AN INVESTIGATION OF

THE ENGINEERING

PROPERTIES OF MUSKEGS

BY

CAPT. S. THOMSON

THE CORPS OF ROYAL CANADIAN

ENGINEERS

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.

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

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

LIST OF FIGURES

LIST OF TABLES

LIST OF PLANS

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

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.

CHAPTER III

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:

$$Mr = S(2\pi rh.r+2\int_0^r 2\pi r^2 .dr)$$
$$= 2\pi r^2 S\ (h+0.67r)$$

in which

Mr = 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

applied moment is simply "FR".

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

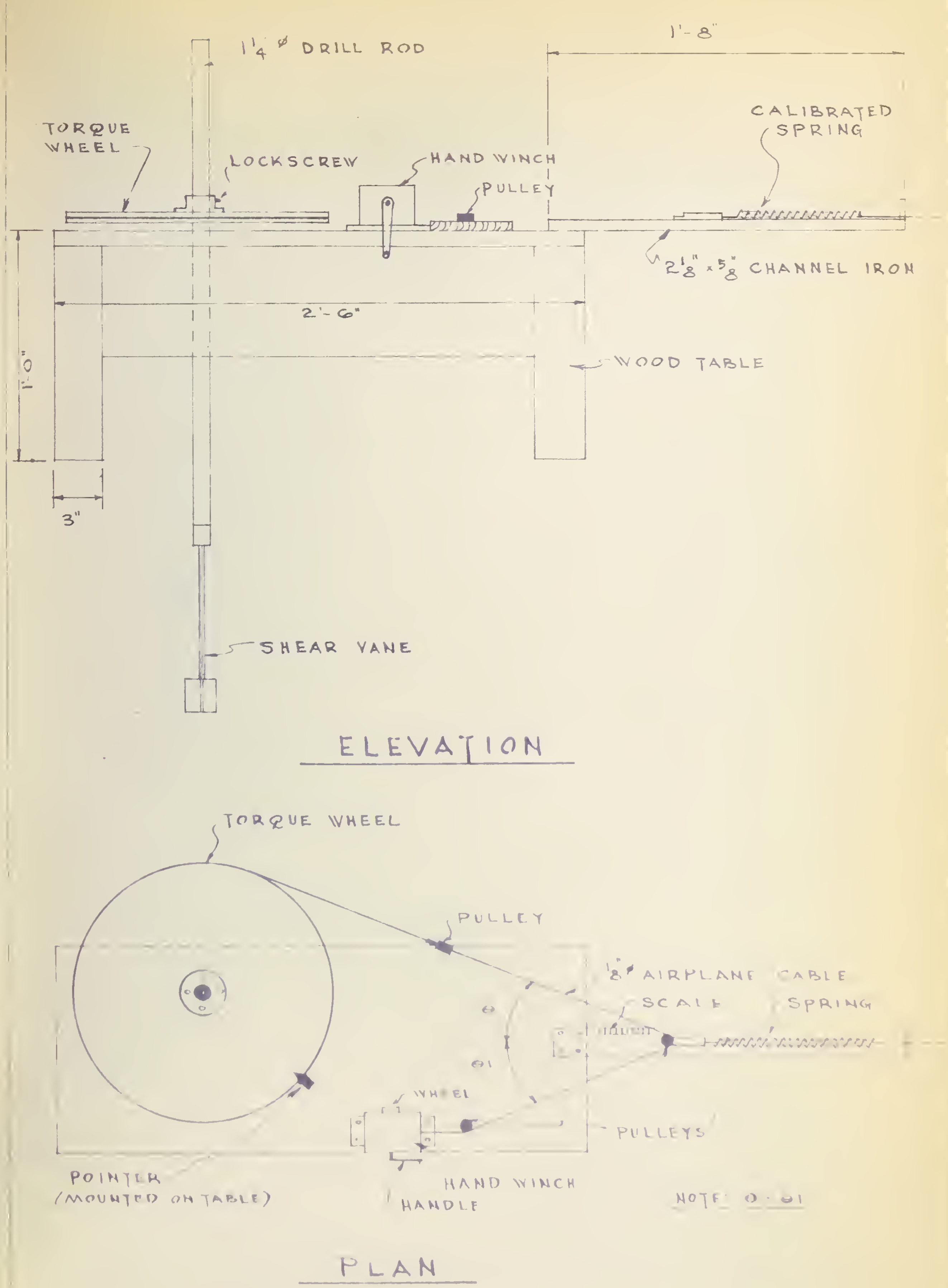
$$FR = 2\ r^2S(h+0.67r)$$

from which

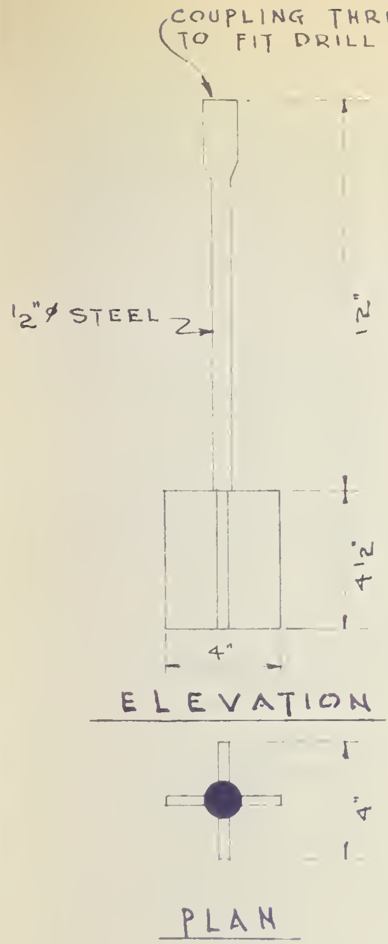
$$S = \frac{FR}{2\pi r^2(h+0.67r)}$$

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 4½" 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

