Panel discussion: Contamination and remediation of fractured clay till

Débat de spécialistes: Contamination et réhabilitation d'une argile à blocaux fracturée

Jens Baumann – *Danish Geotechnical Institute, Denmark*

1 INTRODUCTION

The presentation deals with fractured clay till and focuses on three issues:

1. Clay till as a natural barrier to ground water resources protecting the drinking water.
2. In situ remediation in clay till by venting.
3. Remediation of DNAPL.

2 FRACTURED CLAY TILL

2.1 *General perception and new knowledge*

Clay tills are overconsolidated deposits laid down by a glacier. They are mixtures of clay, silt, sand, gravel and stones with a clay content of 15-20%. Clay till has a low basic hydraulic conductivity of 10^{-9} to 10^{-10} m/sec, and therefore clay till is normally considered an effective barrier with a high adsorption capacity.

However, this is not correct. The last 5-10 years of research mainly in Denmark and Canada has demonstrated

- that clay till is a fractured and dual porosity soil,
- that these fractures completely control the waterflow,
- that clay till has a high bulk hydraulic conductivity in the range of 10^{-5} to 10^{-8} m/sec,
- a very low effective porosity - only a few ‰,
- extremely high flow rates and low adsorption capacity in consequence of this.

Therefore, clay till is absolutely **no** effective barrier - at least not the upper 5-10 m.

2.2 *Last 5-10 years of research*

It used to be a well-known fact that field studies provided at least two orders of magnitude higher hydraulic conductivities than laboratory studies of small samples.

The research has also demonstrated closely spaced fractures within the upper 1 m of the profile, with no predominant orientation of the fractures, and deeper down - 2.5 m - the fractures are more widely spaced and have a pronounced orientation.

The various research projects involved careful mapping of the fractures and large intact blocks (½ m in diameter and ½ m high) of clay till were taken at different levels.

The blocks were sealed with a special rubber membrane and placed in a pressurized tank with controlled temperature and with lines for percolation of water through the sample.

Now different tests were performed, e.g. hydraulic conductivity tests, tracer tests, transport of pesticides and nutrients, and finally a fluorescent dye tracer was added.

The results of the hydraulic block tests showed permeabilities in the range of 10^{-5} to 10^{-8} m/sec depending on the depth, and they correspond very well with the data from the field. The matrix permeabilities of the same clay till were measured in small triaxial cells and found to be in the range of 10^{-9} to 10^{-10} m/sec.

The tests with dye tracer shows that the flow is completely controlled by fractures and that the flow is totally bypassing the matrix.

The conclusion is that clay till is fractured. Fractures control the flow. Clay till has a very high bulk hydraulic conductivity and a very low effective porosity resulting in extremely high flow rates in the fractures and much lower adsorption capacity than expected. So absolutely **no** barrier effect is observed in the upper 5-10 m.

This is of course a serious problem because more than half of the area of Denmark is covered with clay till, and this research basically turns upside down our risk assessments of contaminated sites and the former use of pesticides and nutrients. However, we have only examined the upper 5-10 m, and therefore more research is needed.

2.3 *Future research*

First of all we need to validate these laboratory data by comparing them with data in the field scale.

Students from the University of Copenhagen are establishing two infiltration basins of approx 20 m² each. Basically, they will perform the same types of tests as in the laboratory. After the infiltration test a number of block samples will be extracted and tested at the Danish Geotechnical Institute.

We do not know how deep the fractures go, and of course it is extremely important to know whether the fractures go 5, 10 or 20 m down, or if the fractures penetrate the entire deposit of clay till.

We know from the block tests that the bulk hydraulic conductivity is decreasing with depth. We have entered the results into a computer model and backed out the sizes of the fracture aperture in each test. The aperture also decreases with depth.

In order to predict where and how deep the fractures are we need a geotechnical understanding of the nature of the fractures. The fractures are visible 5-6 m down, but we do not know if they continue. We believe they originate from the loading and unloading of glaciers. We need a complete geotechnical classification of all test sites including vane testing, CPT testing, etc. We do not fully understand the stress situation under an ice cap and after melting off of the ice, and we need a better understanding of the actual stress situation today at the test sites.

We must test the hydraulic parameters under realistic 3-dimensional stress levels corresponding to deeper levels in the profile. Then a correlation must be established between the fact that a particular clay till is fractured and the geotechnical classification and strength parameters of the same till.

The primary objective is to be able to make a geographical mapping of the vulnerability of the ground water. In other words to find an easy way to map fractured clay tills and to predict the depth of fractures in order to decide whether an area shall be used for farming, industry or something else, and by this to minimize the risk of ground water contamination.

3 SOIL VENTING

3.1 *Principle*

Soil venting is one of the most common in situ techniques when it comes to remediation of volatile organic compounds - VOCs. The principle of soil venting is simple. Air is extracted from a number of boreholes and this will start an airflow from the surroundings towards the boreholes. The air will pick up VOCs in the unsaturated zone.

What happens when a dual porosity soil like clay till is contaminated is that contaminants enter the fractures by advection and continue into the matrix by diffusion. The matrix is water saturated while the fractures may be dry. So the diffusion into the matrix is very slow as it takes place in water saturated soil.

When we try to clean up the soil by venting it is easy to reach a low concentration of VOCs in the high permeable fractures. This will change the direction of the diffusion flow - to go **out of** the matrix **into** the fractures. This is the only - and a very slow - way to get the contaminants out of the matrix. It is not possible to increase the speed of the process in any way.

3.2 *Clean up time*

A calculation is made of the time for clean up of the benzene with an initial concentration of 100 g/m^3 with three different fracture spacings and with a stop criteria 1% of the initial concentration in the matrix. The results show clean up times between 3 and 5 years for the close spacing of 10 cm - and more than 100 years for spacings of more than half a metre.

The conclusion is that venting of clay till is an option if fracture spacing is less than 10 cm. This is the case within the upper 2 metres. Deeper in the profile an unrealistic amount of time is needed unless we find a technique to introduce closely spaced fractures.

4 DNAPL REMEDIATION

One of the most serious problems we face when it comes to soil and ground water contamination is the DNAPLs - Dense Non-Aqueous Phase Liquids - including dense chlorinated solvents.

They have been widely used in the industry since the second world war. If it is spilt the pathways of the free product are controlled by fractures and we cannot locate the pools of free product. Even if we could locate the pools we could not do anything about it when it comes to cleaning up. We will have to consider containment or reactive barriers.

This may seem as a very simplified statement, but the fact is that even if it is possible to remove 50% or 70% of the DNAPLs by pumping and treatment, this will not reduce the problem of meeting the extremely low drinking water criteria, and in praxis the ground water is lost as a drinking water resource.