COMPARATIVE RESULTS OF CO-OPERATING LABORATORIES

ON

THE SHEARING RESISTANCE OF OTTAWA SAND

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PREFACE

The Subcommittee on Shearing Resistance of Sails was organized in 1937 as part of the A.S.T.M. Committee D 18 on Soils for Engineering Purposes. The aim of this subcommittee was to study the variations in results of different shear testing machines in order to establish standards of equipment and procedure in the determination of the shearing resistance of soils.

To study the factors affecting the measurement of shearing resistance in soils, the subcommittee selected two materials for investigation. The first was Ottawa Sand representing the ultimate of a cohesionless material, a standard for comparing the various shear testing equipments. The second was a Detroit clay furnished by Prof. W. S. Housel, University of Michigan, representing a soil primarily cohesive.

Only the comparative test results on Ottawa Sand are included in this thesis.

ACKNOWLEDGEMENT

The author wishes to express his appreciation for the guidance and assistance given by Professor Frederick J. Converse in the preparation of this thesis and for access to the results of the various co-operating laboratories.

CO-OPERATING LABORATORIES

1.	California Institute of Technology	Vey and Silberstein
2.	Columbia University	Prof. D.M.Burmister
3.	University of Michigan	A. L. Davies
4.	Princeton University	Prof.G.P.Tschebotareff
5.	U.S.Engineer Laboratory	Fort Peck, Montana
6.	U.S.Engineer Office	Ithaca, New York
7.	U.S.Dept. of Interior	Washington, D.C.

CONTENTS

SHEAR RESEARCH PROGRAM - OTTAWA SAND

Sand passing the No. 20 sieve and retained on the No. 30 sieve is to be compacted in the shear machine at three densities,

(a) The loosest possible condition

(b) The densest state obtainable by vibration, or otherwise

(c) A relative density of 50%

For each density the shearing strength of sand should be obtained under the following normal pressures in tons per sq. ft. perpendicular to the shearing plane:- 0.1, 0.3, 0.5, 0.7, 1.0, 2.0, 3.0 tons per sq. ft. If time is not available to run the full series, it is suggested that alternate pressures in the above list be omitted.

It is proposed that the shearing load be applied in increments of about one-eighth of the estimated ultimate strength, waiting until motion had ceased before applying each increment. If a different method of testing than the preceding is standard for any particular laboratory, it is suggested that this method be also used, and a detailed description turned in with the test results.

Plot normal stress in tons per square foot as abscissas, and ultimate shearing resistance in pounds per square inch as ordinates. Plot the curve for each density separately, but plot all curves on the same sheet.

DISCUSSION ON TESTING APPARATUS

The shearing apparatus of all the cooperating laboratories are of the direct-shear type. Only the University of Michigan has the double shear type; all the others are single shear. Three laboratories place their samples in a circular shear box, whereas the other four laboratories use a square shear box.

Most of the shear boxes differ in thickness. Various methods were used in applying both normal and shearing loads.

Rate of shear loading varied from a constant applied force to a loading applied in increments.

Detailed description of all the shear testing apparatus of the various co-operating laboratories are included in the body of the thesis under the condensed reports on the testing of Ottawa Sand by each laboratory.

CONCLUSIONS

1. Angle of Internal Friction, ϕ.

There is no correlation between the angles of internal friction, ϕ, and the various voids of Ottawa sand. For the same dense void of 33.3%, the angle of internal friction, ϕ, varies from $34^{\circ}\ 45'$ to $54^{\circ}\ 20'$. Likewise, for the loose dry state, the voids range from 37.3% to 41%, whereas the angles of internal friction vary from $23^{\circ}\ 00'$ to $43^{\circ}\ 40'$. The largest ϕ value based upon ultimate shearing stress was given by the double shear testing apparatus of the University of Michigan. The graphs on pages 9 and 10 show the complete range of ϕ values for both dense and loose states.

Although the results of these series of tests are not entirely consistent, it appears that the thickness of the sample has an influence on the value of the angle of friction. The thicker samples tend to give the smaller values for ϕ. There is also a tendency for the shear boxes of larger areas to give the smaller values for ϕ. However, other factors of the shearing apparatus influence the relative ϕ values. These are friction in the apparatus, non-uniform distribution of normal load, pronounced boundary effects in smaller frames and progressive failure in dense sands.

These series of tests show that rate and manner of loading do not appear to have any appreciable influence on the value of the angle of internal friction. However, the results of the U. S. Engineer Laboratory at Fort Peck, Montana, show that the larger load increments in the A.S.T.M. method produce a lower ultimate shearing strength for the sample than was found in the corresponding test made according to the Fort Peck method.

The laboratories co-operating in the shearing testing program under the A.S.T.M. program are few in number and conclusive results cannot be drawn. Each shear testing machine should be calibrated by comparing with actual field observation of the angle of internal friction for various materials.

2. Comparison of Voids at Dense, Medium and Loose States.

The table on the proceeding page shows no correlation between the voids at dense, medium and loose states for the various laboratories. For the purpose of comparison, the dense state of the Ottawa sand is taken as 100% and the medium and loose states are calculated as percentages of the dense state.

OTTAWA SAND

Table - Comparison of Voids at Dense, Medium & Loose States

Cooperating Laboratory	State of Sand			State of Sand		
	Dense	Medium	Loose	Dense	Medium	Loose
	Voids			% of Dense State		
(1) Cal-Tech	32%		38%	100%		84.3%
(2) Columbia Univ.	33.3%		39.8%	100%		83.9%
(3) Univ.of Michigan	33.4%	35.0%	38.0%	100%	95.5%	88.0%
(4) Princeton Univ.	31.0%		41.0%	100%		75.5%
(5) U.S.Eng.Lab., Fort Peck,Mon.	36.0%	38.4%	40.8%	100%	93.8%	88.3%
(6) U.S.Eng.of Ithaca New York	Not given					
(7) U.S.Dept. Int. Washington, D.C.	33.4%	35.0%	37.3%	100%	95.5%	89.5%

SUMMARY OF TEST RESULTS CO-OPERATING LABORATORIES

Tests on Ottawa Sand

1. Ultimate Shearing Stress for Dense State.

Co-operating Laboratory	State of Sand	Voids	Rate of Loading	Shear Box Dimensions cms.	Shear Box Thick. cms.	Sin. or Double Shear	ϕ	Ultimate Shearing Stress: Tons/Sq.Ft. N = Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0	3.5	4.0	Remarks
1. Cal-Tech	Dense, Dry	32.0%	0.085"/min.	6.12 dia.	3.94	Single	24°30'	0.04		0.17	0.25	0.17	0.72	1.30			
2. Columbia Univ.	Dense, Dry	33.3%	0.05 "/min	6.35x8.90	2.60	Single	34°45'		N=0.29 0.21	N=0.55 0.41		N=1.06 0.72	N=1.57 1.09	N=2.09 1.49			
3. Univ. of Michigan	Dense, Dry Dense, Dry	33.4% 33.4%	Eq.Inc.at 10' 3#/ min.	3.50 dia. 3.50 dia.	2.50 2.50	Double Double	51°15' 54°55'	 0.40	0.65 0.65	0.86 0.90	1.22 1.13	1.65 1.55	2.91 3.02	4.08 4.45			
	Dense, Dry	33.4%	Constant	11.48 dia.	7.62	Double	54°20'		N=0.36 0.55		N=0.72 0.98	N=1.44 2.05	N=2.16 2.99		N=3.60 5.02		
4. Princeton Univ.	Dense, Dry Dense, Moi	31.0% 35.0%	Eq.Inc.&Const. Constant	6.0x6.0 6.0x6.0	1.62 1.62	Single Single	39°00' 34°40'	0.11 0.12	0.3	0.44 0.43	0.53	0.79 0.73	1.60	2.41 2.12			
5.U.S.Eng.Lab Fort Peck, Mon	Dense, Dry Dense, Dry	36.0% 36.0%	Increments Increments	10.15x10.15 10.15x10.15	2.54 2.54	Single Single	29°10' 35°00'	0.03 0.04	0.10 0.13	0.31 0.32	0.46 0.45	0.59 0.68	1.04 1.26	1.72 2.07			A.S.T.M. Method Fort Peck Method
6.U.S.Eng.Off Ithaca, N.Y.	Dense, Dry	Not given	Constant	10.15x10.15		Single	24°00'		0.16	0.25	N=1.00 0.49	N=1.32 0.59	0.89	1.35	1.58		
	Dense, Moi	do	Constant	10.15x10.15		Single	24°40'		0.24	0.24	N=1.00 0.45		0.88	1.38			
7.U.S.Dep.Int Wash., D.C.	Dense, Dry	33.4%	Increments	6.35 dia.	2.54	Single	50°00'		N=0.234 0.32	N=0.476 0.60	N=0.718 0.88	N=0.960 1.17	N=1.203 1.46				

