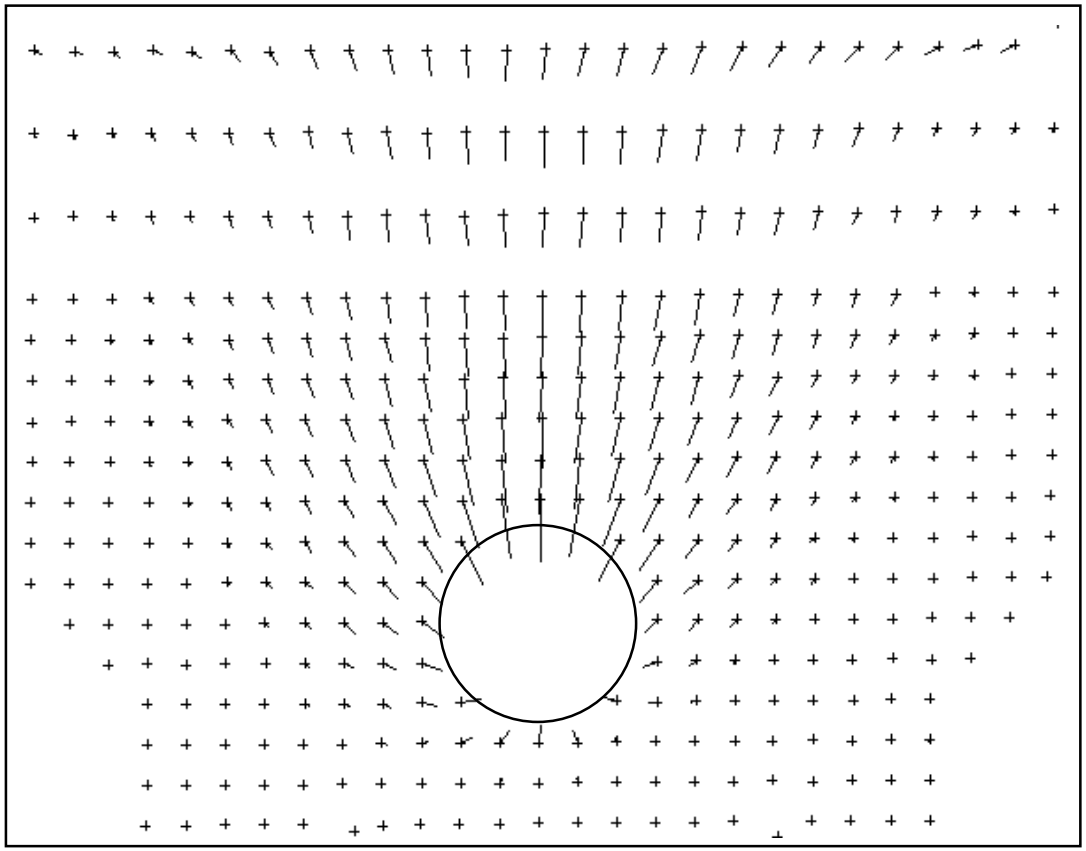
Investigation of subsurface ground movements caused by tunnelling (Grant, 1998)