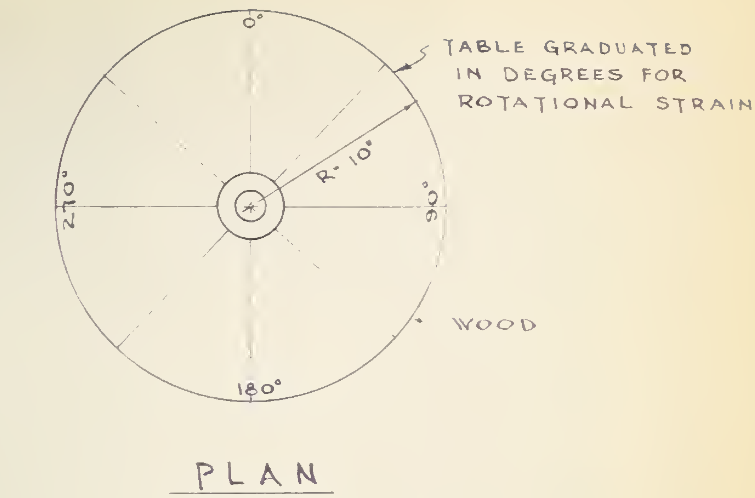


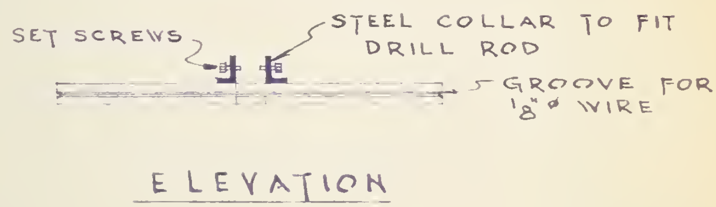
VANE SHEAR APPARATUS
(ASSEMBLY DRAWING)



SHEAR VANE

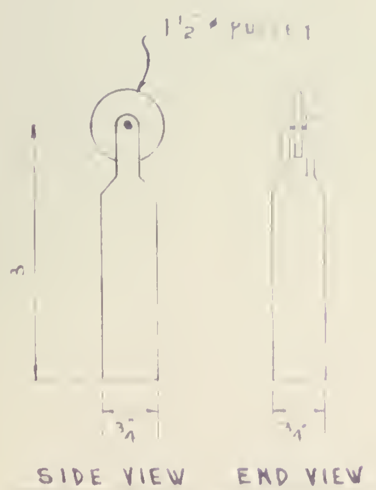
SCALE 1"-6"





TORQUE WHEEL

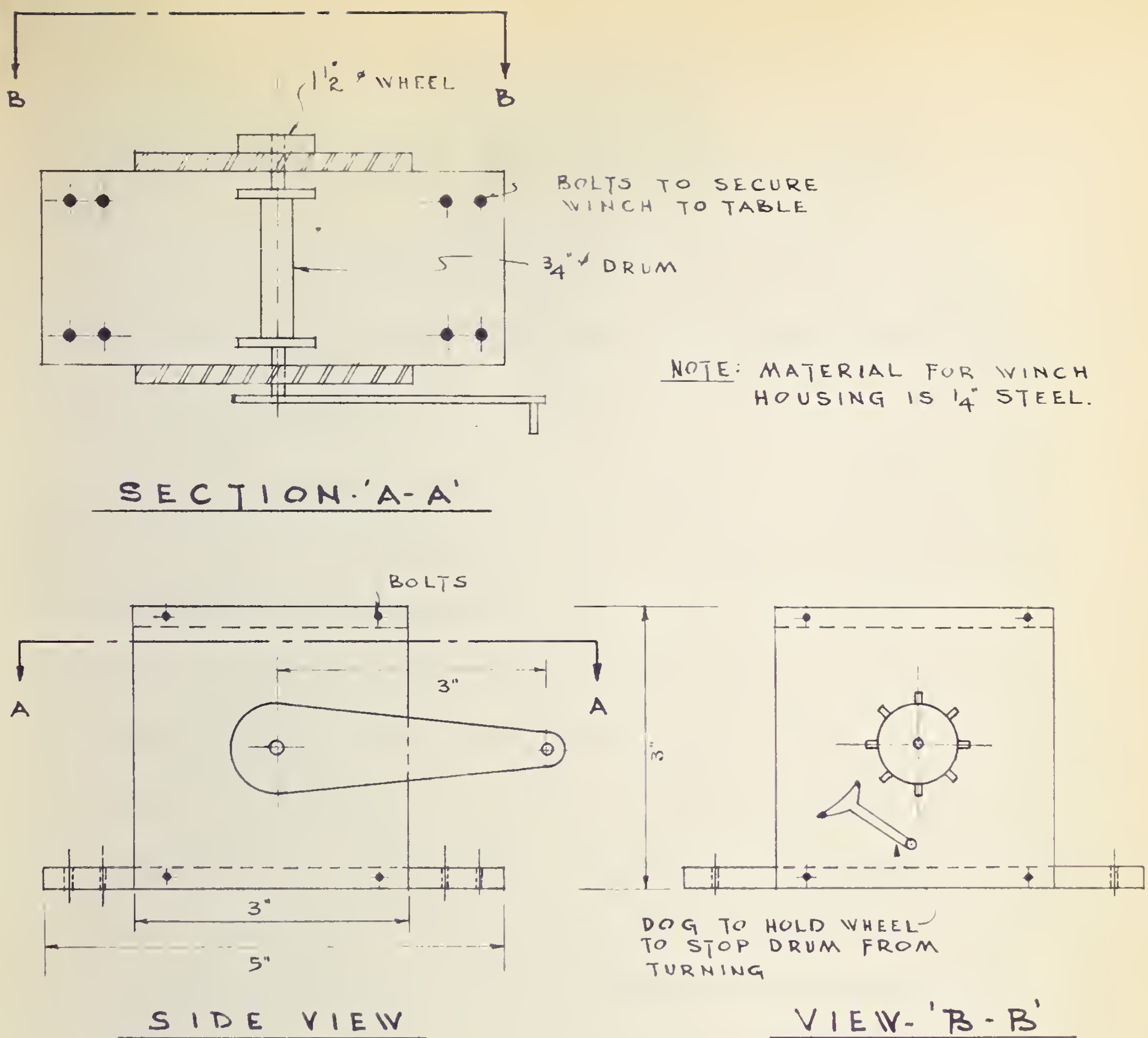
SCALE 1"-10"



STEEL FRICTIONLESS PULLEY

SCALE ½"-1"

DETAILS OF VANE SHEAR APPARATUS PARTS



DETAIL HAND WINCH

SCALE ½"-1"

the formula reduces to:

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

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

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

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.

