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Thermal Conductivity of Deepwater Offshore Sediments

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ABSTRACT

This paper describes thermal conductivity tests conducted on highly disturbed (fluidised) deep water offshore North Sea clay sediment. The variation of thermal conductivity with moisture content was determined using a specially designed 1-dimensional consolidation apparatus. Comparisons were made with results from undisturbed in situ soil cores. The results show very similar values of thermal conductivity for both the undisturbed and fluidised samples for given moisture contents. These values are comparable with results found for similar materials in the North Sea and Gulf of Mexico, but are lower than values typically assumed in current design approaches.

INTRODUCTION

Overview

Burial techniques are commonly used for offshore oil and gas pipelines to take advantage of the thermal insulation of the seabed sediments. Knowledge of the in situ thermal properties of these soils is extremely important for the design of buried pipeline systems. However, burial techniques such as jetting and ploughing can produce considerable disturbance to the structure of these sediments, leading to changes in the thermal properties. This paper describes a laboratory study to investigate the thermal conductivity of highly disturbed (fluidised) deep water offshore North Sea clay sediment. The variation of thermal conductivity with moisture content for a consolidating clay material was determined using a specially designed 1-dimensional consolidation apparatus. Comparisons have been made with results from undisturbed in situ soil cores, and these results are presented and discussed here.

Heat Flow Through Soil

The flow of heat through porous media such as soils and the coupled changes in moisture content can be important for many engineering structures. Examples of such structures include buried pipelines and cables, underground structures, nuclear waste storages and geothermal reservoirs. The 2 major modes of energy transfer in soils are conduction and convection. Conduction involves the propagation of heat within a body by internal molecular motion (and is thus analogous with diffusion), and convection involves transfer of heat due to motion of pore fluid (i.e. mass movement). It has been found that the relative proportions of these modes of energy transfer are a function of grain size, with conduction occurring predominantly in fine-grained soils and convection in coarse-grained soils (Savvidou, 1988).

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KEY WORDS: Clays, jetting, burial, pipeline, thermal conductivity.

The governing general equation for heat transport through porous media is:

$$C\frac{\partial T}{\partial t} = \nabla \cdot (\lambda \nabla T) \tag{1}$$

where C = volumetric heat capacity of the soil, T = temperature, t = time and λ = thermal conductivity.

The thermal conductivity (λ) is defined as the amount of heat transferred in unit time through a unit cross-sectional area, under a unit thermal gradient. This parameter has been investigated for a wide range of soil states, and a comprehensive review of the literature has been presented previously by Farouki (1986). The most common method for determining thermal conductivity in soil is the transient, thermal probe method (Steinmanis, 1982). This consists of a line heat source and temperature sensor. Once the probe has reached thermal equilibrium with the surrounding soil, the temperature of the heat source is rapidly increased and heat is allowed to dissipate into the surrounding soil. Thermal conductivity is a function of the rate of heat dissipation, and this can be determined from a theoretical solution of conductive heat flow from a line source through an infinite homogeneous medium (Carslaw and Jaeger, 1959). This method assumes that significant moisture migration does not occur during the measurement, which is dependent on power input and test duration (Ewen and Thomas, 1987).

Thermal conductivity has been found to be a function of dry density, saturation, moisture content, mineralogy, temperature, particle size/shape/arrangement and the volumetric proportions of solid, liquid and air phases. A number of empirical relationships has been developed to estimate thermal conductivity based on these parameters, e.g. Kersten (1949), de Vries (1963), Johansen (1975), Sundberg (1988), and Tarnawski and Wagner (1992). Whilst the thermal conductivity of onshore soils has been extensively investigated, only a few studies have been conducted on offshore deposits (e.g. Power et al., 1994; von Herzen and Maxwell, 1959). Many deepwater offshore sediments are formed with predominantly silt- and clay-sized particles, since sand-sized particles are rarely transported this far from shore. Hence convective heat loss is limited in these soils, and the majority of heat energy transfer is due to conduction. Recent measurements of thermal conductivity for deepwater soils from the Gulf of Mexico (MARSCO,