

In Situ Shear Strength Data Logging and TDR

Clarke Topp, Mark Edwards and David R. Lapen
Agriculture and Agri-Food Canada
Ottawa, Ontario Canada
Contact: clarketopp@gmail.com

ABSTRACT

Few options exist for convenient field measurement of soil shear strength parameters, especially at different water contents. The Cohron portable sheargraph, a torsional shear device, for *in situ* measurement of field shear strength (Cohron 1963) records both normal and shear stresses during the shear occurrence. Data retrieval involved digitization of the graphs and soil sampling for gravimetric determination of water content – two tedious and time consuming processes. Two load cells – one for shear stress and one for normal stress – were installed in lieu of the coil spring on the sheargraph. The soil grouser head was reconfigured to include a TDR transmission line allowing water content measurement just before shear strength determination. This modified Cohron shear logger was used to measure cohesion and friction angle for two soils – sandy loam and clay loam – at two different water contents.

INTRODUCTION

Soil strength is important for assessing energy requirements for cultivation, plant root growth and development, impact of machinery traffic, and foundation stability. The strength of soil to resist landslide and some forms of erosion are best expressed by techniques that explicitly measure the soil during shear. Regrettably, few options are available for convenient field measurement of soil shear strength at different stress levels and varied water contents. The Cohron portable sheargraph, a torsional shear device, (Cohron 1963) offered attractive possibilities for *in situ* measurement because both normal and shear stresses were measured simultaneously. With an improved sheargraph Ayers (1987) has reported extensive shear strength data and interpretation. The two less attractive operational features of the Cohron sheargraph are, firstly, the mechanical recording of a graph with subsequent graph digitization and, secondly, the need to determine water content by the gravimetric method. We show how we have converted a sheargraph device to a shear logging device which incorporates TDR for water content measurement.

TWO LOAD CELLS AS STRESS TRANSDUCERS

Two load cells were added to a fully operational Cohron Sheargraph to replace the spring and graph system (Fig. 1). Both load cells were placed above the grouser plate (shear head) and below the spring. Although no longer needed the spring was retained as an indicator for the operator to estimate the applied stress(es). The voltage signals from the load cells were recorded by a CR510 datalogger (Campbell Scientific, Inc.). Both load cells use strain gauge bridge technology. The load cell types were, an “S”-shaped sensor with 0 - 100 lb. load range (Intertechnology Ltd.) and a miniature round beam of 50 lb. load capacity (Artech Industries Inc.) for normal and shear stress detection, respectively.

