Call Number: D 103.33: 216	**DateReq:** 3/8/2004	☐ Yes
Location: GEOL USdocs	**Date Rec:** 3/11/2004	☐ No
	Borrower: TXA	☐ Conditional

ILL: 4013321 **Maxcost:** $50ifm **LenderString:** UBY,CAI,*LDL,NTE,IWA

Title: Technical report - Corps of Engineers, U.S. Army, Cold Regions Research and Engineering Laboratory. 11-34 F

Author: Cold Regions Research and Engineering Laboratory (U.S.)

Edition: **Imprint:** Hanover, N.H., Corps of Engineers, U.S. Army, Cold Regions Res

Article: Smith, J. L.: The elastic constants, strength and density of Greenland snow as determined from measurements of sonic wave velocity

Vol: Technical Report 2 **No.:** **Pages:** 18 pages **Date:** 1965

Borrowing Notes: ~~mc~~ mF Ariel

pages 8 + 18 are blank

Fax:

```
ILL: 4013321      :Borrower: TXA     :ReqDate: 20040308 :NeedBefore: 20040407
:Status: IN PROCESS 20040310         :RecDate:          :RenewalReq:
:OCLC: 1188172    :Source: OCLCILL   :DueDate:          :NewDueDate:
:Lender: UBY,CAI,*LDL,NTE,IWA
:CALLNO:  :AUTHOR: Cold Regions Research and Engineering Laboratory (U.S.)
:TITLE: Technical report - Corps of Engineers, U.S. Army, Cold Regions Research
and Engineering Laboratory. :IMPRINT: Hanover, N.H., Corps of Engineers, U.S.
Army, Cold Regions Research and Engineering Laboratory. :ARTICLE: Smith, J. L.:
The elastic constants, strength and density of Greenland snow as determined from
measurements of sonic wave velocity :VOL: Technical Report 216 :NO:
:DATE: 1965   :PAGES: 18 pages   :VERIFIED: <TN:382500>OCLC
ISSN: 0149-3833 [Format: Serial] :PATRON: santos, juan :SHIP TO: Interlibrary
Services/TAMU Libraries/5000 TAMUS/College Station, TX 77843-5000 :BILL TO:
SAME...FEIN 746000531 :SHIP VIA: Ariel 165.91.220.14 :MAXCOST: $50ifm :COPYRT
COMPLIANCE: CCL :FAX: (979)862-4759; ARIEL 165.91.220.14 :E-MAIL: ilsshare@lib-
gw.tamu.edu :BILLING NOTES: BRI USER CODE 51-1281;CAI # DD000806; LHL D10225
:AFFILIATION: ARL,BTP,HARLiC,TEXSHARE,TExpress 41 HOU,TEL:(979)845-5641 :LENDING
CHARGES:        :SHIPPED:        :SHIP INSURANCE:      :LENDING
RESTRICTIONS:  :LENDING NOTES:  :RETURN TO:  :RETURN VIA:
```

ShipVia: Ariel 165.91.220

Return To:

ILL Office Love Library
13th R ST.
University of Nebraska-Lincoln
Lincoln, NE 68588-4103

Ship To:

Interlibrary Services
TAMU Libraries
5000 TAMUS
College Station, TX 77843-5000

NeedBy: 4/7/2004

ILL: 4013321 **Borrower:** TXA

Req Date: 3/8/2004 **OCLC #:** 1188172

Patron: santos, juan

Author: Cold Regions Research and Engineering Lab

Title: Technical report - Corps of Engineers, U.S

Article: Smith, J. L.: The elastic constants, strength and density of Greenland snow as determined from measurements of sonic

Vol.: Technical Re **No.:**

Date: 1965 **Pages:** 18 pages

Verified: <TN:382500>OCLC ISSN: 0149-3833 [For

Maxcost: $50ifm **Due Date:**

Lending Notes:

Bor Notes: mc

Technical Report 216

DETERMINING THE DYNAMIC PROPERTIES OF SNOW AND ICE BY FORCED VIBRATION

North Smith

June 1969

DA TASK 1T062112A13001

U.S. ARMY MATERIEL COMMAND
TERRESTRIAL SCIENCES CENTER
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

PREFACE

This work was performed as part of Cold Regions Research and Engineering Laboratory (CRREL) Project 50, *Dynamic Properties of Greenland Snow*, by Mr. North Smith, Research Civil Engineer, under the general direction of Mr. A.F. Wuori, Chief, Applied Research Branch, and Mr. K.A. Linell, Chief, Experimental Engineering Division, CRREL, U.S. Army Terrestrial Sciences Center (USA TSC). This report was published under DA Task 1T062112A13001, *Cold Regions Research – Applied Research and Engineering*.

The report was technically reviewed by Mr. Henry Stevens and Mr. James Smith. Appreciation is extended to Mr. Roscoe Perham of the Measurement Systems Research Branch who developed the vibration apparatus.

Citation of commercial products or manufacturers is for information only and does not constitute official endorsement or approval.

USA TSC is a research activity of the Army Materiel Command.

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

The complex dynamic Young's and shear moduli, loss factor and Poisson's ratio are presented for naturally compacted glacial snow through a density range of 0.4 to 0.9 g/cm^3. A frequency dependence of the moduli and its effect on the computation of Poisson's ratio is demonstrated. Considerable scatter is exhibited in the loss factor measurements; however, indications are that the loss factors have negligible effect on the modulus computations.

SYMBOLS

ρ = density, g/cm³
R_L = maximum amplitude ratio, longitudinal
R_T = maximum amplitude ratio, torsional
ℓ_L = sample length, longitudinal, cm
ℓ_T = sample length, torsional, cm
f_{R_L} = vibration frequency at ratio = R_L
f_{R_T} = vibration frequency at ratio = R_T
$(\tan \delta/2)_L$ = loss factor, longitudinal
$(\tan \delta/2)_T$ = loss factor, torsional
E^* = complex dynamic Young's modulus
G^* = complex dynamic shear modulus
μ^* = complex dynamic Poisson's ratio

EQUATIONS

$$\tan \delta/2 = \frac{2}{\pi R_{max}}$$

$$E^* \text{ or } G^* = 16\,\ell^2 \rho f^2_{R_{max}} [1 + (\tan^2 \delta/2)]$$

$$E_1 \text{ or } G_1 = E^* \text{ or } G^* \cos \delta$$

$$E_2 \text{ or } G_2 = E_1 \text{ or } G_1 \tan \delta$$

$$\mu^* = \frac{[(E_1 - 2G_1)^2 + (E_2 - 2G_2)^2]^{1/2}}{2G^*}$$

DETERMINING THE DYNAMIC PROPERTIES OF SNOW AND ICE BY FORCED VIBRATION

by

N. Smith

Introduction

The dynamic properties of Greenland snow and ice have been extensively studied using elastic theory for wave propagation. Velocity measurements of seismic waves from explosive detonations on the Greenland Ice Cap by Bentley *et al.* (1957) were analyzed to develop relationships for incompressibility (bulk modulus), rigidity (shear modulus) and Poisson's ratio with depth and density. J.L. Smith (1964) also made sonic velocity measurements on Greenland snow employing transducers and a soniscope. However, these elastic theory methods do not provide the loss factors associated with internal damping.

Nakaya (1959) determined the Young's modulus and corresponding loss factor of Greenland snow and ice from flexural vibration testing of small rectangular bars. This method of testing is not conducive to determining the shear modulus or Poisson's ratio.

Lee (1963) developed a linear viscoelastic criterion for using steady-state sinusoidal vibrations of cylindrical samples to determine the complex Young's and shear moduli, the corresponding loss factors, and a complex Poisson's ratio. This criterion requires measurements of R_{max} (the maximum ratio of the accelerations at the free end of a sample to those at the end attached to a driver) and f_{ro} (the corresponding vibration frequency) for both the longitudinal and torsional modes of vibration.

The vibration apparatus shown in Figure 1 was first tested in Greenland during the summer of 1963 (N. Smith, 1964). Modifications to the apparatus were made by the author after the initial tests. Additional experiments on snow with a density of 0.42 to 0.88 g/cm³ were conducted at Camp Century, Greenland, during the summer of 1964.

This report contains an analysis of the data obtained in 1964 (Appendix B).

Test equipment

A schematic drawing of the test apparatus is shown in Figure 2. Electrical power for the instrumentation was obtained from the camp generators through a 1000 volt-ampere Sola 1% voltage regulator. The output signal of a Hewlett-Packard, Model 200AB audio oscillator with a frequency range of 20 to 40,000 Hz was used to drive a Vibrasonics Model VS-10 bench-type permanent-magnet shaker. The oscillator output was amplified with a 50-w Bogen Model CHB50 power amplifier. The test stand (Fig. 1) was a Sears, Roebuck and Company drill-press stand which supported the shaker on the lower platform and the sample vibration table assembly on the upper platform. The sample vibration table assembly provided a means for producing torsional as well as longitudinal oscillations in the sample. Also, it transferred dead load, which the shaker could not withstand, to the upper platform of the stand through two sets of radial wire springs. The shaker was connected to the table assembly by a 3-v, ¾-in.-diam electromagnet having a maximum force output of 8 lb. The shaker excited the table assembly axially for the longitudinal mode and through a flex-pivot arrangement for the torsional mode. Changing from the longitudinal to the torsional mode was accomplished by switching off the electromagnetic coupling and rotating the upper platform to align the flex-pivot drive with the shaker drive.

