For Reference

NOT TO BE TAKEN FROM THIS ROOM

THESIS
1955 F
#22

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

CAT. No. 1935

LOWE-MARTIN CO. LIMITED

Ex LIBRIS
UNIVERSITATIS
ALBERTAENSIS

AN INVESTIGATION OF
THE ENGINEERING
PROPERTIES OF MUSKEGS
BY
CAPT. S. THOMSON
THE CORPS OF ROYAL CANADIAN
ENGINEERS

Digitized by the Internet Archive
in 2018 with funding from
University of Alberta Libraries

<https://archive.org/details/investigationofe00thom>

ABSTRACT

During a military campaign it may be expedient to construct a temporary or short term road over a muskeg. In such a case it is mandatory to take advantage of whatever shear strength is available in a soil of this type. Since it is the in-situ strength that is of interest, the vane shear apparatus was used to investigate the strength characteristics of organic terrain. This apparatus is based on applying a measurable torque to a set of vanes embedded in the soil. The torque necessary to rotate the vanes, hence shearing the soil, is directly related to the shear strength of the soil. It is necessary to account for frictional resistance encountered during a test.

The site of the trials was a muskeg located approximately at Mile 253 on the Alaska Highway; about 50 miles south of Fort Nelson, B.C. Four test holes were put down to a depth of about 15 feet and vane shear tests were conducted at 18" intervals. The shear strengths measured ranged from 100 to 600 lb. per sq. ft. and the stress-strain curves are similar to those for inorganic soils. Unconfined compression tests indicate the same order of strength as was determined by the vane shear apparatus in field trials. Muskeg soils are also considered to be susceptible to analysis by means of other standard laboratory tests.

It is recommended that a series of quantitative trials be conducted with an improved vane shear apparatus and that these trials be augmented by laboratory tests.

... military ... it may be ... to construct

... temporary on short term ... In such a case it is ... mandatory to take advantage of whatever strength is available in

... of this type. First it is the in-situ strength that is of ... in effect, the ... was used to investigate the strength

characteristics of organic ... This apparatus is based on applying ... a ... to a test of ... in the soil. The ...

necessary to rotate the vane, hence shearing the soil, is directly ... related to the shear strength of the soil. It is necessary to account

for frictional resistance encountered during a test. ... The ... of the ... was a ... located approximately at

... on the ... highway; about 50 miles south of Fort Nelson, ... H.O. ... holes were put down to a depth of about 15 feet and vane

shear tests were conducted at 15' intervals. The shear stress ... measured ranged from ... to ... lb. per sq. ft. and the ...

curves are similar to those for inorganic soils. Unconfined ... comparison to the in-situ ... was determined

by the ... in field trials. ... soils are also ... compared to a ... by means of other standard

laboratory tests. ... It is recommended that a series of comparative trials be

conducted with an improved vane shear apparatus and that these trials ... be ... by laboratory tests.

18515
955(F)
22

THE UNIVERSITY OF ALBERTA
AN INVESTIGATION OF THE
ENGINEERING PROPERTIES OF
MUSKEG

A DISSERTATION
SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

FACULTY OF ENGINEERING
DEPARTMENT - CIVIL

by
Capt. S. Thomson, RCE

EDMONTON, ALBERTA

THE
LONDON
DANCE

THE
LONDON
DANCE

THE
LONDON
DANCE

THE
LONDON
DANCE

ACKNOWLEDGEMENT

The work leading to the Degree of Master of Science, of which this thesis forms a part, was taken under the auspices of the Chief Engineer and the Directorate of Military Training, Canadian Army. These departments were the authority for the inclusion of these studies in the authors Army career and for the provision of the necessary funds.

Dean R.M.Hardy, Faculty of Engineering of the University of Alberta suggested the problem of investigating the properties of muskegs to the Chief Engineer. Since this problem is of general interest and of particular interest to the Canadian Army permission was granted to the author to undertake the first phase of the study of muskeg soils.

Acknowledgement is gratefully made to the Army authorities for posting the author to the University of Alberta and to Dean Hardy and Assistant Professor S.R.Sinclair for the personal interest they afforded the author.

TABLE OF CONTENTS

CHAPTER		PAGE
I	Introduction	1
II	Description of the Site of the Field Tests	4
III	Theory, Description and Operation of the Vane Shear of Apparatus	7
IV	Tests, Observations and Results	18
V	Conclusions, Discussion and Recommendations	35

LIST OF FIGURES

FIGURE		PAGE
1	Ditch Blasted in Muskeg	5
2	Chart for Converting Spring Tension to Shear Strength	13
3	General View of Apparatus	14
4	View of Apparatus Ready to Start a Test	16
5	View of a Test in Progress	16
6	Shear Strength Vs Depth for Sta 419+00	24
7	Shear Strength vs Depth for Sta 420+00	24
8	Shear Strength vs Depth for Sta 421+00	25
9	Shear Strength vs Depth for Sta 422+00	25
10	Stress-Strain Curves for Sta 422 + 00	26
11	Stress-strain Curves for Sta 422 + 00	27
12	Typical Stress-Strain Curves for Remolded and Undisturbed Trials	28
13	e-log P Curve for a Muskeg Soil	33
14	Muskeg Soil Adhering to the Vanes	34

TABLE 1

Page	Chapter
I	I Introduction
II	II Description of the Soil and Test
III	III Theory, Description and Results of the V and Shear of Apparatus
IV	IV Test, Description and Results
V	V Conclusions, Discussion and Recommendations

LIST OF FIGURES

Page	Figure
1	1 Sketch of Apparatus
2	2 Chart for Conversion of Results to Shear Strength
3	3 General View of Apparatus
4	4 View of Apparatus Ready to Start a Test
5	5 View of a Test in Progress
6	6 Shear Strength vs Depth for Sta A10+00
7	7 Shear Strength vs Depth for Sta A10+00
8	8 Shear Strength vs Depth for Sta A11+00
9	9 Shear Strength vs Depth for Sta A12+00
10	10 Stress-strain Curves for Sta A1 + 00
11	11 Stress-strain Curves for Sta A12 + 00
12	12 Typical Stress-strain Curves for Unconsolidated and Undrained Trials
13	13 e-log p Curves for a Mixed Soil
14	14 Sketch of Soil Allowing to the V and

LIST OF TABLES

TABLE		PAGE
A	Test Data From Sta 419 + 00	20
B	Test Data From Sta 420 + 00	21
C	Test Data From Sta 421 + 00	22
D	Test Data From Sta 422 + 00	23
E	Specific Gravity Determination	29
F	Unconfined Compression Test No.1	30
G	Unconfined Compression Test No.2	31
H	Unconfined Compression Test No.3	32

LIST OF PLANS

PLAN NO.		PAGE
1	Assembly Drawing Vane Shear Apparatus	9
2	Details of Vane Apparatus Parts	10
3	Detail of Hand Winch	11

TABLE 1

Page	Item	Value
104	Test Data from Sta 100 + 00	1
105	Test Data from Sta 100 + 00	2
106	Test Data from Sta 100 + 00	3
107	Test Data from Sta 100 + 00	4
108	Specific Gravity Determination	5
109	Unconfined Compression Test No. 1	6
110	Unconfined Compression Test No. 2	7
111	Unconfined Compression Test No. 3	8

TABLE 2

Page	Item	Value
9	Assembly Drawing V no. 1000	1
10	Details of Frame Structure	2
11	Details of Hand Wheel	3

AN INVESTIGATION OF THE ENGINEERING

PROPERTIES OF MUSKEG

CHAPTER I

INTRODUCTION

The construction of a permanent road has, as a prerequisite, a stable base. This fundamental concept poses difficult problems when the use of muskeg soils is anticipated in any phase of permanent road construction. Usually such soils are replaced by a more stable material, or if possible, muskeg terrain is avoided by relocation of the road centre line. The engineering properties of a muskeg that make it unacceptable as a construction material are its very high water content, high compressibility and very low shear strength.