Schematic of centrifuge model

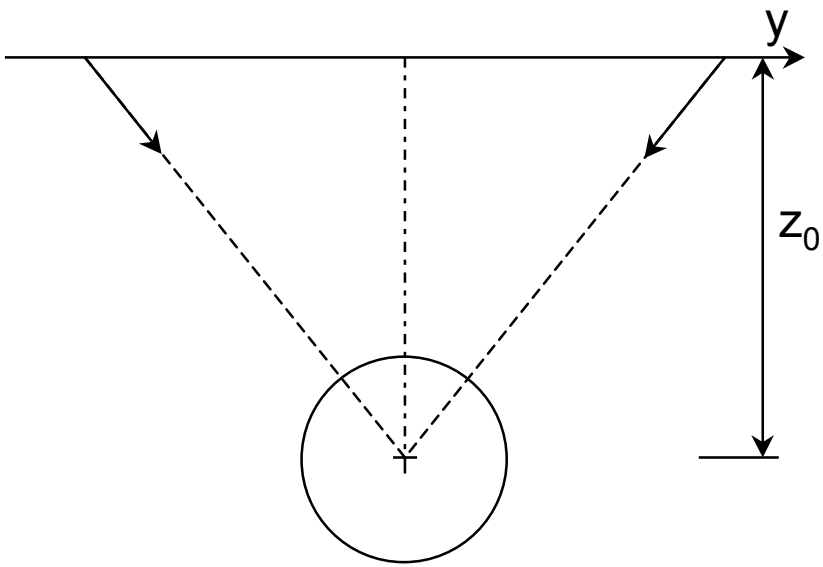
Observed pattern of ground movements

2.5*D* clay above tunnel crown
- water table 0.5*D* below clay surface

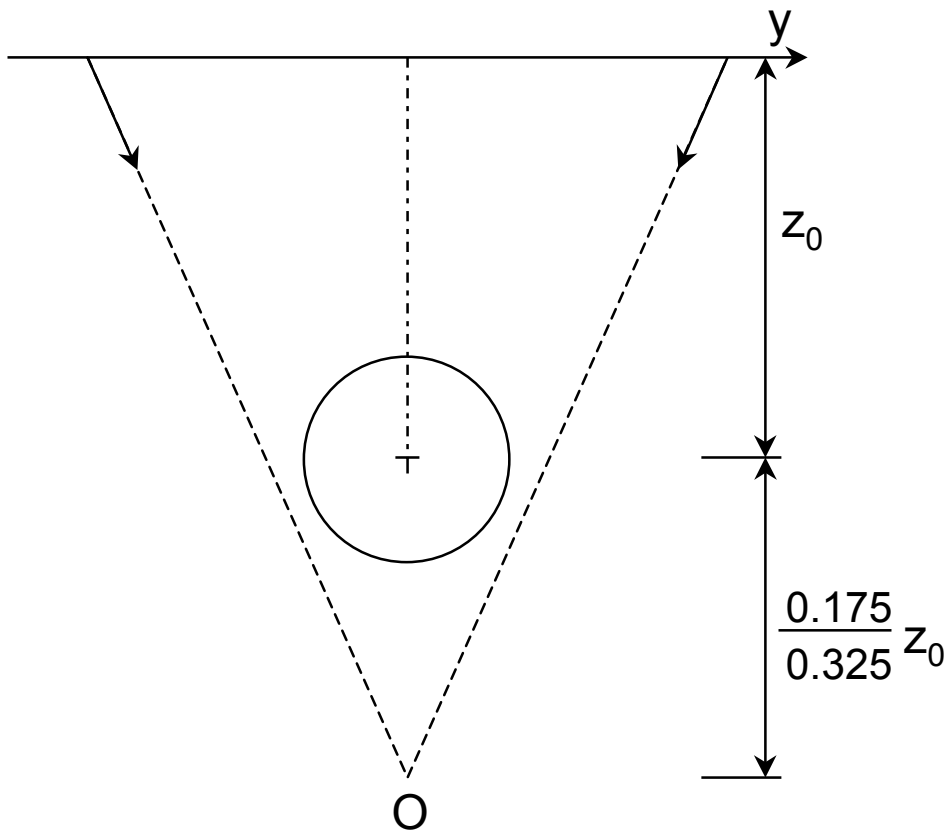


Vector ⟼ equals one millimetre

Vectors of ground movement

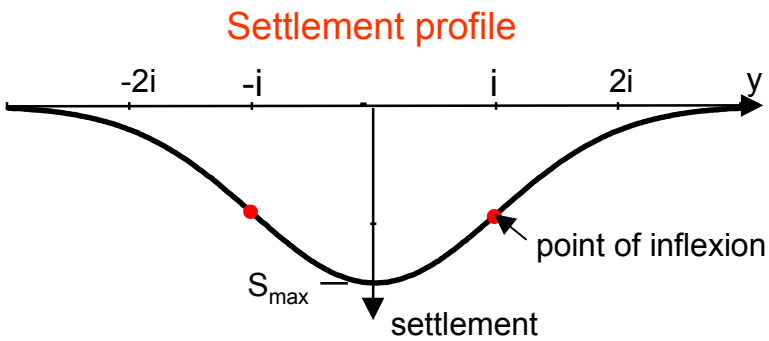


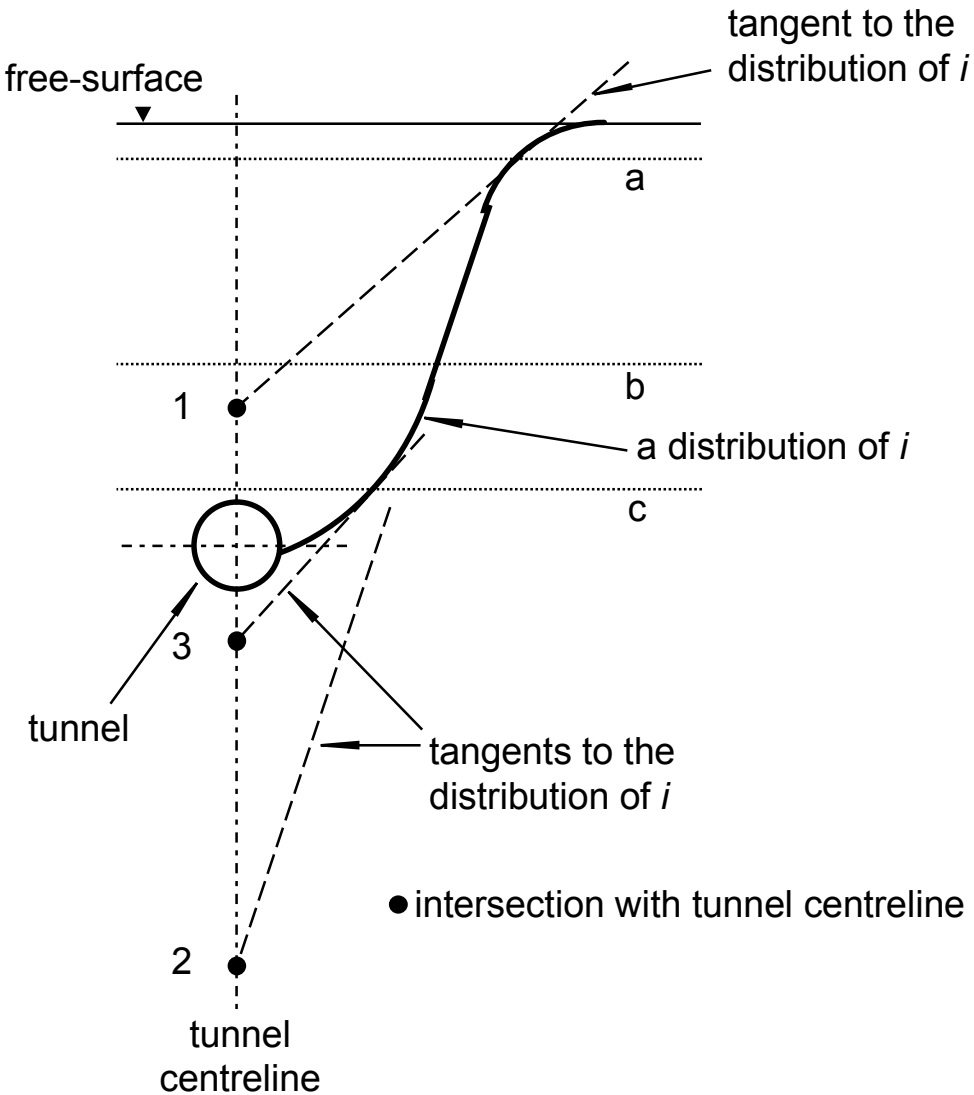
(a) Vectors directed towards axis
(Attewell, 1978; O'Reilly and New, 1982)