2. Maximum Shearing Stress for Dense State

Co-operating Laboratory	State of Sand	Voids	Rate of Loading	Shear Box Dimensions cms.	Shear Box Thick. cms.	Sin. or Double Shear	ϕ	Maximum Shearing Stress: Tons/Sq.Ft. N = Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0	3.5	4.0	Remarks
1. Cal-Tech	Dense, Dry	32.0%	0.085"/min.	6.12 dia.	3.94	Single	35°50'	0.05		0.25	0.46	0.38	1.32	2.09			
2. Columbia Univ.	Dense, Dry	33.3%	0.05 "/min.	6.35x8.90	2.60	Single	43°10'		N=0.29 0.36	N=0.55 0.64		N=1.06 1.16	N=1.57 1.57	N=2.09 2.10			
6.U.S.Eng.Off Ithaca, N.Y.	Dense, Dry	Not given	Constant	10.15x10.15		Single	29°20'		0.22	0.35	N=1.00 0.67	N=1.32 0.86	1.20	1.70	2.05		
	Dense, Moi	do	Constant	10.15x10.15		Single	32°20'		0.22	0.34	N=1.00 0.66		1.19	1.88	2.16	2.61	
7.U.S.Dep.Int Wash., D.C.	Dense, Dry	33.4%	Increments	6.35 dia.	2.54	Single	50°00'		N=0.234 0.32	N=0.476 0.60	N0.718 0.88	N=0.960 1.17	N=1.203 1.46				

SUMMARY OF TEST RESULTS CO-OPERATING LABORATORIES

Tests on Ottawa Sand

3. Ultimate Shearing Stess for Medium State.

Co-operating Laboratory	State of Sand	Voids	Rate of Loading	Shear Box Dimensions cms.	Shear Box Thick cms.	Sin. or Double Shear	ϕ	Ultimate Shearing Stress: Tons/Sq.Ft. N = Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	1.50	2.0	3.0	3.5	4.0	Remarks
3. Univ. of Michigan	Med., Dry	35.0%	Eq. Inc. at 10'	3.50 dia.	2.50	Double	47°20'			0.89	1.15	1.39		2.52	3.58			
	Med., Dry	35.0%	3#/min.	3.50 dia.	2.50	Double	49°45'	0.22	0.57	0.88	1.10	1.36		2.61	3 73			
									N=0.36		N=0.72		N=1.44	N=2.16		N=3.60		
	Med., Dry	35.0%	Constant	11.48 dia.	7.62	Double	45°10'		0.50		0.91		1.55	2.37		3.64		
5. U.S. Eng. Lab	Med., Dry	38.4%	Increments	10.15x10.15	2.54	Single	26°50'	0.02	0.13	0.23	0.39	0.55		0.90	1.54			A.S.T.M. Method
Fort Peck, Mon	Med., Dry	38.4%	Increments	10.15x10.15	2.54	Single	32°05'	0.02	0.12	0.30	0.39	0.62		1.17	1.85			Fort Peck Method
									N=0.234	N=0.476	N=0.718	N=0.960	N=1.203					
7. U.S. Dep. Int Wash., D.C.	Med., Dry	35.0%	Increments	6.35 dia.	2.54	Single	44°20'		0.24	0.47	0.72	0.97	1.17					

SUMMARY OF TEST RESULTS CO-OPERATING LABORATORIES

Tests on Ottawa Sand

4. Ultimate Shearing Stress for Loose State.

Co-operating Laboratory	State of Sand	Voids	Rate of Loading	Shear Box Dimensions cms.	Shear Box Thick. cms.	Sin. or Double Shear	ϕ	Ultimate Shearing Stress: Tons/Sq.Ft. — N = Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	1.50	2.0	3.0	3.5	4.0	Remarks
1. Cal-Tech	Loose, Dry	38.0%	0.085"/min.	6.12 dia.	3.94	Single	23°00'	0.05		0.11	0.23	0.35		0.68	1.19			
2. Columbia Univ.	Loose, Dry	39.8%	0.05 "/min.	6.35x8.90	2.60	Single	32°00'		N=0.29 0.22	N=0.55 0.38		N=1.06 0.69	N=1.57 1.03	N=2.09 1.34				
3. Univ. of Michigan	Loose, Dry	38.0%	Eq.Inc.at 10'	3.50 dia.	2.50	Double	42°40'			0.70	0.86	0.91		1.68	3.05			
	Loose, Dry	38.0%	3#/min.	3.50 dia.	2.50	Double	43°40'	0.21	0.37	0.57	0.76	1.19		2.14	3.08			
	Loose, Dry	38.0%	Constant	11.48 dia.	7.62	Double	27°00'		N=0.36 0.45		N=0.72 0.64		N=1.44 0.92	N=2.16 1.39		N=3.60 2.04		
4. Princeton	Loose, Dry	41.0%	Eq.Inc.&Const.	6.0x6.0	1.62	Single	32°00'	0.09	0.24	0.38	0.48	0.71		1.29	1.90			
	Loose, Moi	47.0%	Constant	6.0x6.0	1.62	Single	30°30'	0.08		0.33		0.59			1.78			
5. U.S. Eng. Lab Fort Peck, Mon	Loose, Dry	40.8%	Increments	10.15x10.15	2.54	Single	24°00'		0.13	0.20	0.32	0.37		0.89	1.31			A.S.T.M. Method
	Loose, Dry	40.8%	Increments	10.15x10.15	2.54	Single	29°45'		0.14	0.31	0.34	0.57		1.12	1.65			Fort Peck Method
6. U.S. Eng. Off Ithaca, N.Y.	Loose, Dry	Not given	Constant	10.15x10.15		Single	24°00'		0.14			0.46		0.90	1.34			
	Loose, Moi		Constant	10.15x10.15		Single	25°40'		0.13	0.23		0.47			1.44		1.88	
7. U.S. Dep. Int Wash., D.C.	Loose, Dry	37.3%	Increments	6.35 dia.	2.54	Single	36°00'		N=0.234 0.21	N=0.476 0.38	N=0.718 0.52	N=0.960 0.70	N=1.203 0.90	N=1.445 1.01	N=1.687 1.25			