However, despite the undesirable properties of muskeg terrain, there are occasions when it must be traversed. The particular problem prompting this investigation is a military operation in which the criteria of normal engineering economy do not apply and in their stead a military economy assumes vital significance. It is quite possible that a road which has a life of only a few passes of a particular type of vehicle would accomplish its purposes. As an illustration of this concept one may consider evacuation of a small fighting force or the problem of a short term supply of an isolated group.

In several instances in the past, failures of roads over muskeg terrain have been investigated. The results of these investigations indicate that there is some degree of shear strength available in the muskeg soils. For a short life road it is desirable,

if not mandatory, that any strength available be taken into account. The size, weight and operating speed of vehicles will be affected by the degree of shear strength available.

Since time is usually limited, as is the case in most military operations, the problem resolves itself into the determination of shear strength of muskegs in-situ and an apparatus suitable to do the job. The determination of in-situ shear strength of soils has several important implications. First is the assurance that the strengths so determined are closer than those that exist in nature at the time of the test than strengths determined by extracting samples. There is always some doubt, no matter how small, that some natural conditions are not being duplicated in laboratory tests.

The idea of the vane shear apparatus as suggested by Vey and Schlesinger in their paper "Soil Shear Tests by Means of Rotating Vanes" was considered to have merit. The reliability of vane shear test results have been adequately proven by the results of other tests conducted in clay soils. Some papers covering this topic are listed in the List of References. Vane shear results are probably less expensive than obtaining and testing laboratory samples since the entire test can be completed in the field during drilling operations. Due also to this latter fact vane shear testing is capable of producing usable results more quickly. An advantage from the military view point is that the entire test is in one unit and not dependent on a rear laboratory set up. However, there is the inherent disadvantage that only certain types of soils are susceptible to being tested by the vane shear apparatus.

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

... ..

The specific problem on which this report is based is whether or not the vane shear principle can be applied to the investigation of muskeg soils. This implies the adoption of a qualitative point of view both in collecting and presenting data. Accordingly, a somewhat crude vane shear device was constructed with the predominant thought of determining whether or not the principle of the apparatus is applicable to muskeg terrain. This thesis deals with the field trials and attempts to justify further field trials aimed at collecting data on the shear strength of organic soils.

N.W.Radforth in his paper "Suggested Classification of Muskeg for the Engineer" defines muskeg as 'organic terrain'. This definition has been accepted in this thesis.

CHAPTER II

DESCRIPTION OF THE SITE

OF FIELD TESTS

During the construction of the Alaska Highway in 1942-43 the time element was considered vital. Inherent in this policy is the fact that many future relocations to a better and less hazardous alignment are necessary. One such relocation is from Mile 249 to Mile 254. The highway in this area is very winding and the last two or three miles tortuously traverses the edge of a muskeg. In addition to the sharp curves making driving tedious, the maintenance problem over the muskeg is very serious. The latter portion of the Mile 249 - 254 relocation of the Alaska Highway was the site of the field trials for this thesis. It is about 50 miles south of Fort Nelson, B.C.

A distance of about 75 feet either side of the proposed centre line was cleared by bull dozer during the winter months. The original vegetation is typical of muskeg terrain and consists of stunted spruce trees and a profusion of Labrador tea and blueberry bushes. The ground surface is hummocky making walking very difficult. In the area cleared by the dozers, the original vegetation has been entirely replaced by a sedge grass type of growth.

The water table is on the surface and when walking each foot sinks 2 or 3 inches. A ditch was excavated by blasting along

one side in an attempt to lower the water table. Figure 1 is a photograph of the ditch. The attempt was, in the main, entirely unsuccessful. Although there is water flowing in the ditch and the soil immediately adjacent is dry, the water is still at the surface less than fifty feet away.

Fig 1 - Ditch blasted in Muskeg
near Mile 253 Alaska Highway

one side in an attempt to lower the water table. It was I
a photograph of the ditch. The attempt was, in the main, entirely
unsuccessful. Although there is water flowing in the ditch and the
soil immediately adjacent is dry, the water is still at the surface
less than fifty feet away.

Fig. 1 - Ditch located in Mukheg
near Mile 203 Alaska Highway

The muskeg material is predominantly organic and fibrous and varies in depth from 12 feet at Station 419+00 to 17 feet at Station 422+00 of the relocation. The organic soil is underlain by a soft blue clay the depth of which was not investigated but which has an unconfined compressive strength in the order of one half ton per square foot at the upper surface of the layer. The organic material varies in colour from bright green at the surface i.e. living vegetation, to a light brown just below the surface to a darker brown near the bottom. On exposure to air the subsurface material rapidly decomposes or oxidates to a dark brown to black.

THE UNIVERSITY OF CHICAGO
DEPARTMENT OF THE HISTORY OF ARTS
AND ARCHITECTURE
1100 EAST 58TH STREET
CHICAGO, ILLINOIS 60637
TEL: 773-936-5000
FAX: 773-936-5001
WWW.HA.UCHICAGO.EDU

THEORY, DESCRIPTION AND OPERATION OF
THE VANE SHEAR APPARATUS

The vane shear apparatus is basically quite simple consisting of measuring the torque required to rotate a set vanes driven into the soil. Since the dimensions of the vanes are known, the only unknown in the resisting moment is the shear strength of the soil.

THEORY

The theory on which the work of this report is based assumes that the soil shears on a cylindrical surface that coincides with the sides and ends of the vanes. The resisting moment may be considered as the product of the first moment of area of the cylindrical surface and the shear strength of the soil. Algebraically this is:

$$\begin{aligned} M_r &= S(2\pi r h \cdot r + 2 \int_0^r 2\pi r^2 \cdot dr) \\ &= 2\pi r^2 S (h + 0.67r) \end{aligned}$$

in which

M_r = the moment of resistance, inch lbs

S = the shear strength of the soil, lbs per sq inch

h = the height of the vanes, inches

r = the radius of the vanes, inches

The torque is applied as a force at the rim of a wheel fixed to the shaft on which the vanes rotate. If the force is designated as "F" and the radius of the wheel as "R" then the

The very first experiment is basically quite simple consisting of measuring the torque required to rotate a set of vanes driven into the soil. Since the dimensions of the vanes are known, the only unknown in the resisting moment is the shear strength of the soil.

THEORY

The theory on which the work of this report is based assumes that the soil shears on a cylindrical surface of radius r inches with the sides and ends of the vanes. The resisting moment may be considered as the product of the limit moment of area of the cylindrical surface and the shear strength of the soil. Algebraically this is:

$$M_r = 2\pi r^3 \tau \quad (1)$$

$$= 2\pi r^3 (n+0.07r)$$

in which

M_r = the moment of resistance, inch lbs
 τ = the shear strength of the soil, lbs per sq inch
 n = the height of the vane, inches
 r = the radius of the vane, inches

The torque is applied as a force at the rim of a wheel fixed to the shaft on which the vanes rotate. If the force is considered as T and the radius of the wheel as R , then the

applied moment is simply "FR".

Since the applied and resisting moments must be equal, therefore:

$$FR = 2 \pi r^2 S(h + 0.67r)$$

from which

$$S = \frac{FR}{2\pi r^2(h + 0.67r)}$$

DESCRIPTION OF APPARATUS

P Plans 1, 2 and 3 illustrate the very simple nature of the apparatus used to conduct the field trials. The entire assembly was made locally and consists of a small, sturdy wooden table, a hand winch, the torque wheel, frictionless pulleys, airplane cable, and two calibrated springs. Two vane sizes were arbitrarily chosen both $4\frac{1}{2}$ " high, having diameters of 2" and 4". The range of shear strength that can be measured depends entirely upon the choice of springs, the radius of the wheel and of the size of the vane. The springs were calibrated in the laboratory by attaching known weights to one end and creating a scale from a small pointer attached to the spring. The calculation of the shear strength at any time is accomplished by substituting field data into the formula. For any given radius of torque wheel and radius of vane the formula may be reduced to a constant times applied force F. For example, with a 10" radius torque wheel, used exclusively in these tests, and a 4" diameter vane

applied moment is unity.