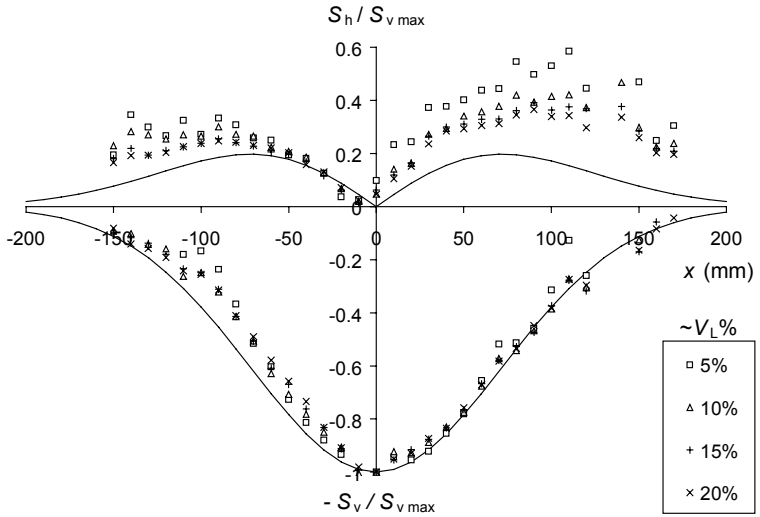
(b) Vectors directed towards point O
(Taylor, 1995b)

Intersections of tangents to the distribution of *i* with the tunnel centreline give directions of movement vectors

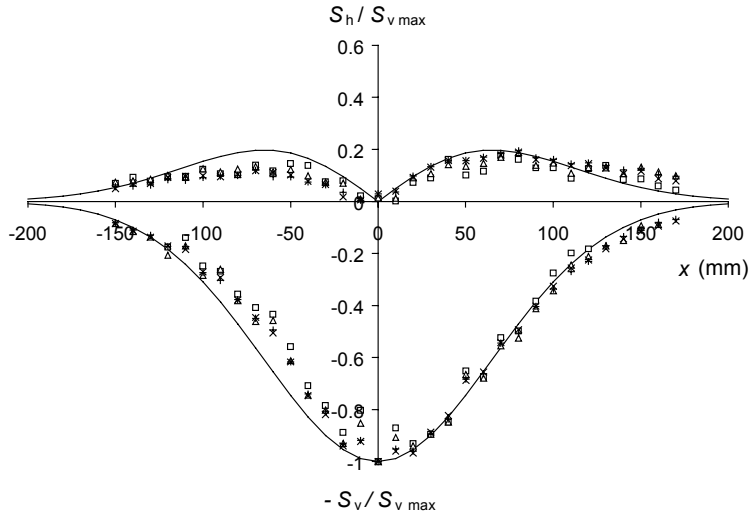




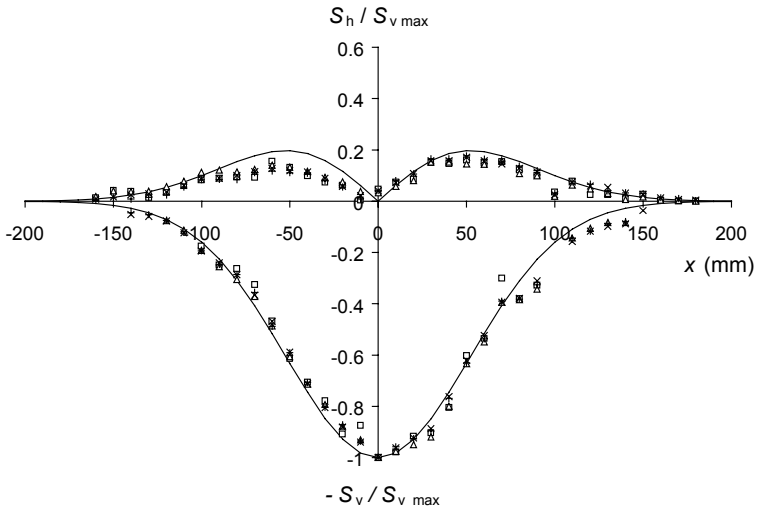
Comparison of measured and predicted vertical and horizontal movements at various subsurface horizons



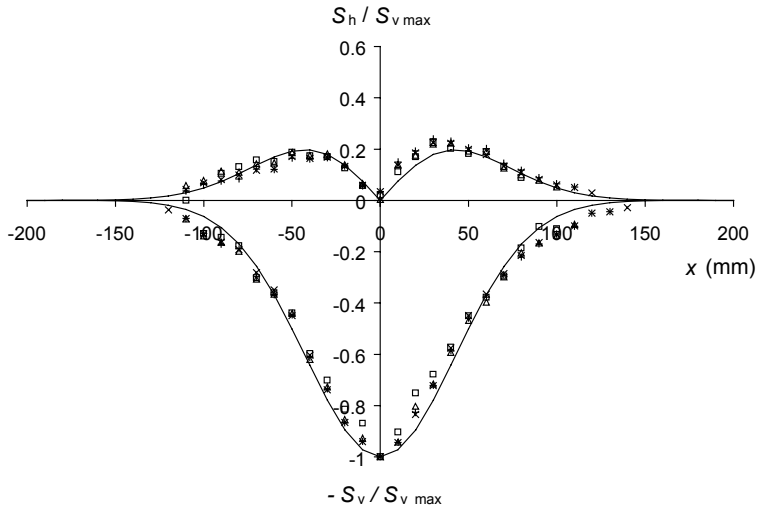
(a) 10mm below ground level (140mm above tunnel axis)



