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MEASUREMENT OF THE SHEAR STRENGTH OF SNOW USING A BEVAMETER AND A HAND-HELD SHEAR DEVICE

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MEASUREMENT OF THE SHEAR STRENGTH OF SNOW USING A BEVAMETER AND A HAND-HELD SHEAR DEVICE

BY

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NOVEMBER 1990

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OTTAWA, CANADA

MEASUREMENT OF THE SHEAR STRENGTH OF SNOW USING A BEVAMETER AND A HAND-HELD SHEAR DEVICE

prepared for

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under Contract

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FOREWORD

This report describes the measurement of the shear strength of snow covers in Fernie, British Columbia, during February 1990, using a bevameter and a hand-hald shear device.

The work was performed by Vehicle Systems Development Corporation, under contract (Serial No. W7702-9-R127/01-XSG) to the Canadian Department of National Defence through the Department of Supply and Services. The Principal Investigator was Dr. J.Y. Wong. The field data were collected by Messrs. J. Preston-Thomas and C. Smith and were processed by Messrs. S.T. Chen, J. Preston-Thomas and C. Smith under the direction of Dr. J.Y. Wong. The Scientific Authority for the Contract was Dr. G.J. Irwin, Vehicle Mobility Section, Defence Research Establishment Suffield.

The measuring equipment, including a bevameter, a hand-held shear device and a terrain data acquisition system, was provided by Vehicle Mobility Section, Defence Research Establishment Suffield. The data on the physical properties of the snow covers, including the temperature, density and grain size distributions, were provided by Vehicle Mobility Section, Defence Research Establishment Suffield and described in Appendix A of a report entitled "Meaurement and Characterization of the Pressure-Sinkage Relationships for Snow Obtained Using a Rammsonde and a Bevameter", by Dr. J.Y. Wong, October 1990.

SUMMARY

The shear data for snow covers in Fernie, British Columbia obtained using a bevameter and a hand-held shear device were evaluated and compared.

It was found that the values of the shear strength parameters derived from data obtained using the hand-held shear device provided by Vehicle Mobility Section, Defence Research Establishment Suffield (DRES) were noticeably different from those obtained using the bevameter. The difficulty in controlling the normal load and the manual reading of the load gauge and spring scale contribute to the uncertainty concerning the reliability of the shear data obtained using the hand-held shear device. The reliability of the data obtained would be greatly dependent upon the skill of the operator. Furthermore, in operation, an external force and not a pure moment is applied to the torque arm to rotate the shear ring of the hand-held device. Consequently, a shear force, in addition to a moment, is developed on the shear ring-terrain interface which would mobilize part of shear strength of the snow. This causes additional difficulty in the proper interpretation of the shear data. Because of these difficulties, it is questionable that the type of hand-held shear device used can play a useful role in collecting reliable shear data for the purpose of predicting vehicle performance.

The bevameter shear device, in comparison with the hand-held device, has the advantages of being able to control the normal load and shear rate. In addition, the data are recorded, thus eliminating the possible human error in reading the load gauge and spring scale. However, the bevameter shear device provided by DRES appears to have a low torsional rigidity. As a result, a pronounced slip-stick phenomenon was observed in operation and a

significant fluctuation of the torque reading was recorded. This causes difficulty in the interpretation of the shearing behaviour of the terrain, particularly in determining the shear deformation modulus used to characterize the shear stress-shear deformation relationship. It is recommended that the bevameter shear device provided by DRES should be modified to eliminate these shortcomings prior to its further use.

1. INTRODUCTION

The Nepean Tracked Vehicle Performance Model, NTVPM, developed by Vehicle Systems Development Corporation, is a comprehensive computer simulation model for predicting and evaluating the tractive performance of tracked vehicles. Its basic features have been validated over a variety of terrains, including mineral terrain, muskeg and snow-covered terrain (Wong, 1986a and 1989a; Wong and Preston-Thomas, 1986 and 1988). NTVPM has been gaining increasingly wide acceptance by industry and governmental agencies. It has been used to assist Hagglunds Vehicle AB of Sweden in the development of a new generation of light armoured fighting vehicle, Combat Vehicle 90, in examining the approaches to the further improvement of the performance of an all-terrain vehicle BV206, and in the evaluation of competing designs for a proposed main battle tank STRV 2000 for the Swedish armed forces (Wong, 1986b and 1989b; Wong and Preston-Thomas, 1989). It has also been employed in the evaluation of the effects of design modifications on the mobility of the main battle tank Leopard C1 for the Canadian Department of National Defence and in the assessment of the mobility of a variety of container handling equipment used by the U.S. Marine Corps (Wong, 1986c, d and e; Wong and Preston-Thomas, 1987a and c). More recently, it has been used to assist Singapore Technologies (Ordnance) in the evaluation of competing designs for a light armoured fighting vehicle.

Vehicle Mobility Section (VMS) of the Defence Research Establishment Suffield (DRES) has entered into an agreement with NATO Panel II/GPE6 to contribute a snow module to the NATO Reference Mobility Model (NRMM). In this connection, VMS has selected NTVPM as the basis for the development of the snow module. NTVPM currently requires terrain parameters, including pressure-sinkage and shear strength parameters, as input. VMS has indicated its desire to explore the possibility of using the pressure-sinkage data obtained with a Rammsonde cone penetrometer as input to NTVPM. This problem has been addressed in the report entitled "Measurement and Characterization of the Pressure-Sinkage Relationships for Snow Obtained Using a Rammsonde and a Bevameter" by Dr. J.Y. Wong, October 1990. In this report, the results of the measurement of the shear strength of snow covers in Fernie, British Columbia, during the period of February 7-21, 1990 are described. The measurements were taken using a bevameter shear device and a hand-held shear device.

The pressure-sinkage data obtained using the Rammsonde together with the shear strength data collected will be used as input to NTVPM for predicting the tractive performance of an all-terrain vehicle BV206. The predicted performance will then be compared with the measured one to evaluate the adequacy of using the pressure-sinkage data obtained using the Rammsonde as input for predicting tracked vehicle performance over snow.

2. MEASUREMENT OF SHEAR STRENGTH USING A BEVAMETER

2.1 The Bevameter

The bevameter technique, originally conceived and developed by Bekker (1969), is based on the premise that terrain properties pertinent to vehicle mobility can best be measured under loading conditions similar to those exerted by an off-road vehicle. A vehicle exerts vertical and horizontal loads on the terrain surface. To simulate these loading conditions, the original bevameter technique comprises two separate sets of tests. One is the plate penetration test and the other is the shear test. In penetration tests, a plate of suitable size is used to simulate the contact area of a vehicle running gear, and the pressure-sinkage relationship of the terrain is measured. Based on the measurements, vehicle sinkage and motion resistance can be predicted. In shear tests, the shear stress-shear displacement relationship and shear strength of the terrain are measured. Based on the results of shear tests, the tractive effort-slip relationship and the maximum traction of a vehicle may be estimated.

The bevameter used in measuring the mechanical properties of the snow covers in Fernie, British Columbia was provided by Vehicle Mobility Section, Defence Research Establishment Suffield and is shown in Fig. 2.1. Two sets of shear rings were used in shear tests. For measuring the internal shearing characteristics of terrain, a shear ring with inner diameter of 14.5 cm, outer diameter of 18.25 cm, and 12 grousers with height of 1 cm was used. For measuring rubber-terrain shearing characteristics, a shear ring of the same size but covered with a layer of rubber was used. The normal load on the shear ring was applied through dead weights. Shear tests were performed under various normal pressures ranging

