GEOLOGICAL SURVEY OF CANADA

OPEN FILE 1708

VISCOSIMETRIC PROPERTIES OF A BEAUFORT SEA SEDIMENT

**Jacques Locat[1], Pavel Kurfurst[2], Marc-André Berube[1],
Jean-Yves Chagnon[1], and Pierre Gelinas[1]**

[1] Groupe de Recherche en Géologie de l'Ingénieur, Department of Geology, Laval University, Ste-Foy, Quebec, Canada, G1K 7P4

[2] Terrain Sciences Division, Geophysics and Terrain Sciences Branch, 601 Booth Street, Ottawa, Ontario, K1A 0E8

Canada

1988

INTRODUCTION

The Geological Survey of Canada has been involved for many years in the mapping of the engineering properties of soils in the Northwest Territories where large areas are underlain by frozen or unfrozen fine-grained sediments. In the case of frozen soils with high ice content or in the case of soft offshore sediments, it could be crucial to be able to calculate or predict the remolded strength or dynamic viscosity of the soil. This is especially true for the case of debris flows, for which run out distances must be predicted. In many cases, the remolded strength can be easily measured by means of the Swedish fall cone (Garneau and LeBihan, 1977). However, this technique is not applicable for materials with liquidity indices higher than 3. Locat and Demers (1987) have extended the correlation between the liquidity index and the remolded strength to liquidity indicies higher than 3 by the use of a viscosimeter. They have proposed various correlations between yield stress, viscosity, remolded strength and liquidity index for sensitive clays of Eastern Canada. This paper reports on laboratory investigations (Locat et al., 1986) carried out on a sample from the Beaufort Sea in order to validate this methodological approach for Beaufort Sea sediments.

SAMPLE CHARACTERISTICS

The sample chosen for the testing (GSC-10) was collected in 1985 in the southern Beaufort Sea. At the time of testing in 1986, the sample had broken apart into several pieces. The sample was grey clayey silt with a silt/clay ratio of 3:1. Organic traces were visible and the total carbon concentration was about 4%. The sample was composed mostly of quartz, feldspar, dolomite, and calcite. The clay minerals included illite, chlorite and mixed-layered minerals (chlorite-vermiculite; Locat et al., 1986). The water content of 34.6% was still well above the plastic limit (26%) and hence drying had not been excessive. However, the moisture content was such that no measurements of the remolded strength could be made with the fall cone. A salt content of 20 g/l was measured on pore water that was extracted from the sample. This value is consistent with the marine origin of the sediment. The geotechnical and physical-chemical characteristics of the GSC-10 sample are summarized in Table 1.

VISCOSIMETRIC TESTS

A rotational viscosimeter HAAKE-ROTOVISCO RV-12 was used to carry out viscosimetric measurements (Locat and Demers, 1987). The equipment, run in a steady state mode, consists of two co-axial cylinders. The inner one, the rotor, is mobile and is connected to a gauge that measures the applied torque. The outer cylinder is stationary and controls temperature through a liquid-cooling system.

The equipment allows testing at various shear rates and records the associated shear stress. The constant yield stress test is done using the maximum speed of 512 rpm until a constant level of torque is reached. The dynamic response test is carried out using the decreasing shear rates. After the rotational speed of 512 rpm is reached, it is reduced to 50% for each stage, then increased to the original rotational speed (i.e. 512, 256, 512, 128, 512, 64 rpm etc.). All tests are carried out at constant temperature. For this particular series, a temperature of 7°C was chosen. Tests are done on samples which are well remolded at a given salinity. The first group of tests was done on samples with salinity maintained at about 30 g/l (Table 2, Figure 1) and decreasing water contents. A second group of tests was carried out on samples with a decreasing salinity (Table 2, Figure 2). The salinity was controlled by adding NaCl solutions and verifying concentrations on extracted pore water with a conductivity meter.