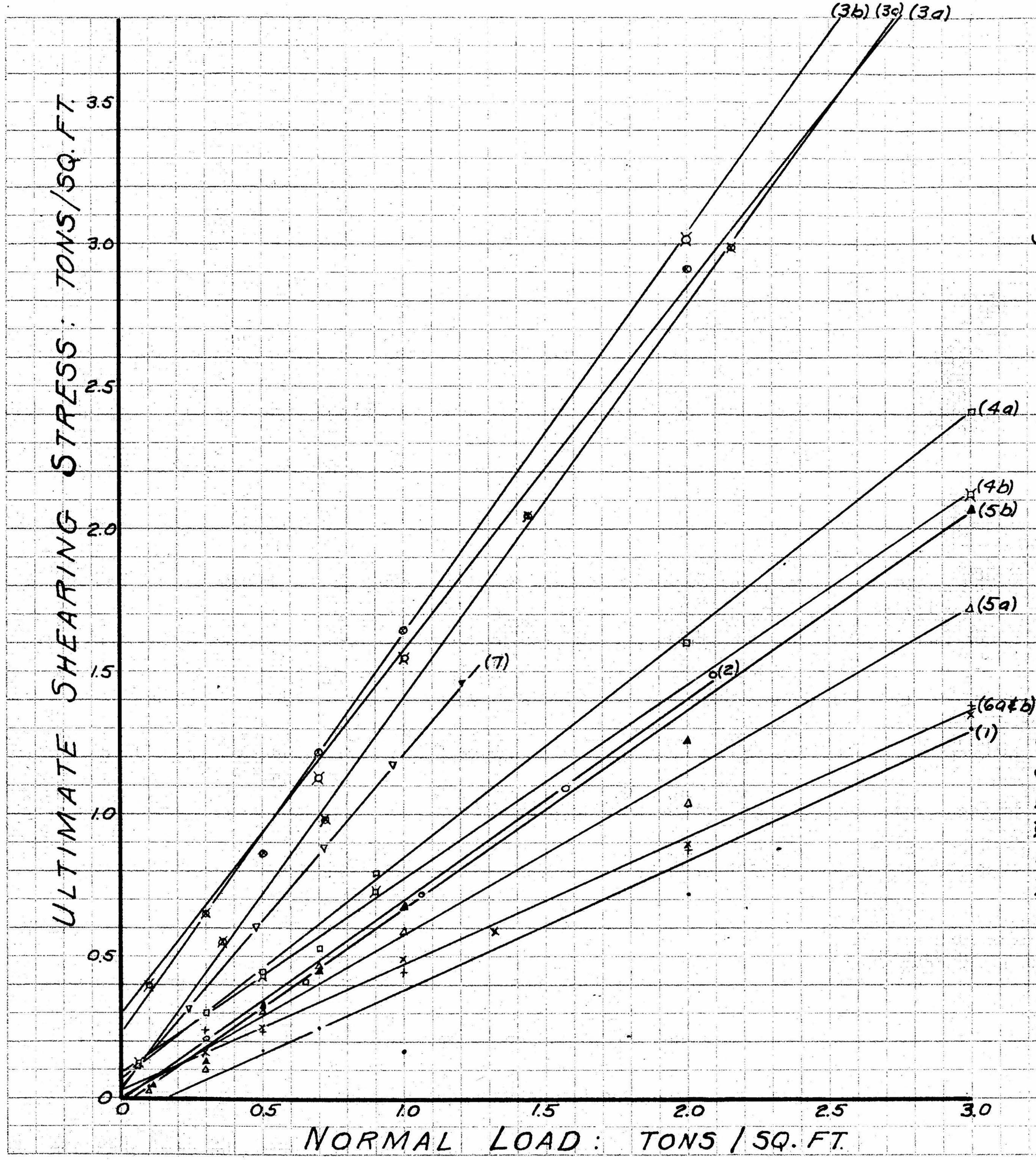
5. Maximum Shearing Stess for Loose State.

Co-operating Laboratory	State of Sand	Voids	Rate of Loading	Shear Box Dimensions cms.	Shear Box Thick. cms.	Sin. or Double Shear	ϕ	Maximum Shearing Stress: Tons/Sq.Ft. — N = Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	1.50	2.0	3.0	3.5	4.0	Remarks
1. Cal-Tech	Loose, Dry	38.0%	0.085"/min.	6.12 dia.	3.94	Single	23°50'	0.07		0.13	0.24	0.36		0.76	1.24			
2. Columbia	Loose, Dry	39.8%	0.05"/min.	6.35x8.90	2.60	Single	32°00'		N=0.29 0.22	N=0.55 0.38		N=1.06 0.69	N=1.57 1.03	N=2.09 1.34				
6. U.S. Eng. Off Ithaca, N.Y.	Loose, Dry	Not given	Constant	10.15x10.15		Single	26°40'		0.14	0.25	N=0.65 0.30	0.49		0.99	1.48		1.91	
	Loose, Moi		Constant	10.15x10.15		Single	25°40'		0.13	0.24		0.51		0.94	1.48		1.98	
7. U.S. Dep. Int.	Loose, Dry	37.3%	Increments	6.35 dia.	2.54	Single	36°00'		N=0.234 0.21	N=0.476 0.38	N=0.718 0.52	N=0.960 0.70	N=1.203 0.90	N=1.445 1.01	N=1.687 1.25			

Comparative Results of Co-operating Laboratories

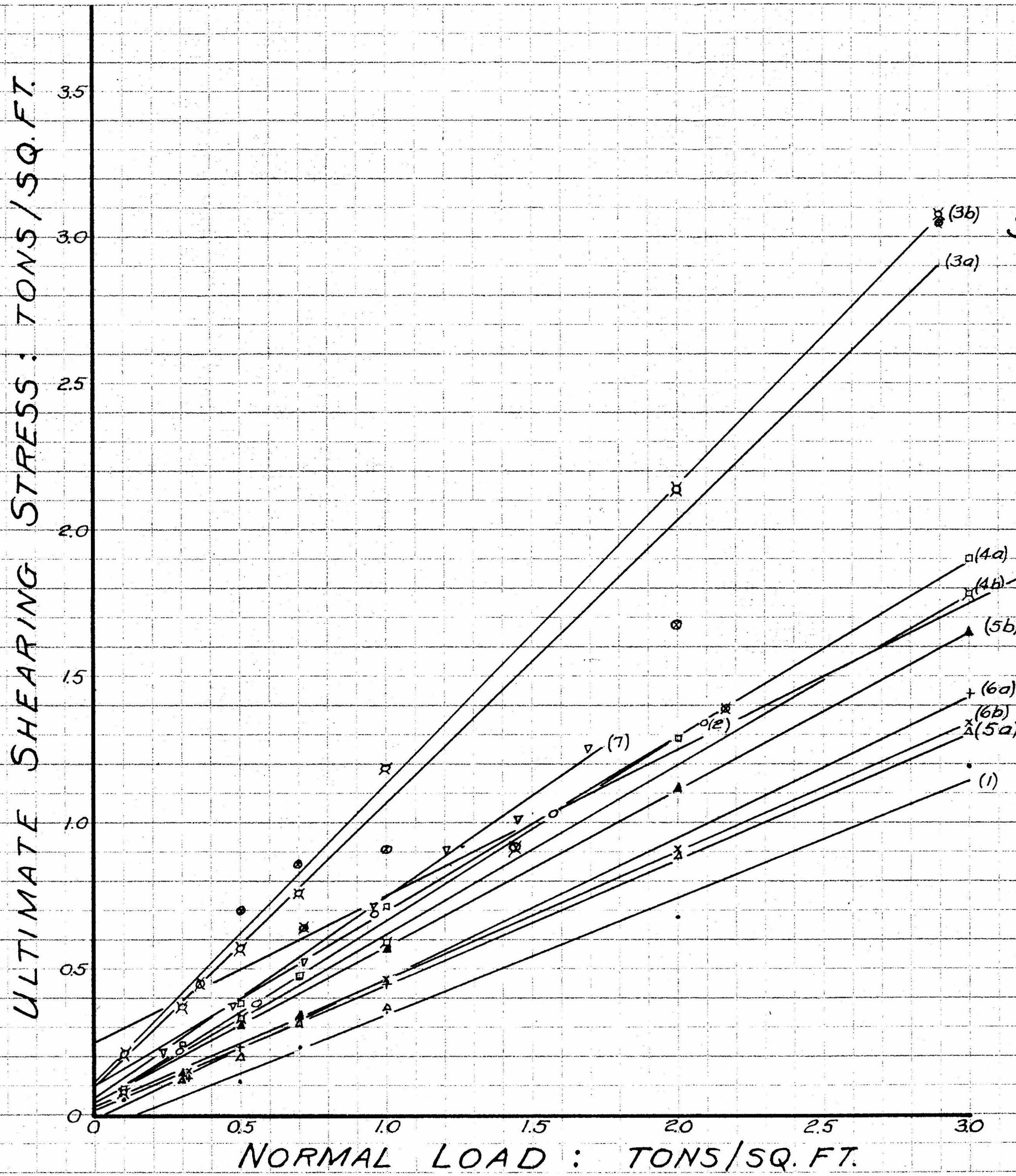
Shearing Tests on Ottawa Sand
- Dense State -