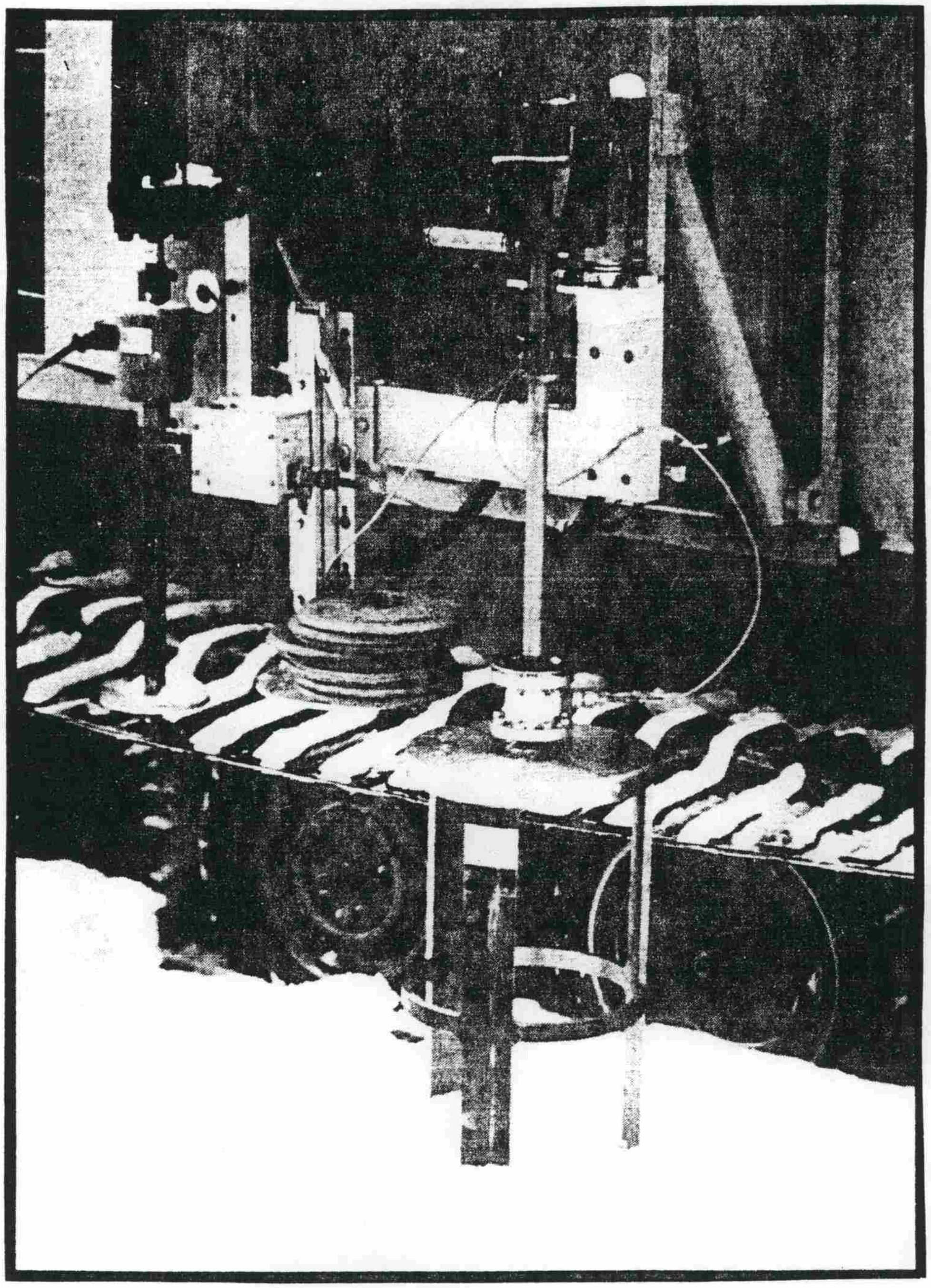

Fig. 2.1 The bevameter shear device used in field tests

from 31.4 to 117.1 kPa. The torque applied to the shear ring was measured using a strain-gauge type torque cell and the angular displacement of the shear ring was monitored using a potentiometer. During the tests, the shear rate as measured at the average radius of the shear ring was approximately 1.0 cm per second.

It should be noted that in soft, fresh snow, the sinkage of the shear ring under normal pressure up to 117.1 kPa would be considerable. To ensure that the normal load applied was fully transmitted to the shear ring without interference, it was mounted on a cage of considerable height, as shown in Fig. 2.1. Furthermore to allow the shear ring to have sufficient sinkage range in fresh snow, it was driven by a hydraulic motor through a relatively long shaft, as can be seen from Fig. 2.1. Because of these design features, the shear device on the bevameter provided by DRES appears to have low torsional rigidity. As a result, a pronounced slip-stick phenomenon was observed and significant fluctuation of the torque acting on the shear ring was recorded during shear tests. This makes it very difficult to interpret the shear data and to derive the shear strength parameters, particularly the shear deformation modulus used to characterize the shear stress-shear displacement relationship.

2.2 Results of Measurements

Figures 2.2 and 2.3 show the internal shearing characteristics of a fresh snow and the characteristics of rubber-fresh snow shearing, respectively. The internal and rubber-terrain shearing characteristics for a preconditioned snow are shown in Figs. 2.4 and 2.5, respectively. The shear displacement shown was calculated from the angular displacement and the average radius of the shear ring.

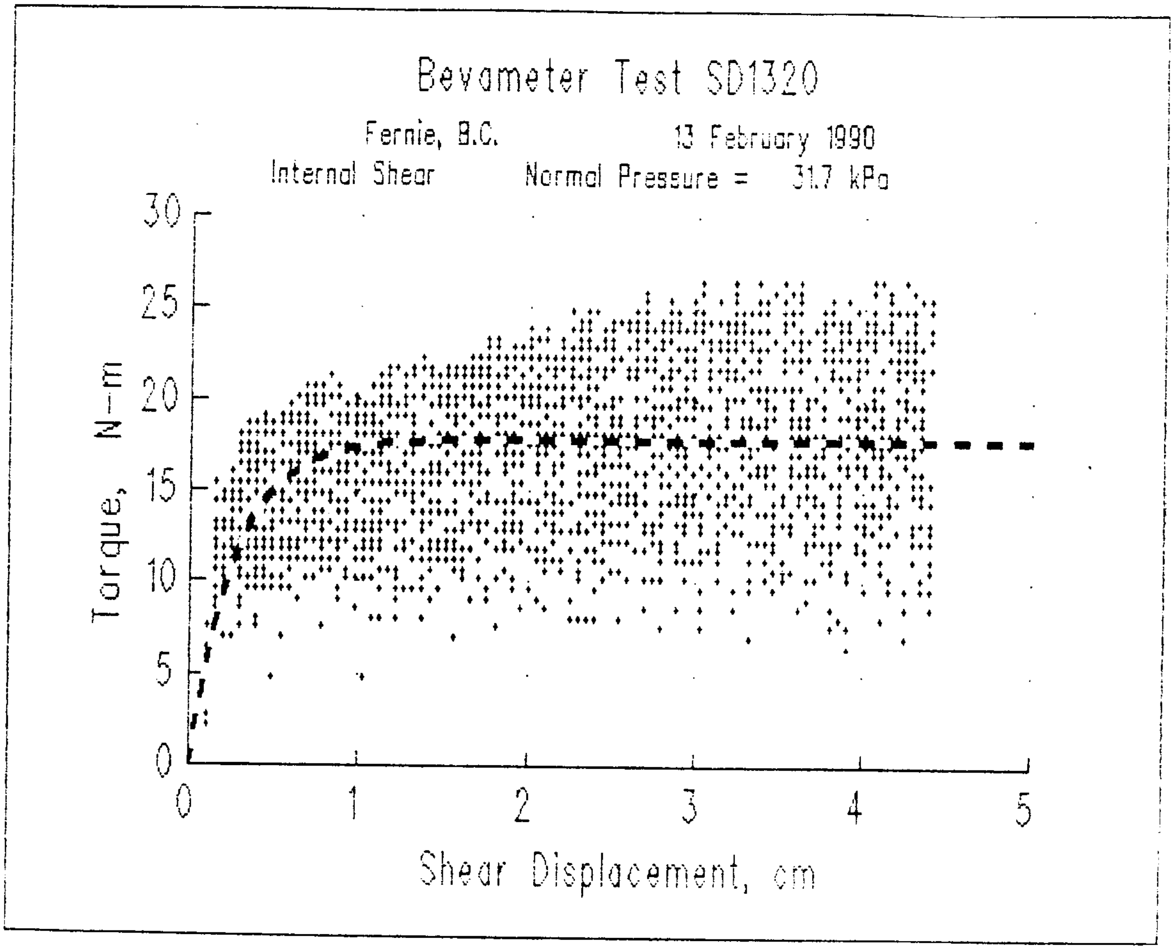

Fig. 2.2 The internal shearing characteristics of a fresh snow obtained using the bevameter shear device