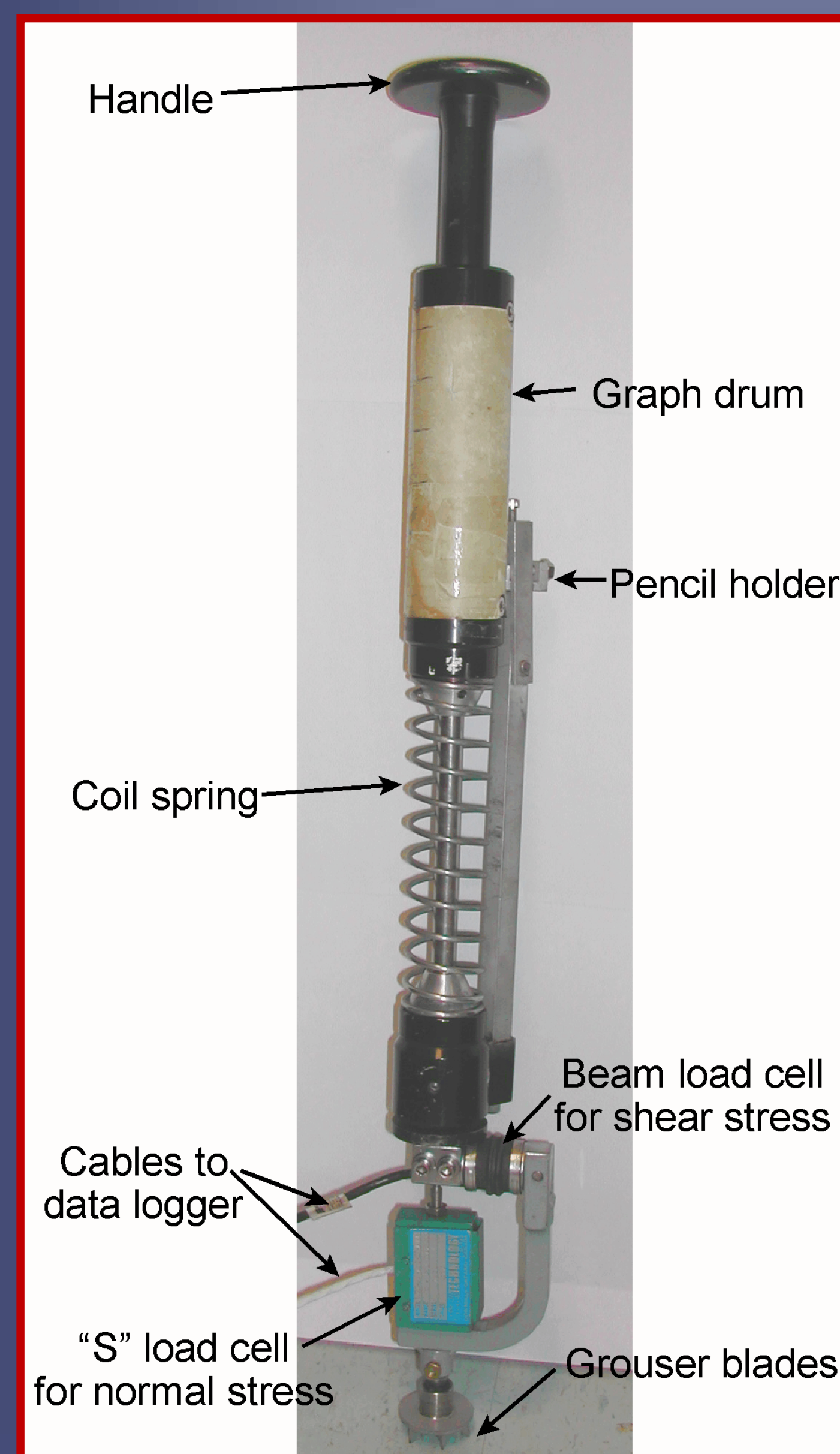


Figure 1: Cohron sheargraph modified with two load cells providing data logging capabilities