Ultimate Shearing Stress vs Normal Load



	No.	Laboratory	Voids	ϕ	State of Sand	Rate of Loading	Single or Double Shear	Shear Box Dim. cm.	Shear Box Thk. cm.
•	1	Cal-Tech	32%	24°30'	Dense, D.	0.085"/min.	S	6.12 d.	3.94
o	2	Columbia Univ.	33.3%	34°45'	Dense, D.	0.05"/min.	S	6.4x8.9	2.60
⊚	3a	Univ. of Michigan	33.4%	51°15'	Dense, D.	Increments	D	3.5 d.	2.50
¤	3b		33.4%	54°55'	"	3#/min.	D	3.5 d.	2.50
⊠	3c		33.4%	54°20'	"	Constant	D	11.5 d.	7.62
□	4a	Princeton Univ.	31%	39°00'	Dense, D.	Increments & Constant	S	6.0x6.0	1.62
⌑	4b		35%	34°40'	Dense, M.	Constant	S	"	"
△	5a	U.S. Eng. Lab.	36%	29°10'	Dense, D.	Increments	S	10.2x10.2	2.54
▲	5b	Fort Peck, Mont.	36%	35°00'	Dense, D.	"	S	"	"
×	6a	U.S. Eng.	Not	24°00'	Dense, D.	Constant	S	10.2x10.2	Not
+	6b	Ithaca, N.Y.	given	24°40'	Dense, M.	"	S	"	given
▽	7	U.S. Dep. Int. Wash. D.C.	33.4%	50°00'	Dense, D.	Increments	S	6.35 d.	2.54

D = Dry
M = Moist



COMPARATIVE RESULTS OF CO-OPERATING LABORATORIES

SHEARING TESTS ON OTTAWA SAND
- LOOSE STATE -

Ultimate Shearing Stress vs Normal Load

	No.	Laboratory	Voids	ϕ	State of Sand	Rate of Loading	Single or Double Shear	Shear Box Dim. cm.	Shear Box Thk. cm.
•	1	Cal-Tech	38%	23°00'	Loose, D.	0.085"/min.	S	6.12d.	3.94
○	2	Columbia Univ.	39.8%	32°00'	Loose, D.	0.05"/min.	S	6.4x8.9	2.60
⊗	3a	Univ. of Michigan	38%	42°40'	Loose, D.	Increments	D	3.5d.	2.50
¤	3b		38%	43°40'	"	3#/min.	D	3.5d	2.50
⊠	3c		38%	27°00'	"	Constant	D	11.5d	7.62
□	4a	Princeton Univ.	41%	32°00'	Loose, D.	Increments & Constant	S	6.0x6.0	1.62
⌧	4b		47%	30°30'	Loose, M.	Constant	S	"	"
△	5a	U.S. Eng. Lab.	40.8%	24°00'	Loose, D.	Increments	S	10.2x10.2	2.54
▲	5b	Fort Peck, Mont.	40.8%	29°45'	"	"	S	"	"
×	6a	U.S. Eng.	Not	24°00'	Loose, D.	Constant	S	10.2x10.2	Not
+	6b	Ithaca, N.Y.	Given	25°40'	Loose, M.	"	S	"	given
▽	7	U.S. Dep. Int. Wash. D.C.	37.3%	36°00'	Loose, D.	Increments	S	6.35d.	2.54

D = Dry
M = Moist

Testing Apparatus

Tests were performed on a Two Ring Direct Shear Testing Machine. Ring area = 4.56 square inches. Ring diameter = 2.41 inches or 6.12 centimeters. Sample thickness = $1\frac{1}{2}$ inches.

The Shear Testing Machine consisted of the following important parts:

(1) A lever to connect the motor to the machine.

(2) Two gears, one small-connected directly to the motor, and one large-connected to the machine. These gears provided a speed reduction such that no appreciable change of shearing speed is experienced with changes of the normal load.

(3) A lead screw on the shaft of the large gear operated in moving

(4) the metal frame containing the lower ring.

(5) A dial gage attached to this lower frame which indicated the amount of movement with respect to

(6) the stationary top frame. This frame consisted of two semicircular parts - one stationary and one removable. The removable part provided for placing and removing the sample.

(7) A dial gage was attached to the lower moving frame so as to give the shearing force at any time.

(8) Apparatus for applying various normal loads to the top face of the soil sample. This consisted of a porous stone

Testing Apparatus

Tests were performed on a Two Ring Direct Shear Testing Machine. Ring area = 4.56 square inches. Ring diameter = 2.41 inches or 6.12 centimeters. Sample thickness = $1\frac{1}{2}$ inches.

The Shear Testing Machine consisted of the following important parts:

(1) A lever to connect the motor to the machine.

(2) Two gears, one small-connected directly to the motor, and one large-connected to the machine. These gears provided a speed reduction such that no appreciable change of shearing speed is experienced with changes of the normal load.

(3) A lead screw on the shaft of the large gear operated in moving

(4) the metal frame containing the lower ring.

(5) A dial gage attached to this lower frame which indicated the amount of movement with respect to

(6) the stationary top frame. This frame consisted of two semicircular parts - one stationary and one removable. The removable part provided for placing and removing the sample.

(7) A dial gage was attached to the lower moving frame so as to give the shearing force at any time.

(8) Apparatus for applying various normal loads to the top face of the soil sample. This consisted of a porous stone

Testing Apparatus (Cont'd)

½" thick placed on the top face of the soil. On this porous stone was placed a similar diameter metal disc with a small hole on top for a metal ball. Balanced on this metal was a horizontal bar from which varying loads were hung.

The speed of the shearing was 0.085 inches per minute. Before placing the two ring sample in the machine, the rings were carefully cleared or separated of each other so there was no rubbing against each other. The intersection of the two rings coincided with the slip plane of the movable frame and stationary top frame.

Summary

These tests indicate that the relative compaction of the sand has little or no effect upon the shearing strength of the sand for low normal loads.

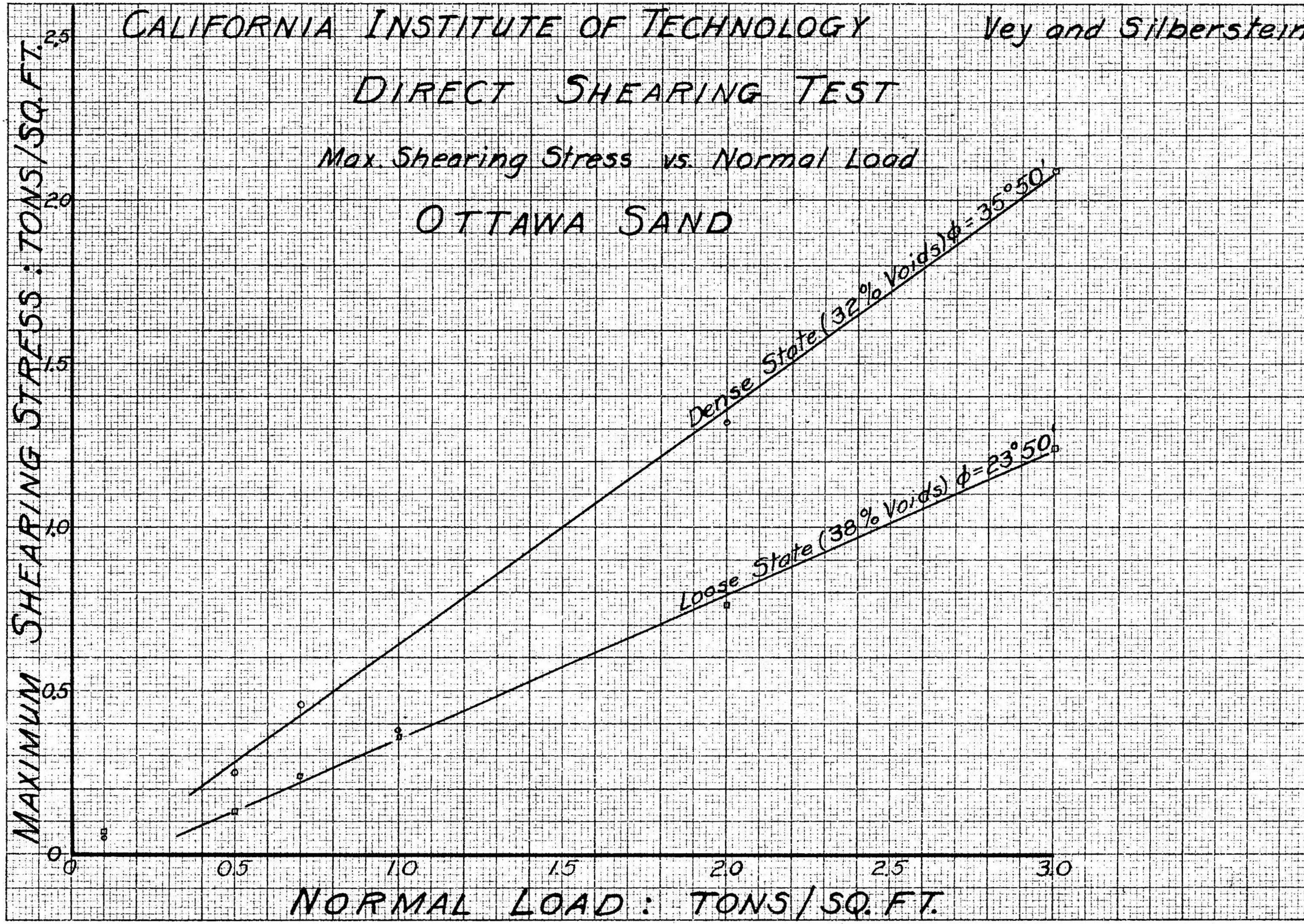
Tests on Ottawa Sand

1. Maximum Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Max. Shearing Stress: Tons/sq.ft. Normal Load: Tons/sq.ft.					
				0.1	0.5	0.7	1	2	3
Dense, dry	32%	0.085"/min.	35°50'	0.05	0.25	0.46	0.38	1.32	2.09
Loose, dry	38%	0.085"/min	23°50	0.07	0.13	0.24	0.36	0.76	1.24