Curves shown in Figures 1 and 2 are used to calculate the rheological parameters. Yield stress is calculated as the equilibrium stress generated at a given shear rate. The equilibrium value of the shear stress is plotted as a function of the shear rate (Figures 1 and 2). The flat section of the yield stress-shear rate curve (at high shear rate) is used to compute the dynamic viscosity (η) which is the slope of the straight line extension of this section of the curve. The yield strength ($\mathcal{T}_c$) is calculated as the intercept of this line with the y-axis (at zero shear rate D). At constant salinity (30 g/l), the yield strength increases with decreasing water content or liquidity index from 75 to 550 Pa for a liquidity index varying from 3.2 to 1.74. For the same liquidity index range, the dynamic viscosity varies from 61 to 1350 mPa.s (Table 2).

CORRELATIONS

Figures 1 and 2 illustrate the relationship between yield strength ($\mathcal{T}_c$) and water content (w): yield strength increases with a decreasing water content. The same relationship exists between the remolded undrained shear strength (Cu_r) and water content (w). At constant plastic and liquid limits, variations in the water content are reflected by changes in the liquidity index (I_L) of the tested sample. Therefore, remolded shear strength (Cu_r), yield strength ($\mathcal{T}_c$), dynamic dynamic viscosity (η) and liquidity index (I_L) are all interrelated. Garneau and LeBihan (1977) proposed a relationship between the remolded shear strength and liquidity index for sensitive clays of Québec. Later, Leroueil et al. (1983) proposed a similar relationship applicable to clays from around the world. The Beaufort Sea sample follows the same relationship (Figure 3).

Figures 4 and 5 are used to compare the results obtained for the Beaufort Sea sample with those of Locat and Demers (1987). These samples were from various sites and contained either salt or fresh water. The relationship between the liquidity index and the yield strength is shown in Figure 4 where the lines A and B represent the envelope of test results of the Champlain Sea samples. The lower curve A is for clays with a low (less than 2 g/l) pore water salinity. The upper curve B is for low plasticity soils with a high pore water salinity. For the Beaufort Sea sample, the change in salinity was not sufficient to displace the relationship towards curve A. The lowest salinity was at 12.4 g/l which is probably still above the critical point of flocculation which is between 0.5 and 2 g/l for sensitive clays (Locat, 1982). When the liquidity index is compared to the dynamic viscosity (Figure 5), the relationship holds but is less clear at liquidity indices below 2.0. This relationship has also been observed for sensitive clays, but at a liquidity index of less than 1.5. These results clearly indicate that the relationships developed for sensitive clays could be applied to Beaufort Sea sediments and hence that similar geotechnical methods can be applied.

DISCUSSION

The Beaufort Sea sample was difficult to test at a liquidity index greater than 3 (for a salinity of 30 g/l). Curves A and B (Figure 4) were obtained for soils tested at a salinity of 0.5 and 30 g/l. This is a greater salinity difference than the one used for the Beaufort Sea soil. The sample tested is a clayey silt which makes it more difficult to test because the particles have a tendency to settle at high water contents. The viscosimetric response of a sample is not only a function of its water content, but also of its plasticity index and mineralogy. Sensitive clays with a similar surface area usually have, due to their physical-chemical characteristics, a much higher clay content (Locat _et_ _al_, 1984) than that found for this Beaufort Sea sample. The size of the particles (flocs) is critical in the viscosimeter tests. If the material is too coarse, settlement occurs in the cylinder and incorrect viscosity measurements are made. More investigations are needed on Beaufort Sea soils to study the role of the grain size and mineralogy and their influence on their rheological behaviour. Various soils of different surface area could be tested at various salinities and temperatures so that salinity-temperature relationships could be developed. Still, it is satisfying to see that these soils behave in such a way that their liquidity index-viscosity relationships remain within what has been observed for Eastern Canada soils. The correlations developed on sensitive soils seems to apply to Beaufort Sea soils, but a more detailed knowledge on the role of soil mineralogy and grain size is needed.