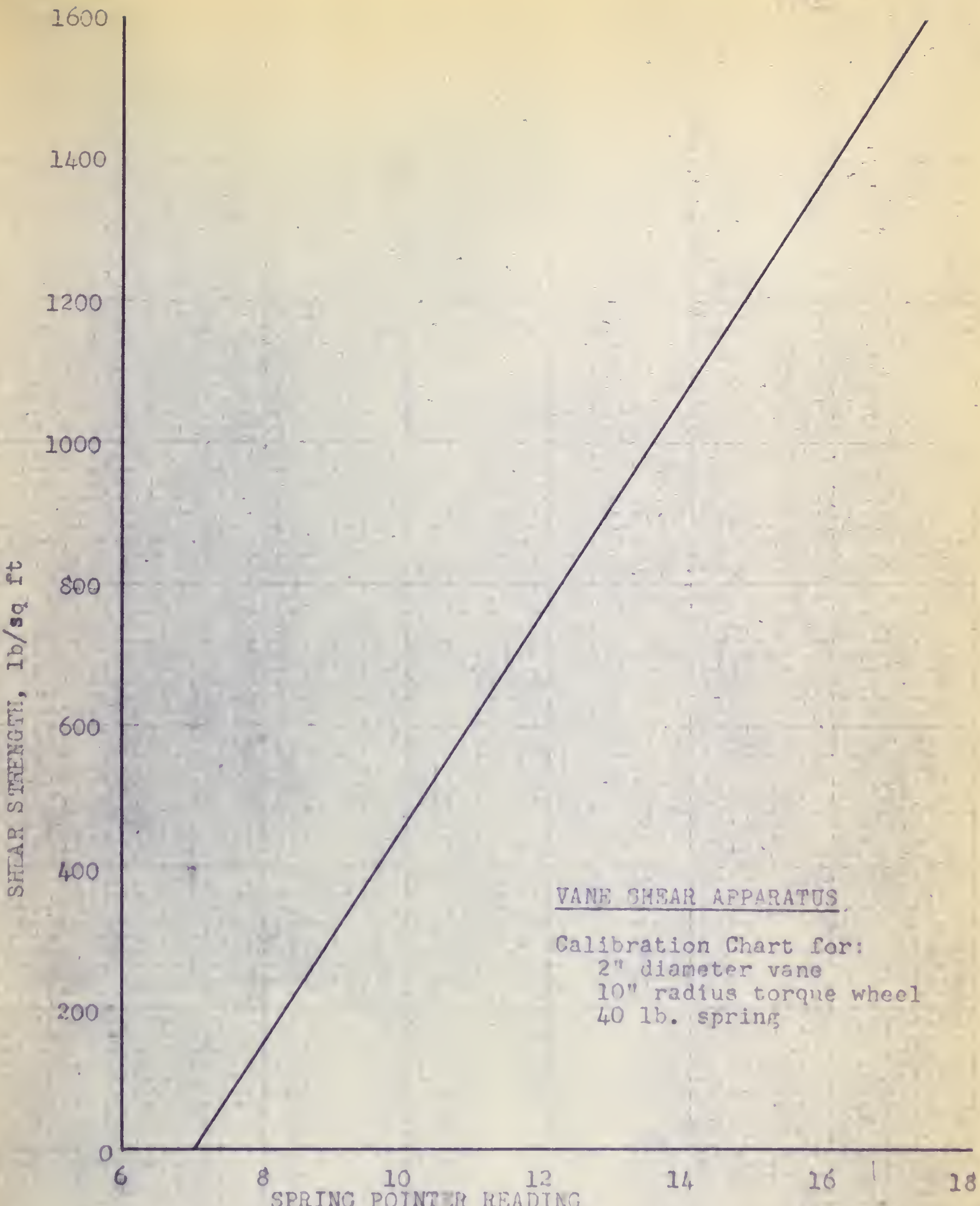


Fig 2 Chart For Converting Spring Tension to Shear Strength

Fig 3 - General View

of the Apparatus

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 ½" 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

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 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 [illegible] degrees per minute. This is approximately equivalent to the laboratory time of commercial type tests.

The vane shear apparatus was supplemented by an Iwan soil testing kit and the 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 quantitive 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.

TABLE 'A'

TEST DATA FROM STATION 419 + 00

pth below Surface	Max.Spring Reading	Vane & Spring	Total Tension lbs.	Friction lbs.	Net Tension lbs.	Shear Strength lbs./ft²	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 'B'

TEST DATA FROM STATION 420 + 00

pth 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 'C'

TEST DATA FROM STATION 421 + 00

th below urface	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	30
						Start Clay	12.5
13.5	11.1	2" - 60	24.0	20	4.0	177	40

TABLE 'D'