It is assumed that the material is elastic.

Therefore:

$$M = \frac{1}{2} \pi (h^2 - h_0^2)$$

from which

$$h = \sqrt{\frac{2M}{\pi(h_0^2 - h^2)}}$$

Substituting in (1)

Equation (1) and (2) illustrates the very close nature of

the two curves as compared with the theoretical curve.

It is seen that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

indicating that the curves are nearly identical, strongly

ELEVATION

PLAN

VANE SHEAR APPARATUS
(ASSEMBLY DRAWING)

ELEVATION

PLAN

SHEAR VANE

SCALE: 1" = 6"

PLAN

ELEVATION

TORQUE WHEEL

SCALE: 1" = 10"

STEEL FRICTIONLESS PULLEY

SCALE: 1/2" = 1"

DETAILS OF VANE SHEAR APPARATUS PARTS

NOTE: MATERIAL FOR WINCH HOUSING IS 1/4" STEEL.

SECTION 'A-A'

SIDE VIEW

VIEW 'B-B'

DETAIL HAND WINCH

SCALE 1/2" = 1"

the formula reduces to:

$$S = 9.8 F \text{ lb per sq. ft.}$$

For a 2" diameter vane and a 10" radius wheel the formula becomes:

$$S = 44.3 F \text{ lb per sq. ft.}$$

Where F is the force applied to the rim of the torque wheel, that is one half of the tension in the spring.

The particular two springs chosen for this apparatus were standard coil springs about $\frac{3}{4}$ inches in diameter locally wound on a steel lathe from spring steel wire. The nominal rated capacities in tension were 80 lbs and 120 lbs, however, due to the fact that the force on the torque wheel is one half the tension in the spring, the springs are referred to in this report as 40 lb and 60 lb respectively. Having chosen the spring to cover the range of strengths necessary and to the sensitivity desired a graph may be drawn up which directly converts the spring pointer reading to a shear strength in any desired units. For the particular machine made up by the author the spring pointer scale was a portion of a centimeter scale. Quite by accident, zero tension in the scale was equivalent to a reading of 6.5. Since the spring pointer reading is merely relative time was not taken to adjust the scale so that zero tension in the spring corresponded to a zero scale reading. An example of such a chart is illustrated by Fig 2. The strain is obtained by graduating the torque wheel in degrees and using a pointer mounted on the table. The test is, by its nature, a controlled strain type.

Fig 3 is a general view of the apparatus set-up ready for a trial. The device underwent a few minor modifications before field use.

$$= 9.2 \times 10^3 \text{ lb. ft.}$$

For a 1/2 diameter wheel and a 1/2 inch wide band, the formula

becomes:

$$= 14.3 \times 10^3 \text{ lb. ft.}$$

where F is the force applied to the rim of the wheel, and r is

its radius in feet.

The vertical force applied to the wheel is

very small, and the wheel is almost perfectly horizontal.

on a steel plate from which it is cut. The wheel is

capacitated to handle a load of 100 lb. and a 1/2 inch wide band.

It is at this point in the design when the wheel is

the wheel, the wheel is designed to handle a load of 100 lb. and

to be perfectly horizontal. The wheel is designed to handle a load of

100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

load of 100 lb. and to be perfectly horizontal. The wheel is designed to handle a

Fig. 3 is a general view of the wheel and band.

a wheel. The wheel is designed to handle a load of 100 lb. and to be perfectly horizontal.

Fig 2 Chart For Converting Spring Tension to Shear Strength

Fig 3 - General View
of the Apparatus

1000 - 1000

1000 - 1000

OPERATION

In the field, drill rods with the vane on the end were inserted in the muskeg and driven 18" beyond the end of the hole into undisturbed soil. The table was then placed over the rods followed by the torque wheel which was locked to the drill rods by set screws in such a way as to provide about $\frac{1}{2}$ " clearance between it and the top of the wooden table. The airplane cable was passed from the hand winch through the pulley rigged to the end of the spring and then around the rim of the torque wheel to a hook provided on the wheel.

To conduct the test, the hand winch was operated to maintain a constant rate of shearing strain. At intervals of 5 degrees, a reading was taken of the spring scale until a strain of about 100 degrees had been effected. For remolded trials the cable was disconnected from the torque wheel and the vanes were rotated through about 6 complete revolutions, the cable was then reconnected and another test run.

The apparatus used is such that two men are required to run a test. One man operates the hand winch which regulates the rotational strain. At predetermined strain increments he calls a signal to the second man who notes the strain and the spring pointer reading.

Figures 4 and 5 are general views of the equipment during field testing.

Fig 4-View of Apparatus
ready to start a test

Fig 5 View of a test
in progress

and the other two are

the same as the first

the same as the first

in the same way

Inherent in the operation of the apparatus is a certain amount of friction. The force required to overcome this friction must be subtracted from the total force applied at the rim of the torque wheel in order to arrive at a true value of the applied moment used in actually shearing the soil. The figure for friction was determined by trial in the field in which a plain rod whose dimensions are the same as those of the vane set-up but minus the vanes themselves. This set-up was placed in the ground in the same manner as for placing the vanes and the test conducted.

The time taken to conduct a test is based on a rotational strain of 6 degrees per minute. This is approximately equivalent to the laboratory time of comparable type tests.

The vane shear apparatus was augmented by an AKER soil testing kit and the accessories to this kit such as drill rods, auger attachment and casing.

Inherent in the operation of the apparatus is a certain amount of friction. The force required to overcome this friction must be subtracted from the total torque applied at the rim of the torque wheel in order to arrive at a true value of the applied moment used in actually operating the wheel. The figure for friction was determined by trial in the field in which a plain rod whose dimensions are the same as those of the vane set-up but minus the vanes themselves. This set-up was placed in the ground in the same manner as for placing the vanes and the test conducted.

The time taken to conduct a test is based on a rotational strain of 5 degrees per minute. This is approximately equivalent to the laboratory time of comparable type tests.

The vane shear apparatus was supported by an iron soil testing kit and its accessories to this kit such as drill rods, auger attachment and casing.

CHAPTER IV

TESTS, OBSERVATIONS AND RESULTS

The field trials consisted of four test holes, one placed at each station from Sta 419 + 00 to Sta 422 + 00 of the relocation. Two procedures were attempted, viz.(i) advancing the vanes without retrieving or cleaning the hole and (ii) augering out the hole before each vane test. For the first procedure the vane was advanced approximately 18 inches for each test, for the second procedure the vane was advanced 18" below the bottom of the casing. The data from each test hole is summarized in Tables A to D inclusive. Since this thesis is primarily qualitative in nature, the results are presented from that point of view rather than on a quantitative basis. Figs. No 6 to 9 inclusive are a plot of the depth at which the tests were conducted versus the shear strength. Stress versus rotational strain curves for the field tests conducted near the surface and near the bottom of the muskeg soil in the boring at Station 422 + 00 are plotted in Fig. No 10 and 11. A typical stress - rotational strain curve for the undisturbed and remolded trials is included at Fig. 12 for Sta 420 + 00.

Several standard laboratory tests were conducted in the soils Laboratory NWHS and are included as part of the general scope of the work. One specific gravity test, one consolidation test and three unconfined compression tests were conducted. The results of these tests are recorded in Tables E to H and Fig. 13.

During a test, the vanes may be caught by a twig or root firmly embedded in the muskeg. Such a happening invalidates a test since a falsely high reading of stress is obtained. An occurrence of this nature is readily apparent to the operator since it is out of line with previous results. The stress builds up then suddenly releases. In muskeg soil this phenomenon must be guarded against and cannot be forecast.

It was found that steps had to be taken to ensure that the table did not rotate bodily about the drill rods as a reaction to the torque applied to the vanes. During tests in the muskeg the table could be easily held by one or other of the operators but in stiffer soil types it is necessary to take a more positive anchoring action such as pinning the table legs with steel pins. Holes in the legs were provided but not used though the idea was tested and found to work.

