Classification and strength of Northumberland Till
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Introduction
Open cast coal mining has taken place in the North East of England for nearly fifty years. Geotechnical investigations for this mining activity were started in the late sixties in order to determine the properties of the overlying superficial deposits. The data from the investigations could be used in the design of soil storage mounds, excavations in overburden and haulage roads. The amount of site investigation has increased over the years especially following the publication of Geotechnical Codes of Practice in 1982 and 1989. These investigations are in addition to the extensive investigations of bedrock conditions.

The site investigation data form a substantial record of the properties of the superficial deposits over a large region of the North East of England stretching between the Rivers Coquet and Wansbeck. Generally the superficial deposits consist of glacial materials. These data are being assessed to allow a model to be developed of the geological and geotechnical processes that have taken place. In this paper the results of a simple statistical study of the classification and strength data are presented.

Sources of information
The area considered, shown in Figure 1, covers about 150km². Detailed investigations of about 20 sites have been carried out.

Figure 1: Plan showing location of sites.

Figure 2: A model of the glacial lithostratigraphy of the Northumberland glacial deposits.
on behalf of the northern region of British Coal Opencast (BCO) using cable tool percussion rigs. These opencast coal production sites are the focus of an infrastructure with coal disposal points, semi permanent coal haulage roads, pit heap reclamation and amenity restoration schemes. Figure 1 shows the location of such sites.

Over 550 boreholes have been sunk and about 50 trial pits excavated. The depths of investigations ranged between two and fifty metres reflecting the thickness of the superficial deposits. The ground conditions are predominantly glacial but do include made ground, peat, dune deposits and alluvium. This paper is only concerned with the glacial deposits.

Laboratory testing was carried out to determine the classification of the soils and assess strength parameters for stability calculations.

Classification of the glacial deposits
The thickness of the glacial deposits varies from 50m to less than 5m. Buried glacial channels do exist but generally rockhead is between ten and twenty metres below ground level. The glacial deposits are primarily lodgement till which can be subdivided into a basal and ablation till. The ablation till is further subdivided into a weathered and unweathered till.

A model of the glacial lithostratigraphy, Figure 2, of the Northumberland glacial deposits was built up from observations of excavated faces in opencast mines and the site investigation data. This model has since been validated in successive exposed faces at the currently active Stobswood site.

Four discrete units have been identified ignoring topsoil, peat and alluvial soils. Unit 1, the uppermost layer, is a weathered ablation till which is generally a firm to stiff mottled sandy silty clay with some gravel. The relatively unweathered ablation till (Unit 2) is generally a stiff dark brown sandy silty clay with some gravel and occasional cobbles. The lower basal till (Unit 3) lies below the ablation till and is generally a stiff to very stiff dark grey sandy silty clay containing much gravel and some cobbles. Boulder sized obstructions are frequently encountered in this unit. The percentage of coarser materials increases with depth through the lodgement till. These till contain lenses of sands, sands and gravels and thickly laminated clays which are grouped together as Unit 4 though in this paper only the laminated clays are discussed.

This model and classification data were assembled from a large database containing in excess of 6000 records collected over a number of years from several sites by different contractors. The site investigations have been carried out in accordance with CP2001:1957 and the current Code of Practice BS5930:1981. The descriptions are remarkably consistent despite the differences in the specifications and the number of operators. This justified the use of the descriptions to produce the model, a model supported by observations of exposed faces.

Site investigation data
Site investigations were primarily carried out to determine the extent of the superficial deposits and the properties pertinent to excavation techniques or stability analyses and occasionally for carriageway or foundation design. BCO has evolved its own standard sampling and laboratory testing regime. Samples are taken every metre and at every change of strata so that the classification, stiffness and strength can be determined.

Figure 3: Atterberg Limits of the glacial deposits, from top: Unit 1, Unit 2, Unit 3, Unit 4.
Figure 4: Variation in water content with depth for each unit, from top: Unit 1; Unit 2; Unit 3; Unit 4.

Figure 5: Variation in plasticity index with depth for each unit, from top: Unit 1; Unit 2; Unit 3; Unit 4.
Figure 6: Variation in undrained shear strength with depth for each unit, from top: Unit 1; Unit 2; Unit 3; Unit 4.

Figure 7: Variation in undrained shear strength with depth for each unit, from top: Unit 1; Unit 2; Unit 3; Unit 4.
The majority of the tests were classification tests, that is tests for water content, Atterberg Limits and undrained shear strength. Undrained unconsolidated triaxial tests are routinely carried out since the results, when used in total stress calculations for spoil mounds, give conservative factors of safety against instability. Many consolidated undrained triaxial tests with pore pressure measurements have been carried out to determine effective strength parameters for stability of excavated faces.