The effect of salinity changes on the remolded strength and texture could also be investigated with an electron microscope coupled with the cold stage plate, (CRYOSCAN), which would enable the observation of the microfabric of a soil mixture without removal of the ice. This should be investigated in relation to similar work on Eastern Canadian soils.

Further studies are recommended to study feasibility of this technique for a wide range of soil materials as well as for different temperature and salinity range. Application of this technique should then be studied for specific sites in permafrost terrains, especially where land and submarine slides occur.

ACKNOWLEDGMENTS

This work was sponsored by NSERC and Fonds FCAR. The authors would like to thank Anne Masson, Michel Bédard and Gaston Breton for their contributions.

REFERENCES

Garneau, R., and Le Bihan, J.P.

1977: Estimation of some properties of Champlain clays with the Swedish fall cone; Canadian Geotechnical Journal, v. 14, p. 571-581.

Leroueil, S., Tavenas, F., and Le Bihan, J.P.

1983: Propriétés caractéristiques des argiles de l'est du Canada; Canadian Geotechnical Journal, v. 20, p. 681-705.

Locat, J.

1982: Contribution à l'étude de l'origine de la structuration des argiles sensibles du Canada; Ph. D. Thesis, University of Sherbrooke, Sherbrooke, Québec, Canada, 514 p.

Locat, J., Masson, A., and Bédard, M.

1986: Caractéristiques géotechniques et rehéologiques d'un sédiment argileux provenant de la mer de Beaufort; Département de Géologie, Université Laval, Québec, Rapport GGL-86-38, 27 p.

Locat, J. and Demers, D.

1987: Viscometric properties of some sensitive clays from Eastern Canada; submitted to the Canadian Geotechnical Journal, Rapport GGL-86-10, 105 p.

Table 1

Geotechnical and physical-chemical characteristics sample - GSC-10

Water content (%)	34.6
Salinity (g/l)	20.0
Liquid limit (%)	52.0
Plastic limit (%)	26.0
Plasticity index (%)	26.0
Water loss at 420° C (%)	4.4
Water loss at 850° C (%)	12.0
Clay fraction (%)	30.0
Specific surface area (m^2/g)	57.0
Calcite (%)	6.2
Dolomite (%)	15.4

Table 2
Results of viscosimetric tests: sample GSC-10

Test	Salinity (g/l)	Water content w (%)	Sensor type	Remolded shear strength Cu_r (kPa)	Liquidity index I_L	Yield strength τ_c	Viscosity η (mPa.s)
1.	30.0	71.3	SV-I	0.33	1.74	550	1350
2.	30.0	77.8	MV-III	0.22	1.99	393	680
3.	30.0	82.4	MV-III	0.17	2.17	287	360
4.	30.0	88.8	MV-III	0.13	2.42	217	134
5.	30.0	98.2	MV-II	---	2.80	121	85
6.	30.0	108.2	MV-II	---	3.20	75	61
7.	16.0	63.3	SV-I	0.29	1.80	540	1350
8.	14.8	68.6	MV-III	0.17	2.00	350	825
9.	12.4	76.5	MV-II	0.10	0.10	210	150