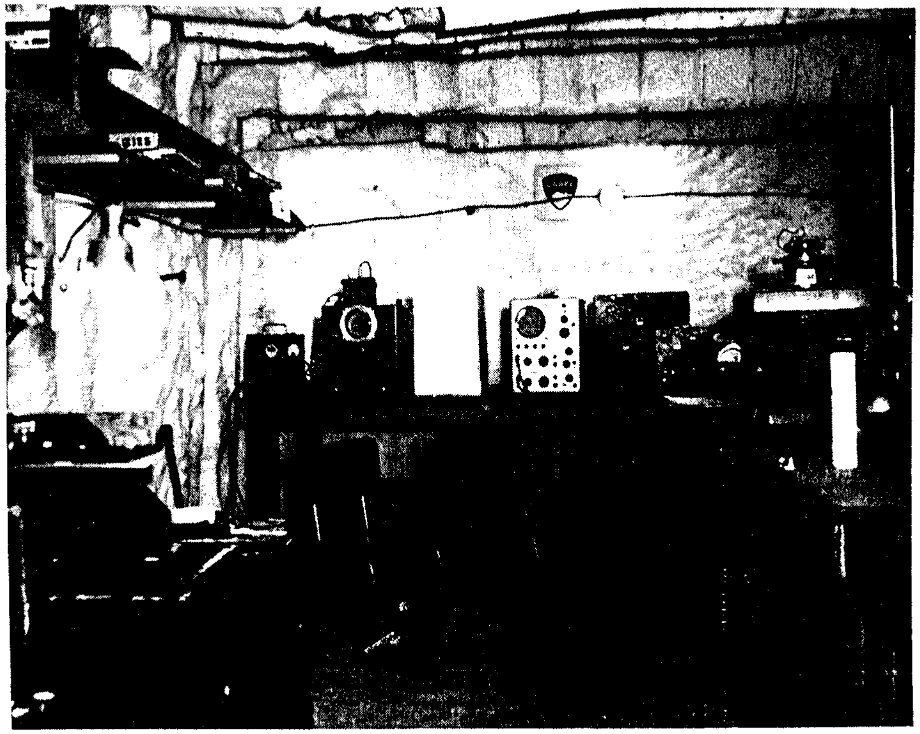

Figure 1. Laboratory and test apparatus at Camp Century, Greenland.

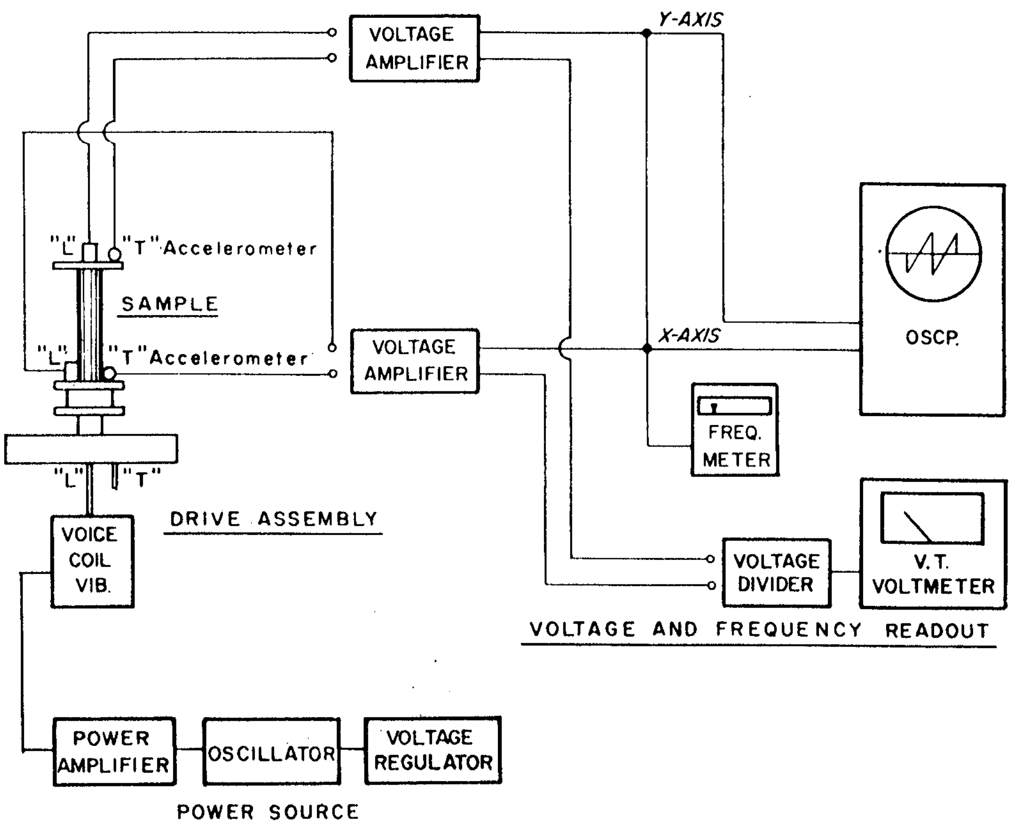

Figure 2. Schematic of dynamic test apparatus.

The oscillations induced in the sample were measured by Columbia Research Laboratories, Inc. piezoelectric accelerometers. The two accelerometers at the bottom of the sample (one for each mode) were stainless steel, Model 504-2, with a crystal sensitivity of approximately 20.0 peak picocoulombs/peak "g," a frequency response range of 0.4 to 5000 Hz, and a mass of 17.0 g. The two accelerometers at the top of the sample were aluminum, Model 675-1, having a crystal sensitivity of approximately 13.0 peak picocoulombs/peak "g," a frequency response of 0.4 to 8000 Hz and a mass of 4.0 g. The accelerometer outputs were amplified with Columbia Research Laboratories, Inc., Model 6000, high input impedance (1000 megohms) amplifiers having a gain adjustment from 0.3 to 100, a maximum voltage output of 60 v peak to peak, and a frequency response range of 4 to 500,000 Hz. Voltage readings were made with a Ballantine Model 300G Sensitive Electronic Voltmeter having a voltage range of 1.0 millivolt to 1000 volts rms in six decade ranges for a logarithmic scale and a frequency response range of 10 to 250,000 Hz. Frequency readings were made with a General Radio Company Type 1142-A Frequency Meter and Discriminator having a frequency range of 3 Hz to 1.5 Mc in five decade ranges for a logarithmic scale and a calibrated interpolation feature which expands the meter scale by a factor of ten, so that one-tenth of any of the five ranges covers the full meter scale. A General Radio Company Type 1454-A Decade Voltage Divider having a voltage ratio range of 0.0001 to 1.0000 in steps of 0.0001 measured the ratio of the voltages from the accelerometers. The accelerometer signals were displayed on a Tektronix, Inc. Type 502 Dual-Beam Oscilloscope, for visual detection of the resonance condition of the vibrating sample.

Sample preparation

Blocks of snow with nominal densities of 0.40, 0.50, 0.55, 0.65 and 0.70 g/cm^3 were cut with an electric chain saw from the walls of the inclined trench and the connecting trench between the Project 6 trench and the main camp. After sonic velocity measurements had been made on the blocks they were cut into cylindrical samples. The sample cutter (Fig. 3) had cutter blades 5.0,