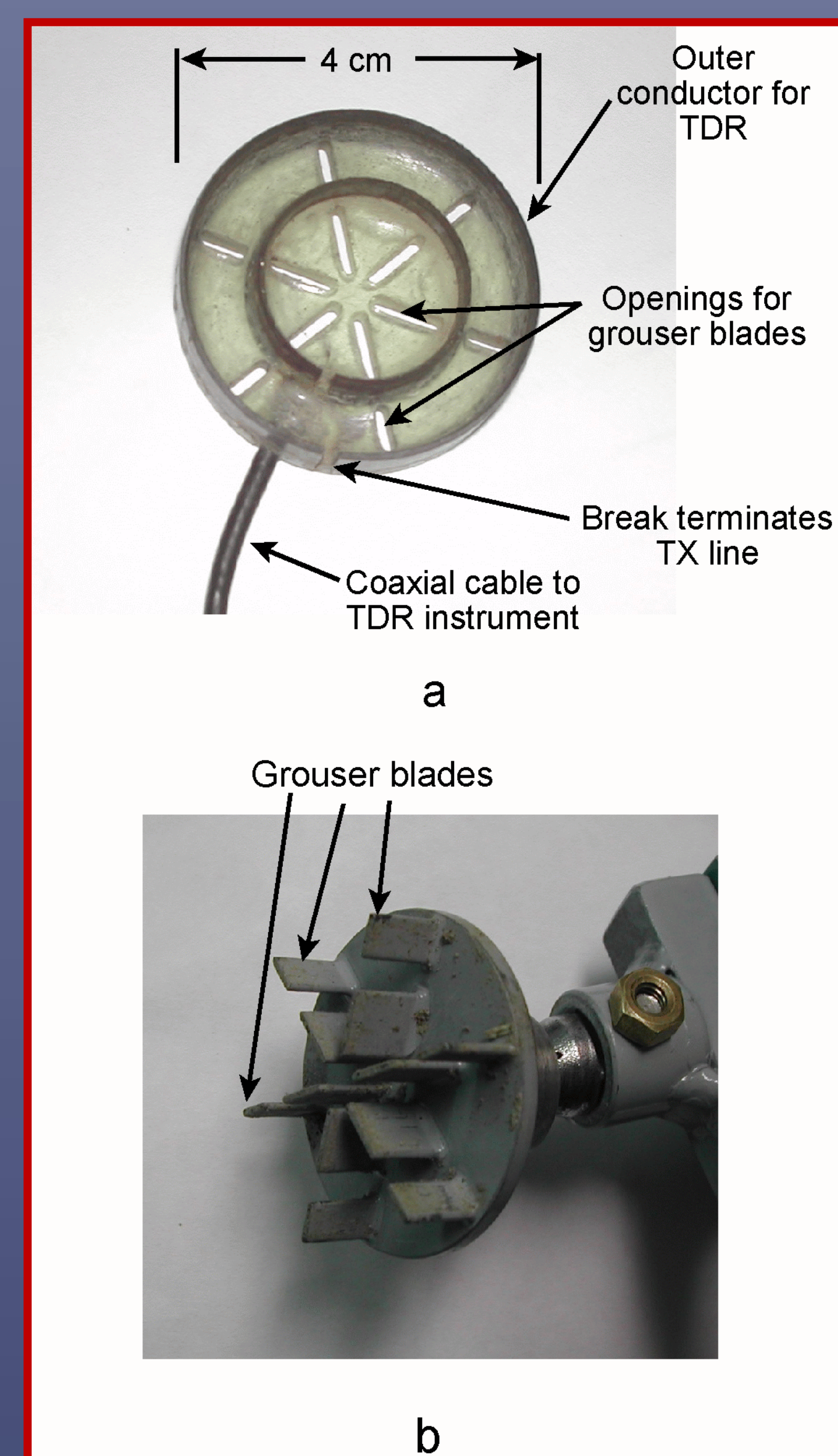


Figure 2: (a) TDR water content sensor configuration, (b) Grouser blade as modified for TDR sensor. These images are as if viewed from within the soil.

WATER CONTENT BY TDR

A parallel pair TDR transmission line was designed to wrap circumferentially in the shear head region (Fig. 2a). The transmission line was two concentric stainless steel cylinders, one cm high with radii of 2 and 1 cm. The outer cylinder was also outer edge of the shear head. These cylinders were mounted with the upper 3 mm of the cylinder mounted in an epoxy resin which formed a flat plate upper surface to the shear head. At a single location in the periphery of the cylinders 2 mm of the circumference was removed to establish the start and end of the TDR transmission line. On each side of this break side in the conductors a 5 pf capacitor was connected between the two conductors to provide a large impedance change to facilitate the TDR analysis. As the length of the two conductors of the TDR line were very different it was necessary to use the procedure given by Robinson et al. (2003) to determine the electrical length as 5.95 cm. The water content sensor responded in manner similar to other TDR probes but with a consistent offset, reading low by 0.031 m³ m⁻³. All TDR measurements were made with TRASE model instruments (Soilmoisture Equipment Corp.)