TEST DATA FROM STATION 422 + 00

pth 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

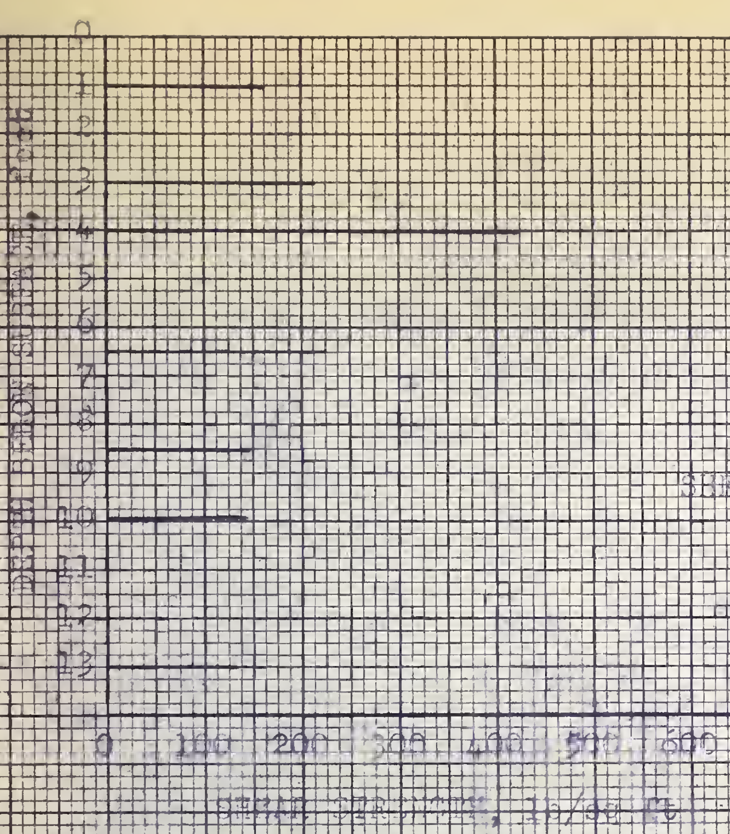


Fig 6
SHEAR STRENGTH VS DEPTH
For Sta. 419+00

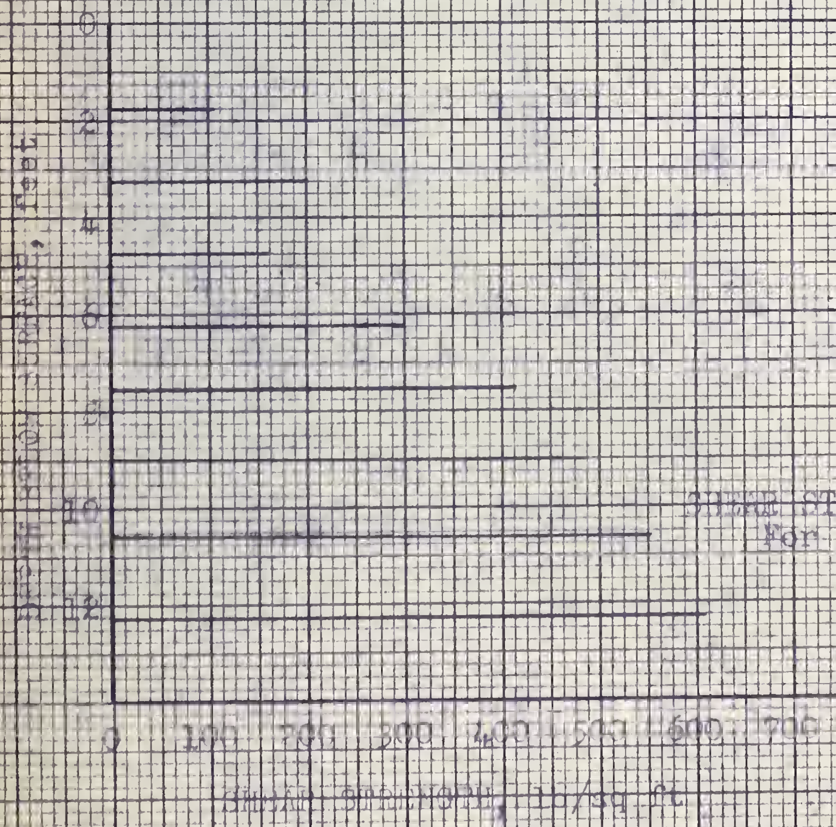


Fig 7
SHEAR STRENGTH VS DEPTH
For Sta. 420+00

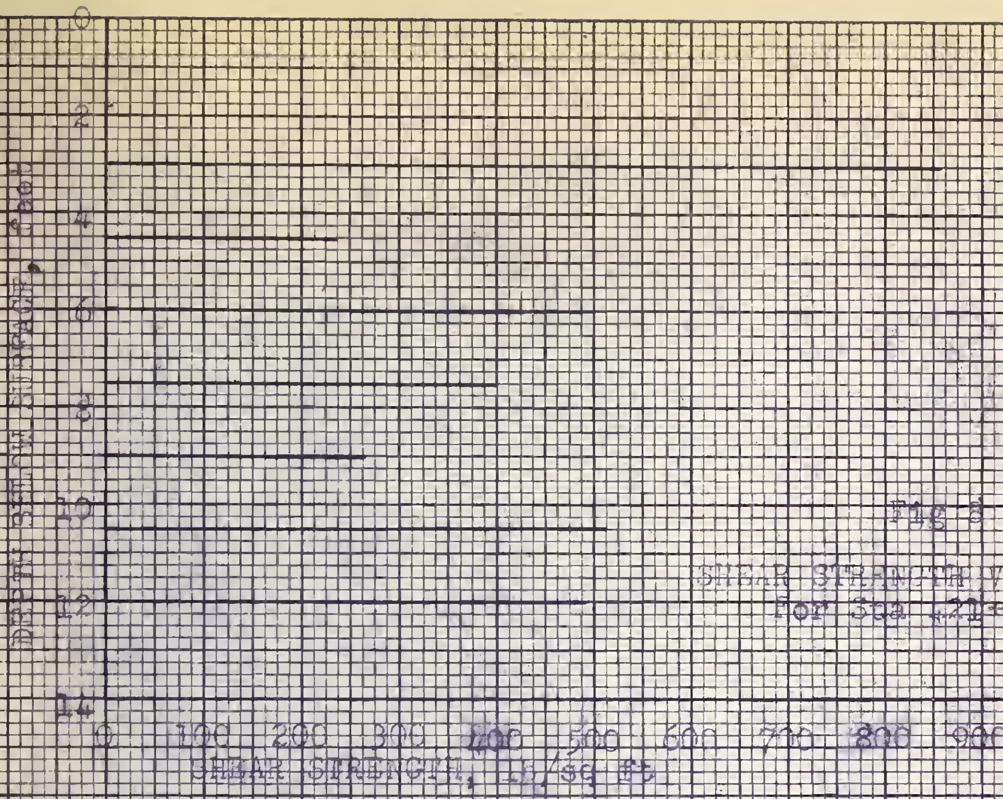


Fig 3

SHEAR STRENGTH VS DEPTH
for Sta 421+00

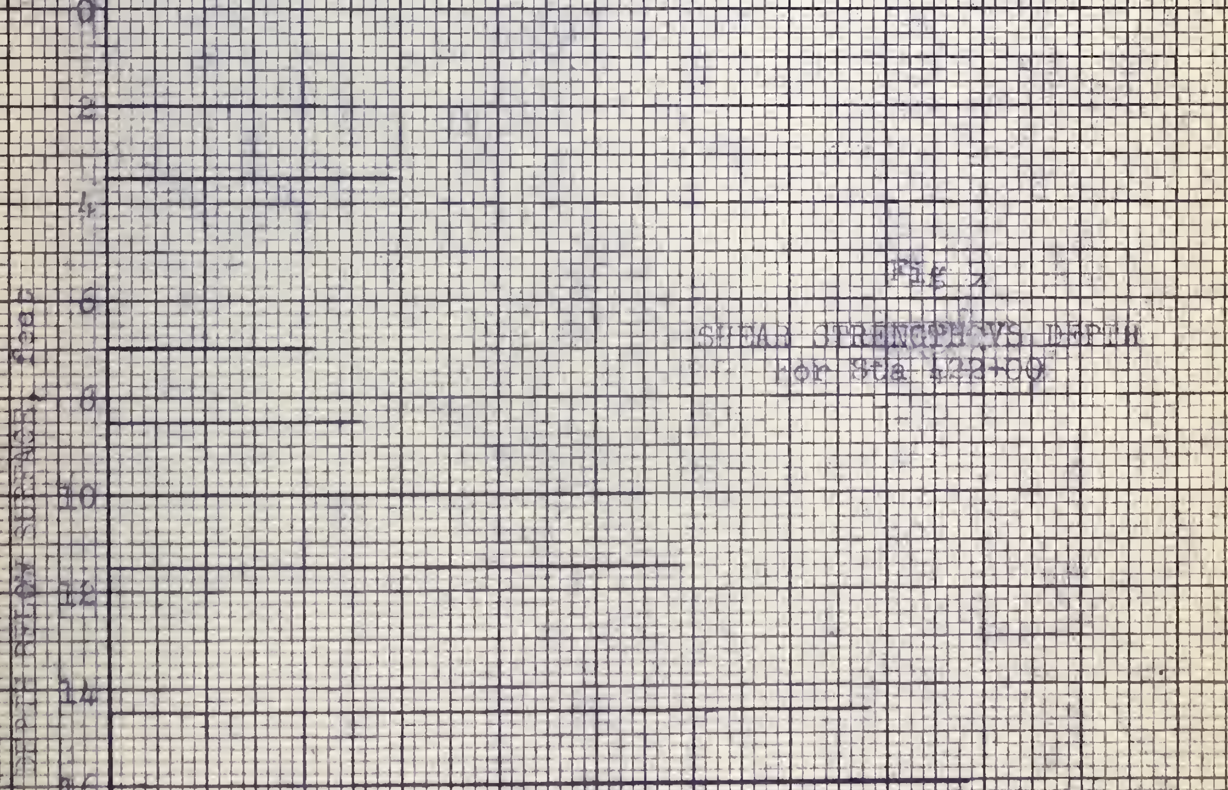


Fig 4

SHEAR STRENGTH VS DEPTH
for Sta 422+00

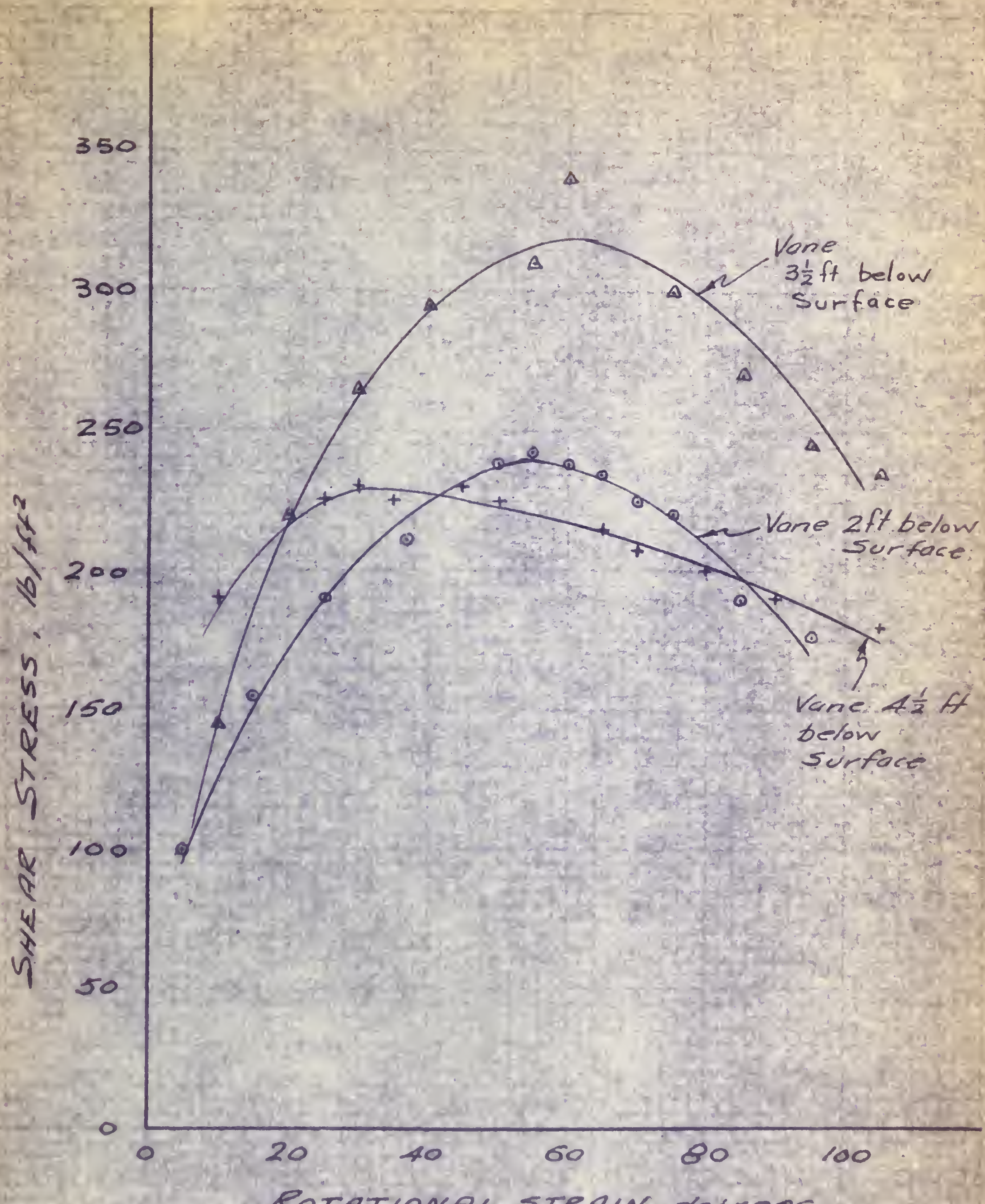


Fig 10 STRESS STRAIN CURVES FOR STA 422+00

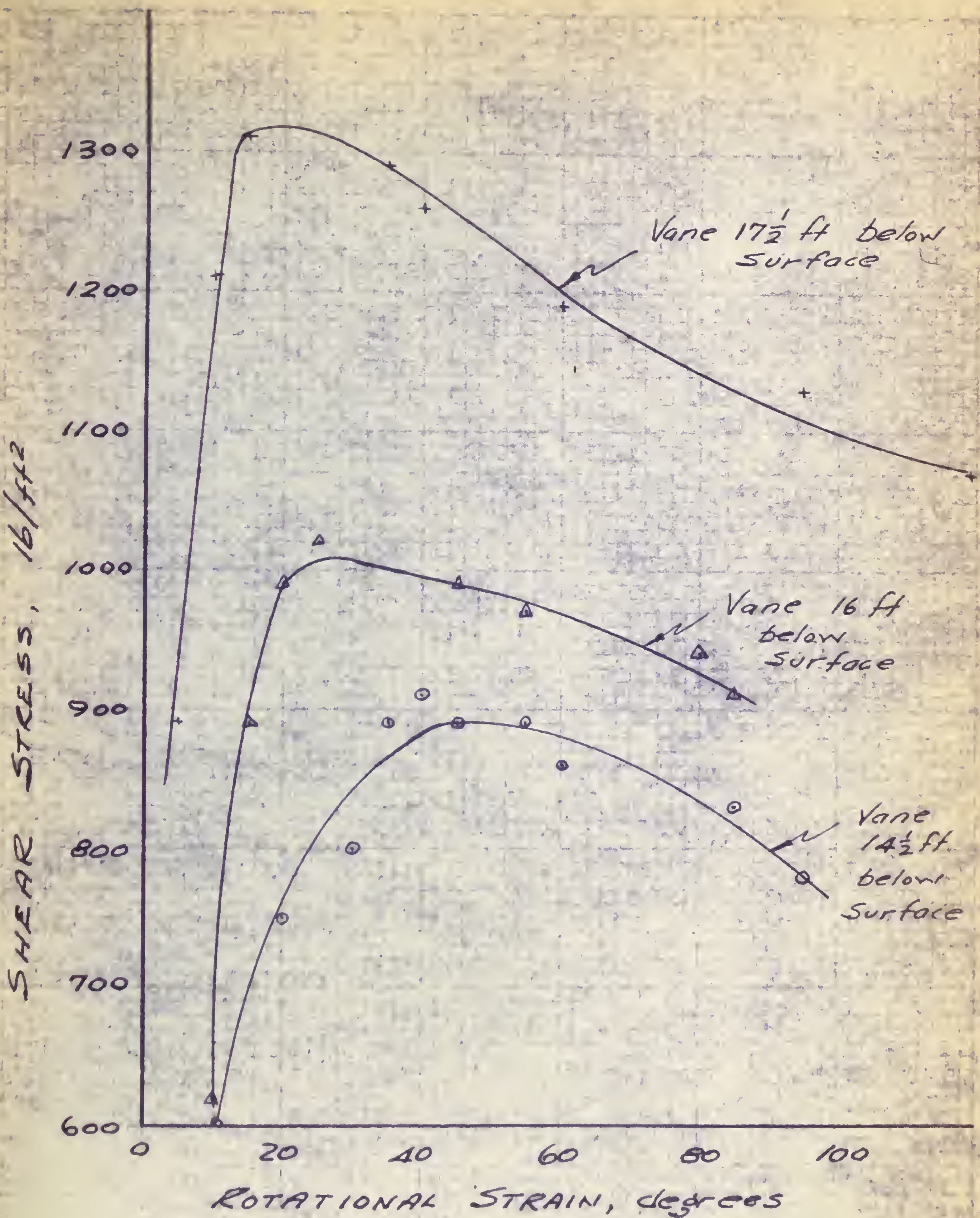


Fig 11 STRESS STRAIN CURVES FOR STA 422+00