2. Ultimate Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/sq.ft. Normal Load: Tons/sq.ft.					
				0.1	0.5	0.7	1	2	3
Dense, dry	32%	0.085"/min.	24°30'	0.04	0.17	0.25	0.17	0.72	1.30
Loose, dry	38%	0.085"/min.	23°00'	0.05	0.11	0.23	0.35	0.68	1.19



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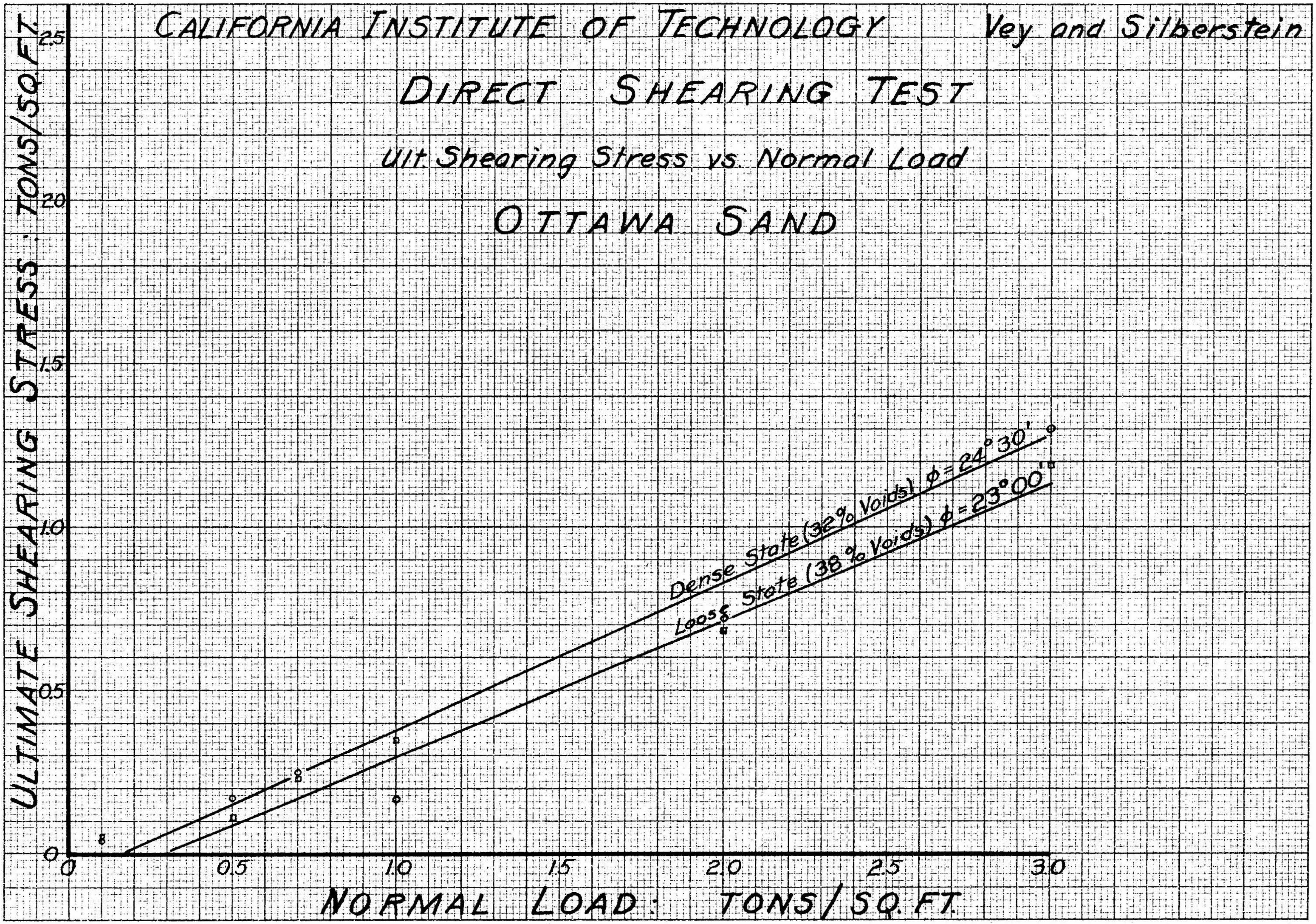
Vey and Silberstein
DIRECT SHEARING TEST
Max. Shearing Stress vs. Normal Load
OTTAWA SAND
Dense State (32% Voids) ϕ = 35°50'
Loose State (38% Voids) ϕ = 23°50'
MAXIMUM SHEARING STRESS : TONS/SQ. FT.
NORMAL LOAD : TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0


CALIFORNIA INSTITUTE OF TECHNOLOGY
Vey and Silberstein
DIRECT SHEARING TEST
Ult. Shearing Stress vs. Normal Load
OTTAWA SAND
Dense State (32% Voids) φ = 24°30'
Loose State (38% Voids) φ = 23°00'
ULTIMATE SHEARING STRESS : TONS/SQ.FT.
NORMAL LOAD : TONS/SQ.FT.
0
0.5
1.0
1.5
2.0
2.5
3.0

Testing Apparatus

The shear box, 2½ in. x 3½ in., is of the direct-shear Harvard type, equipped with a metal tooth grid for the tests on Ottawa sand, and with coarse grade porous stones for the tests on the Detroit clay. The normal pressure is applied on the shearing bench by means of a simple counterbalanced beam system and dead weights. The horizontal shearing load is applied by a motor-operated gear-reduction device through a loading bar, which permits either of two shear tests to be made independently of the other. The horizontal shearing load is measured by means of a calibrated loading ring, fitted with an Ames dial to indicate the deflection of the ring under load. The capacity of the loading ring is about 700 lb. at two revolutions of the 1/10,000 Ames dial. The horizontal shearing deformation and the vertical expansion or compression of the soil during shearing were measured by the Ames dial as indicated. The shear loading device is of the "constant strain" or strain-control type, the rate of shearing being controlled by means of a rheostat and a time-delay relay. The upper half of the shear box is fixed and attached to the calibrated loading ring. The lower half of the shear box is movable and attached to loading standard.

Tests on Ottawa Sand

In each case a known weight of the dried material was placed in the shear box in layers, brought to the desired condition of density, and carefully leveled off with a special adjustable screed. The initial thickness of the layer was carefully determined by means of a calibrated straddle gage and an Ames dial after correcting the volume of the sand for the teeth of the grid, the voids ratio was computed. Two of the series of tests contemplated were completed, for two limiting density states - about the loosest possible condition with an average voids ratio of about 0.66, and a very dense condition with an average voids ratio of about 0.50.

The loose state was obtained by permitting the sand to flow gently out of a small funnel, spreading the sand in layers by moving the funnel back and forth in a regular pattern to fill the shear box. The dense state was obtained by applying vibrating blows to the upper grid until no further volume decrease could be detected by the straddle gage. The initial voids ratio in these tests refers to the voids, either in the loose or dense condition, respectively, under the desired normal loading. This initial voids ratio was computed after observing the change in the vertical dial reading upon application of the desired normal load.