MEASUREMENT SEQUENCE

The water content sensor is inserted into the soil at the surface to be measured and the water content is determined first. Next, the grouser head is carefully inserted into soil through the openings in the water content sensor. Shear strength was then measured at that location from manual normal and shear forces applied to the handle identified in Fig. 1. The sequence of normal and shear stresses were applied as depicted by the numbered arrows in Figure 3. Topp and Lapen (2007) give the detailed procedure for use of the shearlogger and interpretation of data. Test sites were on clay loam and sandy loam soils. Both soils were spring cultivated and at mid-season under corn. The water content was relatively low, as when we expected higher shear strengths. Increased water content was achieved using a watering can after each set of measurements.

RESULTS AND DISCUSSION

The sandy loam soil exhibited steady deformation making it easier to make the shear strength measurements. From data such as these it was relatively straight forward to estimate cohesion and friction angle as shown in Table 1. The procedure for estimating cohesion and friction angle uses data such as those circled in Fig. 3 (Topp and Lapen 2007). For the clay loam soil the stress paths (Fig. 4) showed greater variability than in the sandy loam. This greater variability arose, in part, because of the rapid deformation (brittle fracture) which occurred in most determinations making it difficult to maintain steady stress levels. Another contributor to variability in the clay loam soil was spatial variability. At the times of measurement the soil was cracked which was visual evidence of variable strength patterns which were picked up by the shear strength determinations. In spite of the variability exhibited along the measurement of the stress paths it was possible to estimate peak and ultimate cohesion values along with the corresponding friction angles at the two water content levels Table 1.