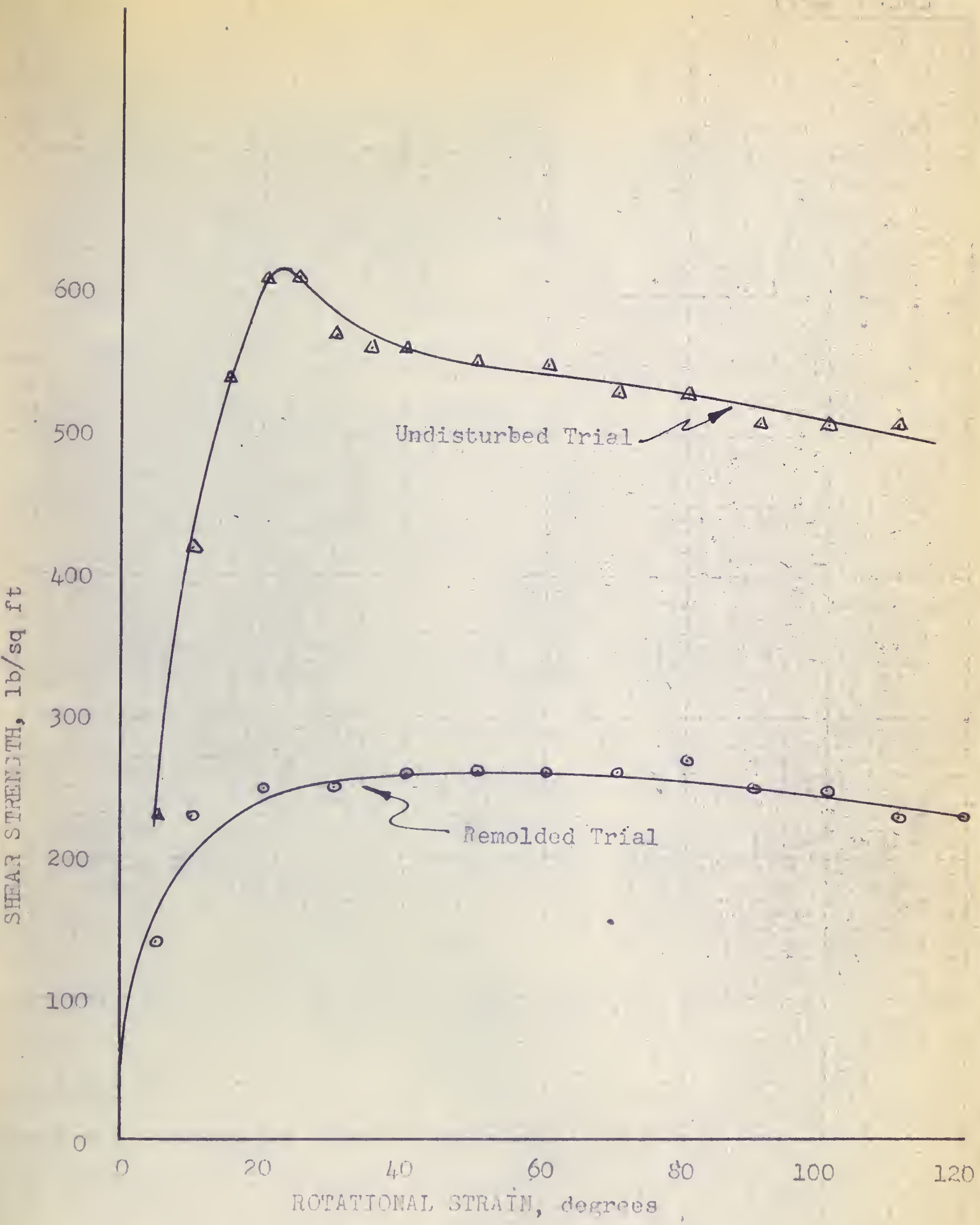


Fig 12 Typical Stress vs Rotational Strain Curves for Undisturbed and Remolded Tests of the Vane Shear Apparatus. Sta 420+00, vane 12 ft below surface.

TABLE 'E'

NORTHWEST HIGHWAY SYSTEM

SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY DETERMINATION

SITE ....254.................. LOCATION.......Prophet Sec......

DATE SAMPLED ..Aug 54................ DATE TESTED ....5 May 55.........

INITIALS ....SS...................

DESCRIPTION OF SAMPLES:

Light brown fibrous organic material.

REMARKS:

Some floating debris made the reading of the meniscus difficult.