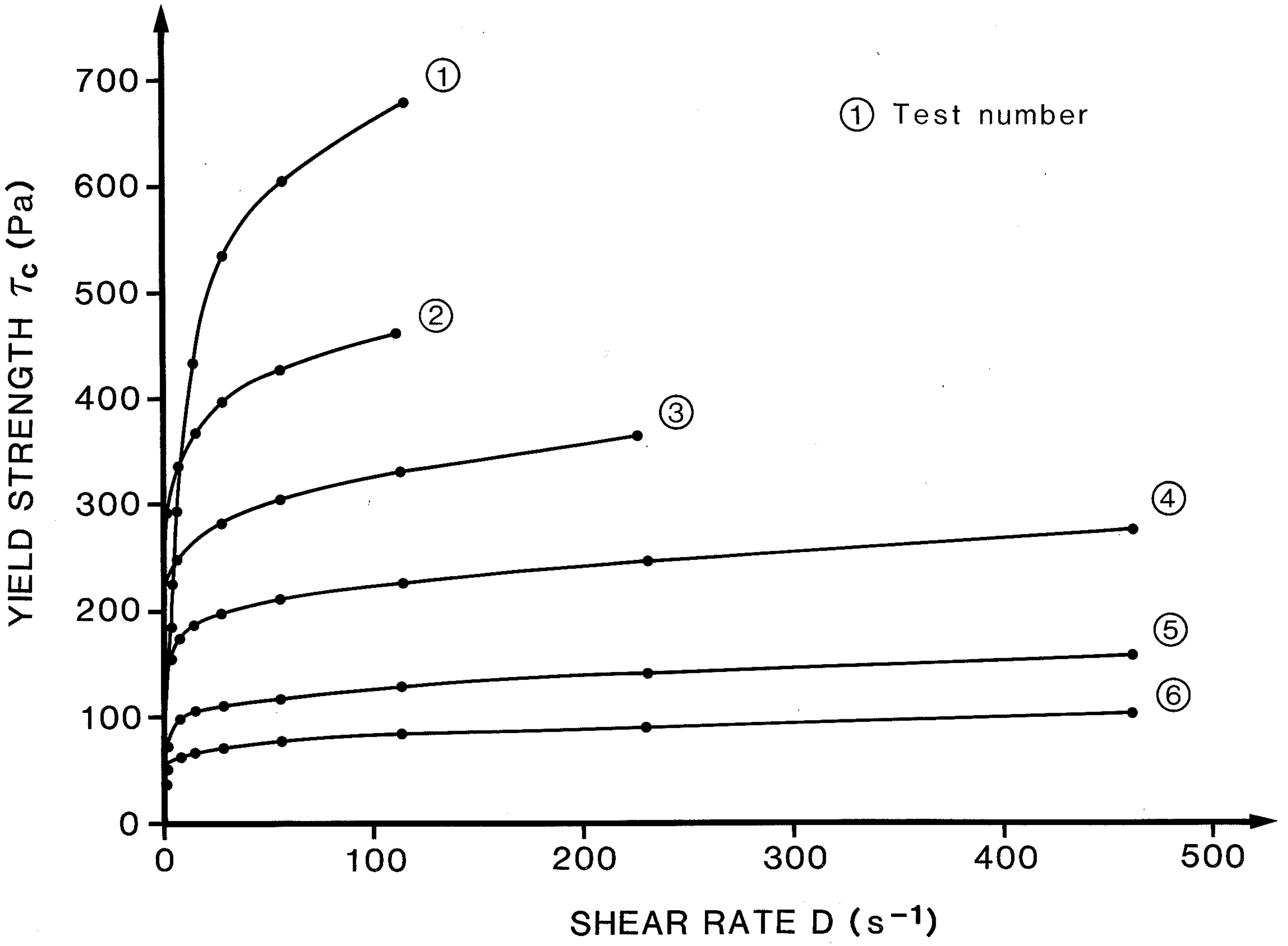

Figure 1 - GSC-10 sample: viscosimetric tests results at a constant salinity