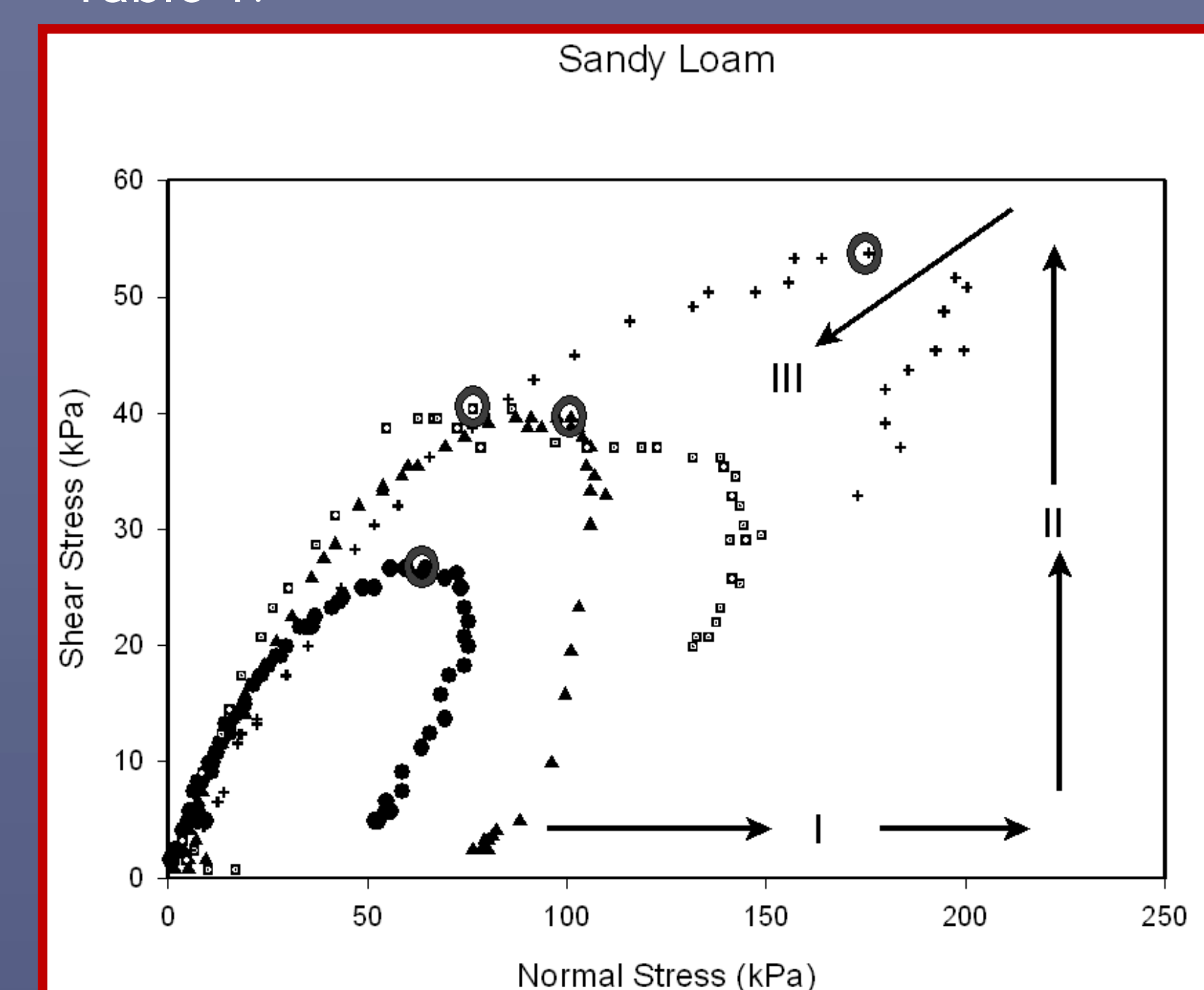


Figure 3: The shear stress path recorded for four measurements in sandy loam soil. The numbered arrows show the sequence along which the normal and shear stresses are applied during each measurement