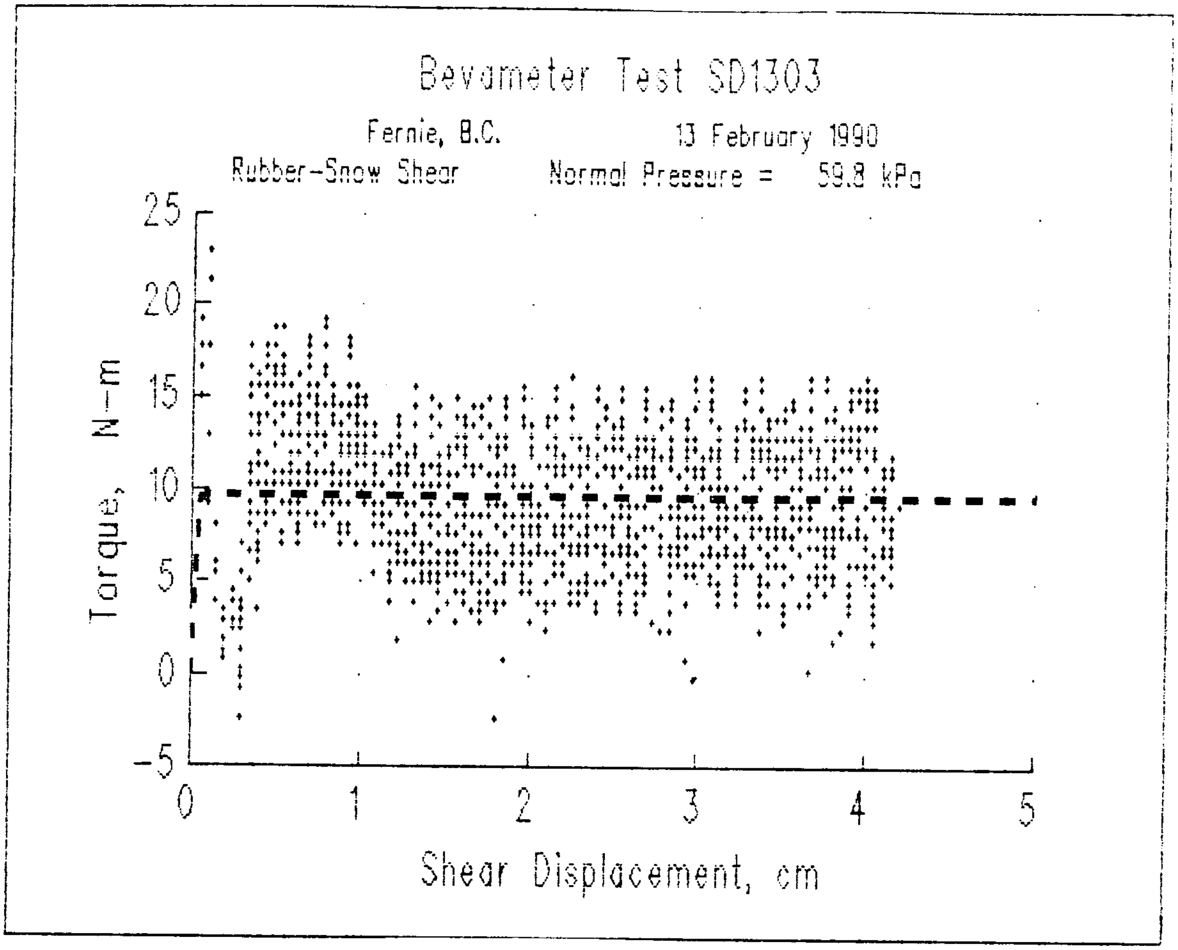

Fig. 2.3 The rubber-fresh snow shearing characteristics obtained using the bevameter shear device

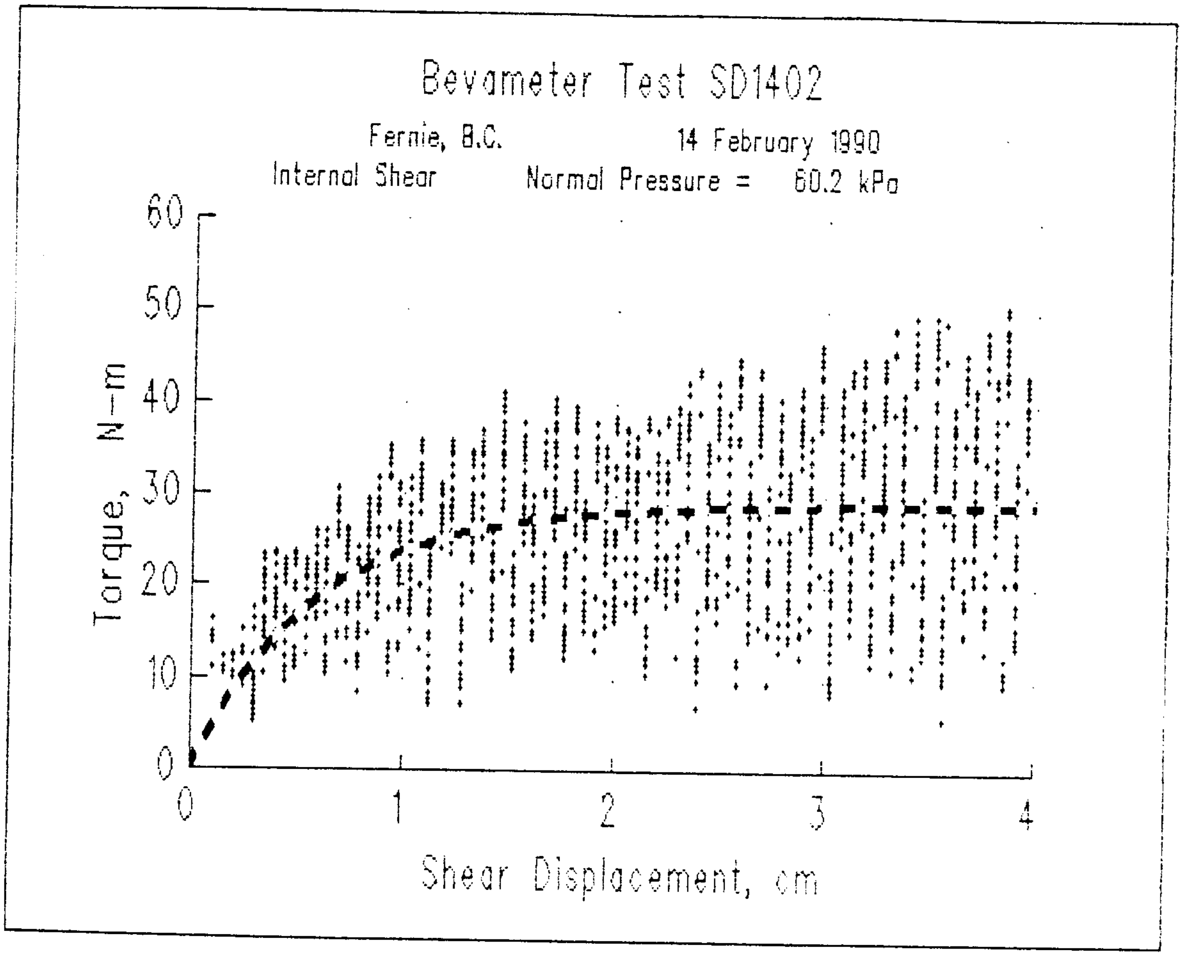

Fig. 2.4 The internal shearing characteristics of a preconditioned snow obtained using the bevameter shear device

