Thermoelectric cooling for precise temperature control of frozen and unfrozen soils
Williams, P. J.

Publisher's version / Version de l'éditeur:

Canadian Geotechnical Journal, 5, 4, pp. 264-266, 1968-12-01

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

THERMOELECTRIC COOLING FOR PRECISE TEMPERATURE CONTROL OF FROZEN AND UNFROZEN SOILS

by

P. J. WILLIAMS

Reprinted from
CANADIAN GEOTECHNICAL JOURNAL
Vol. V, no. 4, November 1968
pp. 264–6

Technical Paper No. 293
of the
Division of Building Research

OTTAWA
December 1968

Price 10 cents

NRC 10491

UN REFROIDISSEUR THERMOÉLECTRIQUE PRÉCIS POUR LE CONTRÔLE THERMIQUE DES SOLS GELÉS OU DÉGELÉS

On a mis au point un nouvel appareil qui permet de contrôler la température dans les limites de ± 1/50°C des échantillons de sols tant au delà que sous le point de congélation. L'appareil est compact et peut être employé sur une table de laboratoire par ailleurs maintenu à température normale.

THERMOELECTRIC COOLING FOR PRECISE TEMPERATURE CONTROL OF FROZEN AND UNFROZEN SOILS

P. J. WILLIAMS *Soil Mechanics Section, Division of Building Research, National Research Council of Canada*

Freezing and subsequent temperature control of soil samples for strength testing and studies of frost action is normally achieved by one of several methods. The entire test apparatus and operator may be located in a cold room. Cold rooms are expensive to operate (except possibly with the Russian practice of using a cellar excavated in permafrost) and are inconvenient working places. Alternatively, a small refrigeration unit (compressor) may be used as a source of cooling liquid, in a laboratory at room temperature. Such an arrangement is demanding of space, and the cooling system commonly has a significant lag in response, such that short-term adjustments in the rate of heat extraction from the sample are difficult. Apparatus has now been developed using thermoelectric cooling as a routine procedure for this kind of work.

Thermoelectric cooling makes use of the Peltier effect (Lechner 1966). The usual practical arrangement is a module consisting of several semiconductor thermocouples connected in series electrically but in parallel thermally. Instead of generating electricity by means of a temperature difference as in the case of thermometric thermocouples, an electric current from an external source is applied to produce a difference in temperature between one set of junctions (one side of the module) and the other.

The use of semiconductor materials in recent years has allowed development of very effective and compact modules. When the "hot" junctions are maintained at some convenient temperature by means of an air- or water-cooled heat sink, the temperature of the "cold" junctions (and of any reasonably sized object thermally connected to them) may be precisely controlled by varying the strength of the electric current. If a soil sample in contact with the cold side is initially at a higher temperature, it will cool to the controlled temperature. The module thus pumps heat from the sample to the warmer heat sink. Peltier modules are

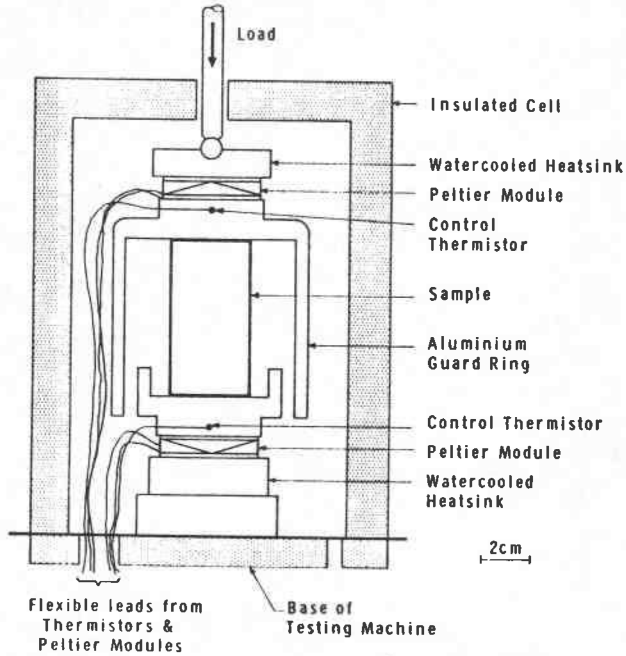

FIGURE 1. Diagram of apparatus as used in compression test

now used in a variety of applications in several fields, including the localized cooling of soil samples (e.g., Anderson 1967).

