Development of an apparatus for static and dynamic creep testing of ice and frozen soils

HAMDY YOUSSEF
Génie civil, École Polytechnique, University of Montreal, Québec, Canada H3C 3A7

ROGER KUHLEMEYER
Dep. of Civil Engineering, University of Calgary, Alta, Canada T2N 1N4

AND

ROWLAND FRENCH
Geo-Physi-Con. Co. Ltd., 5810-2nd St. S.W., Calgary, Alta., Canada T2H 0H2

The development and construction of an apparatus to be used in experimental studies of the effect of vibratory loads on the static creep rate of ice and frozen soils is described. The apparatus is designed for testing two specimens simultaneously, the first under static axial stress and the second under combined stresses. The combined stresses to which the second specimen is subjected consist of static axial stress identical to that of the first specimen and also dynamic shear stress due to sinusoidal torsional vibration applied at the base of the specimen. Both specimens are subjected to identical temperature conditions. Preliminary tests indicated that the apparatus is capable of testing the static and dynamic creep of ice and frozen soils. The cooling capacity of the apparatus is −9°C; the static loading capacity is 3.60 kN. The range of the vibration frequency is from 0 to 1000 Hz.

La présente communication porte sur la mise au point et la construction d'un appareil destiné à des études expérimentales de l'effet de charges vibratoires sur la vitesse de fluage statique de la glace et des sols gelés. L'appareil admet simultanément deux spécimens, l'un soumis à une contrainte axiale statique et l'autre soumis à des contraintes composées. Ces dernières comprennent une contrainte axiale statique, identique à celle imposée au premier spécimen, ainsi que des efforts de cisaillement dynamiques dus à des vibrations sinusoïdales de torsion appliquées à la base du spécimen. Les deux spécimens sont portés à la même température. Les essais préliminaires indiquent que l'appareil permet d'évaluer le fluage statique et le fluage dynamique de la glace et des sols gelés, à une température aussi basse que −9°C. La charge statique maximale est de 3,60 kN. La gamme des fréquences de vibration va de 0 à 1000 Hz.

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Introduction

Approximately 50 per cent of the area of Canada and 85 per cent of the area of the state of Alaska (USA) are subject to conditions of permafrost. Foundations for structures incorporating vibratory loads in cold regions present special problems to the designers. Since the resulting vibration may significantly change the creep that will occur under static loading only, a knowledge of the creep behaviour of ice and frozen soils subject to vibratory loads is needed. To the author's knowledge very few analytical or experimental studies have been conducted to investigate the effect of vibratory loads on the static creep rate of ice and frozen soils. The development and construction of a suitable test set up is the first step of the experimental study.

This paper presents the development and construction of an apparatus for that purpose. The apparatus is designed for testing simultaneously two specimens subject to identical static compression and temperature conditions. One of these specimens is subjected to additional torsional vibration at its base, while its top is free to rotate. This is accomplished by using the modified Drnevich (1976*a*) free-free resonant column apparatus as a vibration device.

Development of the Experimental Apparatus

The experimental set-up, which was developed at the University of Calgary, consists basically of six components, (i) a dynamic creep triaxial cell, (ii) a static creep triaxial cell, (iii) a cooling system, (iv) a static loading system, (v) a dynamic loading system, and (vi) output reading instrumentation to monitor the static load (axial stress), dynamic response of the specimen and the apparatus (frequency and amplitude of vibration), and the temperature of the specimens during test. The general layout of the experimental set-up is shown in Figure 1.

Dynamic and Static Creep Triaxial Cells

The dynamic and static creep triaxial cells are almost identical in their configuration and dimensions. The main difference is that the first cell is designed to incorporate the vibration excitation apparatus and the transducers for monitoring the vibration response of the top and bottom (namely passive and

FIGURE 1. Experimental apparatus in operation.

active) ends of the sample. A description of the dynamic cell components is given in the key to Figure 2.