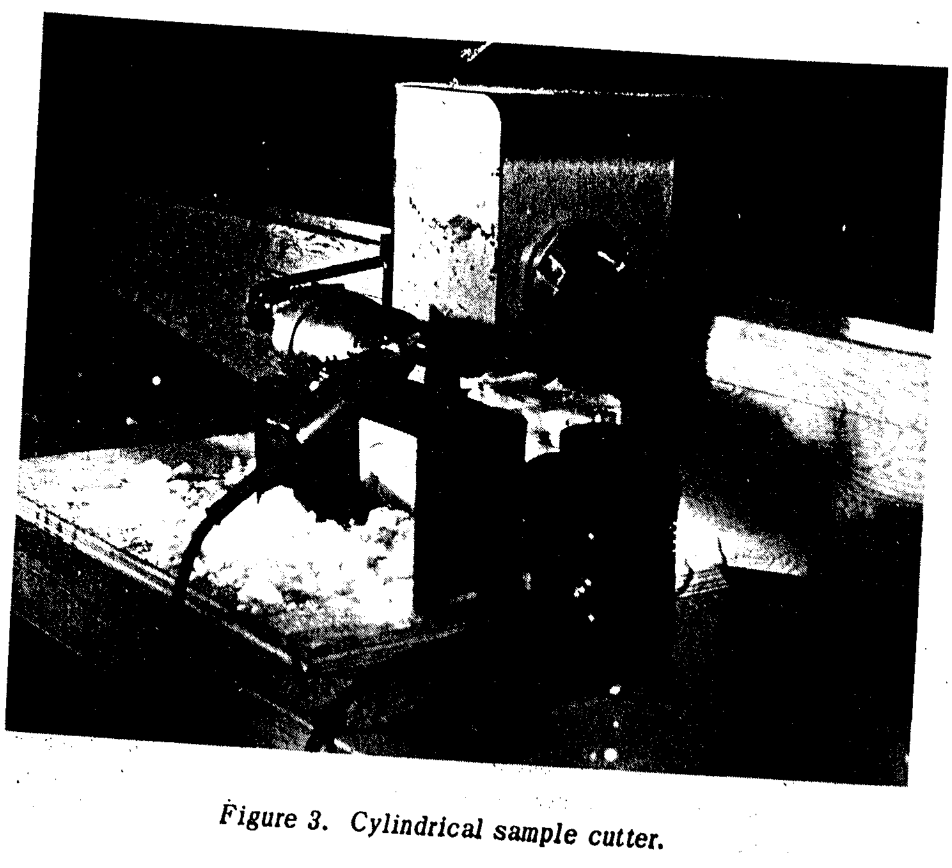

Figure 3. Cylindrical sample cutter.

6.0 and 7.5 cm in diameter. USA CRREL auger core samples with a density of 0.78 g/cm³ were obtained. Additional cores with a density of 0.88 g/cm³ were obtained from the thermal drill project. All the samples tested in 1964 were cut to a nominal diameter of 7.5 cm and had a minimum length to diameter ratio of 4:1 to eliminate boundary reflection effects during vibration. The physical dimensions and weights of the samples were measured with Starrett micrometer and height gage and a Toledo Metrogram electronic balance for density determinations. All tests were performed at ambient temperatures of −15 to −13°C.

Test procedure

The sample vibration table was heated to a temperature slightly above 0C by conduction from a steel plate heated on an electric hot plate. The test sample was set and positioned concentrically and perpendicularly on the vibration table. Before vibration of the sample was started, sufficient time was allowed for the sample to become bonded to the vibration table by freezing. The accelerometers at the base of the sample were attached to the outside edge by freezing. The accelerometers at the top (free end) of the sample were originally mounted on a thin aluminum plate frozen to the sample. The added mass of the plate and two accelerometers lowered the values of the moduli by as much as 18% for the low density samples. The plate was eliminated and the accelerometers were frozen directly to the sample (so that there was only one accelerometer on the sample for each vibration mode); the added mass of the accelerometer then had negligible effect on the moduli.

The fundamental resonant vibration frequency of the sample was determined by varying the input frequency with the oscillator while watching the accelerometer outputs on the oscilloscope. At resonance, a standing quarter-wave in the sample produced a maximum acceleration at the free end and a minimum at the attached end. Theoretically, the acceleration of the attached end would be zero at the nodal point for a perfectly elastic material. Viscoelastic materials develop a standing quarter-wave dependent upon the damping factor (Lee, 1963). By employing the *x-y* curve tracing feature of the oscilloscope the phase shift of approximately 90° between the input and output signals was used as the criterion for rough determination of the fundamental resonance frequency of the sample. The vibration frequency was then varied by the smallest readable increment on the interpolation scale for the particular frequency range until the minimum value of the inverse R_{max} was determined with the voltage divider.

Data analyses

Moduli versus frequency. Samples 29 cm to 55 cm long were tested. Analysis of the data indicated that the moduli for the two vibration modes on the same sample length did not correlate to result in a reasonable computed Poisson's ratio. Figures A1-A3 (Appendix A) show that the moduli increase with increasing frequency. Values of Poisson's ratio, computed from complex Young's modulus and complex shear modulus measured at a given frequency, are reasonable (see Table I).

Moduli versus driving force. During the experiments the drive force as indicated by acceleration was held nearly constant; however, there was some variation for different samples. Figures A4 and A5 show that the moduli do not vary systematically with the maximum acceleration of the input wave for the range of driving forces employed in these experiments.

Loss factor versus frequency. The loss factors ($\tan \delta/2$) computed from the maximum amplitude ratios were plotted against frequency in Figures A6-A10. Considerable scatter is evident but there does not seem to be an established trend between the two parameters. There are indications that the relationship of $\tan \delta/2$ to frequency may not be simple, i.e., a decrease in $\tan \delta/2$ accompanying an increase in frequency. Tan $\delta/2$ may even peak at some frequency and decrease each side of that peak depending on the rheological model which the material response may follow. Indeed, there appears to be a slight trend toward this type of response.

Table I. Complex moduli and Poisson's ratio for frequency of 1000 Hz.

Density (g/cm^3)	Complex Young's modulus (10^{10} $dynes/cm^2$)	Complex shear modulus (10^{10} $dynes/cm^2$)	Complex Poisson's ratio
0.48	1.35	0.550	0.23
0.55	2.13	0.846	0.26
0.62	3.36	1.31	0.28
0.68	4.26	1.66	0.28
0.72	4.95	1.92	0.29
0.88	7.65*	2.98*	0.28

* Frequency = 1200 Hz.

Table II. Loss factors for samples with average length of 31.46 cm.

Sample number	Density (g/cm^3)	Longitudinal length (cm)	Torsional length (cm)	Longitudinal $(\tan \delta/2)_L$	Torsional $(\tan \delta/2)_T$	Average $(\tan \delta/2)_{L,T}$
8-1	0.412	32.70	32.70	0.0395	0.0354	0.0359
8-1	0.412	32.70		0.0327		
4-1(a)	0.482		31.16		0.0233	
4-1(b)	0.482	31.14	31.14	0.0370	0.0317	
4-1(b)	0.482	31.14	31.14	0.0246	0.0320	
4-1(b)	0.482		31.14		0.0313	
4-1(b)	0.482		31.14		0.0324	0.0308
4-1(c)	0.482	31.14	31.14	0.0230	0.0414	
4-1(c)	0.482	31.14	31.14	0.0346	0.0506	
4-2	0.483	33.10	33.10	0.0183	0.0204	
1-1	0.551	29.53	29.53	0.0386	0.0299	0.0342
2-2	0.618	30.50	30.30	0.0341	0.0336	0.0338
6-2	0.660	32.73	32.73	0.0210	0.0292	0.0251
3-3	0.688	30.60	31.50	0.0252	0.0210	0.0231
5-2	0.713	30.70	30.80	0.0137	0.0154	
5-2	0.713	31.63	31.63	0.0152	0.0231	
5-2	0.713	31.63		0.0138		0.0192
5-3	0.717	30.54	30.54	0.0292	0.0237	
7-2	0.735	31.56	31.56	0.0291	0.0092	
7-2	0.735	31.10	31.10	0.0193	0.0150	0.0223
7-2	0.735	31.10		0.0387		
C-20	0.762	31.02	31.02	0.0243	0.0334	
C-20	0.762		31.02		0.0136	0.0202
C-20	0.762		31.02		0.0095	
C-36	0.781	34.08	34.08	0.0070	0.0140	0.0105
72C-2	0.896		32.30		0.0087	0.0063
72C-2	0.896	31.50	31.50	0.0049	0.0052	

Note: Testing temperature = −15 to −13°C.

Loss factor versus driving force. **Figures A11-A13 were plotted to study the effect on the loss factors of slight variations in driving force. There is a trend to an increase in tan $\delta/2$ with** increasing input acceleration, but the scatter of points is so great that quantitative values cannot be obtained with a reasonable degree of confidence.

Loss factor versus density. The test data indicate that the scatter in loss factor measurements was less pronounced for the samples having nearly equal lengths throughout the density range. Table II lists the loss factors for samples with an average length of 31.46 cm which were plotted as a function of density in Figure A14. The loss factors for the two vibration modes did not vary enough in magnitude to warrant separate plots of the relationship to density. Therefore, Figure A14 shows the general relation of the loss factor to density without separation of the effect of frequency or mode of vibration.

Moduli versus density. Values of the moduli for a frequency of 1000 Hz as obtained from Figures A1-A3 are listed in Table I and plotted as a function of density in Figure A15. The moduli have a linear relationship with density above a density of 0.55 g/cm^3; however, below that density a logarithmic relationship is indicated. Empirical equations were not developed for the special case of a single frequency.

Poisson's ratio versus density. The computed complex Poisson's ratio values of Table I are plotted in Figure A16 as a function of density. Extended extrapolations of the moduli-versus-frequency curves result in unreasonable values of Poisson's ratio, indicating that such extrapolation is probably not feasible because the range of frequency used was not sufficient to define the relationship.