Most of the tests were conducted on a makeshift raft placed on the surface of the muskeg primarily to provide a firm base for the vane shear apparatus. The raft also presented a definite amount of convenience to the working crew in that feet were kept drier and walking was much easier.

Fig. 14 illustrates the fibrous material clinging to the vanes when they were retrieved. The mass of soil appeared to be entirely remolded with the fibres having no orientation.

During a test, the vane may be caught by a twig

or root firmly embedded in the mud. Such a happening invalidates a test since a falsely high reading of stress is obtained. An occurrence of this nature is readily apparent to the operator since it is out of line with previous results. The stress builds up then suddenly releases. In muds soft this phenomenon must be guarded against and cannot be forecast.

It was found that steps had to be taken to ensure that the table did not rotate bodily about the drill rods as a reaction to the torque applied to the vane. During tests in the muds the table could be easily held by one or other of the operators but in stiffer soils it is necessary to take a more positive anchoring action such as pinning the table legs with steel pins. Holes in the legs were provided but not used through the idea was tested and found to work.

Most of the tests were conducted on a make-shift rafter placed on the surface of the muds primarily to provide a firm base for the vane shear apparatus. The rafter also presented a definite amount of convenience to the working crew in that feet were kept drier and walking was much easier.

Fig. 14 illustrates the typical material clinging to the vane when they were retrieved. The mud still appeared to be entirely remolded with the fibers having no orientation.

TABLE 'A'

TEST DATA FROM STATION 419 + 00

Depth below Surface	Max.Spring Reading	Vane & Spring	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Shear Strength lbs./ft ²	Pt of Max. Strain Degrees
1'	8.2	2" - 40lb	4.8	1.2	3.6	160	30
3'	9.5	2" - 40	8.8	4	4.8	212	30
4'	11.1	2" - 40	14.6	5	9.6	425	65
6.5'	10.1	2" - 40	11.0	6	5	220	35
8.5'	10.2	2" - 40	11.3	8	3.3	146	20
9.9'	10.7	2" - 40	13.0	9.8	3.2	142	55
13.0'	11.5	2" - 40	16.0	13	3	133	20
						Start Clay 13.5	
14.0'	14.4	2" - 40	26.2	19.3	6.9	306	20
15.5'	13.0	2" - 60	35.6	31.2	4.4	195	25
18'	17.5	2" - 60	62.8	52.7	10.1	448	25

TABLE I

Test results for the various types of steel

Test No.	Yield Point (lb.)	Tensile Strength (lb.)	Elongation (%)	Reduction of Area (%)	Impact (ft.-lb.)	Charpy (ft.-lb.)	Temperature (°F.)
1	30	100	2.0	1.5	20 - 40	10.0	70
2	30	100	2.0	1.5	20 - 40	10.0	70
3	30	100	2.0	1.5	20 - 40	10.0	70
4	30	100	2.0	1.5	20 - 40	10.0	70
5	30	100	2.0	1.5	20 - 40	10.0	70
6	30	100	2.0	1.5	20 - 40	10.0	70
7	30	100	2.0	1.5	20 - 40	10.0	70
8	30	100	2.0	1.5	20 - 40	10.0	70
9	30	100	2.0	1.5	20 - 40	10.0	70
10	30	100	2.0	1.5	20 - 40	10.0	70
11	30	100	2.0	1.5	20 - 40	10.0	70
12	30	100	2.0	1.5	20 - 40	10.0	70
13	30	100	2.0	1.5	20 - 40	10.0	70
14	30	100	2.0	1.5	20 - 40	10.0	70
15	30	100	2.0	1.5	20 - 40	10.0	70
16	30	100	2.0	1.5	20 - 40	10.0	70
17	30	100	2.0	1.5	20 - 40	10.0	70
18	30	100	2.0	1.5	20 - 40	10.0	70
19	30	100	2.0	1.5	20 - 40	10.0	70
20	30	100	2.0	1.5	20 - 40	10.0	70
21	30	100	2.0	1.5	20 - 40	10.0	70
22	30	100	2.0	1.5	20 - 40	10.0	70
23	30	100	2.0	1.5	20 - 40	10.0	70
24	30	100	2.0	1.5	20 - 40	10.0	70
25	30	100	2.0	1.5	20 - 40	10.0	70
26	30	100	2.0	1.5	20 - 40	10.0	70
27	30	100	2.0	1.5	20 - 40	10.0	70
28	30	100	2.0	1.5	20 - 40	10.0	70
29	30	100	2.0	1.5	20 - 40	10.0	70
30	30	100	2.0	1.5	20 - 40	10.0	70

TABLE 'B'

TEST DATA FROM STATION 420 + 00

Depth below Surface	Max. Spring Reading	Vane & Spring	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Shear Strength lbs./ft ²	Pt. of Max. Strain Degrees
1.75'	8.5	2" - 40lb	5.4	3	2.4	106	55
3.25'	10.0	2" - 40	10.6	6	4.6	204	40
4.75'	10.0	2" - 40	10.6	7	3.6	160	85
6.25'	11.2	2" - 40	14.8	8	6.8	300	100
7.55'	12.2	2" - 40	18.4	9	9.4	415	55
9.05'	11.9	2" - 40	17.4	6.4	11	487	45
10.55'	13.1	2" - 40	21.7	9.2	12.5	555	25
12.05'	14.8	2" - 40	27.8	13.8	14	610	20
						Start Clay	12.55
13.55	16.3	2" - 60	55.6	32.6	23	1020	10
15.05	19.4	2" - 60	74.2	41	33	1460	45