In the loose state, the shearing stress increases gradually and continuously to a maximum which is reached at a rather large horizontal deformation of about 0.20 in. for a sample 0.80 in. thick. On the other hand, in the dense state, the shearing stress increases rapidly to a much higher maximum than for the loose state, which occurs at quite a small horizontal deformation, comparatively of about 0.025 in. Thereafter with increasing

Tests on Ottawa Sand (Cont'd)

horizontal deformation the stress drops off in a characteristic fashion quite rapidly to a value about two-thirds to three- fourths of the maximum value. This is of the nature of a rupture failure and is characteristic of shearing failure in the dense state. In the loose state the failure is more of the nature of a plastic flow.

Conclusions

A comparsion with the value obtained for the ultimate stress shows that the loose state and ultimate shear stress for the dense state have almost identical angles of friction with an average of 32 deg., 30 min. For materials, either cohesionless of cohesive, which show a characteristic dropping off of the shear stress after the maximum has been reached, design should be based on the more conservative value of the angle of friction obtained from the ultimate strength. For designs based on the maximum value, progressive failure and the consequent dropping off of the shearing strength would create a serious situation.

Although the results of these series of tests are not entirely consistent nor conclusive, the thickness of the sample appears to have an appreciable influence on the value of the angle of friction, the value tending to smaller for the thick samples than for the thin ones. It also appears from a study of

Conclusions (Cont'd)

the results that the 0.30 in. samples were too thin for the complete development of the usual thickness of the shearing zone.

Thickness of Samples, in.	ϕ, Dense	ϕ, Loose
1.05	42° 45'	32° 25'
0.30	44° 30'	35° 30'
Mean line all thicknesses	43° 30'	33° 30'
Voids ratio	0.49	0.66

Although the initial voids ratio, initial thickness of the sample, and the volume changes during shear were measured very carefully, the results still show inconsistencies. These inconsistencies may result from secondary effects inherent in the direct-shear test method, partly because the size, shape, and tilting of the shear box may affect results, and partly because of the large shearing deformations required to reach the ultimate shearing strength. Because of the progressive nature of the development of shearing resistance along the shearing plane in a shear box, the state of stress in the shearing plane cannot be known exactly. For these reasons the true angle of friction is not obtained, though probably not greatly in error. The direct-shear test method is not an entirely satisfactory one for determining the shearing characteristics of granular cohesionless materials, and the consistency of results is not as good as desirable.

COLUMBIA UNIVERSITY Prof. D.M.Burmister

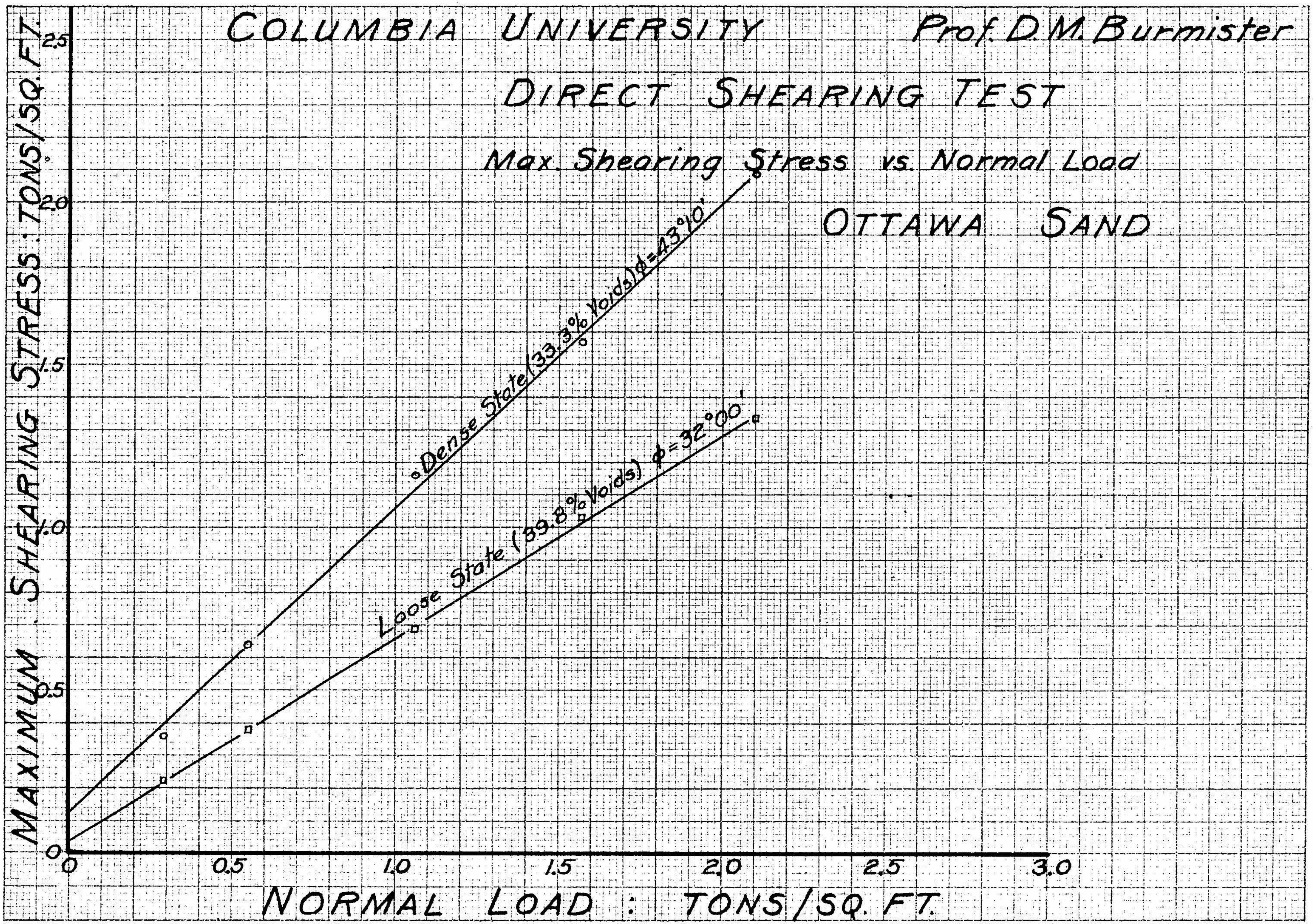
Tests on Ottawa Sand

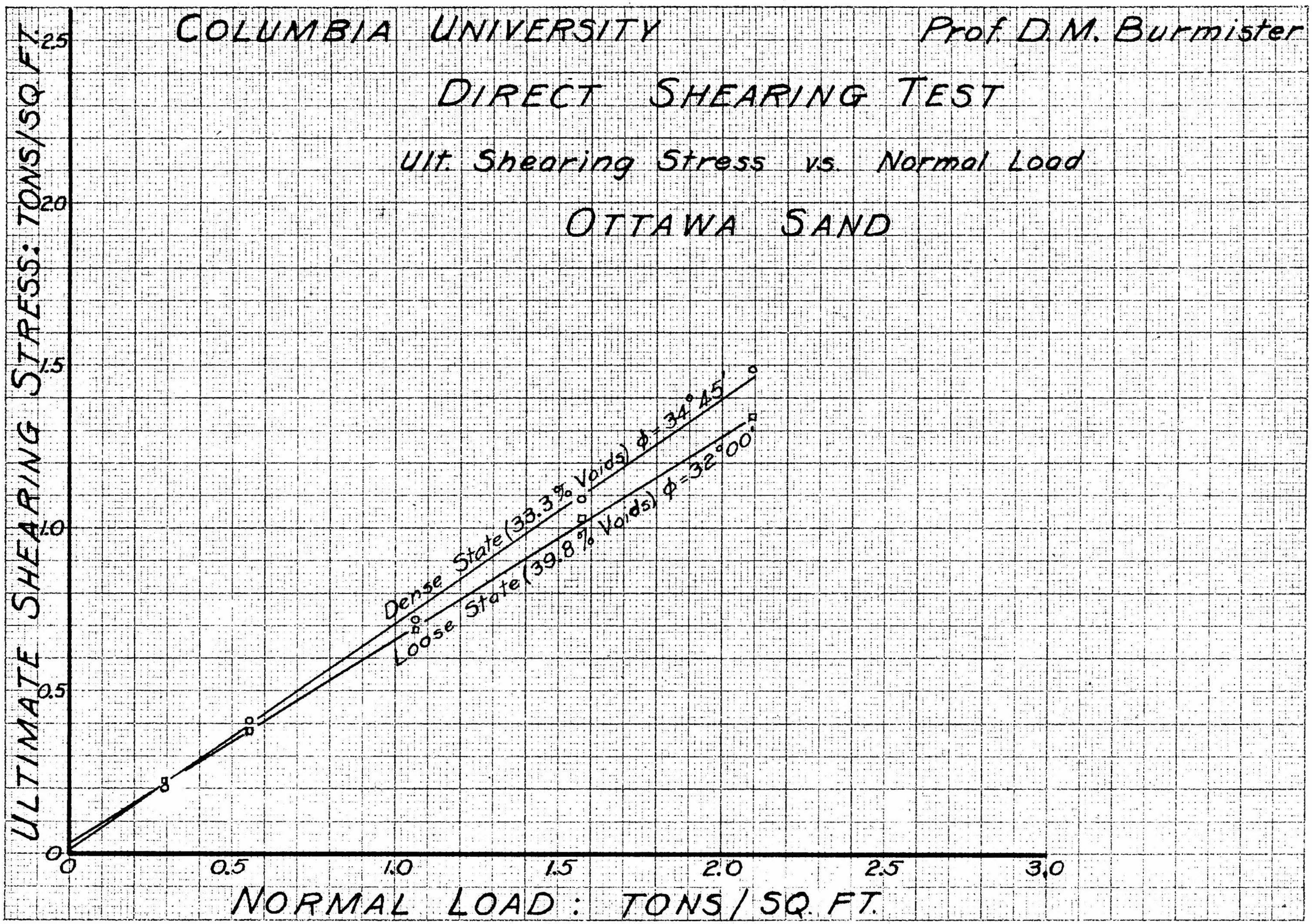
1.Maximum Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Max. Shearing Stress: Ton/sq.ft.				
				Normal Load: Tons/sq.ft.				
				0.29	0.55	1.06	1.57	2.09
Dense,Dry	33.3%	0.05"/min	43° 10'	0.36	0.64	1.16	1.57	2.10
Loose,Dry	39.8%	0.005"/min	32° 00'	0.22	0.38	0.69	1.03	1.34