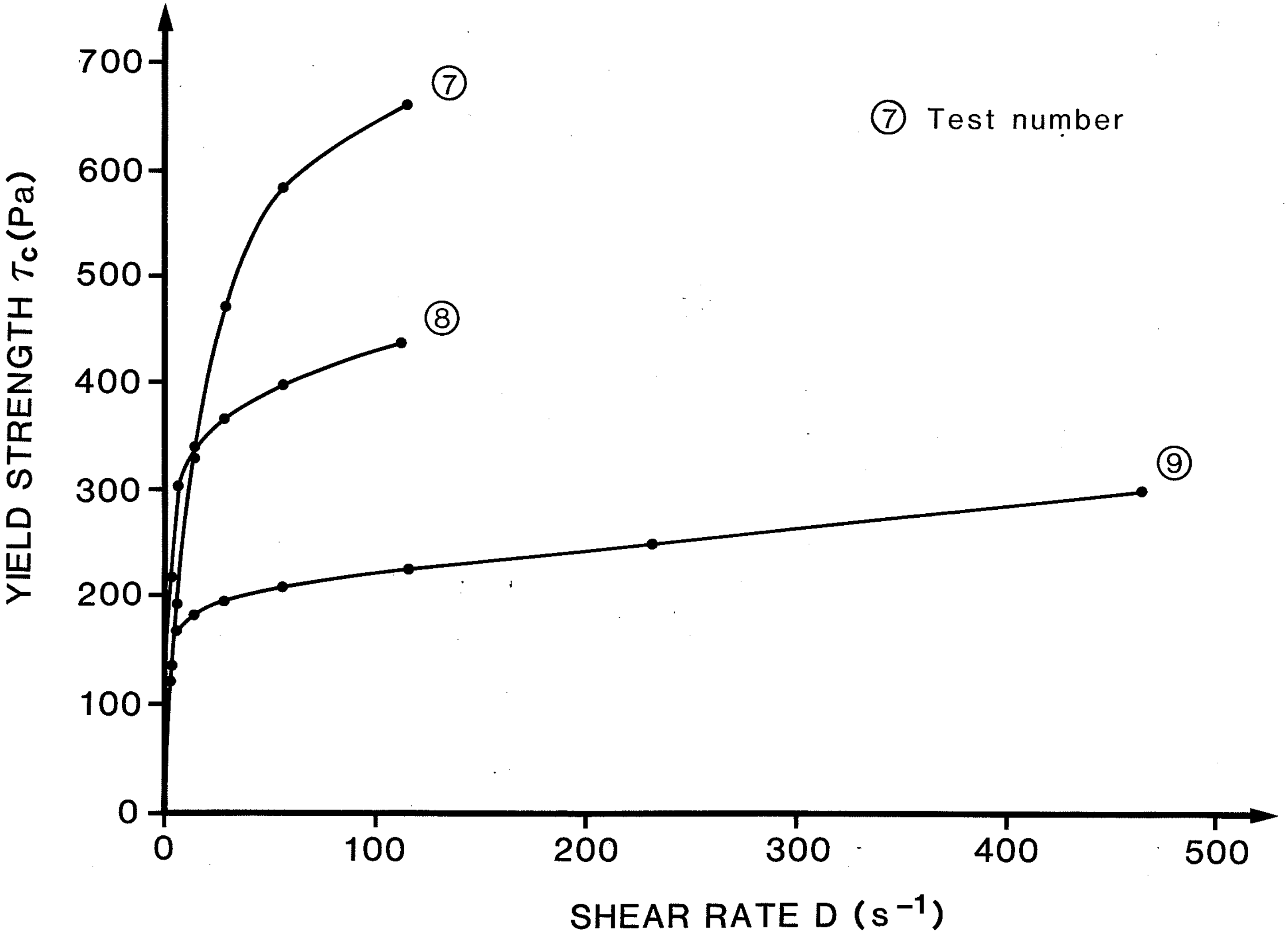

Figure 2 - GSC-10 sample: viscosimetric tests results at various salinities (see Table 2 for test conditions)