TABLE II

TEST DATA FOR 1930 + 10

At below surface	No. of Loadings	Value of Loadings	Total Tension lbs.	Reaction lbs.	W + Tension lbs.	Reaction lbs.	At surface
1.75'	8.5	50 - 50	5.4	3	8.4	100	55
2.25'	10.0	50 - 40	10.0	6	16.0	100	40
2.75'	10.0	50 - 40	10.0	7	17.0	100	40
3.25'	11.5	50 - 40	11.5	8	19.5	100	100
3.75'	12.5	50 - 40	12.5	9	21.5	100	55
4.25'	11.0	50 - 40	11.0	10	21.0	100	45
4.75'	13.5	50 - 40	13.5	11	24.5	100	55
5.25'	14.5	50 - 40	14.5	12	26.5	100	55
5.75'	14.5	50 - 40	14.5	13	27.5	100	55
6.25'	12.5	50 - 40	12.5	14	26.5	100	55
6.75'	13.5	50 - 40	13.5	15	28.5	100	55
7.25'	13.5	50 - 40	13.5	16	29.5	100	55
7.75'	13.5	50 - 40	13.5	17	30.5	100	55
8.25'	13.5	50 - 40	13.5	18	31.5	100	55
8.75'	13.5	50 - 40	13.5	19	32.5	100	55
9.25'	13.5	50 - 40	13.5	20	33.5	100	55
9.75'	13.5	50 - 40	13.5	21	34.5	100	55
10.25'	13.5	50 - 40	13.5	22	35.5	100	55
10.75'	13.5	50 - 40	13.5	23	36.5	100	55
11.25'	13.5	50 - 40	13.5	24	37.5	100	55
11.75'	13.5	50 - 40	13.5	25	38.5	100	55
12.25'	13.5	50 - 40	13.5	26	39.5	100	55
12.75'	13.5	50 - 40	13.5	27	40.5	100	55
13.25'	13.5	50 - 40	13.5	28	41.5	100	55
13.75'	13.5	50 - 40	13.5	29	42.5	100	55
14.25'	13.5	50 - 40	13.5	30	43.5	100	55
14.75'	13.5	50 - 40	13.5	31	44.5	100	55
15.25'	13.5	50 - 40	13.5	32	45.5	100	55
15.75'	13.5	50 - 40	13.5	33	46.5	100	55
16.25'	13.5	50 - 40	13.5	34	47.5	100	55
16.75'	13.5	50 - 40	13.5	35	48.5	100	55
17.25'	13.5	50 - 40	13.5	36	49.5	100	55
17.75'	13.5	50 - 40	13.5	37	50.5	100	55
18.25'	13.5	50 - 40	13.5	38	51.5	100	55
18.75'	13.5	50 - 40	13.5	39	52.5	100	55
19.25'	13.5	50 - 40	13.5	40	53.5	100	55
19.75'	13.5	50 - 40	13.5	41	54.5	100	55
20.25'	13.5	50 - 40	13.5	42	55.5	100	55
20.75'	13.5	50 - 40	13.5	43	56.5	100	55
21.25'	13.5	50 - 40	13.5	44	57.5	100	55
21.75'	13.5	50 - 40	13.5	45	58.5	100	55
22.25'	13.5	50 - 40	13.5	46	59.5	100	55
22.75'	13.5	50 - 40	13.5	47	60.5	100	55
23.25'	13.5	50 - 40	13.5	48	61.5	100	55
23.75'	13.5	50 - 40	13.5	49	62.5	100	55
24.25'	13.5	50 - 40	13.5	50	63.5	100	55
24.75'	13.5	50 - 40	13.5	51	64.5	100	55
25.25'	13.5	50 - 40	13.5	52	65.5	100	55
25.75'	13.5	50 - 40	13.5	53	66.5	100	55
26.25'	13.5	50 - 40	13.5	54	67.5	100	55
26.75'	13.5	50 - 40	13.5	55	68.5	100	55
27.25'	13.5	50 - 40	13.5	56	69.5	100	55
27.75'	13.5	50 - 40	13.5	57	70.5	100	55
28.25'	13.5	50 - 40	13.5	58	71.5	100	55
28.75'	13.5	50 - 40	13.5	59	72.5	100	55
29.25'	13.5	50 - 40	13.5	60	73.5	100	55
29.75'	13.5	50 - 40	13.5	61	74.5	100	55
30.25'	13.5	50 - 40	13.5	62	75.5	100	55
30.75'	13.5	50 - 40	13.5	63	76.5	100	55
31.25'	13.5	50 - 40	13.5	64	77.5	100	55
31.75'	13.5	50 - 40	13.5	65	78.5	100	55
32.25'	13.5	50 - 40	13.5	66	79.5	100	55
32.75'	13.5	50 - 40	13.5	67	80.5	100	55
33.25'	13.5	50 - 40	13.5	68	81.5	100	55
33.75'	13.5	50 - 40	13.5	69	82.5	100	55
34.25'	13.5	50 - 40	13.5	70	83.5	100	55
34.75'	13.5	50 - 40	13.5	71	84.5	100	55
35.25'	13.5	50 - 40	13.5	72	85.5	100	55
35.75'	13.5	50 - 40	13.5	73	86.5	100	55
36.25'	13.5	50 - 40	13.5	74	87.5	100	55
36.75'	13.5	50 - 40	13.5	75	88.5	100	55
37.25'	13.5	50 - 40	13.5	76	89.5	100	55
37.75'	13.5	50 - 40	13.5	77	90.5	100	55
38.25'	13.5	50 - 40	13.5	78	91.5	100	55
38.75'	13.5	50 - 40	13.5	79	92.5	100	55
39.25'	13.5	50 - 40	13.5	80	93.5	100	55
39.75'	13.5	50 - 40	13.5	81	94.5	100	55
40.25'	13.5	50 - 40	13.5	82	95.5	100	55
40.75'	13.5	50 - 40	13.5	83	96.5	100	55
41.25'	13.5	50 - 40	13.5	84	97.5	100	55
41.75'	13.5	50 - 40	13.5	85	98.5	100	55
42.25'	13.5	50 - 40	13.5	86	99.5	100	55
42.75'	13.5	50 - 40	13.5	87	100.5	100	55
43.25'	13.5	50 - 40	13.5	88	101.5	100	55
43.75'	13.5	50 - 40	13.5	89	102.5	100	55
44.25'	13.5	50 - 40	13.5	90	103.5	100	55
44.75'	13.5	50 - 40	13.5	91	104.5	100	55
45.25'	13.5	50 - 40	13.5	92	105.5	100	55
45.75'	13.5	50 - 40	13.5	93	106.5	100	55
46.25'	13.5	50 - 40	13.5	94	107.5	100	55
46.75'	13.5	50 - 40	13.5	95	108.5	100	55
47.25'	13.5	50 - 40	13.5	96	109.5	100	55
47.75'	13.5	50 - 40	13.5	97	110.5	100	55
48.25'	13.5	50 - 40	13.5	98	111.5	100	55
48.75'	13.5	50 - 40	13.5	99	112.5	100	55
49.25'	13.5	50 - 40	13.5	100	113.5	100	55
49.75'	13.5	50 - 40	13.5	101	114.5	100	55
50.25'	13.5	50 - 40	13.5	102	115.5	100	55
50.75'	13.5	50 - 40	13.5	103	116.5	100	55
51.25'	13.5	50 - 40	13.5	104	117.5	100	55
51.75'	13.5	50 - 40	13.5	105	118.5	100	55
52.25'	13.5	50 - 40	13.5	106	119.5	100	55
52.75'	13.5	50 - 40	13.5	107	120.5	100	55
53.25'	13.5	50 - 40	13.5	108	121.5	100	55
53.75'	13.5	50 - 40	13.5	109	122.5	100	55
54.25'	13.5	50 - 40	13.5	110	123.5	100	55
54.75'	13.5	50 - 40	13.5	111	124.5	100	55
55.25'	13.5	50 - 40	13.5	112	125.5	100	55
55.75'	13.5	50 - 40	13.5	113	126.5	100	55
56.25'	13.5	50 - 40	13.5	114	127.5	100	55
56.75'	13.5	50 - 40	13.5	115	128.5	100	55
57.25'	13.5	50 - 40	13.5	116	129.5	100	55
57.75'	13.5	50 - 40	13.5	117	130.5	100	55
58.25'	13.5	50 - 40	13.5	118	131.5	100	55
58.75'	13.5	50 - 40	13.5	119	132.5	100	55
59.25'	13.5	50 - 40	13.5	120	133.5	100	55
59.75'	13.5	50 - 40	13.5	121	134.5	100	55
60.25'	13.5	50 - 40	13.5	122	135.5	100	55
60.75'	13.5	50 - 40	13.5	123	136.5	100	55
61.25'	13.5	50 - 40	13.5	124	137.5	100	55
61.75'	13.5	50 - 40	13.5	125	138.5	100	55
62.25'	13.5	50 - 40	13.5	126	139.5	100	55
62.75'	13.5	50 - 40	13.5	127	140.5	100	55
63.25'	13.5	50 - 40	13.5	128	141.5	100	55
63.75'	13.5	50 - 40	13.5	129	142.5	100	55
64.25'	13.5	50 - 40	13.5	130	143.5	100	55
64.75'	13.5	50 - 40	13.5	131	144.5	100	55
65.25'	13.5	50 - 40	13.5	132	145.5	100	55
65.75'	13.5	50 - 40	13.5	133	146.5	100	55
66.25'	13.5	50 - 40	13.5	134	147.5	100	55
66.75'	13.5	50 - 40	13.5	135	148.5	100	55
67.25'	13.5	50 - 40	13.5	136	149.5	100	55
67.75'	13.5	50 - 40	13.5	137	150.5	100	55
68.25'	13.5	50 - 40	13.5	138	151.5	100	55
68.75'	13.5	50 - 40	13.5	139	152.5	100	55
69.25'	13.5	50 - 40	13.5	140	153.5	100	55
69.75'	13.5	50 - 40	13.5	141	154.5	100	55
70.25'	13.5	50 - 40	13.5	142	155.5	100	55
70.75'	13.5	50 - 40	13.5	143	156.5	100	55
71.25'	13.5	50 - 40	13.5	144	157.5	100	55
71.75'	13.5	50 - 40	13.5	145	158.5	100	55
72.25'	13.5	50 - 40	13.5	146	159.5	100	55
72.75'	13.5	50 - 40	13.5	147	160.5	100	55
73.25'	13.5	50 - 40	13.5	148	161.5	100	55
73.75'	13.5	50 - 40	13.5	149	162.5	100	55
74.25'	13.5	50 - 40	13.5	150	163.5	100	55
74.75'	13.5	50 - 40	13.5	151	164.5	100	55
75.25'	13.5	50 - 40	13.5	152	165.5	100	55
75.75'	13.5	50 - 40	13.5	153	166.5	100	55
76.25'	13.5	50 - 40	13.5	154	167.5	100	55
76.75'	13.5	50 - 40	13.5	155	168.5	100	55
77.25'	13.5	50 - 40	13.5	156	169.5	100	55
77.75'	13.5	50 - 40	13.5	157	170.5	100	55
78.25'	13.5	50 - 40	13.5	158	171.5	100	55
78.75'	13.5	50 - 40	13.5	159	172.5	100	55
79.25'	13.5	50 - 40	13.5	160	173.5	100	55
79.75'	13.5	50 - 40	13.5	161	174.5	100	55
80.25'	13.5	50 - 40	13.5	162	175.5	100	55
80.75'	13.5	50 - 40	13.5	163	176.5	100	55
81.25'	13.5	50 - 40	13.5	164	177.5	100	55
81.75'	13.5	50 - 40	13.5	165	178.5	100	55
82.25'	13.5	50 - 40	13.5	166	179.5	100	55
82.75'	13.5	50 - 40					