Summary and conclusions

These experiments have established that the dynamic moduli of naturally compacted glacial snow vary with frequency. The frequency dependence is more pronounced for the snow with a density below 0.6 g/cm^3.

Small variations of the drive force at low drive levels did not seem to affect the moduli and loss factors.

The loss factor measurements exhibit considerable scatter. However, the magnitude of the loss factors have negligible effect on the modulus computations.

It is thought that the variations in freeze-bonding the accelerometers to the snow samples introduced scatter in the loss factor measurements. Ideally, an optical system with sufficient motion detection resolution should be employed to determine the source of the scatter.

These conclusions may not apply exactly to test results obtained at a testing temperature different than -15 to -13°C.

Literature cited

Bentley, Pomeroy and Dorman (1967) Seismic measurements on the Greenland Ice Cap, Part I: Studies at 75° 59'N 56° 05'W. New York: Columbia University.

Lee, T-M (1963) Method of determining dynamic properties of visco-elastic solids employing forced vibration. *Journal of Applied Physics*, vol. 34, no. 5, p. 1524-1529. Also U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Research Report 122.

Nakaya, U. (1959) Visco-elastic properties of snow and ice in the Greenland Ice Cap. U.S. Army Snow, Ice and Permafrost Research Establishment (USA SIPRE) Research Report 46.

Smith, J.L. (1965) Elastic constants, strength and density of Greenland snow as determined from measurements of sonic wave velocity. USA CRREL Technical Report 167.

Smith, N. (1964) Dynamic properties of snow and ice employing forced vibration. USA CRREL Technical Note (unpublished).

Stevens, H.W. (1963) Test apparatus and procedure for the determination of dynamic properties of soils. USA CRREL Technical Note (unpublished).

APPENDIX A: GRAPHS

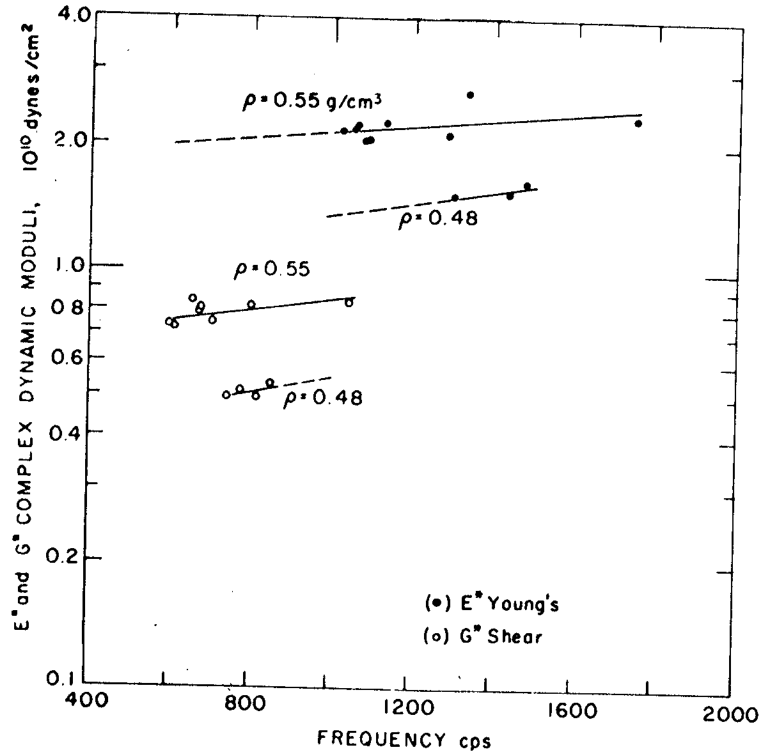

Figure A1. Moduli vs frequency.

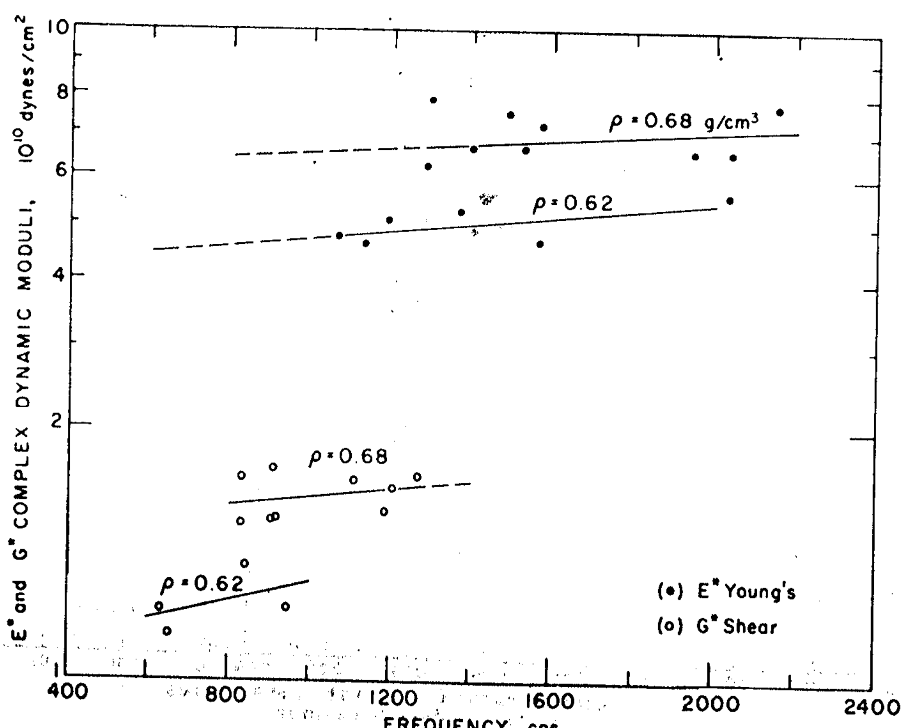

Figure A2. Moduli vs frequency.

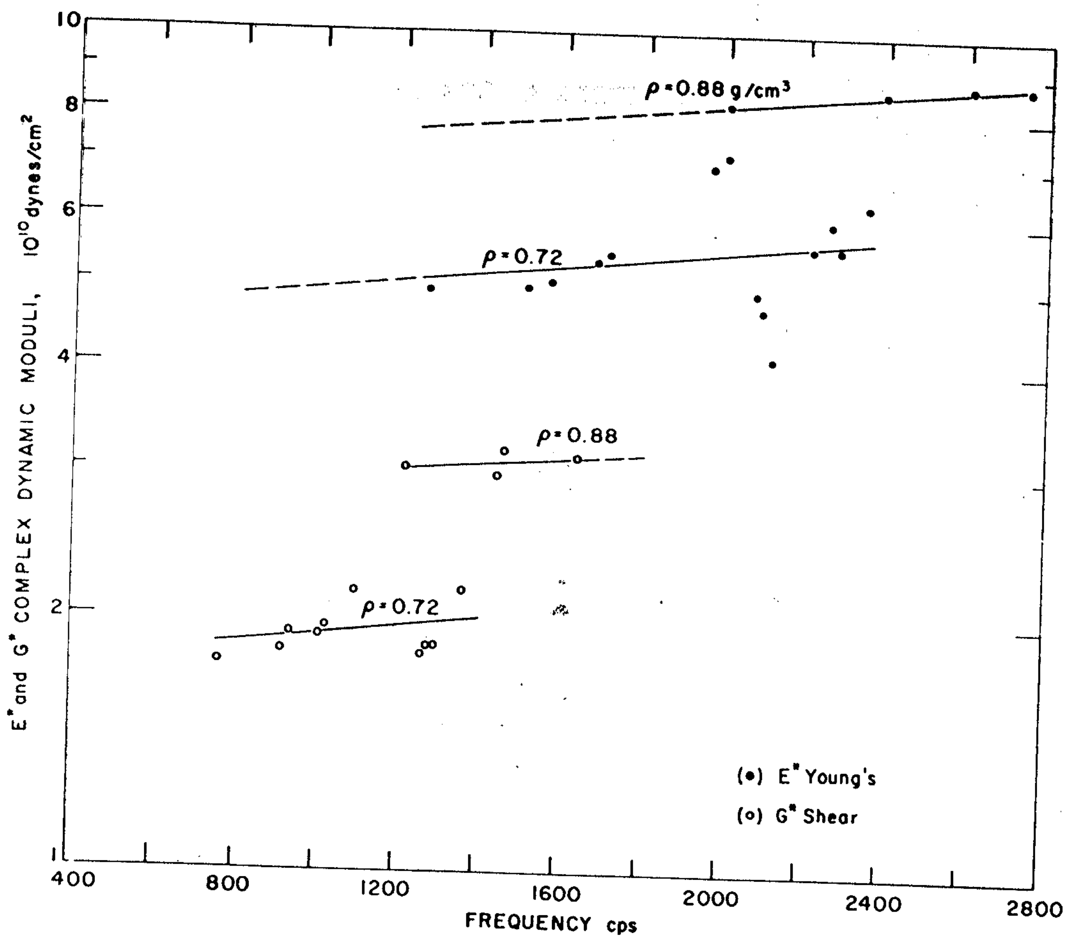

Figure A3. Moduli vs frequency.