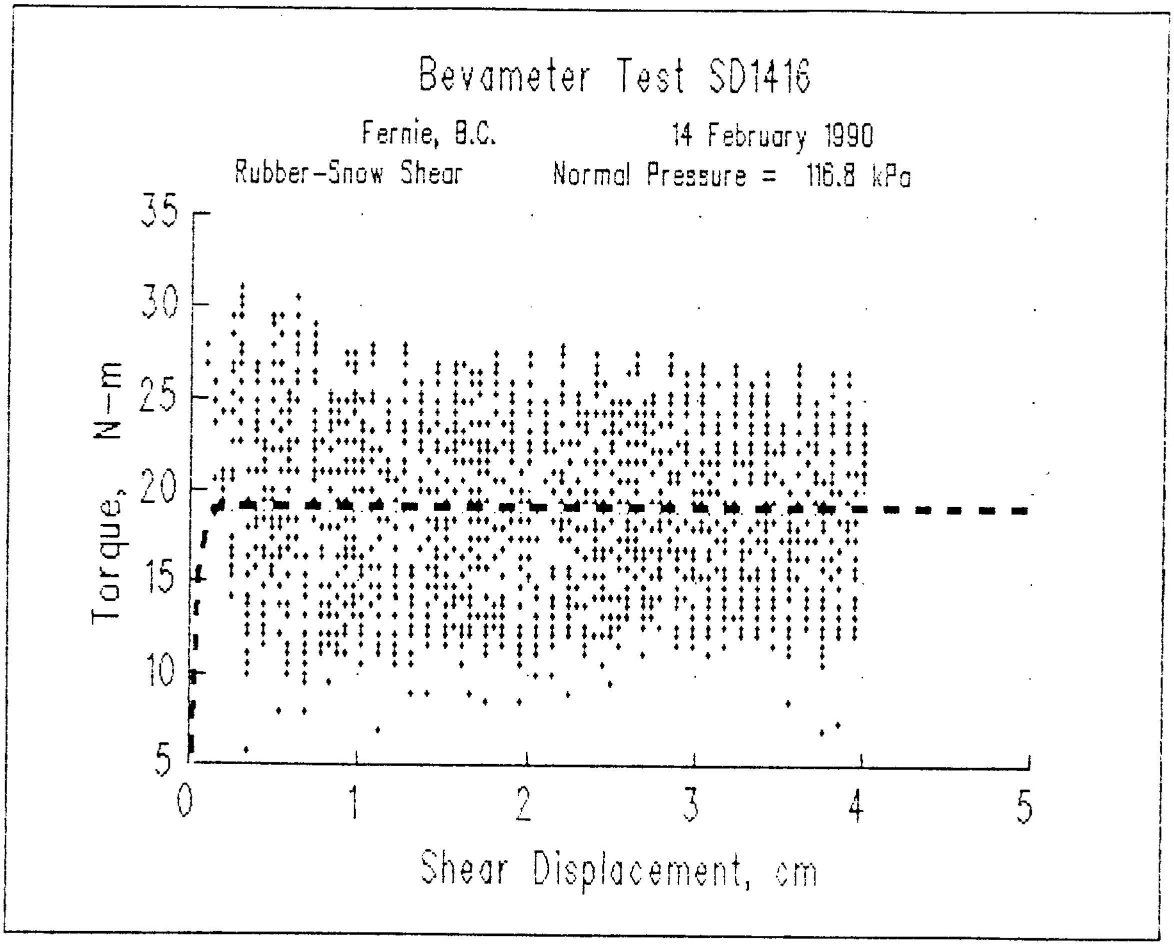

Fig. 2.5 The rubber-preconditioned snow shearing characteristics obtained using the bevameter shear device

It can be seen from the figures that during the shear tests considerable oscillation took place and the torque acting on the shear ring fluctuated in a wide range. This caused considerable difficulty in characterizing the shearing behaviour of the snow covers tested, particularly the values of the shear deformation modulus used to characterize the shear stress-shear displacement relationship. This will be discussed further in the next Section.

A complete set of results on the measurement of the shearing characteristics of the fresh and preconditioned snow in Fernie, British Columbia, obtained using the bevameter shear device provided by DRES during February 7-21, 1990 is given in Appendix A.

2.3 Analysis of the Shear Data Obtained Using the Bevameter

2.3.1 Shear Strength Parameters

It has been generally accepted that the Mohr-Coulomb equation shown below can be used to describe the shear strength of various types of terrain, including snow:

$$S_{\max} = c + p \tan \phi \tag{2.1}$$

where S_{max} is the maximum shear stress, c is cohesion (adhesion), p is the normal pressure, and ϕ is the angle of shearing resistance.

To derive the shear strength parameters c and ϕ , from the shear data, the measured maximum torques T at various normal pressures p were fitted with a straight line as shown in Fig. 2.6. Using the least squares technique, the slope of the line, $\tan \theta$, and its intercept T_0, can be determined as follows:

$$\tan \theta = \frac{\Sigma T_m p - \Sigma p \Sigma T_m / N}{\Sigma p^2 - (\Sigma p)^2 / N} \tag{2.2}$$

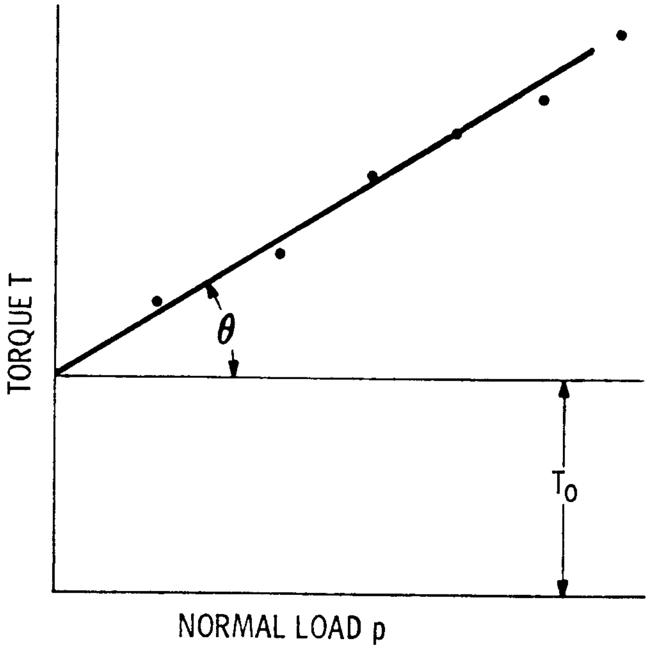

Fig. 2.6 The relationship between torque and normal pressure obtained using a shear ring

and

$$T_0 = \Sigma T_m / N - \tan\theta \Sigma p / N \tag{2.3}$$

where T_m is the measured steady torque at a given normal pressure p, and N is the number of data points used in curve fitting.

In deriving, the shear strength parameters, c and ϕ , it is assumed that the cohesion acts on both the bottom and the two vertical surfaces of the shear ring, the height of which is equal to the grouser height h, and that the frictional component of the shear stress acts only on the bottom of the shear ring. Based on these assumptions, the values of c and ϕ can be derived (Bekker, 1969)

$$\tan\phi = \tan\theta / \left[(2\pi/3)\left(r_0^3 - r_i^3\right)\right] \tag{2.4}$$

and

$$c = T_0 / \left[(2\pi/3)\left(r_0^3 - r_i^3\right) + 2h\pi\left(r_0^2 + r_i^2\right)\right] \tag{2.5}$$

where r_0 and r_i are the outer and inner radius of the shear ring, respectively, and h is the grouser height. For a shear ring covered with a thin layer of rubber for determining rubber-terrain shearing characteristics, the effect of h may be neglected.

Tables 2.1 and 2.2 show the values of c and ϕ for the fresh and preconditioned snow, respectively, obtained using the above-noted procedure.

2.3.2 Shear Stress-Shear Displacement Relationship

The shear stress-shear displacement relationships of terrain are required as input to NTVPM for predicting the tractive effort-

Table 2.1 Shear Strength Parameters for Fresh Snow Obtained Using a Bevameter

Date		Internal Shearing	Rubber-Snow Shearing
Feb. 09	c, kPa		0
	Phi, deg		10.04
	Goodness of Fit, %		60.45
Feb. 12	c, kPa	0	0
	Phi, deg	23.86	10.31
	Goodness of Fit, %	100.0	85.03
Feb. 13	c, kPa	0	0.82
	Phi, deg	28.62	11.52
	Goodness of Fit, %	73.33	92.38
Feb. 19	c, kPa	7.86	
	Phi, deg	17.8	
	Goodness of Fit, %	63.67	
Feb. 20	c, kPa	0	0
	Phi, deg	29.63	13.65
	Goodness of Fit, %	84.86	78.80

Table 2.2 Shear Strength Parameters for Preconditioned Snow Obtained Using a Bevameter

Date		Internal Shearing	Rubber-Snow Shearing
Feb. 14	c, kPa	1.16	0
	Phi, deg	28.00	10.73
	Goodness of Fit, %	91.96	86.03
Feb. 15	c, kPa	0	0
	Phi, deg	30.68	9.30
	Goodness of Fit, %	92.29	100.0
Feb. 16	c, kPa	0.106	0.076
	Phi, deg	27.67	11.24
	Goodness of Fit, %	92.57	94.27
Feb. 19	c, kPa	0	0
	Phi, deg	31.28	16.62
	Goodness of Fit, %	80.25	93.01

slip relationship of a tracked vehicle. To characterize the shear stress-shear displacement relationship of the snow covers tested, the following equation proposed by Janosi and Hanamoto was used (Janosi and Hanamoto, 1961; Bekker, 1969; Wong, 1989a; Wong and Preston-Thomas, 1983)

$$S = S_{\max}\left[1 - \exp\left(-j/K\right)\right] \tag{2.6}$$

where S is the shear stress; S_{max} is the maximum shear stress, j is the shear displacement which can be calculated from the angular displacement and the average radius of the shear ring, and K is usually referred to as shear deformation modulus.