Studies of freezing soils, involving samples of various sizes and under many different test conditions have been made for more than ten years at the Division of Building Research, National Research Council, Ottawa. The possible advantages of thermoelectric cooling for this purpose became apparent: the potentially small size of the equipment involved, the potentially very high precision with which the rate of heat removal could be controlled, and the stability of temperature likely to be achieved. Special problems also presented themselves and possibly account for the fact that apparatus of the type described below apparently has not previously been developed.

The apparatus shown (Figure 1) has been used for uniaxial compression tests of frozen soils. Many of its features can be easily adapted for investigations of, for example, frost heave, and the apparatus may also be used for testing of unfrozen samples where precise temperature control is required. The thermoelectric units are situated so as to break the main paths of thermal conduction to the exterior of the cell—that is, the steel load-bearing pedestal and piston. The modules thus carry the applied axial load. Tests established that the characteristics of the thermoelectric module were not significantly affected at stresses in excess of 40 kg/cm². The stresses on the module during testing of frozen soils are not likely to exceed 50 per cent of this value. The exposed edges of the modules are waterproofed with silicone rubber sealant.

Heat removal from the sample is uniaxial. The air space between the sides of the sample and the outer cell wall substantially limits lateral conductive heat exchange with the exterior, and the presence of the two aluminum guard rings prevents radiative exchange. The cell can be placed in a conventional loading press or frame and is wrapped in insulating material (Figure 1). No further precautions are necessary to prevent any influence of the laboratory ambient temperature on the sample.

The precise temperature control of the sample end plates, and thus of the sample, is achieved by an electronic unit controlling the currents to the modules at all times. The circuitry was designed by Mr. E. L. R. Webb of the Radio & Electrical Engineering Division (Webb 1968).

It operates on the negative feedback or servo principle. The resistance of the "control" thermistor in an end plate is compared in a Wheatstone bridge circuit, with a preset resistance equal to that of the thermistor at the desired temperature. Any difference results in an error signal which in turn is amplified to control the current flow to the module. The temperature of the end plate may thus be brought to and maintained at the desired value. Each module is controlled independently. Two such servo systems are used to control the ends of the sample in Figure 1. The two systems are independent except for the thermal connection through the sample, and certain common electrical components.

Tap water serves to cool the warm side of the module, circulating in a coiled channel in the end plate. Typical values of 100 for the loop gain result in the degeneration of outside disturbances by a similar factor of 100. Tests showed that the temperature of running tap water varies through 5°C in Ottawa. Such a variation was found to affect the controlled temperature (i.e. for a given setting) by about .05°C. The tap water is therefore first passed through a reservoir, maintained with a simple thermostat heater at 14°C. At temperature equilibrium the sample temperature remains constant to $\pm$0.02°C for a period of days. For the initial freezing of samples (which requires extraction of large quantities of heat) the circuit may be controlled to allow the maximum current to pass through the modules. This gives a rate of heat extraction of about 4 cal/sec and produces freezing of saturated samples of a standard size in less than an hour, often as little as a few minutes.

The apparatus for frozen soil strength testing has been in use for over a year. Thermoelectric apparatus similar to that described appears to have many potential uses. It is to be available commercially in the near future.

ACKNOWLEDGMENTS

Technical assistance during construction and testing of the apparatus was given by J. L. Boyd. This note is a contribution from the Division of Building Research, National Research Council, and is published with the approval of the Director of the Division.

REFERENCES

ANDERSON, Duwayne M., 1967. Phase composition of frozen montmorillonite water mixtures from heat capacity measurements. *Cold Regions Res. and Eng. Lab. Res. Rept. 218.*

LECHNER, W., 1966. Peltier cooling. *Philips Tech. Rev.* 27: 113–30.

WEBB, E. L. R., 1968. Equivalent circuit model for thermoelectric temperature controllers. *Bull. Radio and Electrical Eng. Division*, National Research Council of Canada, *18*, 1.