(b) 30mm below ground level (120mm above tunnel axis)

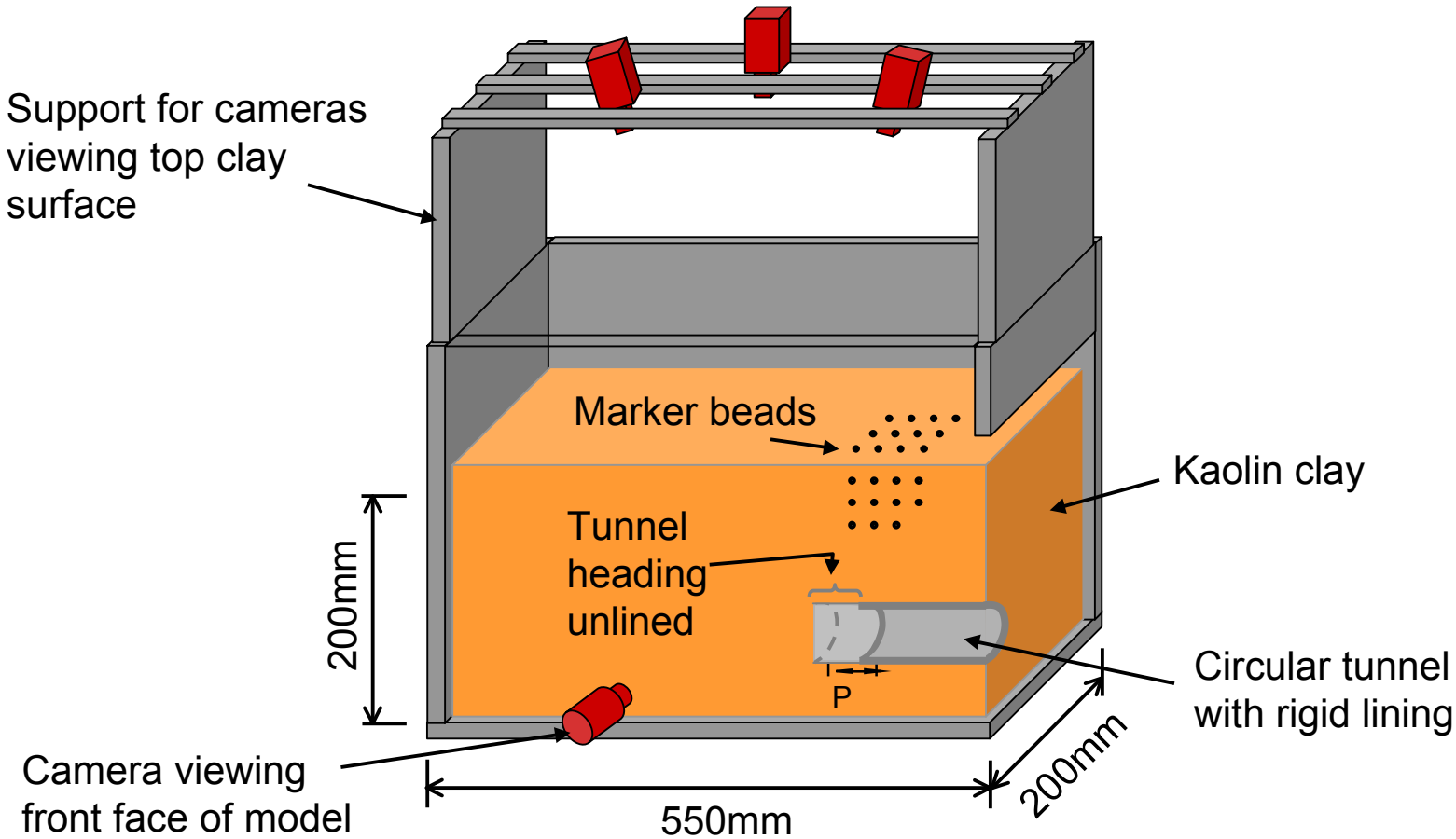


(c) 70mm below ground level (80mm above tunnel axis)