To obtain the best value of K for a given set of data, the following procedure based on the weighted least squares method was used (Wong, 1980). Rearranging Eq.(2.6) and taking logarithms, one obtains

$$\ln\left(1 - S/S_{\max}\right) = -j/K \tag{2.7}$$

If an equal liability to error for all observations is assumed, then the appropriate value of K can be obtained by minimizing the value of the following function using a weighting factor of $(1-S/S_{max})^2$,

$$F = \Sigma\left(1 - S/S_{\max}\right)^2\left[\ln\left(1 - S/S_{\max}\right) + j/K\right]^2 \tag{2.8}$$

To obtain the value of K that minimizes the above function, the first partial derivative of F with respect to K is taken and set to zero. This leads to the following condition

$$\Sigma\left(1 - S/S_{\max}\right)^2 j\left[\ln\left(1 - S/S_{\max}\right) + j/K\right] = 0 \tag{2.9}$$

From Eq.(2.9), the appropriate value of K that minimizes the error in curve fitting is given by

$$K = \frac{-\,\Sigma\,(1 - S/S_{\max})^2\, j^2}{\Sigma\,(1 - S/S_{\max})^2\, j \ln(1 - S/S_{\max})} \qquad (2.10)$$

An attempt was made to derive the value of K from the shear data obtained using the bevameter shear device provided by DRES. However, as mentioned previously, because of the fluctuation of the torque acting on the shear ring and the excessive scattering of the shear data as shown in Figs. 2.2-2.5, no reliable values of K can be derived.

3. MEASUREMENT OF SHEAR STRENGTH USING A HAND-HELD SHEAR DEVICE

3.1 The Hand-Held Shear Device

A hand-held shear device provided by DRES was also used for measuring the shear strength of the snow covers in the field. The general features of device is shown in Fig. 3.1. The original device used a circular plate. However, as noted in Section 2.1, the bevameter shear device used a shear ring. To be able to compare the data obtained using the hand-held shear device with those obtained using the bevameter shear device, the original hand-held device was modified. The modified device can be fitted with 2 sizes of shear ring, one with outer diameter of 10 cm and inner diameter of 8 cm and the other with outer diameter of 15 cm and inner diameter of 12 cm. The shaft connecting the shear plate with the torque arm in the original device shown in Fig. 3.1 was replaced with a plexiglass tube of approximately one meter high.

During shear tests, the normal load on the shear ring was applied manually and was measured using a load gauge, as shown in Fig. 3.1. To measure the torque required to rotate the shear ring, a spring scale as shown in Fig. 3.1 was installed between the handle and the torque arm connected with the shear ring through the plexiglass tube. The geometry of the hand-held shear device is schematically shown in Fig. 3.2.

The tangential force F_t applied on the torque arm can be calculated from the spring force F read from the scale

