Introduction

The extent of glacial deposits

- Glacial soils amount to 60% of the soils in the UK
- Globally 10%
- Most major cities and national infrastructure in the UK are founded on glacial soils

Particle size distribution

Till can contain a range of particle sizes from clays to boulders and can vary from clay matrix dominant till that contains discrete granular particles to clast-dominated tills, which contain some fines; they can be fissured and laminated.

Spatial variation
Typical tripartite sequence

sand
sand and gravel
laminated clay
laminated clay
sand and gravel

red brown mottled sandy silty CLAY containing some gravel and lenses of sand
red brown sandy silty CLAY containing lenses of sand, sand and gravel and laminated clay
grey sandy silty CLAY containing gravel, cobbles and boulders
layers of laminated clay or sand and gravel

partially soliflucted ablation till
melt out till
weathered basal lodgement till (Eyles and Sladen, 1981)
lodgement till
basal lodgement till

shear zone

Till is more variable than any other sediment known by a single name’ (Hambrey, 1994)

Groundwater flow

Proposal
- in situ and laboratory tests gave acceptable values of hydraulic conductivity within lower till
- site lower till as natural liner
- hydraulic conductivity of upper till unacceptable
- construct liner

Results of Public Inquiry
- lenses of more permeable material within lower till raise mass conductivity
- leachate likely to contaminate surrounding area
- need to construct liner

Result
- abandon project

Instability

Recommended 1:2.5 slopes in ‘boulder clay’

- laminated clay layers are zones of weakness causing instability
- extensive water-bearing sands and gravels cause instability and surface erosion

Groundwater

Consultants Proposal
- construct 15m long 500mm diameter bored piles within till

Contractors Proposal
- construct 20m long 400mm diameter bored piles using open hole techniques

Actual Construction
- encountered water-bearing layer of sand and gravel at 19m
- fully cased 20m long piles

Glacial soils are a hazard
• Clay matrix tills fall on T-line
• Scatter in undrained strength due to sampling and natural variability
• Empirical classification correlations do not apply

- Density and water content more consistent
- Density indicative of heavily overconsolidated clay

Impact of sampling on strength

- Pore pressure development is a function of soil stiffness
- Pore pressure dissipation is a function of hydraulic conductivity
- Clay matrix tills are relatively impermeable but their stiffness means that
  - Some of the load is taken by the soil skeleton
  - And the rate of pore pressure dissipation is relatively rapid

\[ c_i = \frac{k}{m} \gamma_v \]

- Hence tills behave as partially drained soils
- Undrained shear strength is an underestimation of mobilised strength

Selection of design parameters is challenging
Deposits from Ice Sheets - initial advance

- Subglacial melt out deposits (sands and gravels) and non-deformed (laminated clay), outwash deposits within partly homogenised matrix

- Basal deposits: compacted into place through shearing and compression
  - Degree of compression varies with drainage conditions

Deposits from Ice Sheets - initial recession

- Sorted deposits: fluvioglacial features
- Basal deposits: compacted into place through shearing and compression

Subsequent advance

- Basal deposits: compacted into place through shearing and compression
- Degree of compression varies with drainage conditions

Impact of numerous glacial periods

- Basal deposits: compacted into place through shearing and compression
- Degree of compression varies with drainage conditions
- Can include 'compactified' ablation deposits

Clarity of description

- Sand and gravel
- Ice marginal
- Retreat

- Deposits from Ice Sheets - initial advance
  - Subglacial melt out deposits including lacustrine deformation

- Numerous glacial periods

- Distal
- Pro-glacial
- Proximal
- Advance
- Flow
- Retreat
- Continental lodgement
- Distal
- Advance
- Retreat
Proposed tripartite sequence

Concept of consolidation

Geotechnical model

Assessing strength

Characteristic strength
Stiffness

- Stiffness degradation is typical of fine grained soils

Hydraulic conductivity

- Hydraulic conductivity is a function of fine particle content and stress level
- But fabric will dominate permeability

Parameter selection process

- Regional geology to create likely geological profile
- Regional geotechnics to create likely classification and mechanics properties
- Site specific geology from boreholes samples, and exposures
- Site specific geotechnics to identify matrix classification based on geological features, PSD, PI and density
- Site specific geotechnics to identify matrix classification
- Site mechanical properties to determine mechanical properties of matrix
- Site characteristics identified from matrix and fabric

Table 7

<table>
<thead>
<tr>
<th>Parameter Selection</th>
<th>Regional</th>
<th>Site Specific</th>
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<tbody>
<tr>
<td>Mean Characteristic Values</td>
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<tr>
<td>Schneider (low)</td>
<td>Cautious mean (low)</td>
<td>Cautious mean (high)</td>
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<td>Bayes mean</td>
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<tr>
<th>Parameter</th>
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<th>Site Specific</th>
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<tbody>
<tr>
<td>γb (Mg/m³)</td>
<td>2.00</td>
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<td>w (%)</td>
<td>21.5</td>
<td>19.74</td>
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<tr>
<td>P_L (%)</td>
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<td>L_L (%)</td>
<td>46.5</td>
<td>43.18</td>
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<td>s_u (kPa)</td>
<td>99</td>
<td>76</td>
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<td>2.023</td>
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<tr>
<td>w (%)</td>
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<td>P_L (%)</td>
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<td>L_L (%)</td>
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<tr>
<td>s_u (kPa)</td>
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Taking into account regional database

- Based on coefficient of variation
- e.g. active pressures
- e.g. bearing capacity

Conclusions
<table>
<thead>
<tr>
<th>Glacial till composition</th>
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<tbody>
<tr>
<td>Many glacial clay tills</td>
</tr>
<tr>
<td>• Are sub-glacial tills</td>
</tr>
<tr>
<td>• Are a combination of deformation and lodgment tills</td>
</tr>
<tr>
<td>• Contain remnants of previous glaciations including ablation deposits and local derived lodgment till</td>
</tr>
<tr>
<td>• Contain new lodgment material from a remote source</td>
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<tr>
<td>• Are very dense because of the action of compression and shearing during deposition</td>
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<table>
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<th>Glacial till properties</th>
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<tbody>
<tr>
<td>• Are dense and stiff</td>
</tr>
<tr>
<td>• Density and stiffness is a function of the mode of deposition and not necessarily due to consolidation</td>
</tr>
<tr>
<td>• Contain softer and less dense material</td>
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<tr>
<td>• Ablation deposits within lodgment/deformation till</td>
</tr>
<tr>
<td>• Are normally consolidated or over consolidated</td>
</tr>
<tr>
<td>• Degree of consolidation depends on drainage profile and stiffness of underlying soils</td>
</tr>
<tr>
<td>• Behave as a 'drained' material because of the stiffness even though they are of low permeability</td>
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