TABLE 'C'

TEST DATA FROM STATION 421 + 00

th below surface	Max. Spring Reading	Vane & Spring	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Shear Strength lbs./ft ²	Pt. of Max. Strain Degrees
1.85	8.1	2" - 40 lb	3.8	2.7	1.1	5	5
3.0	13.7	2" - 40	23.8	4.5	19.3	850	65
4.5	10.4	2" - 40	12.0	6.7	5.3	235	35
6.0	12.7	2" - 40	20.2	9	11.2	495	70
7.5	12.7	2" - 40	20.2	11.2	9	400	55
9.0	12.5	2" - 40	19.4	13.5	6	266	40
10.5	14.7	2" - 40	27.4	15.7	11.7	520	45
12.0	11.7	2" - 60	27.8	18	9.8	435 Start Clay	30 12.5
13.5	11.1	2" - 60	24.0	20	4.0	177	40

TABLE 1

TEST DATA FROM 1911 + 12

Face below	Max. Spring Head in Feet	Valve & Spring Feet	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Gate Strength lbs.	Pct. of Max. Spring Feet
8.5	5.1	2" - 40 lb	3.8	0.7	4.5	5	5
9.0	13.7	2" - 40	23.8	4.2	19.6	850	65
9.5	10.4	2" - 40	18.0	6.7	11.3	325	35
10.0	15.7	2" - 40	20.2	9	11.2	465	40
10.5	13.7	2" - 40	20.2	11.2	9	400	55
11.0	12.5	2" - 40	19.4	13.2	6	260	40
11.5	14.7	2" - 40	27.4	12.7	14.7	280	45
12.0	11.7	2" - 60	17.2	12	5.2	435	30
12.5	11.1	2" - 60	24.0	20	4.0	175	40

Start of V 12.5

TABLE 'D'

TEST DATA FROM STATION 422 + 00

Depth below Surface	Max. Spring Reading	Vane & Spring	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Shear Strength lbs./ft ²	Pt. of Max. Strain Degrees
2	14	4" - 40 lb	24.8	3	21.8	214	55
3½	16	4" - 40	32.0	3	29.0	294	55
7	13.6	4" - 40	25.4	3	21.4	210	45
8½	15.4	4" - 40	29.8	3	26.8	263	45
10	23.7	4" - 40	59.6	3	56.6	555	55
11½	9.8	2" - 60	16.2	3	13.2	575	40
14½	10.5	2" - 60	20.6	3	17.6	782	40
16	10.9	2" - 60	23	3	20.0	886	25
17½	12.0	2" - 60	27.6	3	24.6	1091 Start Clay	15 18'
19	14.0	2" - 60	39.6	3	36.6	1625	25

Table 1

Test data for the 1000 ft. test

ft. of test section	Test section No.	Test section No.	Test section No.	Test section No.	Test section No.	Test section No.
25	100	100	100	100	100	100
25	100	100	100	100	100	100
45	100	100	100	100	100	100
45	100	100	100	100	100	100
25	100	100	100	100	100	100
25	100	100	100	100	100	100
45	100	100	100	100	100	100
45	100	100	100	100	100	100
25	100	100	100	100	100	100
25	100	100	100	100	100	100
15	100	100	100	100	100	100
15	100	100	100	100	100	100
25	100	100	100	100	100	100

DEPTH BELOW SURFACE, FEET

0
1
2
3
4
5
6
7
8
9
10
11
12
13

0 100 200 300 400 500 600

SHEAR STRENGTH, lb/sq ft

Fig. 6
SHEAR STRENGTH VS DEPTH
For Sta. 419+00

DEPTH BELOW SURFACE, FEET

0
2
4
6
8
10
12

0 100 200 300 400 500 600 700

SHEAR STRENGTH, lb/sq ft

Fig. 7
SHEAR STRENGTH VS DEPTH
For Sta. 420+00

FIG 10 STRESS STRAIN CURVES
FOR STA 422+00

Fig 11 STRESS STRAIN CURVES
FOR STA 422+00

Fig 12 Typical Stress vs Rotational Strain Curves for Undisturbed and Remolded Tests of the Vane Shear Apparatus. Sta 420+00, vane 12 ft below surface.

TABLE 'E'

NORTHWEST HIGHWAY SYSTEM

SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY DETERMINATION

SITE254..... LOCATION.....Prophet Sec.....
 DATE SAMPLEDAug 54..... DATE TESTED5 May 55.....
 INITIALSSS.....

DESCRIPTION OF SAMPLES:

Light brown fibrous organic material.

REMARKS:

Some floating debris made the reading of the
meniscus difficult.

	TRIAL 1	TRIAL 2
SAMPLE NO.	1	
FLASK NO.	725	
WT. OF FLASK / DRY SOIL	133.69	
WT. OF FLASK	129.91	
WT. OF DRY SOIL, WS	3.78	
WT. OF FLASK / SOIL / WATER W_{FSW}	628.67	
WT. OF FLASK / WATER W_{FW}	627.54	
TEMPERATURE OF WATER	27°C	
SPECIFIC GRAVITY OF SOIL PARTICLES	1.42	

TABLE 1

TABLE 1
 TABLE 1
 TABLE 1

TABLE 1
 TABLE 1
 TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 'F'

UNCONFINED COMPRESSION TEST

LOAD ON FAN GM	DIAL RDG.	TOTAL STRAIN	UNIT STRAIN	I-U	NEW AREA (SQ.CM.)	COMP. STRENGTH KG CM ²
0	1.000					
10 gm	.565	.435	.132	.868	12.91	0.08

On addition of the 10 gm increment it would not take up the load
but failed by shear after considerable decrease in length.

(1.2 lb/sq in)

Date.....4 May 55..... SiteMile 254.....
 LocationMuskeg 419 + 00..... Technician ..S.T.....
 Sample Length ..3.30"..... Sample diameter ...1.6".....
 Original cross section area = $0.7854 (\text{dia})^2 = \dots\dots\dots 12.95 \text{ cm}^2$
 Total Weight wet and tare ...218.15 gm SKETCH OF FAILURE
 Weight dry and tare93.41 gm
 Weight water124.74 gm
 Weight tare77.01 gm
 Weight of dry soil16.40 gm
 Moisture Content760%...

[illegible][illegible]

TABLE 'G'
UNCONFINED COMPRESSION TEST

LOAD ON PAN GM.	DIAL RDG.	TOTAL STRAIN	UNIT STRAIN	1-U	NEW AREA (SQ. CM.)	COMP. STRENGTH KG CM ²
0	8.0					
10	8.12	.12	.04	.96	18.2	0.055
20	8.32	.32	.11	.89	19.7	0.10
30	8.45	.45	.15	.85	20.6	0.15 Kg/Cm ²

= 310 lb/sq ft.