Cooling System

Five refrigeration units (Hotpack Canada) Ltd., Model No. 603340) have been used, two for each triaxial cell and one for cooling the cold room which contains the apparatus. One refrigeration unit circulates the cold antifreeze through the cell base and inner coils which surround the specimens, the second refrigeration unit circulates the cold antifreeze in the outer coil around the cell. An antifreeze bath inside the cell has been used to insure uniform temperature around the specimen. Precision thermistors (YSI 44004 Model) are located inside the cap and base plates and, also, around the specimens to monitor the temperature. From long-term tests the cooling system has been proved to control the temperature of the specimen in the range of 0 to $-9°C$ with a maximum fluctuation of $\pm$ 0.2°C.

Static Loading System

A regulated nitrogen pressure is supplied from a nitrogen tank to a gas reservoir, which was introduced to the system as a precaution against pressure fluctuations; this reservoir is designed and checked for a maximum pressure of 6900 kN/m^2 (1000 psi). The regulated nitrogen pressure was supplied to the pressure cylinders inside the two cells through four pressure lines connected in parallel. Each pressure line is connected to the corresponding gas cylinder, this allows supply of identical nitrogen pressure inside the loading cylinders which forces the piston to move downward; this pushes the brass bracket downward with the designed force. The two tension rods in each cell transfer the load to the loading cross bar, which applies axial static loading to the specimen through

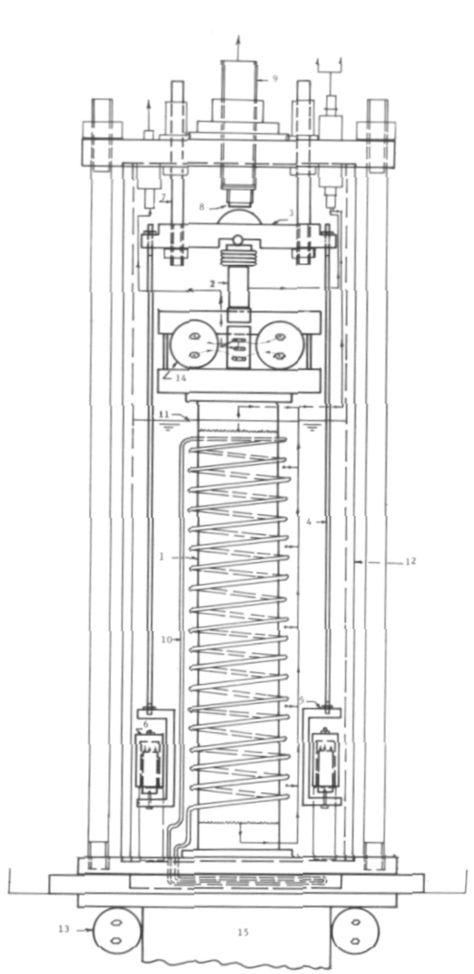

FIGURE 2. Dynamic creep triaxial cell.

Key to Figure 2

1 Ice or frozen soil specimen.
2 Load cell and thrust bearing.
3 Loading bar to transfer the load from the two tension rods to the thrust bearing and then to the specimen. It has another two functions: firstly, mounting a displacement transducer target for measurement of vertical displacement, and secondly, as a holder of the two alignment bars for the non-tilting device.
4 Tension rods to transfer the load from the bracket (5) to the loading bar (3).
5 Static loading brass bracket to transfer the load from the piston to the tension rod (4).
6 Pressure cylinder and piston.
7 Two alignment rods to prevent tilting of the specimen. These two rods are fixed to the loading bar (3) penetrated the triaxial cell top plate, and adjust vertically by two pushings.
8 Kaman non-contacting vertical displacement transducer.
9 Displacement transducer threaded holder shaft.
10 Inner cooling coils.
11 Antifreeze bath (cooling media).
12 Outer acrylic tube chamber.
13 Active velocity transducers.
14 Passive velocity transducers.
15 Vibration device.

the thrust bearing, the load cell, and the cap plate. This system achieved its objective of applying equal and simultaneous axial static load to both specimens and also without interaction with, or interference from, the torsional vibration system. Actual tests of two ice samples subjected to static load of 260 kN/m^2 for a period of 475 hours showed that the control of the static loading during the period of the test was satisfactory. The load was constant and equal on both specimens. The specimens were insured to be axially loaded during the test period by using a non-tilting device described by Youssef (1979).

