“Prediction of Construction Conditions in Landfill Cells Using Geophysical Surveys”

Definition of the problem

The EU Landfill Directive requires that by 2020 the UK must have dramatically reduced the amount of biodegradable municipal waste sent to landfill. The Government set out its vision for sustainable waste management in Waste Strategy 2000, the national waste strategy. Currently, around 54% of commercial and industrial waste and 83% of municipal waste is sent to landfill. This means that even with a significant reduction in the percentage of waste sent to landfill leading up to 2020, new landfill sites will still be required. Country-wide, and particularly in South East England, available void space in old mineral workings, traditionally used for waste disposal, is rapidly running out (Waste Strategy, 2000). This means future landfill will have to be excavated or created above ground level in previously unused sites.

In addition to the pressures to site landfill away from productive agricultural land and land deemed suitable for housing developments, it is necessary that landfill not be sited anywhere where leaked landfill leachate could enter groundwater. Areas where the superficial deposits consist of clay–rich glacial tills are an attractive proposition because a thick clay till layer should, in theory, prevent the movement of leaked leachate into underlying groundwater aquifers. Clay extracted to create below-ground storage space can often be reworked to form the landfill liner and cap, reducing money spent by the landfill owners on expensive geomembranes or on importing suitable liner material (Clark and Davies, 1996).

However, the preference for siting landfill on clay-rich tills can lead to problems, as such tills often contain sand and gravel bodies that can be saturated or connected to underlying aquifers. Some landfill sites have experienced problems with high rates of water flow into excavations which have cut into sand bodies connected to underlying aquifers. These bodies had not been detected by conventional borehole and trial-pit led site investigations. Such sand and gravel bodies can also act as flow routes for leachate leakage. The presence of glaciofluvial sands and gravels within clay tills is recognised as a problem throughout the wider geotechnical industry, as such deposits occur in an unpredictable pattern and can cause local variations in the engineering properties of a till across a site (Trenter, 1999; Croxford, 1996).

In standard geotechnical and environmental investigations, the typical approach is to use direct sampling methods, such as borehole sampling, trial pit observations, and laboratory and in-situ tests, in order to characterise the site. However, the combination of high data density in the vertical plane to a sparse lateral distribution of sampling points means that small features such as narrow sand bodies can potentially be missed.

Geophysical investigative methods are proposed as an alternative method of detecting permeable bodies within glacial tills, since many geophysical techniques have the capacity to collect continuous information on the subsurface. This feature is very attractive to landfill operators, as their primary concern is to determine whether highly permeable deposits are present within till, and if so, to determine their location, dimensions and connectivity.

Many geophysical methods also offer the opportunity to derive such hydrologically and geotechnically useful properties from the geophysical data; for example, permeability can be derived from electrical conductivity and geotechnical stiffness parameters from seismic wave velocities.

Objectives

The problem can be reduced to two research objectives; to develop geophysical methods to:

1. better detect and delineate subsurface anomalies.

2. provide quantitative information on subsurface properties.

The project so far has concentrated on determining what needs to be done to achieve these objectives. In the initial stages, this has meant considering what types of data should be collected, and from where. This has involved identification of:

1. what types of deposit are most representative of those in areas where landfills are likely to be sited.

2. those geophysical techniques which are most suitable for use over such deposits.

3. ways in which the application and/or processing of these techniques can be improved, and which techniques have the most potential for improvement.

4. sites on which to carry out survey that are representative of larger areas, in order that the selected techniques can be developed and tested.

Progress to date

1. The areas of interest for the project have been defined as those areas covered by ‘subglacial landsystem’ deposits in the UK. Such areas are typified by thick, fine-grained sediments which can contain glaciofluvial gravels and sands in interconnected subglacial channels. Such deposits can be up to tens of metres thick, attaining substantial thickness in the English lowlands. They cover most of Norfolk and substantial areas of the Midlands, northern England and the east of Scotland (Trenter, 1999).