Date 28 Oct 54

Location Muskeg

Sample Length 3.0"

Original cross section area = $0.7854 (\text{dia})^2 = 17.5 \text{ cm}^2 (2.71 \text{ in}^2)$

Weight wet and tare 59.74.

Weight dry and tare 26.52.

Weight water 24.22.

Weight tare Can No 3 21.76.

Weight of dry soil 4.76.

Moisture content 510%.

Site 419 + 00 depth 11-12.5

Technician

Sample diameter 1.86 inches

SKETCH OF FAILURE

7. 1

LOAD ON 7-10 (lb)	LOAD ON 11-12 (lb)	LOAD ON 13-14 (lb)	LOAD ON 15-16 (lb)	LOAD ON 17-18 (lb)	LOAD ON 19-20 (lb)
0	0	0	0	0	0
10	10	10	10	10	10
20	20	20	20	20	20
30	30	30	30	30	30

It will be seen that the

Location	Depth (m)	Temperature (°C)	Salinity (‰)	Density (σ _t)	Sound velocity (m/s)	Transmittance (%)	Color	Turbidity (NTU)	Chlorophyll (µg/L)	Diatoms (µg/L)	Algae (µg/L)	Plankton (µg/L)	Detritus (µg/L)	Organic matter (µg/L)	Inorganic matter (µg/L)	Total matter (µg/L)	Notes	
Station 1	0.5	18.5	35.2	1.024	1480	95	15	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01	Clear water, no visible organisms
Station 2	1.0	18.2	35.1	1.023	1475	92	18	12	6	3	1.5	0.8	0.3	0.15	0.08	0.04	Small diatoms visible	
Station 3	1.5	17.8	34.9	1.022	1470	88	22	15	8	4	2.5	1.2	0.5	0.25	0.12	0.06	Many diatoms, some green algae	
Station 4	2.0	17.5	34.7	1.021	1465	85	25	18	10	5	3.5	1.8	0.7	0.35	0.18	0.09	Large diatoms, green algae, some brown algae	
Station 5	2.5	17.2	34.5	1.020	1460	82	28	20	12	6	4.5	2.2	0.9	0.45	0.22	0.11	Many diatoms, green algae, brown algae, some red algae	
Station 6	3.0	16.8	34.3	1.019	1455	78	32	22	14	7	5.5	2.8	1.1	0.55	0.28	0.14	Many diatoms, green algae, brown algae, red algae, some blue-green algae	
Station 7	3.5	16.5	34.1	1.018	1450	75	35	24	16	8	6.5	3.2	1.3	0.65	0.32	0.16	Many diatoms, green algae, brown algae, red algae, blue-green algae, some cyanobacteria	
Station 8	4.0	16.2	33.9	1.017	1445	72	38	26	18	9	7.5	3.8	1.5	0.75	0.38	0.18	Many diatoms, green algae, brown algae, red algae, blue-green algae, cyanobacteria, some larger organisms	
Station 9	4.5	15.8	33.7	1.016	1440	68	42	28	20	10	8.5	4.2	1.7	0.85	0.42	0.20	Many diatoms, green algae, brown algae, red algae, blue-green algae, cyanobacteria, larger organisms, some detritus	
Station 10	5.0	15.5	33.5	1.015	1435	65	45	30	22	11	9.5	4.8	1.9	0.95	0.48	0.22	Many diatoms, green algae, brown algae, red algae, blue-green algae, cyanobacteria, larger organisms, detritus, some organic matter	

TABLE 'H'
UNCONFINED COMPRESSION TEST

LOAD ON FAN GM.	DIAL RDG	TOTAL STRAIN	UNIT STRAIN	1-U	NEW AREA (SQ.CM.)	COMP. STRENGTH KG CM ²
0	7.00	0				
20	7.07	0.07	.018	.982	18.6	.108
40	7.23	.23	.06	.94	19.5	.205
60	7.38	.38	.10	.90	20.3	.295
80	7.60	.60	.157	.843	21.7	.37
100	7.91	.91	.238	.762	24.0	.42 Kg/Cm ²

$$= .43 \text{ tn/ft}^2$$

$$= 860 \text{ lb/ft}^2$$

Date 28 Oct 54

Location Muskeg

Sample Length 3.82" 9

Original cross section area = $0.7854 (\text{dia})^2 = \dots\dots\dots 18.3 \text{ cm}^2 \dots\dots\dots$

Weight wet and tare 125.20

Weight dry and tare 85.07

Weight water 40.13

Weight tare 76.52

Weight of dry soil 8.55

Moisture content 470%

Site Mile 254

Technician ST & FHB

Sample diameter 1.9"

SKETCH OF FAILURE

TABLE III

PERCENTAGE OF WATER IN SOIL

Soil Sample No.	Moisture Content (%)	Gravimetric Water Content (%)	Specific Gravity	Void Ratio	Porosity (%)	Degree of Saturation (%)
100	1.91	1.34	2.65	0.91	45.2	100
80	1.80	1.21	2.51	0.80	40.0	100
60	1.38	0.90	2.10	0.38	18.2	100
40	1.23	0.80	2.00	0.23	11.5	100
20	0.97	0.75	1.95	0.07	3.4	100
0	0.00	0.00	1.00	0.00	0.0	0

$\gamma_s = 2.65 \text{ g/cc}$

$\gamma_w = 1.00 \text{ g/cc}$

Moisture content	1.91
Gravimetric water content	1.34
Specific gravity	2.65
Void ratio	0.91
Porosity	45.2
Degree of saturation	100
Weight of dry soil	1.34
Weight of water	0.57
Weight of soil	1.91
Volume of dry soil	0.50
Volume of water	0.13
Volume of soil	0.63
Moisture content	1.91

Fig. 14 Muskeg soil adhering
to the vanes of the apparatus

Fig. 14. Muscles of the arm and shoulder
to the arm of the apparatus

CHAPTER V
CONCLUSIONS, DISCUSSION AND
RECOMMENDATIONS

CONCLUSIONS

From a study of the graphs of strength versus depth there appears to be an increase of strength with depth. The relationship is very approximate and the relationship of shear strength to overburden pressure (C/P) is very erratic. There appear to be strong layers, perhaps due to another type of plant growth but these may be confused with falsely high readings due to the vane becoming enmeshed in roots or twigs.

The shear strength measured ranged from a low of about 100 lbs. per sq. ft. to a maximum in the order of 600 lbs. per sq. ft. At a depth of 10 feet the available strength is some 400 lbs. per square foot at stations 420, 421 and 422 but the presence of the lower strength of 150 lb. per sq. ft. at the same depth at Station 419 casts sufficient doubt on the figures that it would be unsafe to accept a general figure for strength over any given area.

The stress-strain curves of Graphs 10, 11 and 12 are not unique but rather what would be expected. There is generally a pronounced peak to the curve occurring between 30 and 55 degrees of rotational strain. The remolded curves are lacking the pronounced peak of the undisturbed trials and instead reach and practically

maintain a maximum value. The degree of sensitivity is low ranging from a low of 1.6 to a high of 2.4. As was noted at the end of Chapter 1V and Fig. 14 the soil is entirely remolded and loses any structural identity. In its natural state interlocking fibres are plainly visible and it is suggested that some degree of strength is imparted to this soil by its fibrous nature.

Table E is a specific gravity determination indicating the organic nature of the material. Normally any specific gravity less than about 2.4 is treated with suspicion. This particular test cannot be treated with the same accuracy as can a normal specific gravity determination due to bits of floating debris making the reading of the meniscus difficult. However, the order of figure is indicated.

Tables F, G and H are the results of unconfined compression tests. The samples were extracted by Shelby tubes following the standard soil sampling techniques and tested using the normal controlled stress type of laboratory compression apparatus. The shear strengths, assuming that the shear strength is one half the unconfined compressive strength, are in the same order as determined in the field. There is one comment that may have some effect and that is the very high compressibility of the muskeg. A Shelby tube forced into the soil 18" only resulted in a sample about 6" or 7" long. However, despite this the results are comparable

which indicates the validity of the results of the vane shear apparatus.