Dynamic Loading System

Drnevich (1976*a*) free-free resonant column apparatus (Serial No. 106) was modified and employed to apply vertical loads without influencing the free vibration characteristics of the sample-apparatus system. A vertical cylinder of ice or frozen soil is subjected to steady-state sinusoidal vibration at its base with the other end free except for a light, relatively rigid cap. The input motion and output sample resonance are both observed and measured with piezoelectric transducers attached to the cap and base plates at the passive and active ends of the specimen.

Schematic diagrams illustrating the dynamic loading system as well as associated dynamic test equipment are shown in Figure 3. Electrical signals from the sine wave oscillator to the coils cause torsional vibration of the active beam. The dynamic creep triaxial cell, is bolted to the active-beam attachment plate. The torsional vibration of the active beam is transmitted, to the base of the specimen (active end). The electrical connections consist mainly of two circuits, namely the power circuit and the transducer circuit. A spectrum analyzer (Model 3580 A- Hewlett Packard) has been used to determine the frequency spectrum before starting the test, and then a frequency near the sample resonant frequency is selected for the long-term test using the sine-wave oscillator. An X-Y oscilloscope, a phase meter, an ac-voltmeter with analog output, and strip chart recorders have been used to monitor the vibration response of the active- and passive-end transducers.

The dynamic characteristics of the system as a torsional vibration device have been checked and found to be acceptable. The frequency spectrum has been recorded during actual testing of an ice sample with the antifreeze bath inside the triaxial cell chamber. The apparatus resonant frequency has been found to be 32.15 Hz and the sample resonant frequency 168.30 Hz. The range of the vibration frequency is from 0 to 1000 Hz.

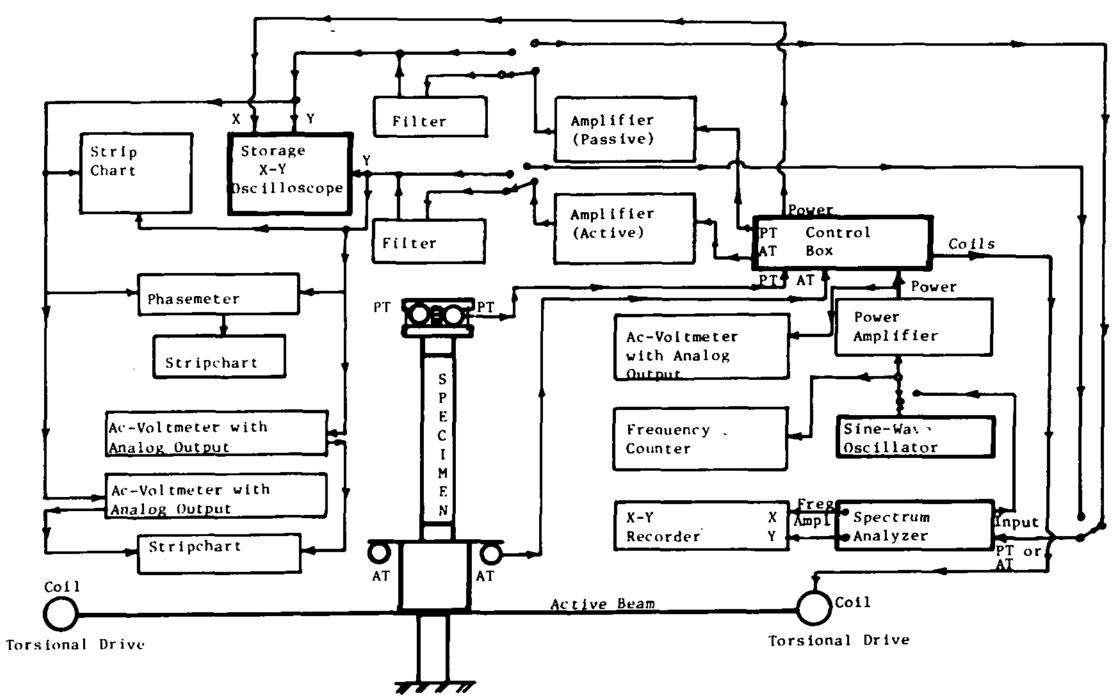

FIGURE 3. Schematic of forced vibration dynamic test equipment. AT and PT = Active and Passive Velocity Transducers.