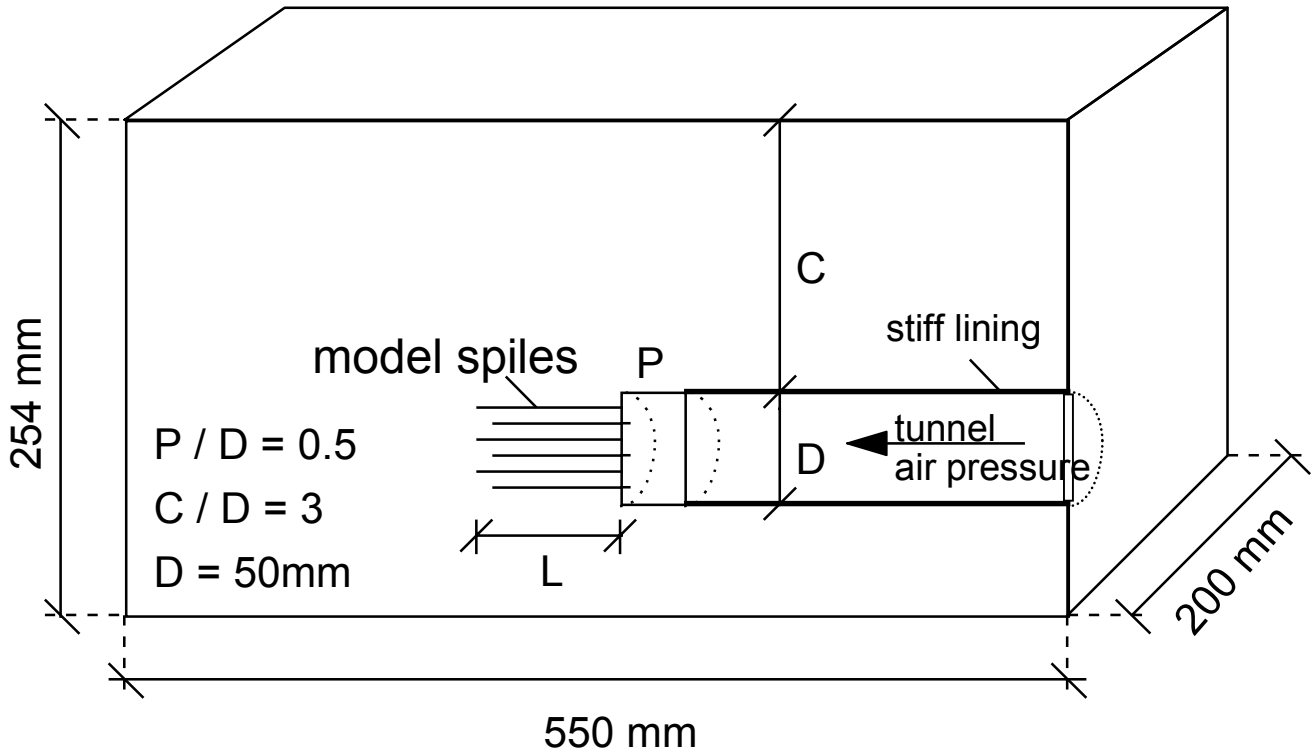
(d) 100mm below ground level (50mm above tunnel axis)

Centrifuge model testing: tunnel heading with spile face support *(Calvello and Taylor, 1999)*