2. Ultimate Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Ton/sq.ft.				
				Normal Load: Tons/sq.ft.				
				0.29	0.55	1.06	1.57	2.09
Dense,Dry	33.3%	0.05"/min	34° 45'	0.21	0.41	0.72	1.09	1.49
Loose,Dry	39.8%	0.005"/min	32° 00'	0.22	0.38	0.69	1.03	1.34


COLUMBIA UNIVERSITY
Prof. D.M. Burmister
DIRECT SHEARING TEST
Max. Shearing Stress vs. Normal Load
OTTAWA SAND
Dense State (33.3% Voids) φ=43°10'
Loose State (39.8% Voids) φ=32°00'
MAXIMUM SHEARING STRESS : TONS/SQ. FT.
NORMAL LOAD : TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0


COLUMBIA UNIVERSITY
Prof. D.M. Burmister
DIRECT SHEARING TEST
Ult. Shearing Stress vs. Normal Load
OTTAWA SAND
Dense State (33.3% Voids) φ = 34° 45'
Loose State (39.8% Voids) φ = 32° 00'
ULTIMATE SHEARING STRESS: TONS/SQ. FT.
NORMAL LOAD: TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0

Testing Apparatus

For all shear tests this laboratory uses a cylindrical soil specimen with optional provision for applying normal pressures at the ends and a movable section for causing failure in double shear.

The two sets of apparatus used differ principally in cross-sectional area of specimen, one being 1 ½ square inches in area or 1.38 inches in diameter and the other 16 square inches in area or 4.52 inches in diameter. These two sizes of cylinders provide for free lateral expansion of the sand during shearing failure while shearing strains are measured by Federal dials sensitive to 1/1000 of an inch.

Testing Procedure

It has been observed that shearing deformations involved in such granular soils were relatively small and that failure always occurred abruptly. Therefore, it appeared feasible to conserve time by eliminating small increments with corresponding small deformations at the beginning of each test.

For Group I, using the small cylinder, shear force was applied in increments to failure with each increment held constant for the 10-minute time interval. Readings of shearingstrain were made at 2-minute intervals to determine whether or not equilibrium had been obtained before the application of the following increment.

Testing Procedure (Cont'd)

Group II, also employing the small cylinder, differing from Group I in that the shearing force was applied at a uniform rate per minute, the rate being noted for the individual series. Group III, differing from Groups I and II in that use was made of the large cylinder, was otherwise similar to Group II in that the shear force was applied at a uniform rate. With these so-called rapid shear tests, no continuous record of deformation was possible. However, the ultimate value of strain immediately before failure was observed and recorded together with the exact shearing force required to produce it.

Conclusions

A great majority of tests in each series showed good general agreement and appeared to follow consistently the straight line relationship adopted. It might be expected theoretically that these straight lines should all converge at the origin for such a strictly granular material, inasmuch as sand can obviously sustain no shear force without confinement. This has not been found to be the case, however, either in this or similar investigations conducted by this and other laboratories.

Although the exact source of the divergence cannot be definitely stated, at least a portion of it is felt to be due to experimental inaccuracy in the apparatus while the remainder may possibly be considered as "apparent cohesion". The effect has been

Conclusions (Cont'd)

shown as an intercept on the vertical axis and has been considered in determining the angle of internal friction. This cohesion may be produced by the reduction of void content in the test specimen as normal load is applied. Thus in a particular series of tests, all of those specimens were prepared at a definite porosity, the application of increasingly higher normal pressures would produce increasingly higher densities until some maximum density controlled by the initial mechanical arrangement of particles is obtained. Further increase in normal pressure would produce no additional consolidation of the specimen and an equilibrum condition would be established. The net result of such an increase in density of specimens during testing would be shear values which increase not only as direct function of the normal load but also as some function of the density change, until the maximum density inherent to the initial arrangement has been obtained. Thereafter the expected direct relationship between normal load and shear should hold.

UNIVERSITY OF MICHIGAN A. L. Davies

Tests on Ottawa Sand

1. Summary of Tests using 1½ sq. in. cylinder.

Group	State of Sand	Voids	Loading
Group I	Dense, Dry	33.4%	Equal increments
	Medium, Dry	35.0%	Equal increments
	Loose, Dry	38.0%	Equal increments
Group II	Dense, Dry	33.4%	Continuous 3#/min. 1 lb./sq.in. per min. shearing stress
	Medium, Dry	35.0%	Continuous 3#/min. 1 lb./sq.in. per min. shearing stress
	Loose, Dry	38.0%	Continuous 3#/min. 1 lb./sq.in. per min. shearing stress

2. Summary of Tests using 16 sq. in. cylinder.

Group	State of Sand	Voids	Loading
GroupIII	Dense, Dry	33.4%	Uniform rate of 3.2 lb./min. or 1.o lb./sq. in. shear stress. Excessive vibration required to produce this density in such a large sample caused wear of particles and consequent error in test results unless new material was used after every third test.
	Medium, Dry	35.0%	Uniform rate of 5 lb./min. or 1.56 lb./sq.in. shear stress. Equal increments for two tests.
	Loose, Dry	38.0%	Uniform rate of 3.2 lb./min. or 1.0 lb./ per sq.in. shear stresses. Very flat angle because of considation of sand from loose density in horizontal position.