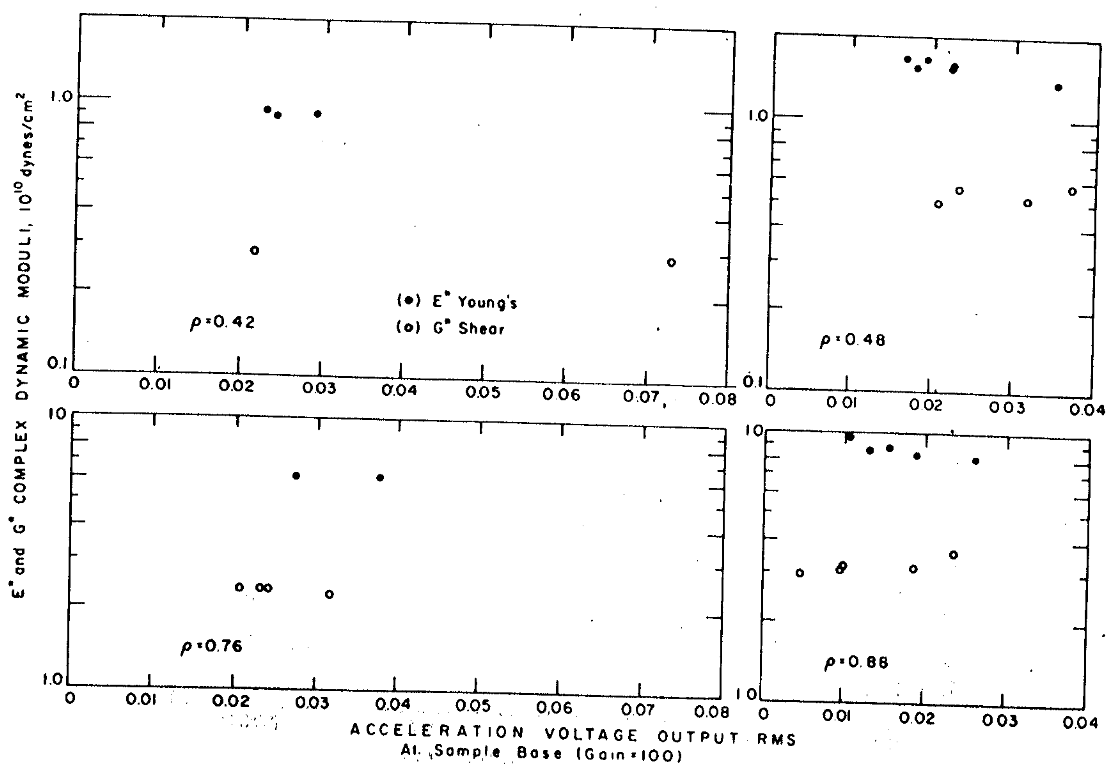

Figure A4. Moduli vs driving force for various frequencies.

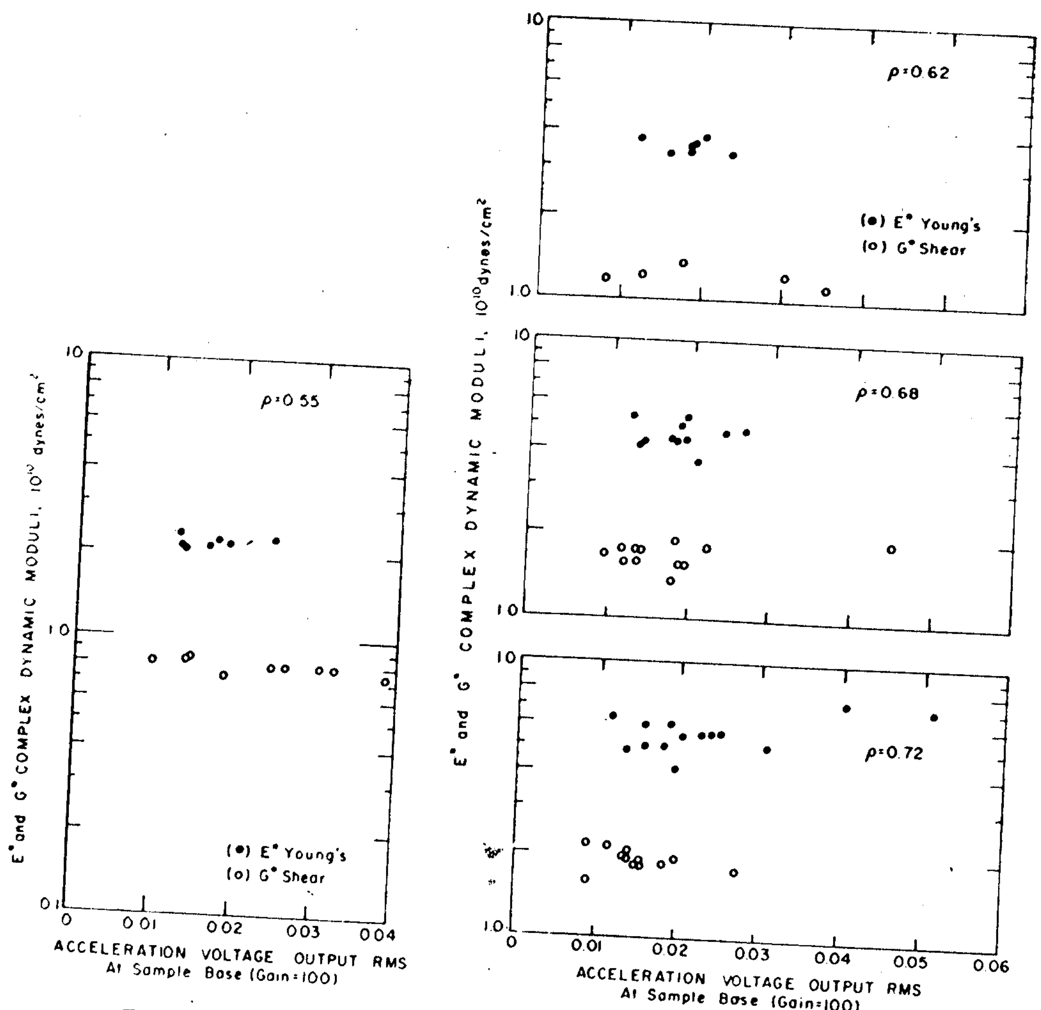

Figure A5. Moduli vs driving force for various frequencies.

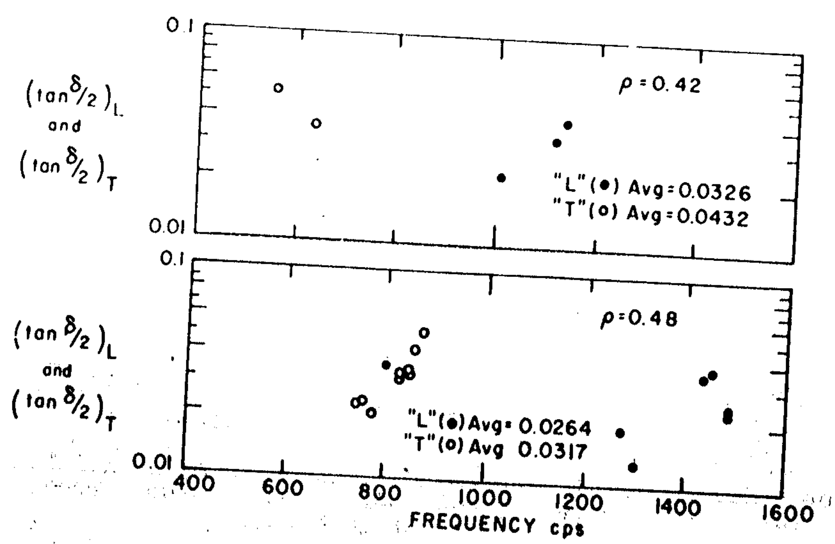

Figure A6. Loss factor vs frequency.

