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The France-Canada Joint Study of Deformation of an Experimental Pipe Line by Differential Frost Heave

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ABSTRACT

The deformation by frost heave of a 16-m length of 273-mm-diameter pipe carrying gas at -2° to -5°C has been investigated for eight years in a major experimental study. Thermal and hydrological conditions and other environmental factors were carefully controlled allowing accurate measurement of pipe deformation and stresses and of various soil conditions. The experiment was designed to show the effects on a buried pipeline of crossing a transition from a soil very susceptible to frost heave to one much less so. Major deformations were observed that were not completely reversed by thawing. The stresses developed in the pipe are the result of the complex thermodynamic behaviour of the soil at the time of freezing and when already frozen.

INTRODUCTION

The design of pipelines for construction in cold regions and especially where permafrost occurs, requires attention to the stresses produced in the pipe by thermodynamic effects arising from the freezing of the surrounding soil. The phenomenon of frost heave is well-known to highway engineers: Water moves towards freezing soil, giving rise to volume increases often far in excess of those arising from the simple expansion of the pore water on freezing. Such frost-heaved soils are characterised by layers or lenses of ice (segregated ice), present in abundance through the soil. The amount of ice depends on the type of soil as well as the ambient thermal, stress and moisture conditions. A pipeline traversing soils which undergo uneven heave is exposed to the risk of large deformations (Williams, 1989).

EXPERIMENTAL FACILITY

To ascertain the extent of such deformation and how it occurs, an experiment was set up in a controlled environment provided by an 8-m by 18-m hall with a soil-filled trough. The facility is located at the CNRS Centre de Géomorphologie, Caen, France. A 16-m length of 273-mm-diameter pipeline was buried at 33-cm depth traversing two soils, half the length being in a silt and half in a sand (Fig. 1). The soils were placed in the trough in 30 cm lifts, very carefully compacted to uniform densities. The pipe was placed on the surface at the desired elevation and further lifts placed around it.The temperature of the air above the soil surface was controlled to within 0.5°C, and gas was circulated through the pipe with temperature control to within 0.2°C. To ensure a uniform average temperature along the axis of the pipe, gas flow was reversed every 6 hours (since otherwise the air temperature typically dropped by 2°C along the length of the pipe). Four cycles of freezing and thawing were carried out from 1982 to 1989. The duration and temperatures applied are shown in Table 1.

The freezing of the ground that occurred during the first period is shown in Fig. 2. The frost line penetrates more rapidly in the sand because of the smaller amounts of latent heat released.

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KEY WORDS: Gas pipelines, freezing ground, frost heave.

Event	Date from	to	Operating Conditions Air/Ground temp. (°C)	Pipe Temp. (°C)
1st Freeze	21/09/82	08/06/83	-0.75	-2.0
1st Thaw	08/06/83	17/10/83	4.0	-2.0
2nd Freeze	17/10/83	18/09/85	-0.75	-5.0
2nd Thaw	18/09/85	01/02/86	4.0	ambient
Reinstru-mentation	01/02/86	03/03/86	-	-
3rd Freeze	03/03/86	25/02/87	-0.75	-5.25
3rd Thaw	25/02/87	21/05/87	4.0	ambient
Shutdown	21/05/87	06/01/88	-	-
4th Freeze	06/01/88	24/05/89	-0.75	-5.25

Table 1 Timetable of experiments

Properties of the soils used are shown in Table 2 and Fig. 3. Rheological properties of the materials in the frozen state are described in Geotechnical Science Laboratories (1986). Silts typically are very prone to frost heave whereas sands are not. The specifications for the pipe are given in Table 3.

SPECIFIC INSTRUMENTATION AND OBSERVATIONS

Pipe Deformation

Deformation of the pipe was determined by:

(a) optical levelling of survey rods protruding through but isolated from the soil by a casing, attached to the pipe at 50 cm intervals; and,

(b) interpretation of the readings of 22 pairs (paired top and bottom of pipe) of electrical resistance strain gauges attached to the pipe from 40 to 145-cm apart.

In addition, during the first cycle of freezing, confirmation of pipe deformation was provided by observations with a mechanical measuring device which spanned the tops of three adjacent rods.

Fig. 4 (first cycle) shows the deformation of the pipe resulting from frost heave of the silt soil, which started almost immediately when flow of the gas commenced (day 0). As the annulus of frozen soil around the pipe enlarged (Fig. 2), heaving continued with progressive deformation of the pipe. In this cycle, freezing conditions (cold gas flow and freezing surface temperature) were maintained for 276 days, followed by thawing and subsequent consolidation under ambient (uncontrolled) air temperatures for 130 days.

After the first cycle of freezing and thawing the pipe did not return completely to its original position. Indeed, as each of the