Lessons learned from Cambridge (UK) Soil Models.
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Trench & Tunnel heading damage

1) Tunnel faces can be supported by compressed air, or as in Crossrail, by earth pressure balance.

2) A trench for a sewer pipe with a backdrop has a deep cut face without heading support pressure.

3) Centrifuge model tests with authentic soil states revealed new heading damage mechanisms.
Crossrail – 550 tonne tunnelling machine Elizabeth being lowered into 40m deep shaft at Limmo Peninsula
Sir Denis Rooke
1924-2008

Sir Edwin Chadwick
1800-1890
Bazalgette's sewer system. Image: N. Barton, "Lost Rivers of London" (Modified)
A backdrop will reduce sewer flow rate, but will cause deep trench-heading damage.
Kusakabe’s model tests for British Gas
1980 centrifuge-model test by PhD research student Osamu Kusakabe (now Professor, Tokyo Institute of Technology) showed axisymmetric circular shaft failure mechanism.
Alternative soil strength models and theories

Terzaghi’s Equation
Strength on a slip surface
\( \tau = \sigma' \tan \phi' + c' \).

Taylor’s CS+Interlocking
\( \tau = \sigma' \tan \phi_d + \sigma' \left( \frac{dy}{dx} \right) \).

Cam-clay Strength
\( \tau = (\text{aggregate CS friction}) + (\text{interlocking}) \).

An increment \( d\varepsilon \) of plastic distortion unloading and reloading soil grains will dissipate “frictional” work
\( dW = M \rho' \, d\varepsilon \).

Grain-aggregate mechanics in typical slopes at rest.

- The typical effectively stressed grain-aggregate in CS critical states with \( V_\lambda = V + \lambda \ln p' = \Gamma \) is a heap of sand at rest in an hour-glass.
- No dust is seen in an hour glass. Any grain damage would have made dust hence internal-friction in sand must dissipate energy by elastic collisions of grains without damaging the grains.
Interlocking in Taylor’s MIT shear box tests

Taylor’s interlocking strength component. \( \tau = \mu \sigma' + \sigma'(dy/dx) \)

\( \mu \sigma' \) friction

Positive interlocking \( \sigma'(dy/dx) \)

Strength = friction + interlocking

Peak drained strength at P; see Schofield (2006) Géotechnique

\( \tau = \mu \sigma' + \sigma'(dy/dx) \)

\( \phi' \) friction

\( \phi_d \) friction

\( \sigma'(dy/dx) \)

\( \sigma' \)