2. The geophysical and direct site investigation techniques that have most potential for achieving the project objectives have been identified. These include:

   Electrical Resistivity Tomography (ERT). This technique uses arrays of electrodes placed on the ground surface in lines or grids, through which electrical current is injected into the ground. The product of an ERT survey is a model of the geoelectrical structure of the ground. The geoelectrical structure of the ground is affected primarily by the rock or soil type, and the technique is particularly good at distinguishing between sands and clays. The geoelectrical model can be 2D or 3D. In both cases the accuracy of the model reduces with increasing depth below the surface.

   Seismic Reflection. In seismic reflection surveys, receivers (geophones) are laid in a line or a grid. A source of seismic waves is activated (for example a hammer hitting a plate), and the time taken for the energy generated to travel from the source, reflect off of a subsurface interface and travel to many geophones is used to determine the depth of the interface and the seismic velocity of the subsurface. This allows the construction of a 2D or 3D model of the velocity structure of the ground.

   Spectral Analysis of Surface Waves (SASW). As wells as projecting energy into the ground (body waves, used in seismic reflection survey), a seismic source will produce waves that travel along the ground surface (surface waves). Although surface waves do decrease rapidly in amplitude with depth, near the surface they are of a very large amplitude, and can provide useful information about the structure of the shallow subsurface. Surface waves can be used to image the shallow subsurface in places where reflection surveys may fail to do so. The output of a SASW survey is a 1D plot of seismic velocity with depth. SASW data can be further processed to give a 1D profile of small-strain soil stiffness with depth.

   Cone Penetrometry (CPT) and Resistivity Cone Penetrometry (RCPT). Cone penetrometry is an invasive geotechnical technique that involves pushing a series of rods into the ground. The first rod has a cone attached to it that is mounted with sensors, which can detect various parameters. The most basic form of CPT is used with to determine the deposit type. Other geotechnical parameters, such as the undrained shear strength of clays, can also be estimated. Adding cones with different sensors, such as geophones or electrodes, allows the recording of other parameters, such as seismic velocities and electrical resistivity (RCPT).

3. Potential type-sites have been identified. The sites are covered by glacial tills of approximately 5m to 20m thickness, which have been proven (by observation of cliff or quarry exposures, site investigation data or reports from engineering works) to contain granular bodies large enough to be potential or proven causes of problems during engineering works. Site visits were carried out over August 2004, and geophysical surveys carried out. Due to the requirements of finding suitable type-sites, the geophysical survey undertaken was intended primarily to act as reconnaissance. For this reason, only ERT survey was carried out, since the field operations are relatively quick and the processing time is much shorter than that of seismic reflection, but the technique is sufficiently accurate to give an idea of the structure of deposits, when combined with limited ground-truthing

information. Two sites have been identified as potential field sites for acquisition of more extensive data sets in the 2005 field season, and application of the CPT technique to one site is planned.

Training

Training received over the first ten months of the PhD consisted of:

- attending a series of lectures and practicals on the interpretation of Vertical Seismic Profiles (VSPs).
- attending a series of practicals using the ProMAX seismic reflection processing package.
- training in the Spectral Analysis of Surface Waves (SASW) field technique.

Future plans

In order to improve our ability characterise future landfill sites in the areas of interest (i.e. to delineate sand and gravel bodies within thick clay till sequences, and provide quantitative information on geotechnical properties of such sequences) we propose to:

1. Develop an approach that uses Resistance Cone Penetration Test (RCPT) results to provide a geoelectrical reference model for the processing of Electrical Resistance Tomography (ERT) data acquired from the ground surface. Use of direct resistance measurements from RCPT to constrain ERT data processing (inversion) will produce a more accurate geoelectrical model of the subsurface. In particular it should help to reduce the tendency for ERT structure to become less accurate at depth.

2. Extend 1D Spectral Analysis of Surface Waves (SASW) into 2D by processing adjacent SASW tests. The output of this will be a 2D model of the seismic velocity and small-strain stiffness with depth. However, as this approach uses purely ground surface acquired data it is likely to suffer from decreasing accuracy with depth.

3. Lab testing of samples of deposits will be undertaken to investigate the stiffness of the deposits at small strains, in order to compare these readings with the stiffness profiles obtained from SASW testing at different frequencies.

References

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