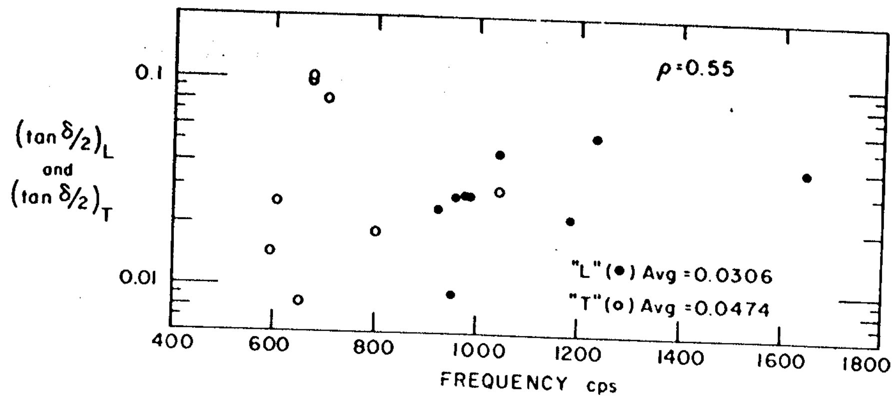

Figure A7. Loss factor vs frequency.

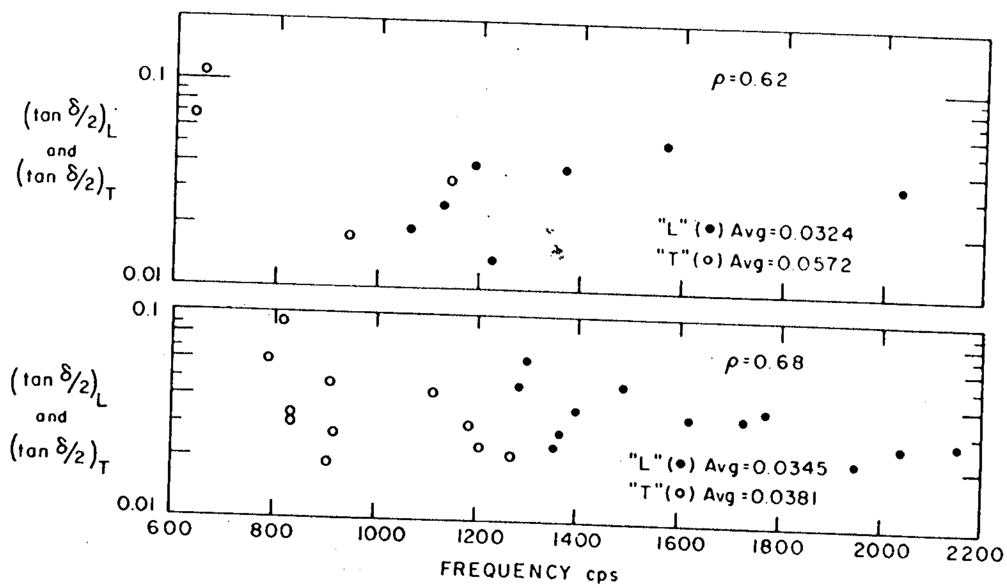

Figure A8. Loss factor vs frequency.

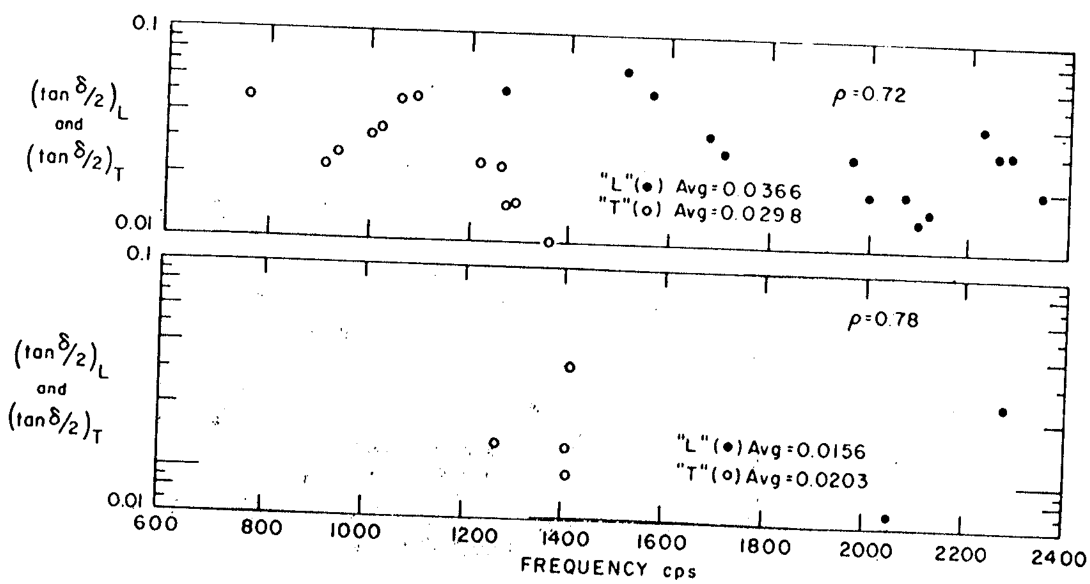

Figure A9. Loss factor vs frequency.

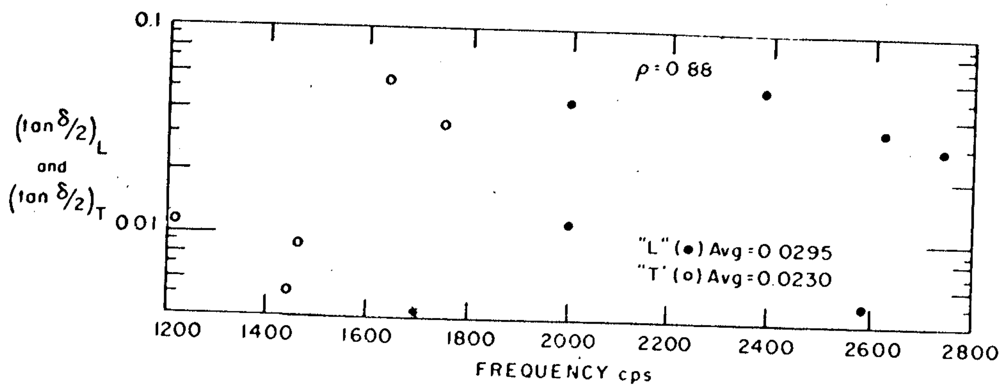

Figure A10. Loss factor vs frequency.

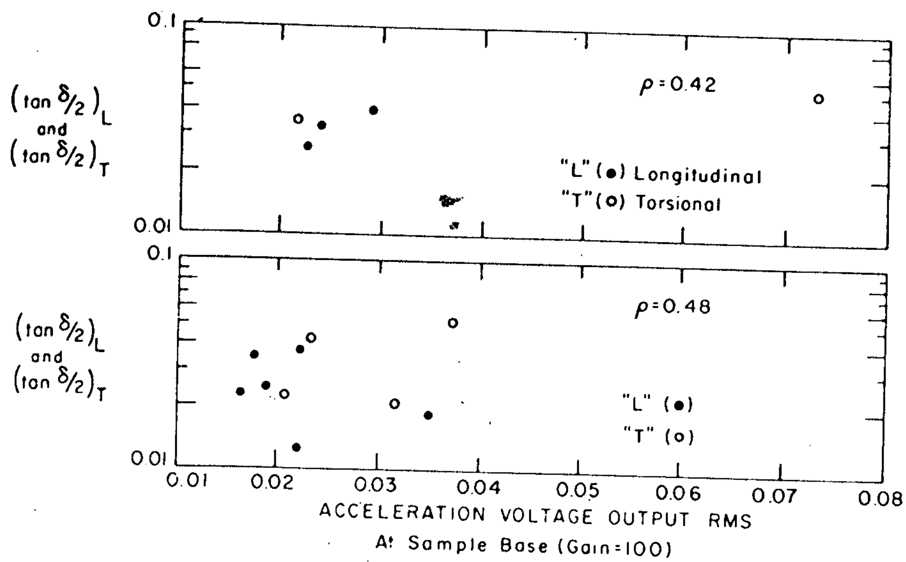

Figure A11. Loss factor vs driving force.

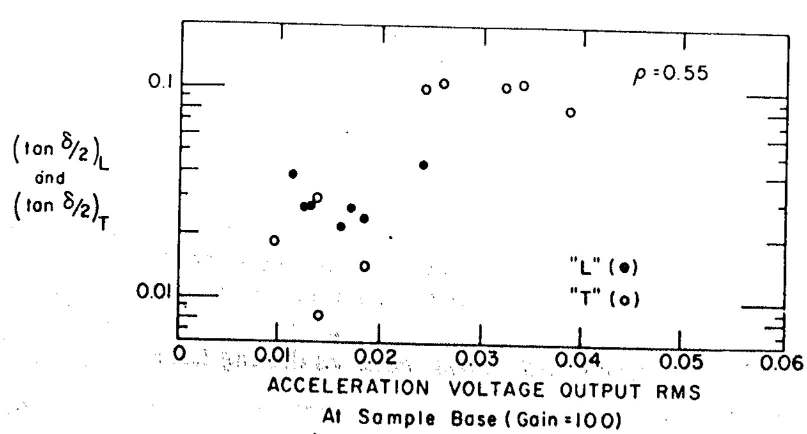

Figure A12. Loss factor vs driving force.