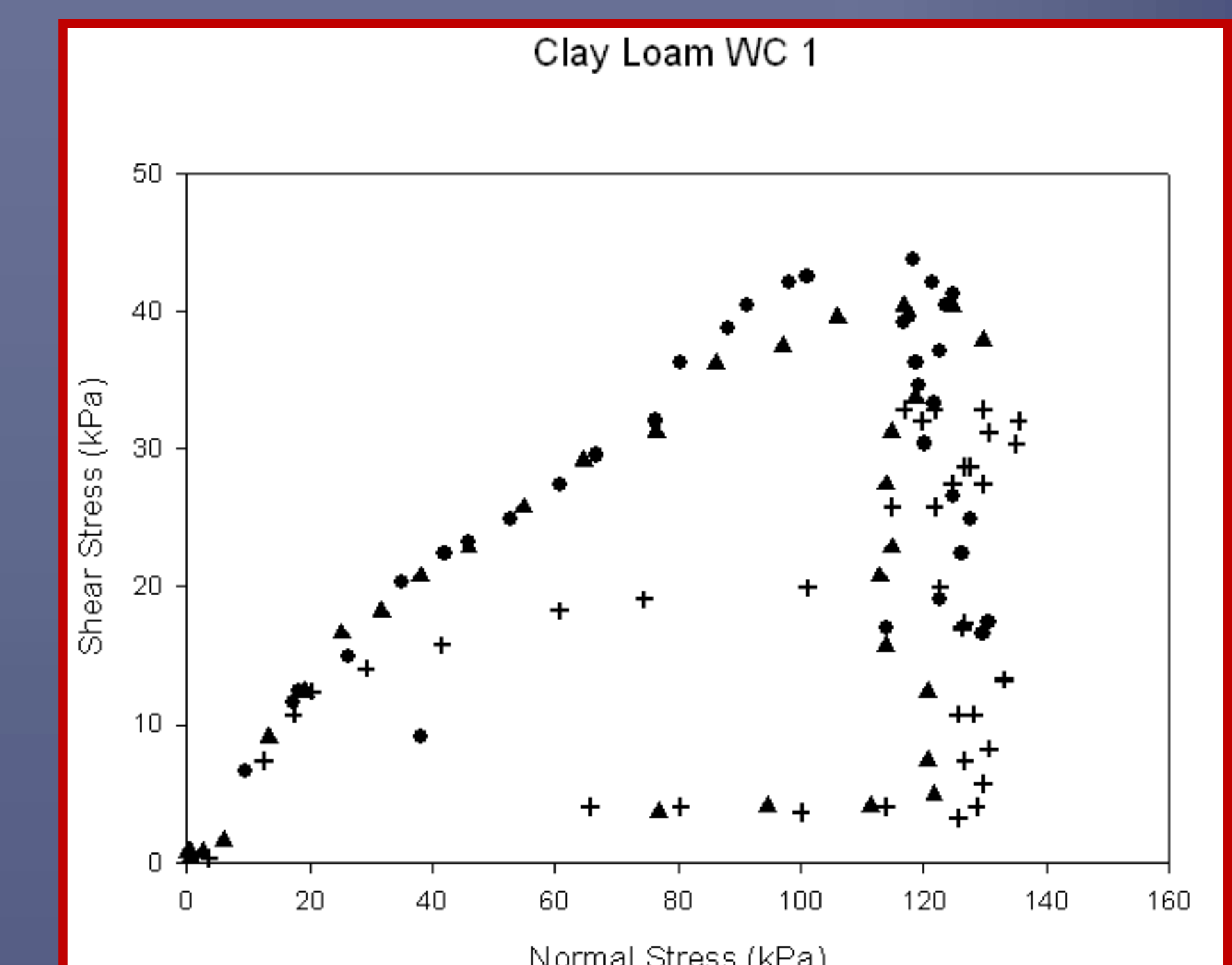


Figure 4: Shear stress paths from clay loam soil at lower water content. The three measurements were aimed to be replicates with a targeted maximum normal stress of 125 kPa. The crosses show both peak and ultimate shear processes have occurred.

CONCLUSIONS

- The precision of the data appears to be equivalent between sheargraph and shearlogger.
- The shearlogger has reduced the measurement and analysis times by over a factor of three and removed a considerable amount of the operator tedium.
- Digitizing the shear strength measurement through the use of load cells with the incorporation of the TDR water content measurement, has greatly improved the versatility and usefulness of the sheargraph.

Ayers, P.D. 1987. Utilizing the torsional shear stress test to determine soil strength-properties relationships. *Soil and Tillage Research* 10:373-380.

Cohron, G.T. 1963. Soil Sheargraph. *Agr. Engng.* 44: 554-556.

Robinson, D.A., S.B. Jones, J.M. Wraith, D. Or, S.P. Friedman. 2003. A review of advances in dielectric and electrical conductivity measurements in soils using time domain reflectometry. *Vadose Zone J.* 2:444-475.

Topp, G.C. and D.R. Lapen. 2007. Field Soil Strength. Ch. 60, *In* M.R. Carter and E.G. Gregorich, Eds., *Soil Sampling and Methods of Analysis, 2nd Ed.*, Lewis Publ. of CRC Press, Boca Raton, FL, 783-801.

Table 1: Cohesion, friction and water content of soils from the field shearlogger tests

Soil	Cohesion (kPa)		Friction angle (°)		R ²		WC (m ³ m ⁻³)	St Dev
	peak	ultimate	peak	ultimate	peak	ultimate		
Sandy loam	9.7	-	12.8	-	0.612	-	0.216	0.027
Clay loam	24.5	7.3	6.7	10.4	0.496	0.824	0.140	0.017
Clay loam	16.3	5.9	18.4	14.4	0.846	0.679	0.207	0.018

In Situ Shear Strength Data Logging and TDR

Clarke Topp, Mark Edwards and David
Lapen

Agriculture and Agri-Food Canada
Ottawa, Ontario Canada

Contact: clarketopp@gmail.com