Test Procedures

After stabilization of the temperature, static load is applied simultaneously to both specimens until a quasi-steady creep rate is achieved. Note that the steady creep rate should be the same for both specimens, since they are from the same type of ice and subject to the same static loading and temperature conditions. Upon reaching the steady creep rate, torsional vibration is also applied to one of the test specimens at a frequency near the specimen resonant frequency. The statically tested specimen continues to be subjected to static loading only.

Preliminary Creep Test Results

Preliminary tests were conducted to verify the capability of the apparatus for testing the static and dynamic creep of frozen specimens.

Two creep tests (475 hours in duration) have been conducted on four polycrystalline ice specimens (394 mm long and 76 mm in diameter) subject to temperature of $-3°C$ and static axial compressive stress of 260 kN/m^2. The measured secondary creep rate of the tested specimens was $0.44 \times 10^{-8}/s$, which is consistent with the creep data obtained from many different sources (e.g. 1, 5). The maximum shear stress that could be developed in the specimen, due to the dynamic load, was 5.14 kN/m^2 which is approximately one per cent of the shear strength of the specimen. Under these conditions, no effect of the torsional vibration on the static axial creep rate was recorded. Extensive long-term tests must be carried out on specimens with different diameters and subject to various combinations of temperature and static and dynamic stresses to study the dynamic effect. These tests are time consuming and beyond the scope of this paper. However, the developed apparatus appears to be capable of carrying out such tests.

Conclusions

The developed apparatus is capable of testing two frozen specimens simultaneously, the first one under static axial stress and the second one under combined stresses. The combined stresses consist of a static axial stress identical to that of the first one and a dynamic torsional shear stress. Both specimens are subjected to identical temperature conditions. The apparatus is capable of testing ice and frozen soil specimens in the temperature range of 0 to $-9°C$, and applying axial static load up to 3.60 kN. The vibration device of the apparatus is capable of applying sinuosoidal torsional vibration at the base of the dynamically tested specimen with frequency range from 0 to 1000 Hz.

Knowing the amplitude and frequency of vibration as well as the specimen and apparatus characteristics it is possible to calculate the shear strain, the dynamic shear modulus, and the damping ratio using the Drnevich (1976*b*) computer program (RESCOL 4). These data are useful for any possible theoretical treatment of the problem at hand, based on the creep test results which could be obtained using the developed apparatus (Youssef 1979).

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References

BARNES, P. AND WALKER, J.C. 1971. The Friction and Creep of polycrystalline Ice. Proc. Royal Soc., London, England, A-324, pp. 127–155.

DRNEVICH, V.P. 1976*a*. Free-Free Resonant Column Apparatus Operating Manual. Soil Dynamics Instruments, Inc., Lexington, Kentucky, U.S.A., 1976, Apparatus Serial No. 106.

———. 1976*b*. A User's Manual for the FORTRAN computer program entitled RESCOL 4. Dep. Civil Eng., Univ. Kentucky, Lexington, Kentucky, USA.

———. 1977. Resonant-Column Testing-Problems and Solutions. Proc. Dynamic Geotech. Testing — ASTM Special Technical Publication 654.

———. 1978. Resonant Column Test. Report no. S-78-6, Geotech. Lab., U.S. Army Eng. Waterways Exp. Station, P.O. Box 631, Vicksbury, Miss. 39180, USA.

GLEN, J.W. 1955. The Creep of polycrystalline Ice. Proc. Royal Soc., London, England, A-228, pp. 519–538.

YOUSSEF, H. 1979. Development of a Testing Apparatus for static and Dynamic Creep of Ice and Frozen Soils. M.Sc. Thesis, Univ. Calgary, Alberta, Canada.