	TRIAL I	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 '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...............

Site ....Mile 254.............

Location ....Muskeg 419 + 00.......

Technician ..S.T..................

Sample Length ..3.30"..................

Sample diameter ...1.6"...........

Original cross section area = 0.7854 (dia)^2 = ...12.95 cm^2........

Total Weight wet and tare ...218.15.gm

Weight dry and tare 93.41.gm

Weight water ....124.74.gm.

Weight tare 77.01.gm

Weight of dry soil ....16.40.gm.

Moisture Content ....760%...

SKETCH OF FAILURE

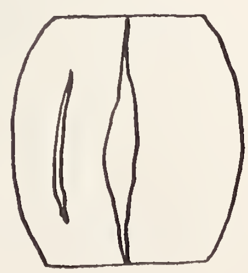


TABLE 'G'

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........

Site ....419 + 00 depth 11-12.5........

Location ....Muskeg........

Technician ....

Sample Length ....3.0"........

Sample diameter ....1.86 inches........

Original cross section are = 0.7854 (dia)^2 = ...17.5 cm^2 (2.71 in^2)........

Weight wet and tare ....50.74.

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%.

SKETCH OF FAILURE

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 tn/ft^2

= 860 lb/ft^2

Date ....28 Oct 54..........

Site ....Mile 254..........

Location ....Muskeg..........

Technician ....ST & FHB..........