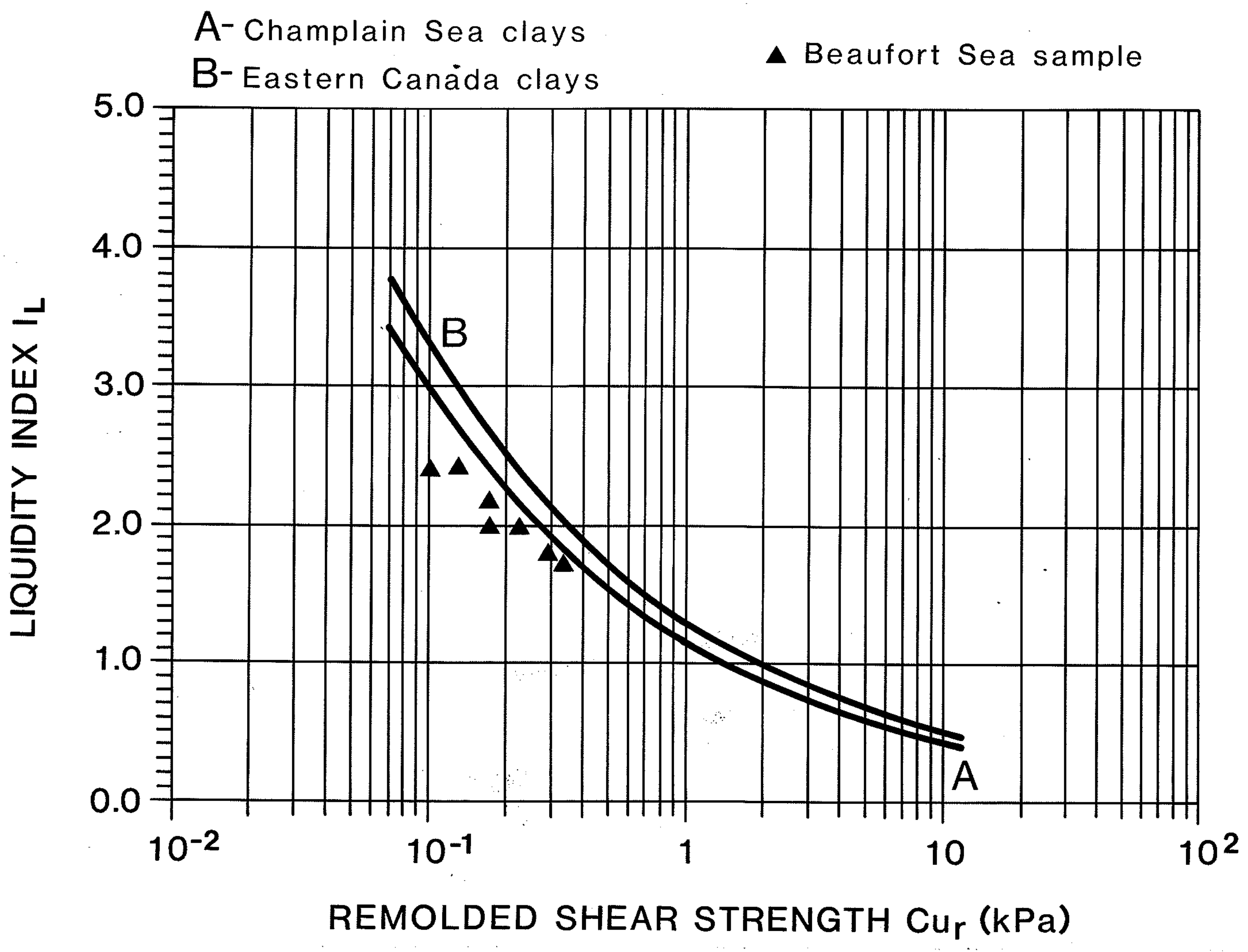

Figure 3 - Relationship between liquidity index and remolded shear strength (see Table 2 for test conditions)