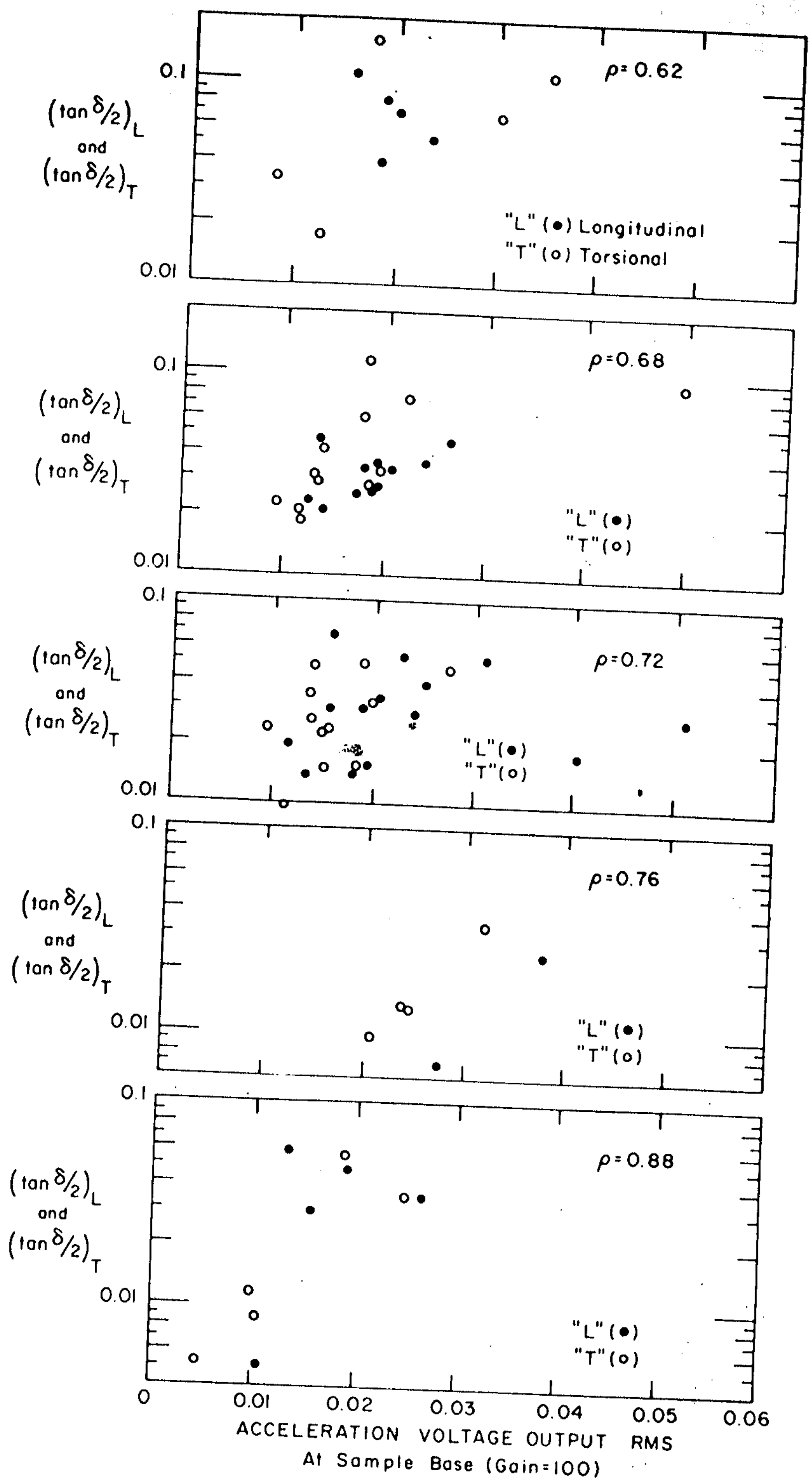

Figure A13. Loss factor vs driving force.

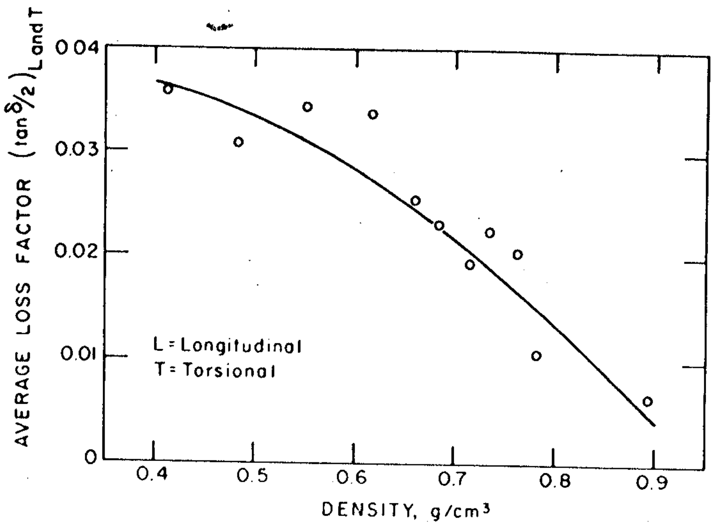

Figure A14. Loss factor vs density (average sample length = 31.46 cm).

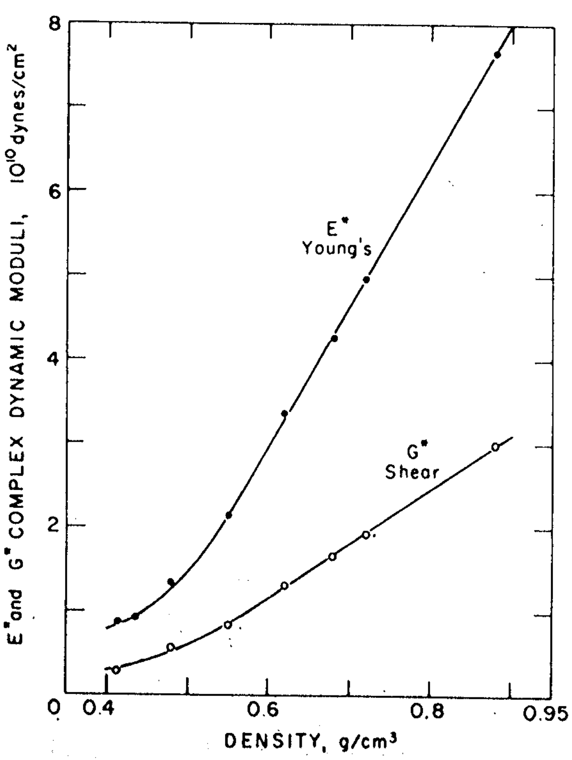

Figure A15. Moduli vs density (frequency = 1000 Hz).

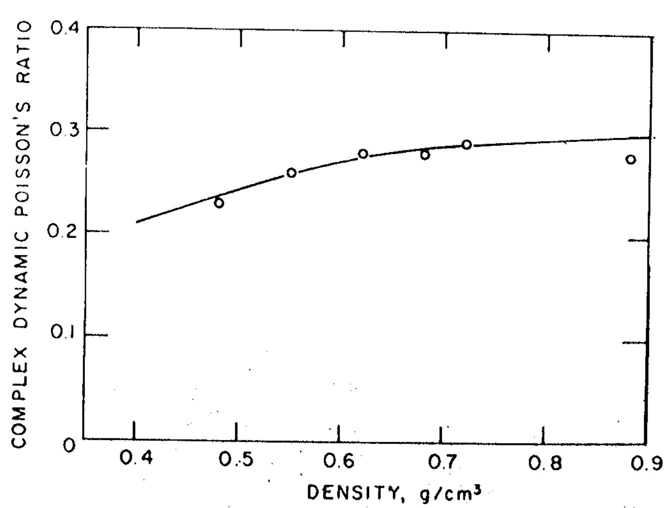

Figure A16. Poisson's ratio vs density.