Sample Length ....3.82"..........9

Sample diameter ....1.9"..........

Original cross section area = 0.7854 $(dia)^2$ = ...18.3 cm^2..........

Weight wet and tare ....125.20..........

Weight dry and tare ....85.07..........

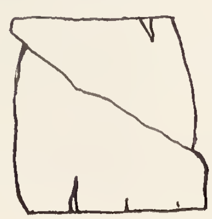
Weight water ....40.13..........

Weight tare ....76.52..........

Weight of dry soil ....8.55..........

Moisture content ....470%..........

SKETCH OF FAILURE



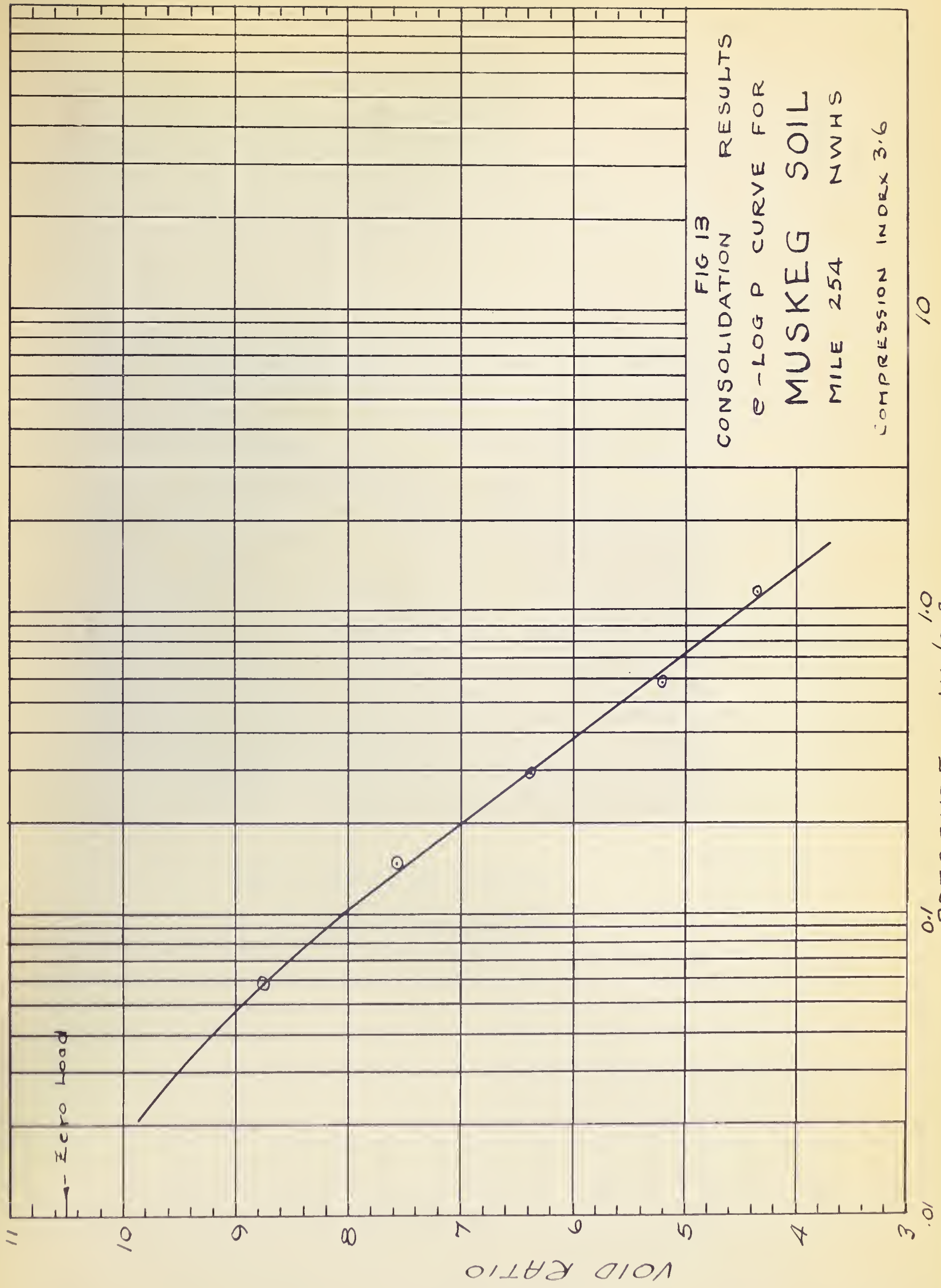


FIG 13
CONSOLIDATION RESULTS
e - LOG P CURVE FOR
MUSKEG SOIL
MILE 254 NWHS
COMPRESSION INDEX 3.6

Fig. 14 Muskeg soil adhering
to the vanes 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 presser (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 occuring 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 lV 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 (34 sq. cms. cross section area) and about one inch in thickness at the start of the test. Graph No. 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 using 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 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. [illegible] in his paper "Vane tests in the alluvial [illegible] of the river [illegible]" assumes that the radius of the cylinder on which shear takes place is slightly greater than the radius of the vanes. [illegible] and [illegible] in their paper "The [illegible] 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 soil [illegible] 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 soil 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 [illegible]. Replacement of the wooden parts by [illegible] 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

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 (a nd 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.

properties of muskeg can be proven, this is [illegible] the organic nature of muskeg that [illegible] indicates that this type of soil is susceptible to exploration by means of some other testing. Further, many of the standard laboratory tests are suitable for determining other properties of this particular terrain. Among these tests are the: specific gravity, unconfined compression (a or qu [illegible] 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 remember also in accepting 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 gain quantitative data concerning the properties of organic soils based on a more precise [illegible] research. Interest in these [illegible] in the [illegible] of the [illegible] of the moves. [illegible] tests under laboratory conditions [illegible] to [illegible] indications of the [illegible] organic [illegible] of the [illegible]. These tests may be suggested by laboratory work.

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.