$$F_t = F \cos\alpha \tag{3.1}$$

and

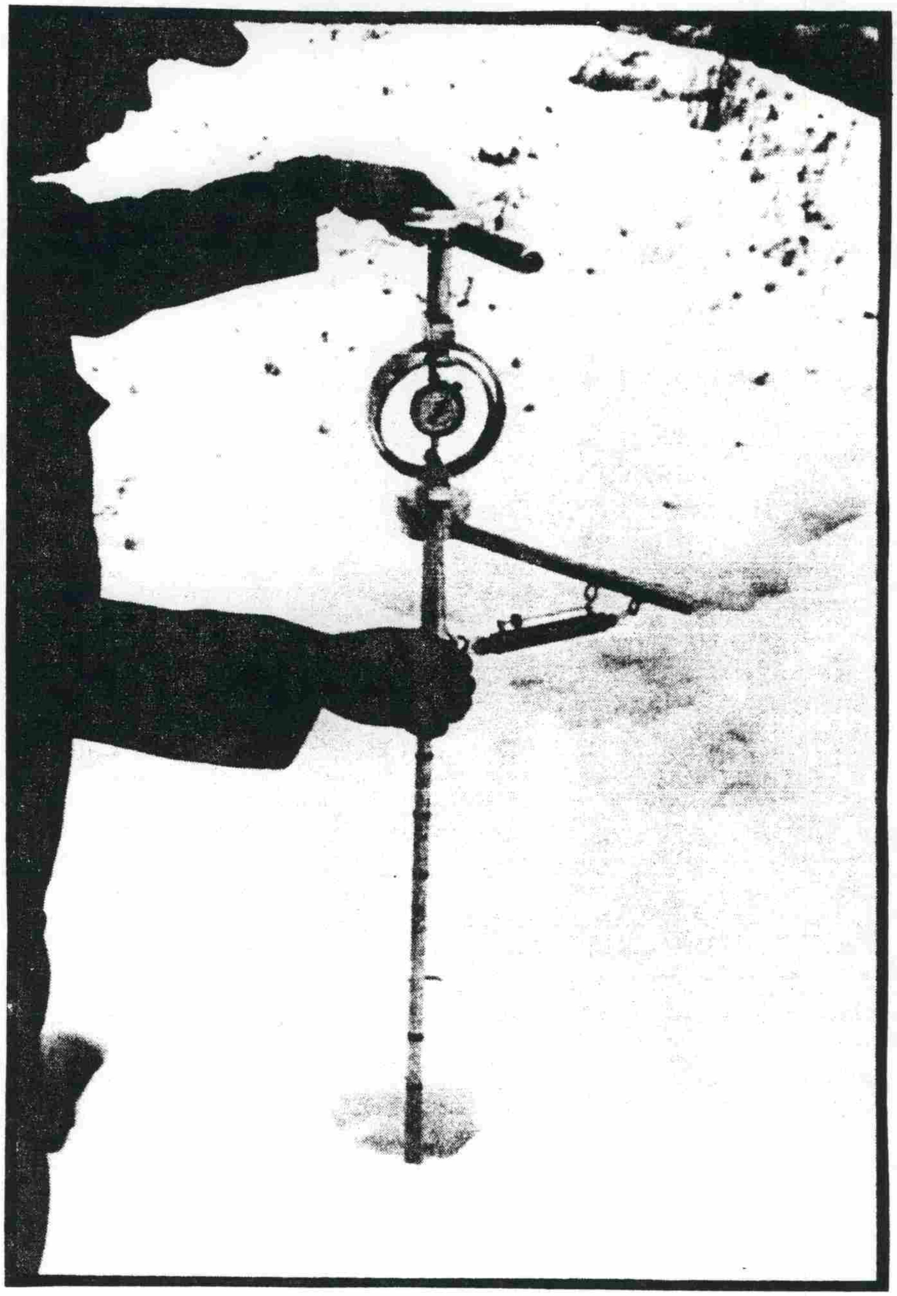

Fig. 3.1 The original hand-held shear device provided by DRES

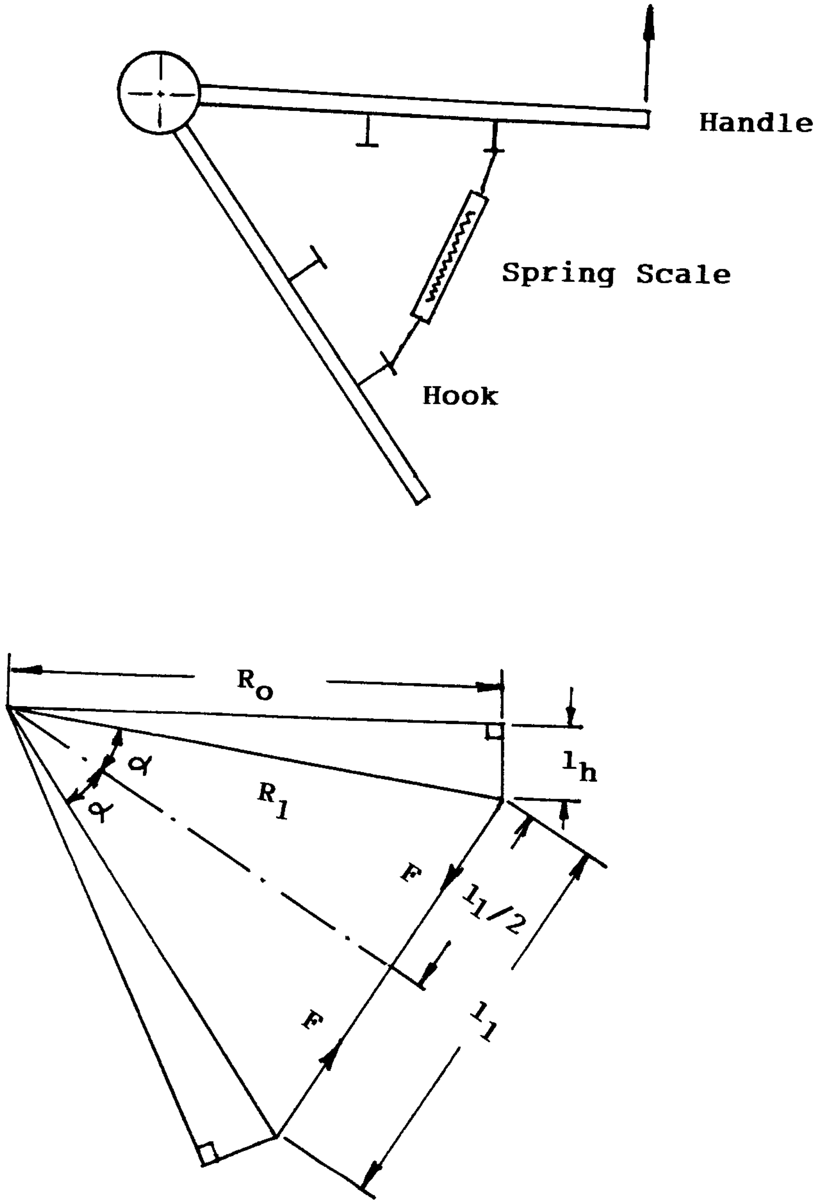

Fig. 3.2 The geometry of the hand-held shear device

$$\begin{aligned}\alpha &= \sin^{-1}(\ell_1/2R_1)\\ &= \sin^{-1}[(\ell_0 + F/k_s)/2R_1]\end{aligned} \tag{3.2}$$

where ℓ_0 is unstretched length of the spring scale and k_s is the stiffness of the spring. Other parameters used in Eq.(3.2) are shown in Fig. 3.2.

The torque applied to the shear ring M can be calculated from the tangential force F_t as follows:

$$M = F_t R_1 \tag{3.3}$$

and

$$R_1 = \left(R_0^2 + \ell_h^2\right)^{1/2} \tag{3.4}$$

where R_0 is the distance between the rotating axis and the hook for the spring scale and ℓ_h is the hook length.

In comparison with the bevameter shear device, the hand-held shear device is simple in design and portable. However, there are a number of problems associated with the use of the hand-held shear device. For instance, as the normal load on the shear ring is applied manually by hand, it is extremely difficult, if not impossible, to keep it at a constant level. It was observed that during shear tests, owing to the effects of slip sinkage and the nonuniformity of the snow structure (such as the presence of ice layers), the normal load on the shear ring could vary in a wide range. This makes the interpretation of the shear data extremely difficult. Furthermore, it was found difficult to maintain the device in a vertical position during tests. As a result, part of the plexiglass tube connecting the shear ring and the torque arm would be in contact with the snow surface, particularly in soft, fresh snow where the sinkage of the shear ring was considerable. This generates additional shear stresses on the plexiglass tube surface in contact with the snow and a higher torque is required to rotate the shear device. This would lead to an overestimate of the shear strength of the snow. In addition, the spring force and the normal load were read by eye, and during tests they usually fluctuated in a wide range. This would introduce considerable human error in the shear data. The reliability of the shear data obtained using the hand-held device is highly dependent on the skill of the operator.

It should also be pointed out that in operating the hand-held shear device, an external force and not a pure moment is applied to the torque arm. As a result, a shear force, in addition to a moment, would be developed on the shear ring-terrain interface. This shear force would mobilize part of the shear strength of terrain and introduces further uncertainty to the reliability of the shear data obtained using the hand-held shear device.

3.2 Results of Measurements

During the shear tests, two readings of the spring force were taken, one was the maximum spring force (corresponding to the maximum torque applied to the shear ring) and the other was the spring force when the shear ring had undergone a considerable amount of angular displacement, referred to as the "residual" force. The maximum spring force corresponds to the peak value of the shear strength, while the "residual" force corresponds to the residual shear strength of the terrain.

Figure 3.3 shows the variations of the maximum and residual torque with normal stress for the internal shearing of a fresh snow, while Fig. 3.4 shows similar relationships for the rubber-snow shearing. The internal and rubber-snow shearing characteristics for a preconditioned snow obtained using the hand-held shear device are shown in Figs. 3.5 and 3.6, respectively.

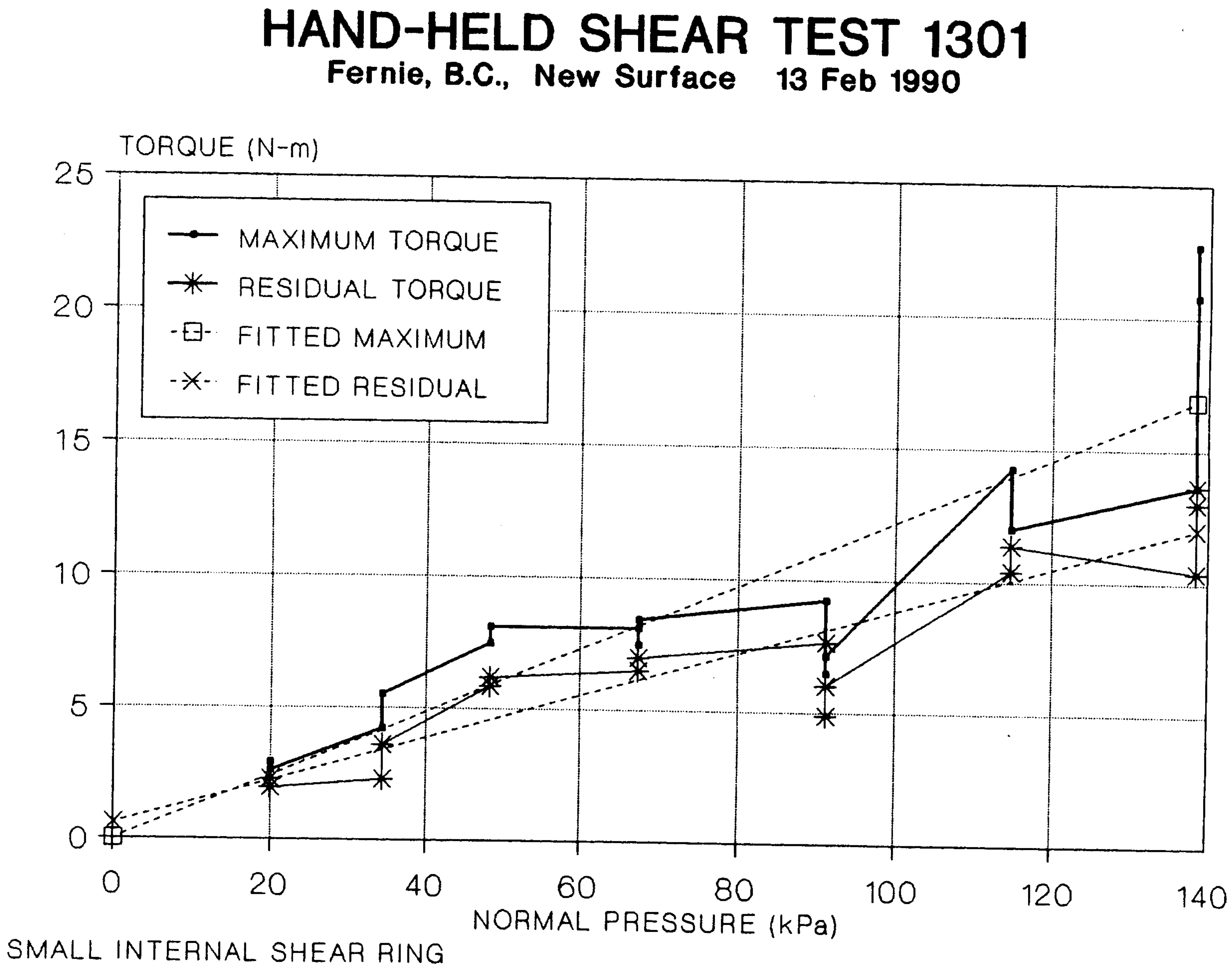

Fig. 3.3 Data for internal shearing characteristics of a fresh snow obtained using a hand-held shear device