Most tests were carried out on samples from Unit 2 since this is the most common foundation material for soil storage mounds. The strength of Unit 3 is generally, within one profile, greater than that of Unit 2 therefore any postulated failure mechanism will lie above Unit 3. The presence of laminated clay, which tends to be in lenses, can govern the stability of mound or face though it is often difficult to determine whether any laminated clay in a borehole forms a lens which extends over a sufficiently large area to cause concern.

Parameter selection – classification tests

Summaries of the classification data are shown in Figures 3-6. The data were assembled on a spreadsheet and divided into the units according to their accompanying descriptions. An indication of the density of data is shown on the Figures using contours. The percentage figure on a contour represents the amount of data within that area. The inner area represents the most densely populated area. As expected there is considerable scatter in the data which reflects the variation in fabric though certain statements and trends can be noted.

Sladen & Wrigley (1983) suggest that data from lodgement tills should lie about the T line on the Cassagrande plot. The data shown here do lie about the T line but the axis of the most densely populated area lies above that line. The tills are clays of medium to low compressibility. In general the basal till is less compressible than the upper ablation till. There is very little difference between the unweathered and weathered ablation till.

The water content is similar to the plastic limit in all cases and generally reduces with depth. The plasticity index also reduces with depth. Note that this refers to the finer fraction of the till. It does not necessarily represent the properties of the till though matrix dominant tills in which the coarse fraction is less than 40% will behave as clays, the effect of the coarser material being negligible.

Undrained shear strength is a function of water content and soil fabric. Several relationships have been suggested in the literature. These include, for overconsolidated clays, a relationship based on overconsolidation ratio and overburden pressure (Ladd et al, 1977); for normally consolidated clays, a relationship based on plasticity index and overburden pressure (Skempton, 1957); and for remoulded clays, a relationship based on liquidity index (Wroth & Wood, 1979).

Details of the groundwater regimes at these sites are not known in sufficient detail, therefore no relationships with effective overburden pressure could be established. Tills generally are insensitive therefore it is reasonable to assume that the remoulded strength is similar to the undisturbed strength. Figure 7 shows the variation of undrained shear strength with liquidity index. Average lines drawn through the data for each unit are approximately parallel to the proposed relationship for remoulded soils that is

\[ c_a = 170 \ e^{-4.84i} kN/m^2 \]  

(1)

Figure 8: Effective strength parameters for each unit based on the stress state at failure.

Figure 9: The effective strength parameters for Unit 2 normalised with respect to its intrinsic properties.
Table 1: Typical values of classification parameters in terms of lithological units (values in brackets show minimum and maximum values).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Units</th>
<th>Water content (%)</th>
<th>Plasticity index (%)</th>
<th>Dry density (Mg/m³)</th>
<th>Shear strength (kN/m²)</th>
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<tr>
<td>0-5</td>
<td>1-8</td>
<td>21</td>
<td>20</td>
<td>1.70</td>
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<td>2-8</td>
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<tr>
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<td>2-8</td>
<td>16</td>
<td>16</td>
<td>1.84</td>
<td>185</td>
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<tr>
<td>20-25</td>
<td>3-8</td>
<td>15</td>
<td>15</td>
<td>1.90</td>
<td>200</td>
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<tr>
<td>25-30</td>
<td>3-10</td>
<td>10</td>
<td>13</td>
<td>1.93</td>
<td>200</td>
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</tbody>
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Table 2: Typical values of classification parameters in terms of depth divisions.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Water content (%)</th>
<th>Plasticity index (%)</th>
<th>Dry density (Mg/m³)</th>
<th>Shear strength (kN/m²)</th>
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<td>1.93</td>
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The intrinsic value of effective stress for the water content and limits of each specimen. The scatter is significantly reduced suggesting that the variation in strength is due to local variations in the physical properties of the till. The normalised curves are based on average intrinsic properties proposed by Burland. Recent tests on these tills have confirmed that their intrinsic compression properties conform with the proposal of Burland.

Applications of the database

This database was developed following the needs of BCO to have preliminary indications of the properties of the coastal till in the Northumberland. It supplements site investigations and can be used as a framework to assess the quality of data and identify the units present in any borehole.

Table 1 gives summary of all the results of the classification tests showing the average values and range of values. Table 2 gives summary of the variation in properties with depth. Note that the average shear strength and range of strengths increases with depth.

An estimate of effective strength parameters can be obtained from Figure 8. A better estimate can be obtained from Figure 9 if the water content and limits of the specimen are known.

Conclusions

Site investigation data and geological records have been interpreted to produce a database for coastal tills in the Northumberland. Four main Units have been identified from which a model has been produced. This model conforms with observed excavations.

Profiles of data for each Unit have been prepared. The trends are similar to those published elsewhere though with a larger database it is possible to note significant differences between the different tills. These can be used for an initial assessment of properties of till in the region and as a framework to assess the quality of data from any additional site investigation. This database does not replace good quality site investigation which should be routinely carried out for any engineering project. It supplements site investigation data.

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References


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