A consolidation test was run on a sample of the muskeg soil. The specimen was 2.6 inches in diameter (34 sq. cms. cross section area) and about one inch in thickness at the start of the test. Graph No. 13 is the e-Log P curve for the soil. As would be expected there is an excessive degree of consolidation under very small loads. The specimen decreased in thickness by approximately 50% under a load of 1.2 tons per sq. ft. Corresponding to this consolidation are the very high void ratios, many in excess of four. Since the soil is saturated the accompanying moisture contents are very high. The coefficient of permeability as calculated from the data obtained during the consolidation test is in the order of 10^{-10} cm. per second at a pressure of one ton per sq. foot. The water retentive or absorption properties of the soil may have considerable influence on this soil characteristic.

DISCUSSION

There is some discussion concerning the assumptions regarding the actual surface on which shear takes place when the vanes are rotated. The first assumption is that the stress is uniform on the sides and ends of the cylinder traced by the vane. Though there may be some question of the validity of this assumption, it has been made by other investigators and for this reason has been adopted for this report.

which indicates the validity of the results of the vane shear

apparatus.

A consolidation test was run on a sample of the muskeg soil. The specimen was 2.6 inches in diameter (2.4 sq. cm. cross section area) and about one inch in thickness at the start of the test. Graph No. 1 is the e-log p curve for the soil. As would be expected there is an excessive degree of consolidation under very small loads. The specimen decreased in thickness by approximately 50% under a load of 1.2 tons per sq. ft. Corresponding to this consolidation are the very high void ratios, many in excess of four. Since the soil is saturated the accompanying moisture contents are very high. The coefficient of permeability as calculated from the data obtained during the consolidation test is in the order of 10^{-10} cm. per second at a pressure of one ton per sq. foot. The water retentive or absorption properties of the soil may have considerable influence on this soil characteristic.

DISCUSSION

There is some discussion concerning the assumptions regarding the actual surface on which shear takes place when the vanes are rotated. The first assumption is that the stress is uniform on the sides and ends of the cylinder traced by the vane. Though there may be some question of the validity of this assumption, it has been made by other investigators and for this reason has been adopted for this report.

The second assumption concerns the radius of cylinder of soil sheared during a test. For this report it has been assumed that the shearing takes place on the cylinder traced out by the tips of the blades during rotation. A. W. Skempton in his paper "Vane Tests in the Alluvial Plain of the River Forth near Grangemouth" assumes that the radius of the cylinder on which shear takes place is slightly greater than the radius of the vanes. Lea and Benedict in their paper "The Foundation Vane Tester' for Measuring In-Situ-Shear Strength of Soil" have a slightly different shape of vane in that the ends are tapered, that is the shape of the solid generated by rotation is a cylinder surmounted by a cone at each end. Because of the qualitative nature of this thesis the vanes used by the author have square ends hence the solid generated is a cylinder. The difference in shape of the ends of the vane, from theoretical considerations, will result in the square ended vane giving higher readings from a test. Which particular vane shape yields the most accurate results is a problem that will have to be solved by a series of quantitative tests. The thickness of the material constituting the vanes is not thought to be a serious problem as long as sufficient stiffness is maintained with a minimum thickness to avoid as much disturbance as possible when the vanes are forced in the ground.

The apparatus used in these tests was rather crude and many modifications could readily be conceived to improve its functioning. Replacement of the wooden parts by metal would improve

The second set of cylinders

[illegible]

The subject was used in these tests with a few errors and

and a number of services of the same kind are available on request.

the weathering properties. The scales were merely drawn on paper and covered with sheet plastic. Metal parts could be engraved with a more accurate and permanent scale. Shorter and stronger springs would reduce the size of the apparatus thus decreasing its bulk.

As was mentioned previously the shear strength of the soil must be calculated from the net tension in the spring, that is, any inherent friction must be subtracted from the observed spring tension. The friction may be considered as consisting of two components, one due to the apparatus and the other the friction between the soil and the rods. The first of these two can largely be eliminated by ball or thrust bearings, particularly where the rods pass through the table. The friction between the rods and the soil can be minimized by forcing the vanes a set distance beyond the bottom of the hole for each test. It would only be necessary then to take an occasional test for the frictional resistance. The twist in the drill rods themselves may or may not be worthy of consideration depending on their size and length.

The "Foundation Vane Tester" has been designed to take friction into account by means of a special graph mounted on the torque table. It is described in the paper by Lea and Benedict mentioned previously in this chapter.

CONCLUSIONS

It is felt that the application of the principle of the vane shear apparatus to the investigation of the engineering

The weathering properties. The samples were roughly ground on a mill and covered with about 1/2 inch of water. A few minutes later a more accurate and complete analysis would reduce the rate of the spreading than covering the soil.

As was mentioned previously the amount of the soil

must be calculated from the test results in the table, that is, any

inherent friction must be subtracted from the observed spring

tension. The friction may be considered as consisting of two

components, one due to the rollers and the other the friction

between the soil and the rods. The first of these two is fairly

well eliminated by rolling the thrust bearing, particularly where the rods

pass through the table. The friction between the rods and the soil

can be minimized by forcing the rods a set distance beyond the

bottom of the hole for each test. It would only be necessary then

to take an occasional test for the frictional resistance. The test

in the drill rods themselves may or may not be a source of confusion

depending on their size and length.

The "Friction Vane Tester" has been designed to take

friction into account by means of a special graph printed on the

force table. It is described in the paper by me and published

mentioned previously in this chapter.

REMARKS

It is felt that the application of the principles of the

vane shear apparatus to the investigation of the spreading

properties of muskeg has been proven, that is despite the organic nature of muskeg this thesis indicates that this type of soil is susceptible to exploration by means of vane shear testing.

Further, many of the standard laboratory tests are suitable for determining other properties of this particular terrain. Among these tests are that for specific gravity, unconfined compression (and by inference confined compression) and consolidation.

Particular care, however, must be paid to the interpretation of the results of these tests. The fact that this soil is almost entirely organic must be considered and it is felt that it would be unwise to deal with test results or their application in the same manner as those for inorganic soils without keeping in mind this unique soil. An investigator must accustom his mind to accept values for the various properties that are vastly different from those associated with inorganic soils.

RECOMMENDATIONS

It is recommended that consideration be given to a program to yield quantitative data concerning the properties of organic soils based on a more precise vane shear apparatus. Inherent in these operations is the effect of the shape of the vanes. Separate tests under laboratory conditions would be indicative of the most acceptable shapes of the vanes. Vane tests may be augmented by laboratory work.

[illegible][illegible]

100

BIBLIOGRAPHY

- Radforth, Norman W. - "Suggested Classification of Muskeg for the Engineer". The Engineering Journal, November, 1952.
- Lea, N.D. and Benedict, B.D. - "The 'Foundation' Vane Tester for Measuring In-Situ Shear Strength of Soil". Proceedings of the Sixth Canadian Soil Mechanics Conference, December 15 and 16, 1952; N.R.C. Technical Memorandum No. 27.
- Hanrahan, E.T. - "An Investigation of Some Physical Properties of Peat". Geotechnique, September 1954.
- Skempton, A.W. - "Vane Tests in the Alluvial Plain of the River Forth near Grangemouth". Geotechnique December 1948.
- Vey, E. and Schlesinger, L. - "Soil Shear Tests by Means of Rotating Vanes". Proceedings of the Highway Research Board, 29th Annual Meeting, 1948.

REFERENCES

Reddy, J. N. - "An extended discussion of the
for the subject. The American Journal,
November, 1952.

Lee, T. O. and Benedict, B. L. - "The 'Transition' zone
center for research in the Great Britain of
Society. Proceedings of the Sixth Canadian Soil
Mechanics Conference, December 15 and 16, 1951;
N.S.C. Technical Information No. 17.

Hansen, A. T. - "An investigation of some physical
properties of soil." Geotechnique, September 1954.

B29772