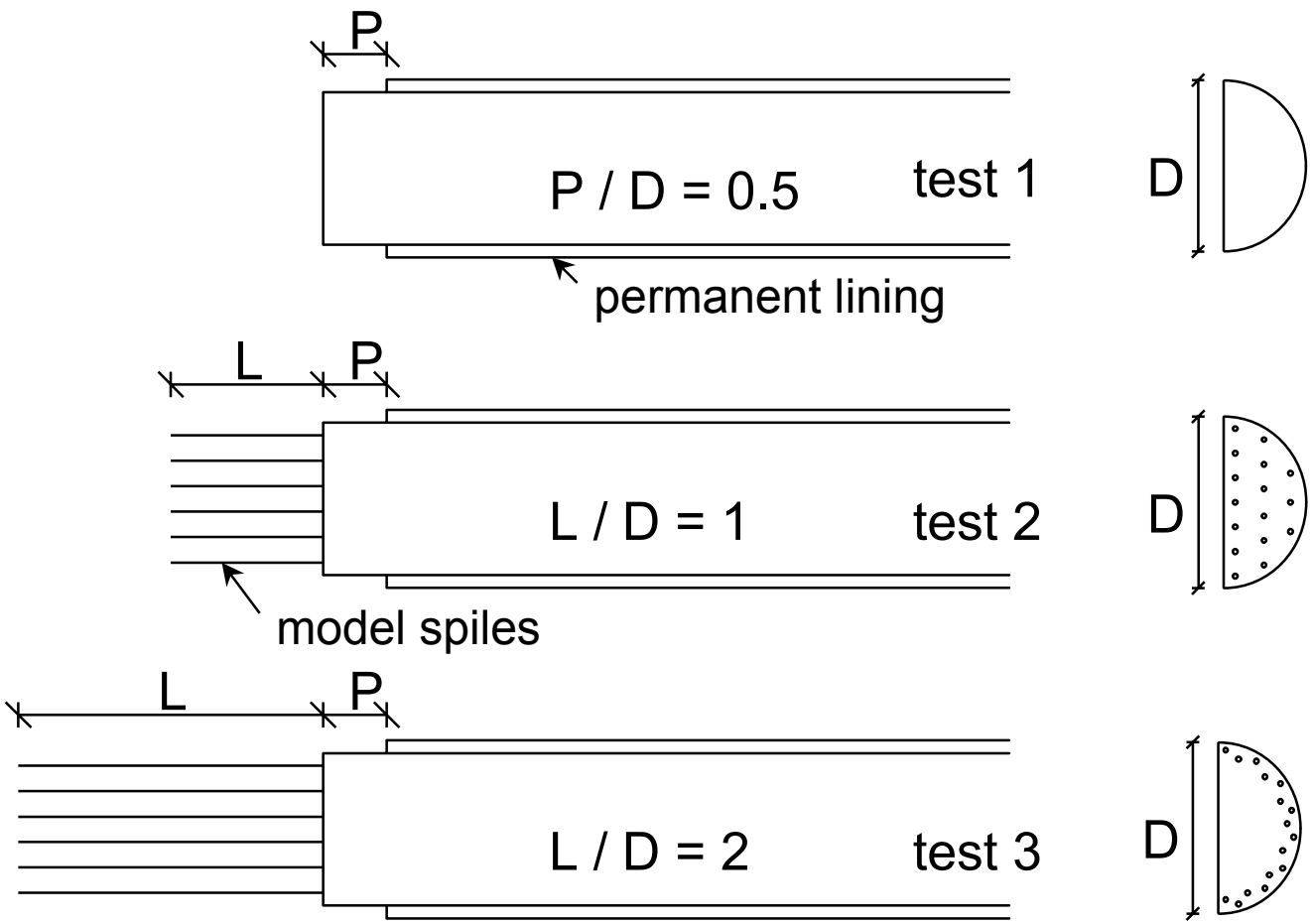


Schematic of centrifuge model

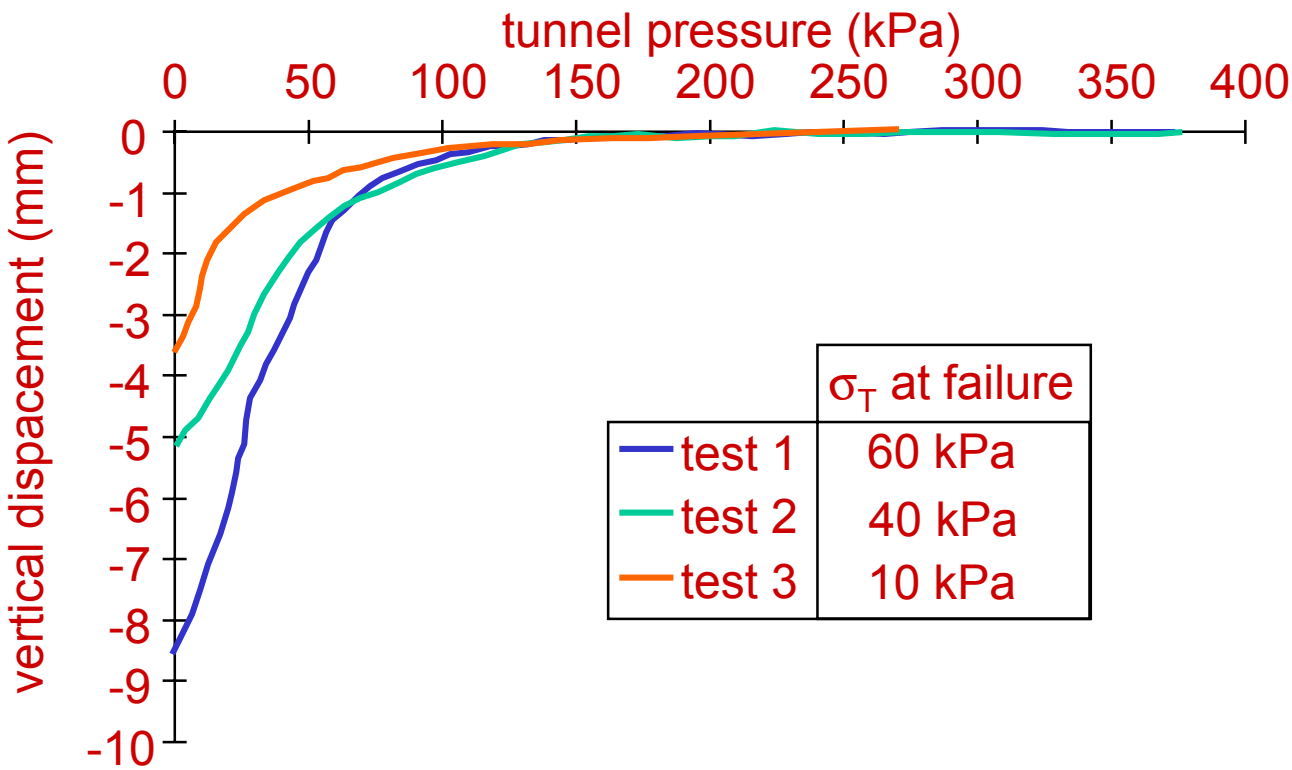
Centrifuge model testing: tunnel heading with spile face support



Spile arrangements used in the test programme



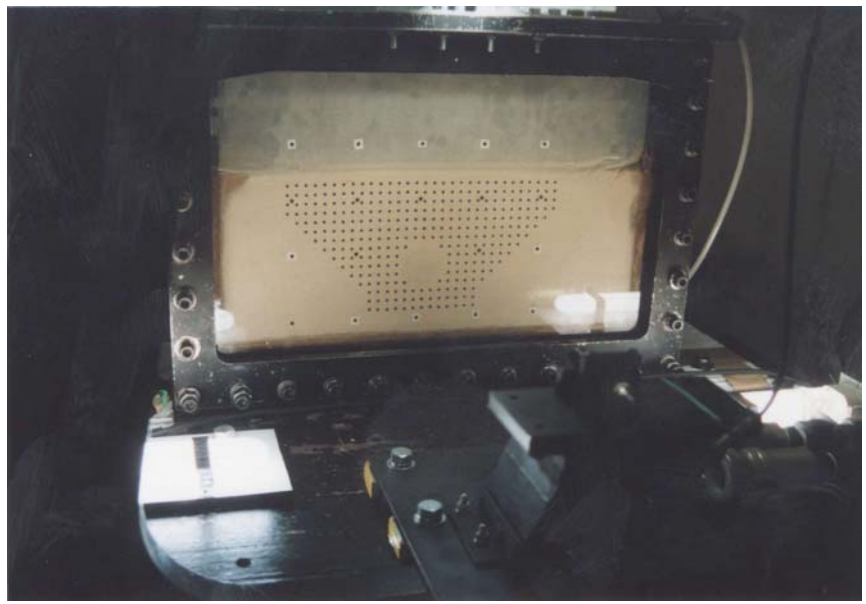
Surface settlement above tunnel heading



Centrifuge Tests of Deformation Mechanisms in Nail Reinforced Sand Ground around Shallow Tunnels (*Honda et al, 2001*)