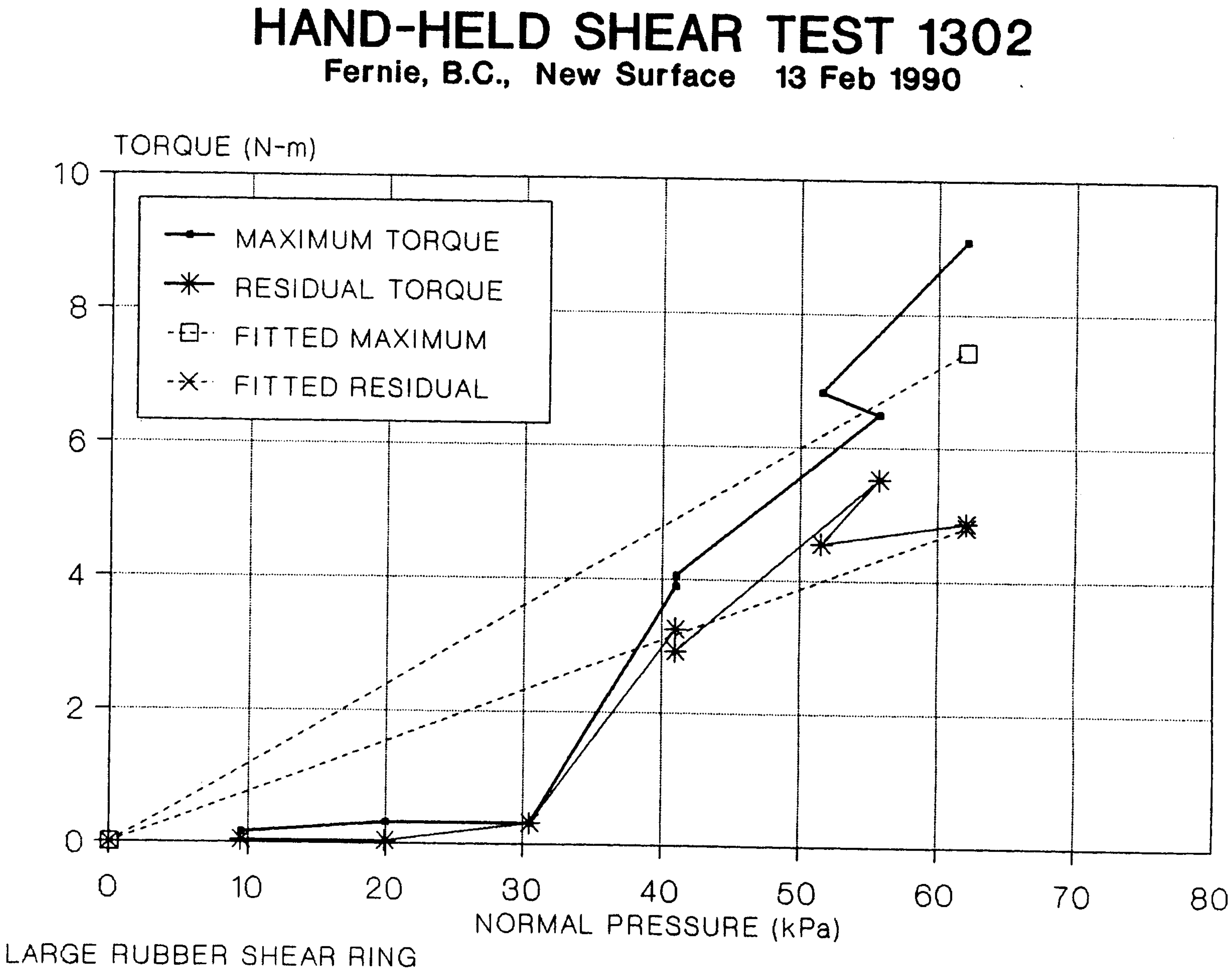

Fig.3.4 Data for rubber-fresh snow shearing characteristics obtained using a hand-held shear device

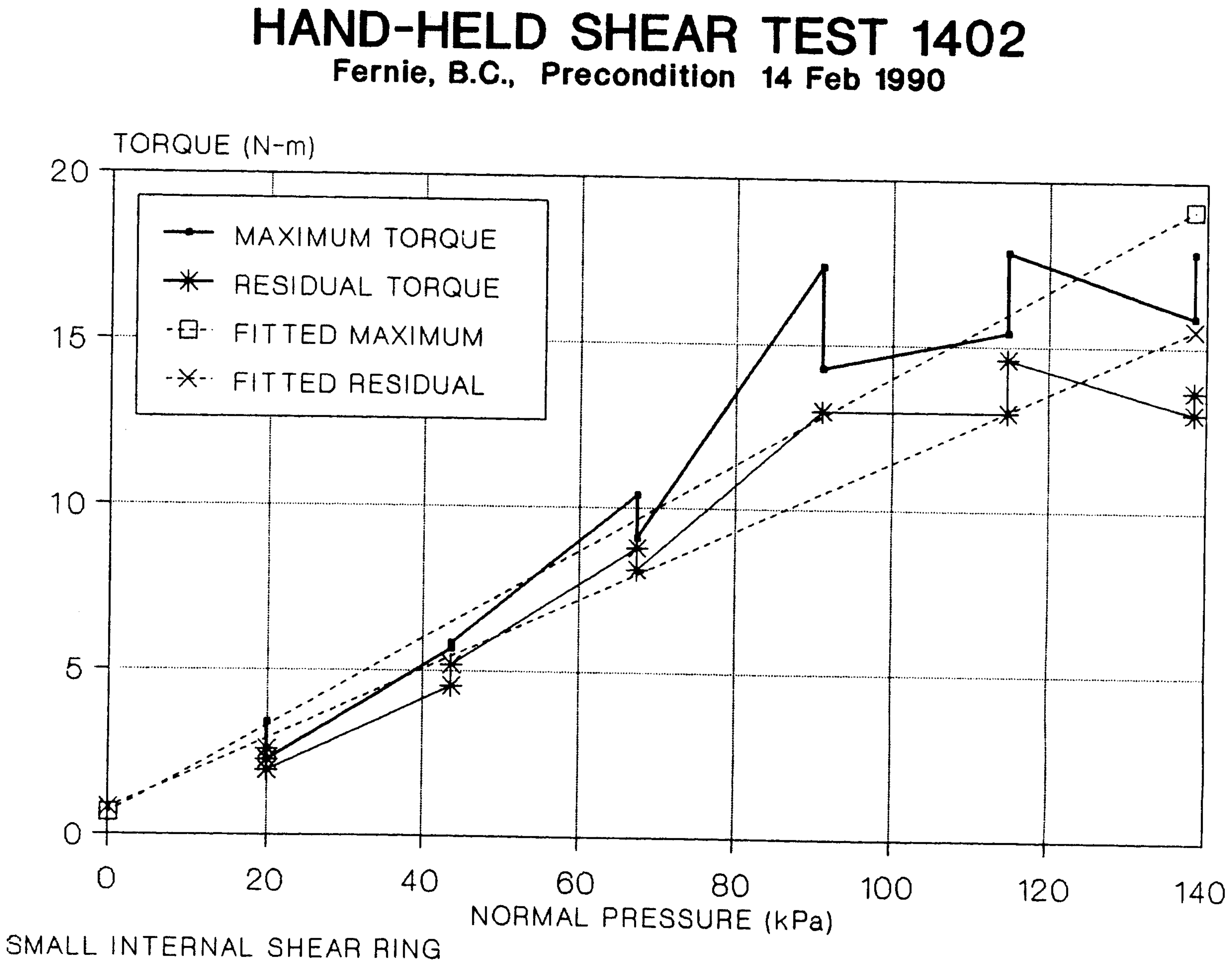

Fig. 3.5 Data for internal shearing characteristics of a preconditioned snow Obtained using a hand-held shear device

