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Briefing

Excavations in gassy soils

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Gassy soils are soils that contain gases under positive pressure. They can have a significant impact on the stability of excavations. This briefing note summarises two cases in southern Ontario, Canada, that highlight the importance of continued research into the behaviour of gassy soils.

1. INTRODUCTION

Gassy soils are defined as soils that contain gases under positive pressure, and are differentiated from unsaturated soils in which the gas pressure is neutral or negative. Gassy soils have been encountered in various locales around the world. For example, British research has focused on gassy offshore sediments. In Canada, gassy soils have been encountered in at least three locations: the Fraser River Delta at Vancouver, British Columbia; the Athabasca Oil Sands in north-east Alberta; and in south-west Ontario around Sarnia.

The Fraser River Delta and the Athabasca Oil Sands cases have been known and studied for many years. However, the gassy soils near Sarnia have only recently been recognised, and have not been previously reported in the geotechnical literature. The conditions at the Canadian sites discussed above are briefly summarised in Table 1, along with the conditions studied by British researchers. In this table a *biogenic* gas source indicates that the gas is due to recent biological activity; *petrogenic* indicates that the gas source is nearby or underlying petroleum gases.

A full assessment of the differences in behaviour between the different gassy soils, and the consequent differences in constitutive relationships, is beyond the scope of this brief. Rather, the objective of this brief is to highlight the importance of continued research into gassy soil behaviour by summarising two cases in southern Ontario where the gassy nature of the soil had a significant impact on the stability of excavations in or above the gassy soil layer.

2. CASE STUDIES

The local geological conditions around Sarnia, in south-western Ontario, Canada, consist of about 40 m of glacial till overlying sedimentary bedrock formations of the Devonian Period. The till soils are believed to have been deposited in a glaciolacustrine environment, and they consist of massive to laminated clayey silt soils with shale clasts, and discontinuous lenses and pockets of silt and sand. The upper approximately 5 m consists of a fractured, desiccated crust, underlain by about 35 m of low permeability over consolidated to normally consolidated soils. In addition, a discontinuous granular basal till zone, up to 1 m thick, is encountered in some locations between the lower till and bedrock. Groundwater conditions consist of a perched water zone generally within the upper fractured till, and a confined groundwater zone located within the basal till and upper bedrock.

The area is a centre for the oil and gas industry, and it is expected that the dissolved gases in the groundwater originate from the underlying sedimentary bedrock, within which the oil and gas are located. The venting of gases is often encountered in boreholes drilled into, or close to, the top of the confined basal till aquifer.

2.1. The St Clair River Tunnels

The St Clair River Tunnels consist of two adjacent rail tunnels under the St Clair River, connecting Sarnia, Ontario, and Port Huron, Michigan. The first tunnel was built between 1886 and 1891, and the second tunnel from 1993 to 1995. Significant construction difficulties were encountered during construction of the first tunnel, and an unanticipated deep-seated slope movement occurred during construction of the second tunnel. It has recently been recognised that the conditions encountered during construction of both tunnels are related to the presence of dissolved gases in the local groundwater.

Dittrich *et al.* conducted a detailed study of the conditions encountered during construction of both tunnels.[1,2] This study will be the source of future papers, and thus only a brief description is provided below. The construction difficulties encountered during construction of the first tunnel included the following.

(*a*) Stiff clay soils became spongy and soft to very soft, and the clay flowed upwards into excavations as fast as it was removed.
(*b*) Natural gas discharged from a fissure that opened up, followed by an intrusion of fine sand and water.
(*c*) Several slope failures occurred.

The second tunnel was constructed immediately north of the

Site	Gassy offshore sediments	Fraser River Delta	Athabasca Oil Sands	Sarnia, Ontario vicinity
Location	Offshore (deltaic and marine)	Offshore (deltaic)	Onshore	Onshore
Soil type	Fine-grained, underconsolidated to normally consolidated	Loose sands	Overconsolidated sands	Fine-grained, normally consolidated to overconsolidated
Gas source	Biogenic	Biogenic	Petrogenic	Petrogenic
Implications of concern	Slope instability, consolidation behaviour	Slope instability due to tidal unloading or seismic events	Slope instability due to mining of oil sands	Slope instability due to excavations
Selected references	3–5	6–8	9, 10	1, 2

Table 1. Summary of conditions at selected sites with gassy soils

existing tunnel. During excavation to widen the north side of the approach in Sarnia, the following was noted.

(*a*) Horizontal movements on the upper part of the north slope were downslope and less than 5 mm, as anticipated.
(*b*) Horizontal movements on the lower part of the north slope were less than 5 mm, but towards the slope.
(*c*) Initial unanticipated deep-seated downslope movements of 20–25 mm were noted on the untouched south slope; they were due to a block movement along a relatively thin shear zone located about 15 m below the base of the excavation.
(*d*) A local bedrock high, accompanied by a local high point in the underlying confined aquifer, was located below the south slope where all the south slope movement was concentrated.

Remedial measures to address the slope movements were ultimately successful. Finite-element analyses by Dittrich *et al.*[1,2] indicate that the slope movements can be explained by incorporating gassy soil behaviour into the models, which suggests that the slope movements were due to the development of a deep plastic soil zone in response to unloading caused by the various stages of excavation for the approach to the tunnels.

2.2. Landfill excavation near Sarnia

The design and operation of a landfill located near Sarnia, Ontario, are based on continuous excavation of sub-cells, followed by placement of waste and a compacted clay cap. A geotechnical assessment and limit equilibrium stability analyses had been conducted to identify suitable excavation depths, slope lengths, and duration of exposure. During excavation and waste filling operations, lateral slope movements, base heave, and pore water pressures are monitored.

Following excavation to a depth of 25 m for a new sub-cell in September 1999, venting of gas and water were noted in three separate locations. It was noted that.

(*a*) The venting was greatest through natural discontinuities in the undisturbed native soils.
(*b*) The venting dissipated with time.
(*c*) Chemical analyses indicated that the vented water originated from the underlying confined aquifer, and the vented gas originated from the underlying bedrock.
(*d*) Pressure tests indicated gas pressures in excess of 70 kPa above atmospheric pressure at one venting location.
(*e*) A local bedrock high, accompanied by a local high point in the underlying confined aquifer, was located under the area of the observed venting.

The observed venting phenomenon locally compromised the low-permeability till, and the sub-cell was largely lost for waste disposal. The occurrence of the phenomenon at this location, when it had not previously occurred for adjacent excavations to the same depth, was attributed to the combined effects of (a) a reduction in the mobilised shear strength of the soil (relative to that assumed in stability calculations) due to the exsolution of the dissolved gas in the porewater during unloading, and (b) the presence of a local bedrock high beneath the venting area, which was associated with

(*a*) gas in higher amounts and at a higher pressure than in adjacent zones
(*b*) a 2 m reduction in the thickness of the overlying till, resulting in a lower confining pressure for the gas, and a shorter path length for gas and water movement.

3. CONCLUSIONS

Owing to the potentially significant impacts of gassy soils on the performance of excavations and the economic implications of either overly conservative design or failure to recognise the potential problems due to gassy soils, further research is warranted into the behaviour of normally consolidated to overconsolidated gassy soils during unloading, and into improving estimates of stability under these conditions.

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