Temporary stability of slopes cut in London Clay

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Deep excavations at Terminal 5

- Bottom-up construction
- Open cut excavations for economy
- Maximum depth 22m
- Cut slopes to be as steep as possible
- Stand-up time up to 1/2 years
Temporary stability of deep cuts in London Clay

- To predict stand-up time of deep cuts using numerical analyses and so optimise slope geometry – maximum steepness and minimum excavation and backfill?

- Only after calibration against case histories of temporary slope failures (Bradwell, Prospect Park, Wraysbury)

Constitutive model for London Clay
Soil model used

\[ G = G(p', \varepsilon_d) \]
\[ K' = K'(p', \varepsilon_v) \]

Small strain stiffness curves in extension

Secant (3G)/p' or K'/p'

Axial strain or volumetric strain (%)
Shear strain, $\gamma$ (%)

Shear stress, $\tau$ (kPa)

Displacement across a 0.5m thick layer, $\Delta$ (m)

Predicted behaviour in drained simple shear

Behaviour in undrained triaxial extension
Swelling in oedometer test

Non-linear permeability model: $k = k_0 e^{-b \cdot p'}$

Test (depth: 13.55m)
Short-term slope failure at Bradwell

Excavated slope at Bradwell
Predicted rupture surface at Bradwell by FE analysis

Predicted rupture surfaces by LE and FE method of analysis
Short-term (undrained) failures at Bradwell

- Can be analysed in terms of effective stresses using the same constitutive model and soil parameters as for the delayed failures of cuttings in London Clay
- Role of progressive failure is small, and concentrated in the area around the toe of the slope
- Soil stiffness is of importance in estimating the short-term stability
Prospect Park failure 9 weeks after excavation

Tectonic shear surface in London Clay at Prospect Park
11.6m

Slip surface

Cut-off wall

Terrace Gravels

London Clay

Tectonic shear zone

London Clay

Typical cross section at Prospect Park

With shear

No shear

Movement vectors during excavation
Pore pressures at the end of excavation

Horizontal movements at the top of London Clay during excavation
Plastic shear strains just prior to collapse

Horizontal movements at top of London Clay after excavation – Zero suction
Horizontal movements at top of London Clay after excavation – With shear zone

Key factors determining time to failure

- Presence of tectonic shear
- Previous site history
- Surface suction; 25kPa gave the best match to observed time to failure
- Permeability profile and non-linearity
- Ko – if tectonic shear zone is absent
- Progressive failure – rate of drop from peak to residual strength
Predicted failure mode for 5m bermed 1:1 slopes at T5

Surface suction 25kPa

Predicted failure mode for 5m bermed 1:1 slope at T5

Surface suction ‘zero’
Lessons for the future

- Monitor movements to identify presence of tectonic shears or development of basal shear
- Take measures to maintain suctions at slope surface
- Monitor suctions
- Differentiate between drying beds and lagoons
- Check sensitivity to Ko, k and surface suction