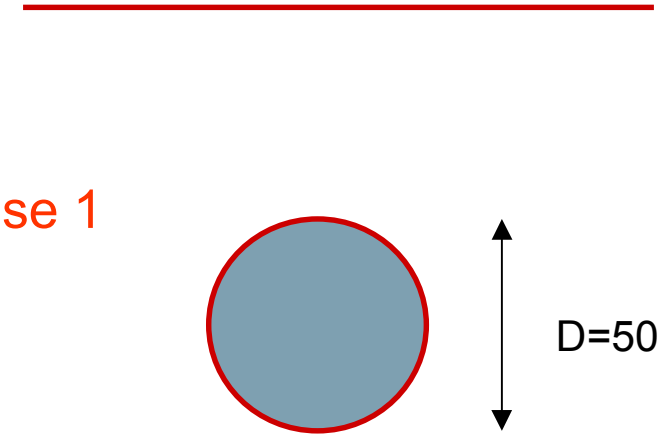


Geotechnical centrifuge



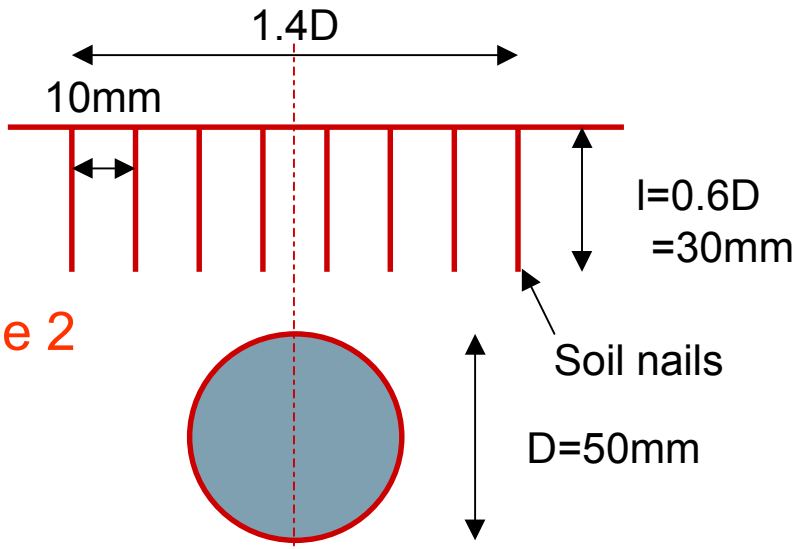
Model ground

Patterns of soil nails

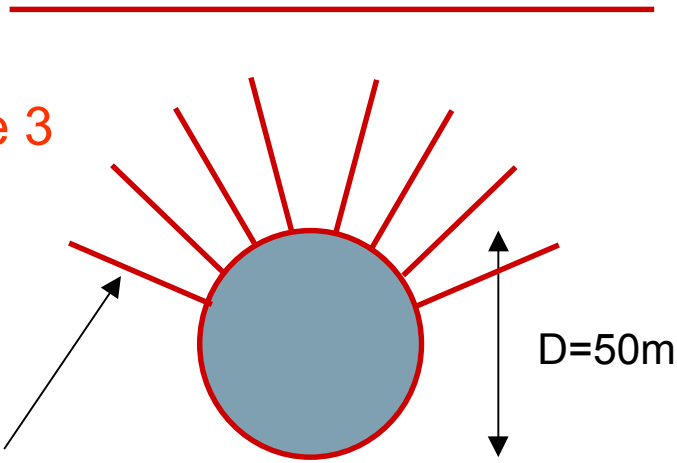


Case 1

D=50mm



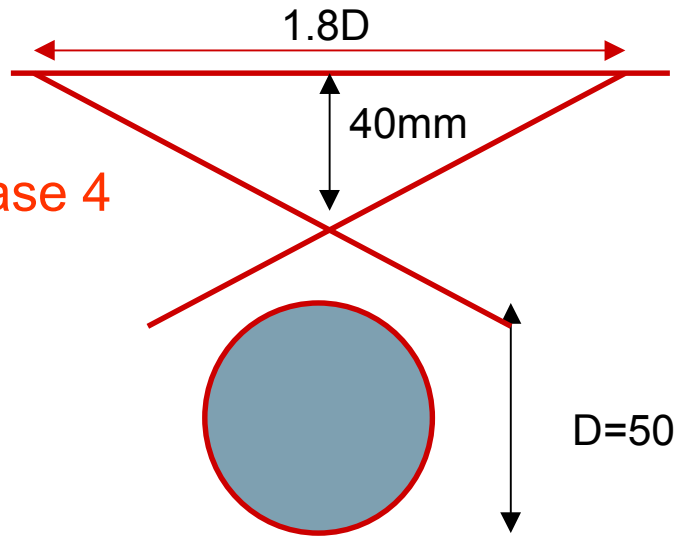
Case 2



Case 3

D=50mm

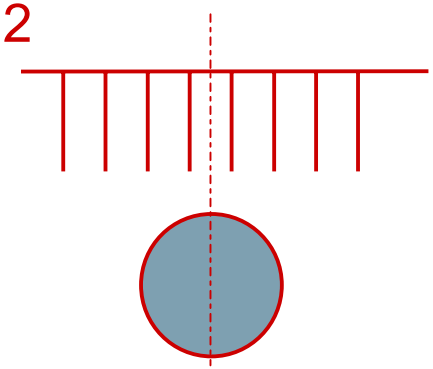
Soil nails, l=30mm, Direction:30, 45,
60 & 75(deg.) from horizontal.