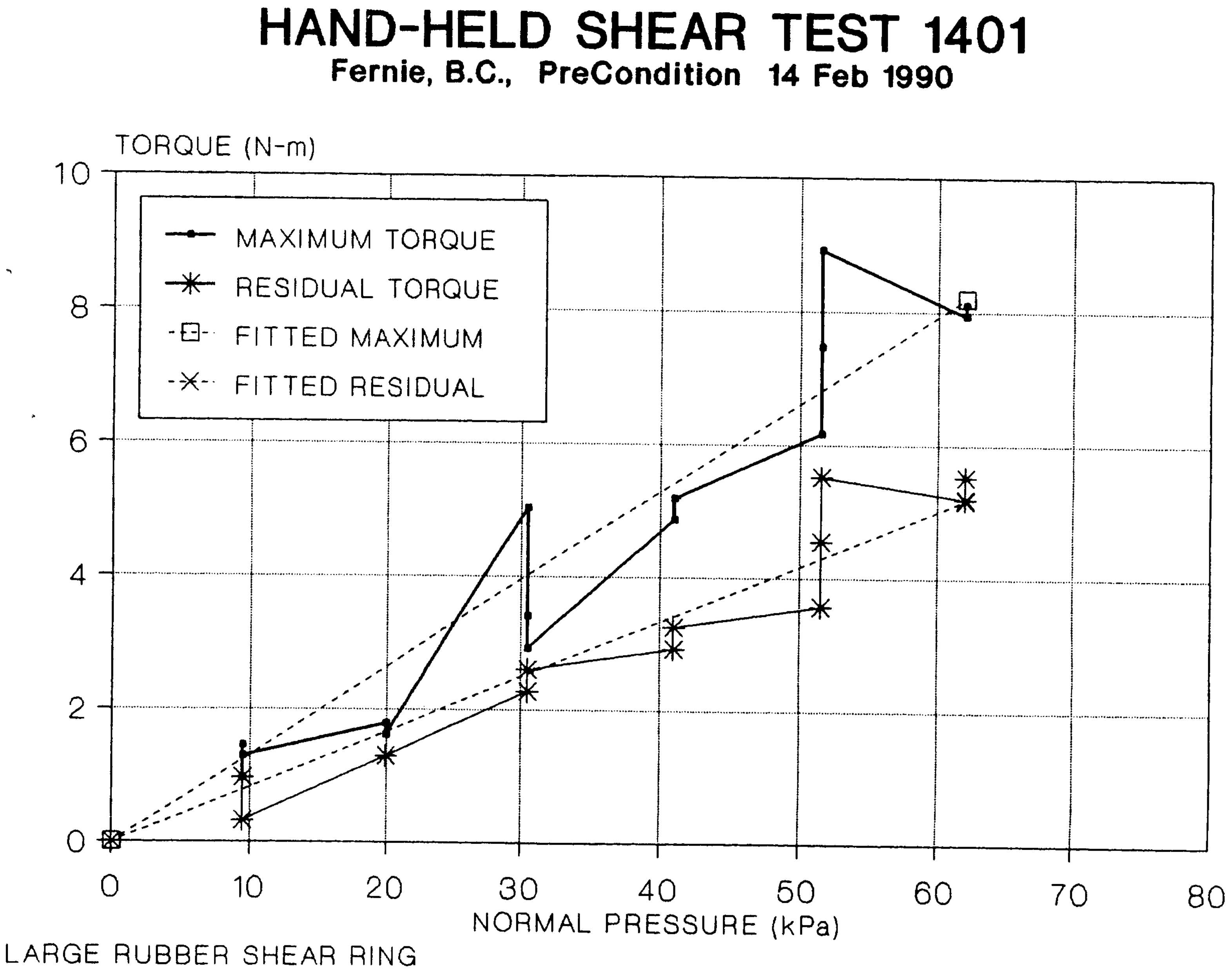

Fig. 3.6 Data for rubber-preconditioned snow shearing characteristics obtained using a hand-held shear device

A complete set of results on the measurement of the shearing characteristics of fresh and preconditioned snow in Fernie, British Columbia, obtained using the hand-held shear device is given in Appendix B.

Following the procedures outlined in Section 2.3.1, the values of the shear strength parameters, c and ϕ , were derived from the shear data obtained using the hand-held shear device and are given in Tables 3.1 and 3.2 for the fresh and preconditioned snow, respectively. Both the maximum and residual shear strength parameters are given in the tables.

In comparison with the values of the shear strength parameters derived from the shear data obtained using the bevameter shear device shown in Tables 2.1 and 2.2, the values derived from shear data obtained using the hand-held shear device are considerably different. For instance, the mean value for the angle of the residual internal shearing resistance for the fresh snow obtained using the hand-held shear device shown in Table 3.1 is 35.39°, whereas that obtained using the bevameter shear device shown in Table 2.1 is 24.98°. For the preconditioned snow, the mean value for the angle of the residual internal shearing resistance obtained using the hand-held shear device shown in Table 3.2 is 39.61°, whereas that obtained using the bevameter shear device shown in Table 2.2 is 29.40°.

It was interesting to note that similar discrepancies between the values of the shear strength parameters obtained using the bevameter and those obtained using the hand-held shear device were also reported by Irwin (1987). For a snow in the region of Golden, British Columbia, the angle of internal shearing resistance obtained using the bevameter was 18.1°, whereas that obtained using the hand-held shear device was 28°-30.5° (Irwin, 1987).

Table 3.1 Shear Strength Parameters for Fresh Snow Obtained Using a Hand-Held Shear Device

		Internal Shearing		Rubber-Snow Shearing	
Date		Maximum	Residual	Maximum	Residual
Feb. 09	c, kPa	1.85	1.34		
	Phi, deg	40.78	31.10		
	Goodness of Fit, %	79.11	80.07		
Feb. 12	c, kPa	3.19	.00	.46	1.40
	Phi, deg	43.45	39.96	16.23	6.51
	Goodness of Fit, %	86.39	73.20	77.59	79.57
Feb. 13	c, kPa	.01	1.52	.00	.00
	Phi, deg	43.58	32.86	15.53	10.17
	Goodness of Fit, %	70.89	80.00	58.66	61.86
Feb. 20	c, kPa	6.42	1.93	.00	.00
	Phi, deg	45.34	37.63	18.98	11.35
	Goodness of Fit, %	80.41	74.40	85.88	74.56

Table 3.2 Shear Strength Parameters for Preconditioned Snow Obtained Using a Hand-Held Shear Device

		Internal Shearing		Rubber-Snow Shearing	
Date		Maximum	Residual	Maximum	Residual
Feb. 14	c, kPa	1.68	2.09	.00	.00
	Phi, deg	46.26	39.77	17.04	10.93
	Goodness of Fit, %	81.50	81.71	80.20	81.83
Feb. 15	c, kPa	.00	.59	1.46	.00
	Phi, deg	52.88	44.22	18.36	10.93
	Goodness of Fit, %	89.60	88.63	83.65	87.29
Feb. 16	c, kPa	1.97	3.90	1.02	.82
	Phi, deg	44.32	32.22	16.54	9.03
	Goodness of Fit, %	86.52	90.41	77.27	87.97
Feb. 19	c, kPa	.00	.56	.24	1.18
	Phi, deg	51.54	42.21	16.30	7.26
	Goodness of Fit, %	80.70	74.21	74.53	91.78

4. OBSERVATIONS

A. Based on the field data collected, it is found that there are considerable discrepancies between the values of the shear strength parameters measured by the hand-held shear device and those by the bevameter shear device. The difficulties in controlling the applied normal load on the shear ring and in reading the load gauge and spring scale contribute to the uncertainty concerning the reliability of results obtained using the hand-held shear device. The reliability of the data is highly dependent on the skill of the operator. Furthermore, in operation, an external force and not a pure moment is applied to the torque arm to rotate the shear ring. Consequently, a shear force, in addition to a moment, is developed on the shear ring-terrain interface which would mobilize part of shear strength of the terrain. This would cause additional difficulty in the proper interpretation of the shear data.

Because of the problems mentioned above, it is questionable that the type of hand-held shear device described can play a useful role in collecting reliable shear data for the purpose of predicting vehicle performance.

B. The bevameter shear device, in comparison with the hand-held shear device described, has the advantages of being able to control the normal load and shear rate. In addition, the data are recorded, thus eliminating the possible human error in reading the load gauge or spring scale. However, the bevameter shear device provided by DRES appears to have a low torsional rigidity. As a result, a pronounced slip-stick phenomenon was observed and a significant fluctuation of the torque reading was recorded during tests. It is recommended that the bevameter shear device provided by DRES should be modified to eliminate the problems noted above, prior to further use.

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