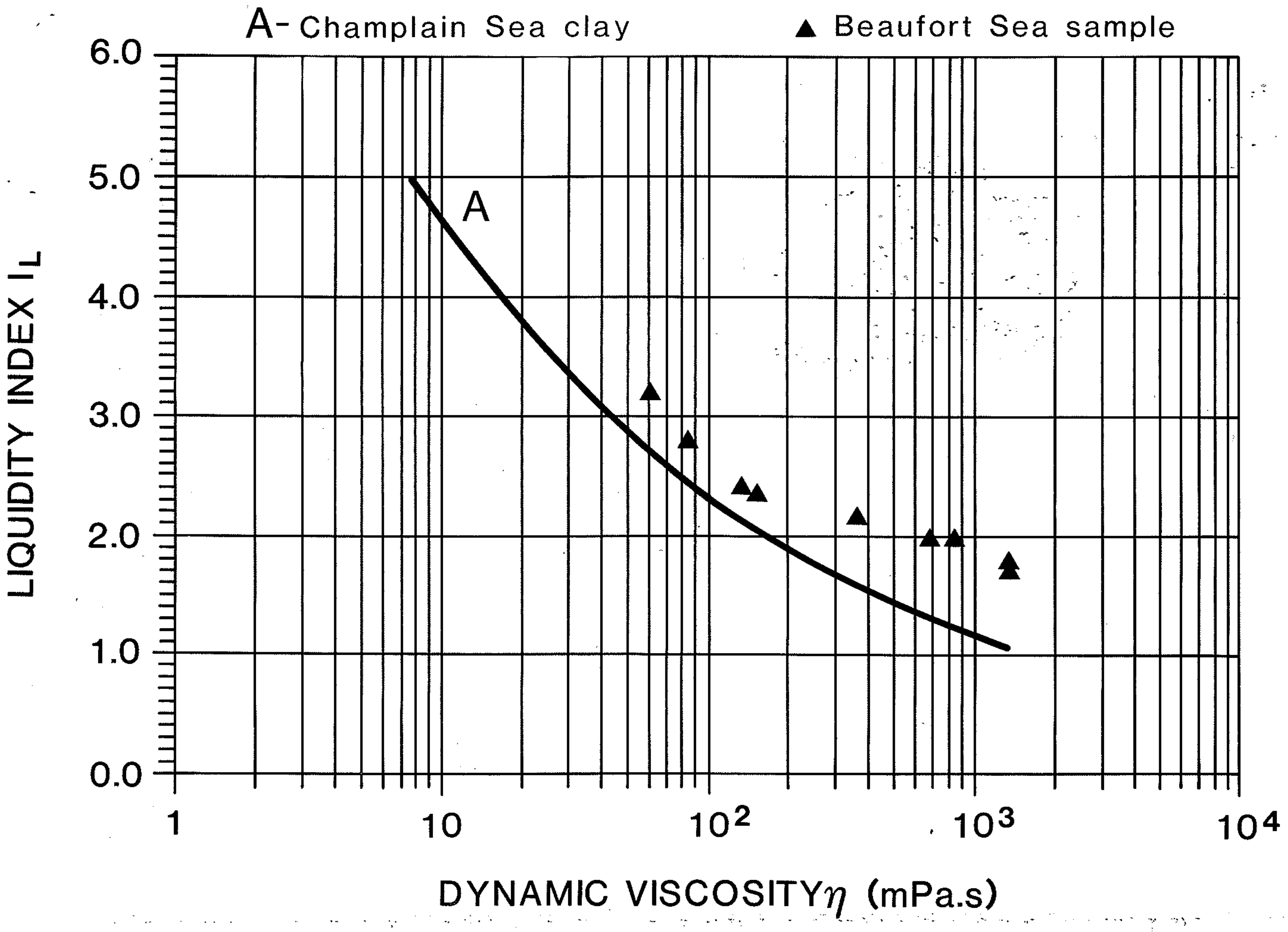

Figure 5 - Relationship between liquidity index and dynamic viscosity