APPENDIX B: EXPERIMENTAL DATA

Sample number	Density (g/cm^3)	Longitudinal length (cm)	Torsional length (cm)	Longitudinal frequency (H_z)	Torsional frequency (H_z)	Reciprocal of maximum longitudinal amplitude ratio ($1/R_L$)	Accelerometer output voltage at base of sample (gain = 100) $(VB)_L$	$(VB)_T$	Reciprocal of maximum torsional amplitude ratio ($1/R_T$)	Complex dynamic moduli, (10^{10} dynes/cm^2) Long.	Tors.	Loss factors Long.	Tors.
8-1	0.412	32.70	32.70	1133	633	0.0620	.0322	.0240	0.0555	0.905	0.282	0.0395	0.0354
8-1	0.412	32.70		1117		0.0514	.0267			0.879		0.0327	
8-2	0.435	36.20	36.20	1012	555	0.0403	.0228	.0730	0.0800	0.934	0.281	0.0257	0.0510
4-3	0.478	34.20	34.20	1300	743	0.0199	.0214	.0202	0.0354	1.512	0.494	0.0127	0.0225
4-1(a)	0.482	48.77		800		0.0548				1.174		0.0349	
4-1(a)	0.482	31.16	31.16	1240	755	0.3030			0.0366	1.151	0.427	0.1968	0.0233
4-1(b)	0.482	31.14	31.14	1454	849	0.0581	.0236	.0216	0.0498	1.581	0.539	0.0370	0.0317
4-1(b)	0.482	31.14	31.14	1486	833	0.0386	.0202	.0237	0.0502	1.651	0.519	0.0246	0.0320
4-1(b)	0.482		31.14		832				0.0491		0.518		0.0313
4-1(b)	0.482		31.14		848				0.0508		0.539		0.0324
4-1(c)	0.482	31.14	31.14	1488	856	0.0362	.0175	.0248	0.0650	1.656	0.548	0.0230	0.0414
4-1(c)	0.482	31.14	31.14	1435	873	0.0543	.0189	.0395	0.0795	1.540	0.570	0.0346	0.0506
4-2	0.483	33.10	33.10	1269	778	0.0288	.0350	.0318	0.0321	1.363	0.512	0.0183	0.0204
1-1	0.551	47.42	47.42	1053	605	0.0145			0.0392	2.196	0.725	0.0092	0.0250
1-1	0.551	29.53	29.53	1747	1044	0.0606	.0202	.0227	0.0470	2.346	0.838	0.0386	0.0299
1-2	0.551	41.48	41.48	1334	701	0.0856		.0452	0.1260	2.699	0.745	0.0546	0.0805
1-3	0.557	47.19	47.19	1059	653	0.0433	.0176	.0145	0.0131	2.226	0.846	0.0276	0.0083
1-3	0.557	37.90	37.90	1285	800	0.0345	.0206	.0124	0.0288	2.114	0.819	0.0220	0.0183
1-4	0.551	48.51	48.51	1021	595	0.0379	.0185	.0185	0.0221	2.163	0.734	0.0241	0.0141
1-4	0.551	44.65	44.65	1132	672	0.0694	.0262	.0350	0.1610	2.252	0.794	0.0442	0.1031
1-4	0.551	44.65	44.65	1079	672	0.0430	.0142	.0263	0.1560	2.046	0.794	0.0274	0.0998
1-4	0.551	44.65	44.65	1086	671	0.0434	.0138	.0370	0.1683	2.073	0.794	0.0276	0.1079
1-4	0.551	44.65	44.65	1086	675	0.0434	.0138	.0283	0.1700	2.073	0.801	0.0276	0.1089
2-2	0.618	37.10	37.10	1568	945	0.0836	.0233	.0188	0.0276	3.346	1.215	0.0533	0.0176
2-2	0.618	30.50	30.30	2035	1142	0.0536	.0363	.0147	0.0527	3.809	1.184	0.0341	0.0336
2-2	0.618	51.32	51.32	1129	658	0.0402	.0250	.0382	0.1715	3.319	1.128	0.0256	0.1099
2-2	0.618	44.20	44.20	1370	842	0.0618	.0235	.0220	0.2440	3.626	1.370	0.0394	0.1575
2-3	0.618	55.00	55.00	1065	637	0.0308	.0184	.0303	0.1063	3.393	1.214	0.0196	0.0679
2-1	0.622	50.16		1227		0.0221	.0132			3.770		0.0141	
2-1	0.622	50.16		1190		0.0638	.0201			3.546		0.0406	
6-1	0.660	45.24	45.24	1486	910	0.0722	.0300	.0253	0.1180	4.772	1.790	0.0460	0.0753
6-1	0.660	42.27	42.27	1570	907	0.0569	.0294	.0146	0.0293	4.607	1.552	0.0362	0.0187
6-1	0.660	41.91	41.91	1526	919	0.0521	.0222	.0230	0.0413	4.319	1.566	0.0332	0.0263

Sample number	Density (g/cm^3)	Longitudinal length (cm)	Torsional length (cm)	Longitudinal frequency (H_Z)	Torsional frequency (H_Z)	Reciprocal of maximum longitudinal amplitude ratio ($1/R_L$)	Accelerometer output voltage at base of sample (gain = 100)		Reciprocal of maximum torsional amplitude ratio ($1/R_T$)	Complex dynamic moduli, (10^{10} dynes/cm^2)		Loss factors	
							$(V_B)_L$	$(V_B)_T$		Long.	Tors.	Long.	Tors.
6-2	0.660	32.73	32.73	1945	1187	0.0329	.0221	.0214	0.0458	4.230	1.594	0.0210	0.0292
3-2	0.688	50.94	50.94	1357	818	0.0363	.0126	.0505	0.1425	5.228	1.911	0.0231	0.0912
3-2	0.688	30.90		2157		0.0418	.0309			4.878		0.0266	
3-3	0.688	30.60	31.50	2040	1268	0.0395	.0290	.0186	0.0330	4.290	1.756	0.0252	0.0210
3-3	0.692	51.66	44.70	1294	789	0.0953		.0207	0.0933	4.948	1.377	0.0609	0.0596
3-3	0.692	44.70	44.70	1399	833	0.0560	.0222	.0226	0.0516	4.330	1.535	0.0357	0.0329
3-3	0.692		32.39		1209			.0151	0.0358		1.698		0.0228
3-1	0.689	47.62	47.62	1284	836	0.0722	.0144	.0132	0.0460	4.121	1.747	0.0460	0.0293
3-1	0.689	50.67	50.67	1363	817	0.0429	.0195	.0134	0.1756	5.258	1.889	0.0273	0.1126
3-1	0.689	35.56	35.56	1620	1114	0.0521	.0300	.0204	0.0656	3.658	1.780	0.0332	0.0418
5-2	0.713	30.70	30.80	2095	1297	0.0214	.0222	.0301	0.0242	4.719	1.820	0.0137	0.0154
5-2	0.713	31.63	31.63	2120	1263	0.0239	.0311	.0250	0.0363	4.124	1.823	0.0152	0.0231
5-2	0.713	31.63		2075		0.0216	.0289			4.920		0.0138	
5-4	0.715	43.87	43.87	1567	935	0.0823	.0263	.0162	0.0409	5.406	1.925	0.0525	0.0260
5-4	0.715	43.87	43.87	1512	917	0.1059	.0182	.0174	0.0355	4.967	1.845	0.0676	0.0226
7-3	0.717	40.64	40.64	1680	1006	0.0518	.0254	.0248	0.0500	5.348	1.918	0.0330	0.0318
7-3	0.717	40.38	40.38	1710	1024	0.0438	.0290	.0173	0.0545	5.470	1.961	0.0279	0.0347
5-3	0.717	30.54	30.54	2285	1221	0.0459	.0262	.0151	0.0372	5.587	1.595	0.0292	0.0237
5-1	0.719	39.54	39.54	1965	1066	0.0425	.0660	.0180	0.0748	6.945	2.044	0.0271	0.0476
5-1	0.719	39.54	39.54	2000	1095	0.0282	.0520	.0243	0.0778	7.194	2.156	0.0180	0.0496
7-2	0.735	31.56	31.56	2260	1361	0.0457	.0304	.0184	0.0144	5.979	2.168	0.0291	0.0092
7-2	0.735	31.10	31.10	2350	1278	0.0303	.0191	.0248	0.0235	6.281	1.858	0.0193	0.0150
7-2	0.735	31.10		2215		0.0607	.0412			5.580		0.0387	
7-1	0.735	51.10	51.10	1267	760	0.0816	.0308	.0273	0.0740	4.929	1.774	0.0520	0.0471
C-20	0.762	31.02	31.02	2280	1409	0.0381	.0416	.0349	0.0525	6.098	2.329	0.0243	0.0334
C-20	0.762		31.02		1406			.0254	0.0213		2.319		0.0136
C-20	0.762		31.02		1409			.0229	0.0149		2.329		0.0095
C-36	0.781	34.08	34.08	2052	1262	0.0110	.0273	.0242	0.0220	6.096	2.311	0.0070	0.0140
55-B	0.858	29.10	29.10	2652	1640	0.0533	.0342	.0245	0.0864	8.010	3.127	0.0340	0.0551
55-B	0.858	29.10	29.10	2745	1750	0.0443	.0203	.0309	0.0541	8.759	3.560	0.0282	0.0345
72C-1	0.895	37.90	37.90	2000	1215	0.0710	.0190	.0098	0.0179	8.228	3.036	0.0452	0.0114
72C-2	0.896	32.30	32.30	2390	1460	0.0834	.0155	.0118	0.0137	8.543	3.188	0.0532	0.0087
72C-2	0.896	31.50	31.50	2585	1444	0.0077	.0129	.0055	0.0082	9.505	2.966	0.0049	0.0052