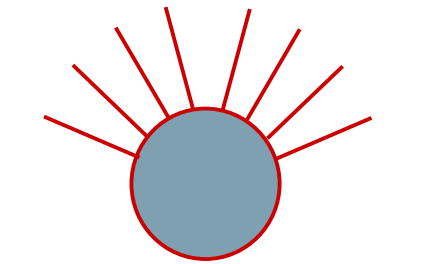
Case 4

Settlement response

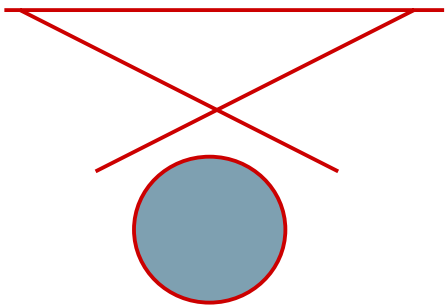
Case 2

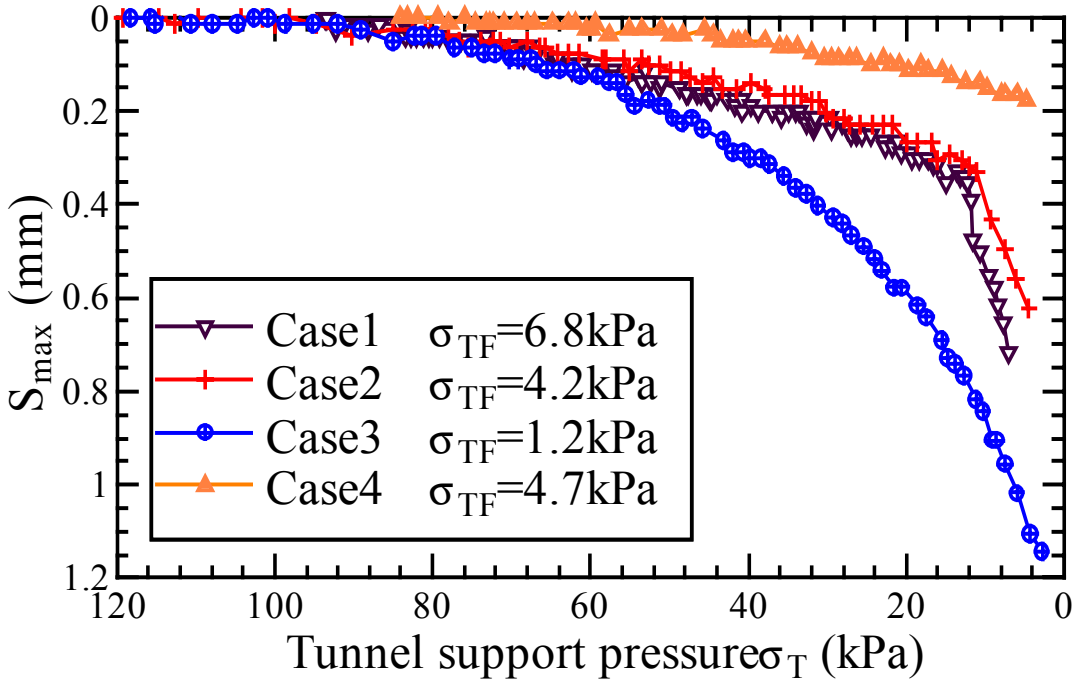


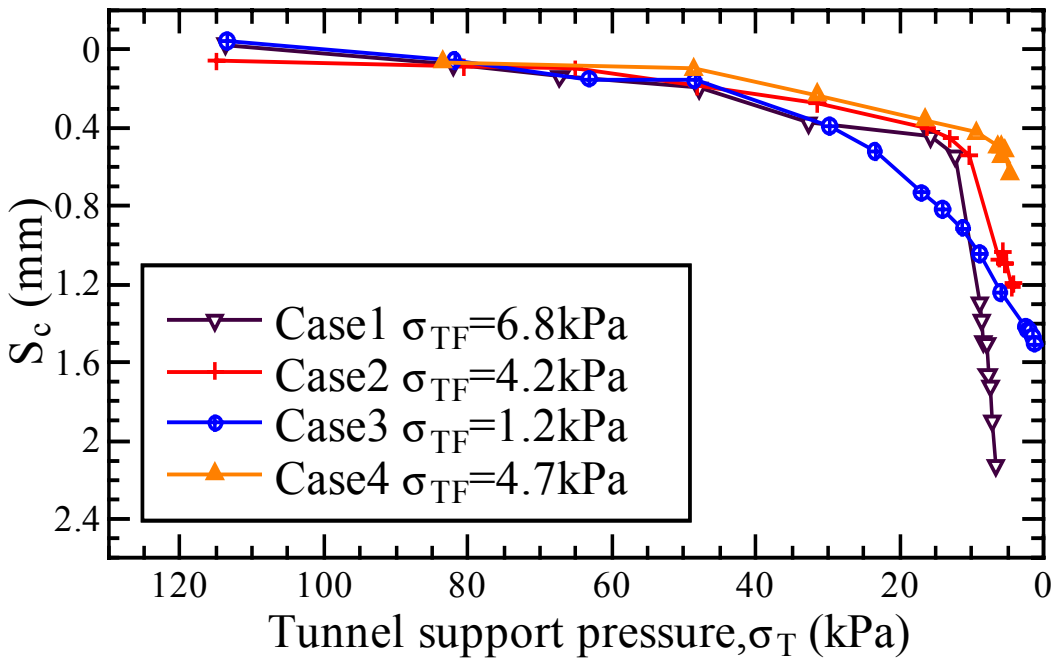
Case 3



Case 4







General Comments

- Centrifuge modelling allows many construction related problems to be investigated, including those involving ground reinforcement.
- The mechanisms by which ground movements develop due to different forms of construction need to be properly understood if these movements are to be controlled to acceptable magnitudes. The ability to measure accurately ground movements using image analysis has “revolutionised” centrifuge testing permitting pre-failure events and mechanisms to be studied in detail.
- Generalised but detailed investigations reveal patterns of behaviour that can inform design and analysis. Centrifuge test results allow convincing verification for analyses, which then permits numerical extrapolation to other geometries and situations.
- Case history data are useful, and centrifuge modelling allows a variety of scenarios to be investigated in detail so that the generic problem can be understood.