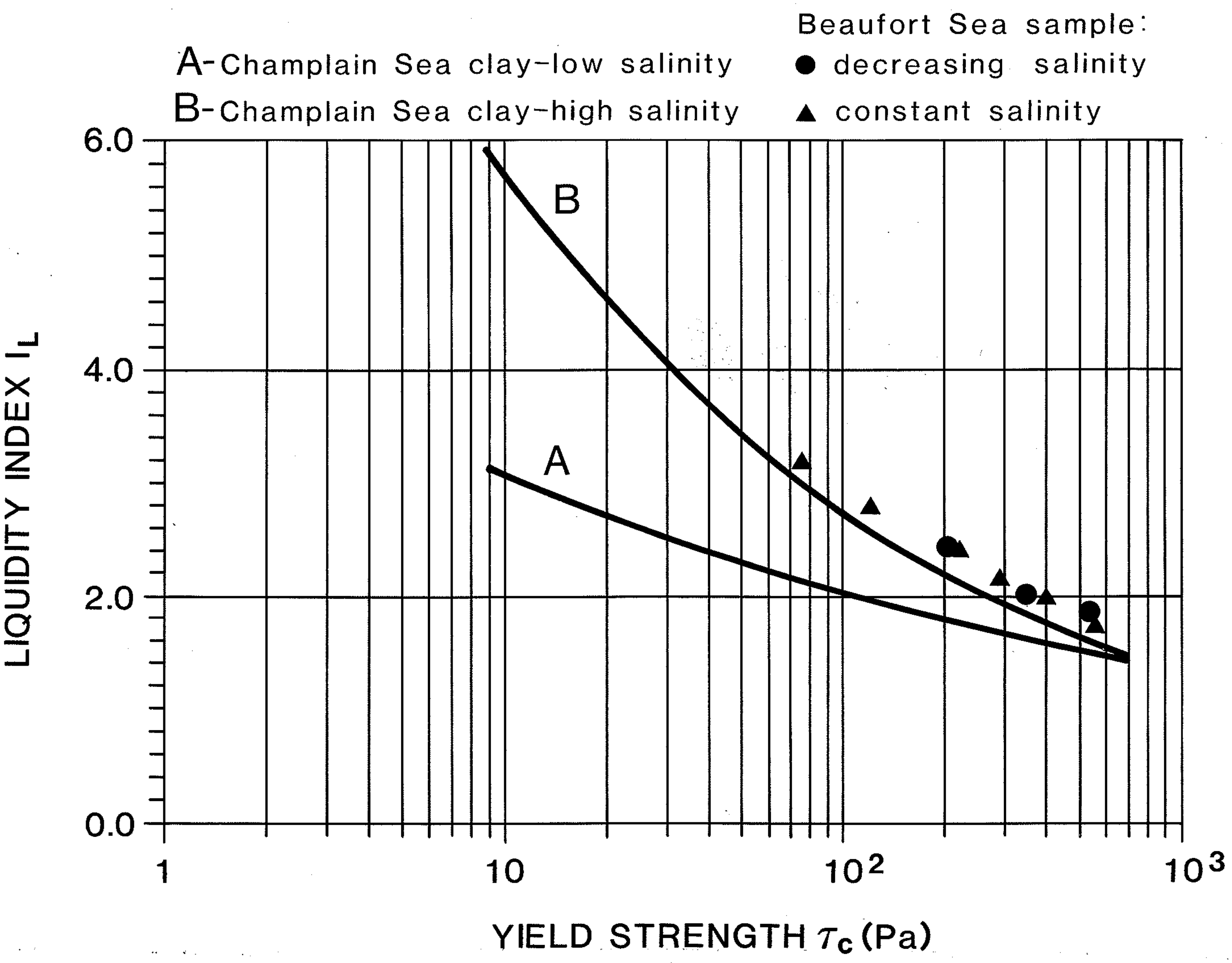

Figure 4 - Relationship between liquidity index and yield strength