UNIVERSITY OF MICHIGAN A. L. Davies

Tests on Ottawa Sand

Group I

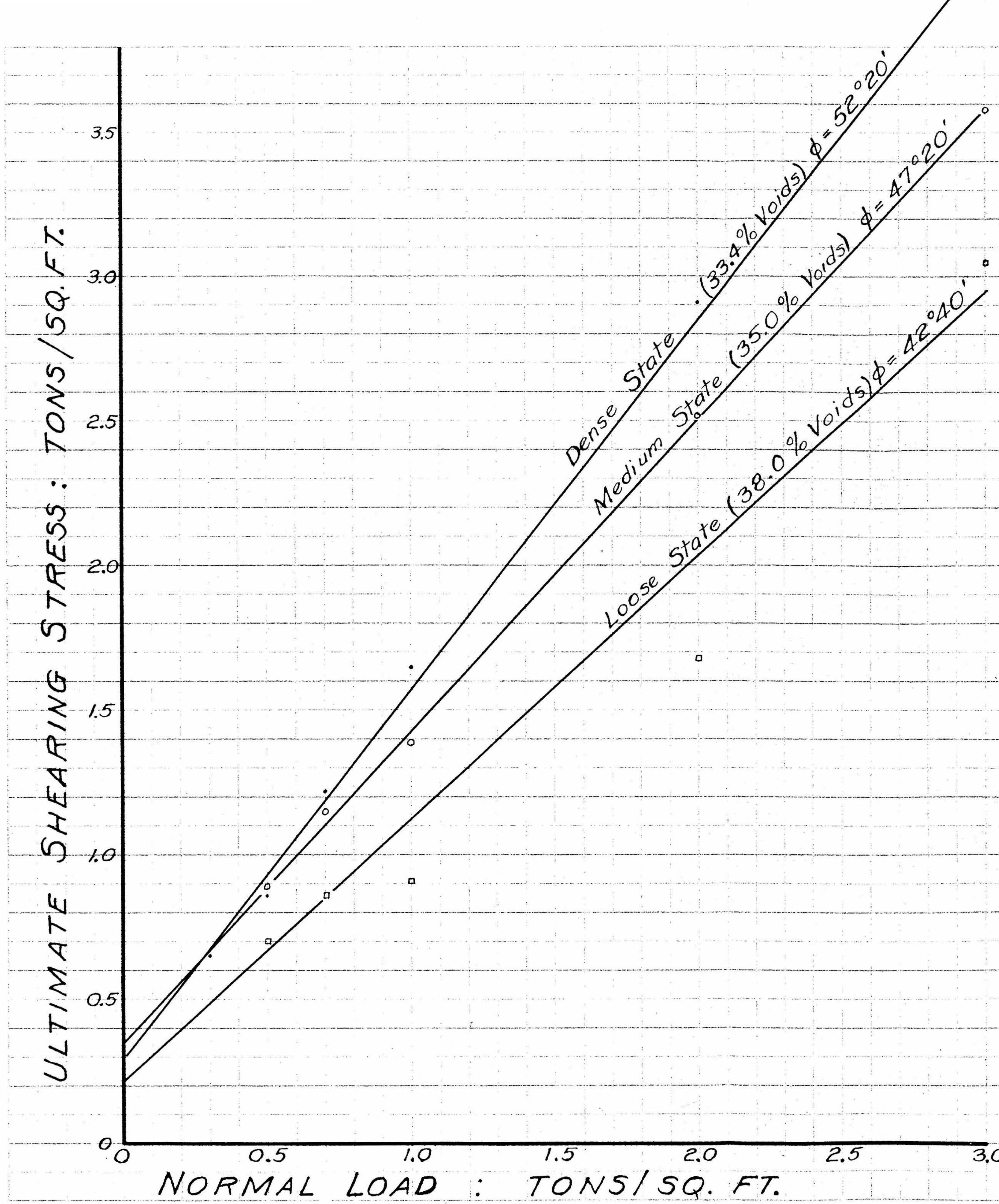
State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons./sq. ft. Normal Load: Tons/sq. ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
Dense, Dry	33.4%	Equal Increments at 10 min	52°20'	---	0.65	0.86	1.22	1.65	2.91	4.08
Med., Dry	35.0%	do	47°20'	---	---	0.89	1.15	1.39	2.52	3.58
Loose, Dry	38.0%	do	42°40'	---	---	0.70	0.86	0.91	1.68	3.05

Group II

State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/sq. ft. Normal Load: Tons/sq. ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
Dense, Dry	33.4%	3#/min.	55°10'	0.40	0.65	0.90	1.13	1.55	3.02	4.45
Med., Dry	35.0%	do	49°45'	0.22	0.57	0.88	1.10	1.36	2.61	3.73
Loose, Dry	38.0%	do	43°40'	0.21	0.37	0.57	0.76	1.19	2.14	3.08

Group III

State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/sq. ft. Normal Load: Tons/sq. ft. 0.36	0.72	1.44	2.16	3.60
Dense, Dry	33.4%	Constant	54°20'	0.55	0.98	2.05	2.99	5.02
Med., Dry	35.0%	do	45°10'	0.50	0.91	1.55	2.37	3.64
Loose, Dry	38.0%	do	27°00'	0.45	0.64	0.92	1.39	2.04



UNIVERSITY OF MICHIGAN

A. L. Davies

DOUBLE SHEARING TEST ON OTTAWA SAND

Ult. Shearing Stress vs Normal Load

Group I: 1½ sq. in. Cylinder

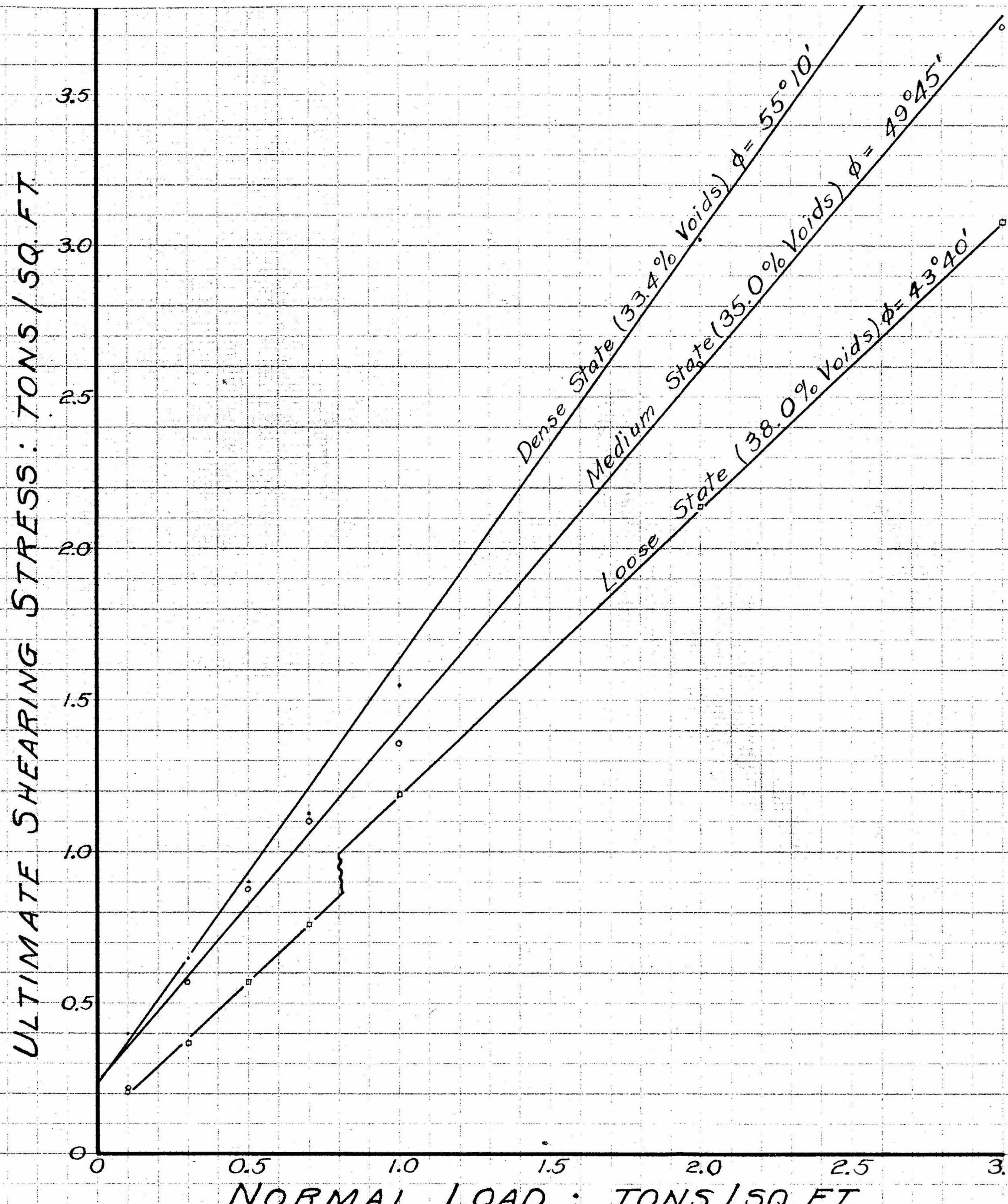
Rate of Loading = Equal Increments at 10 min.

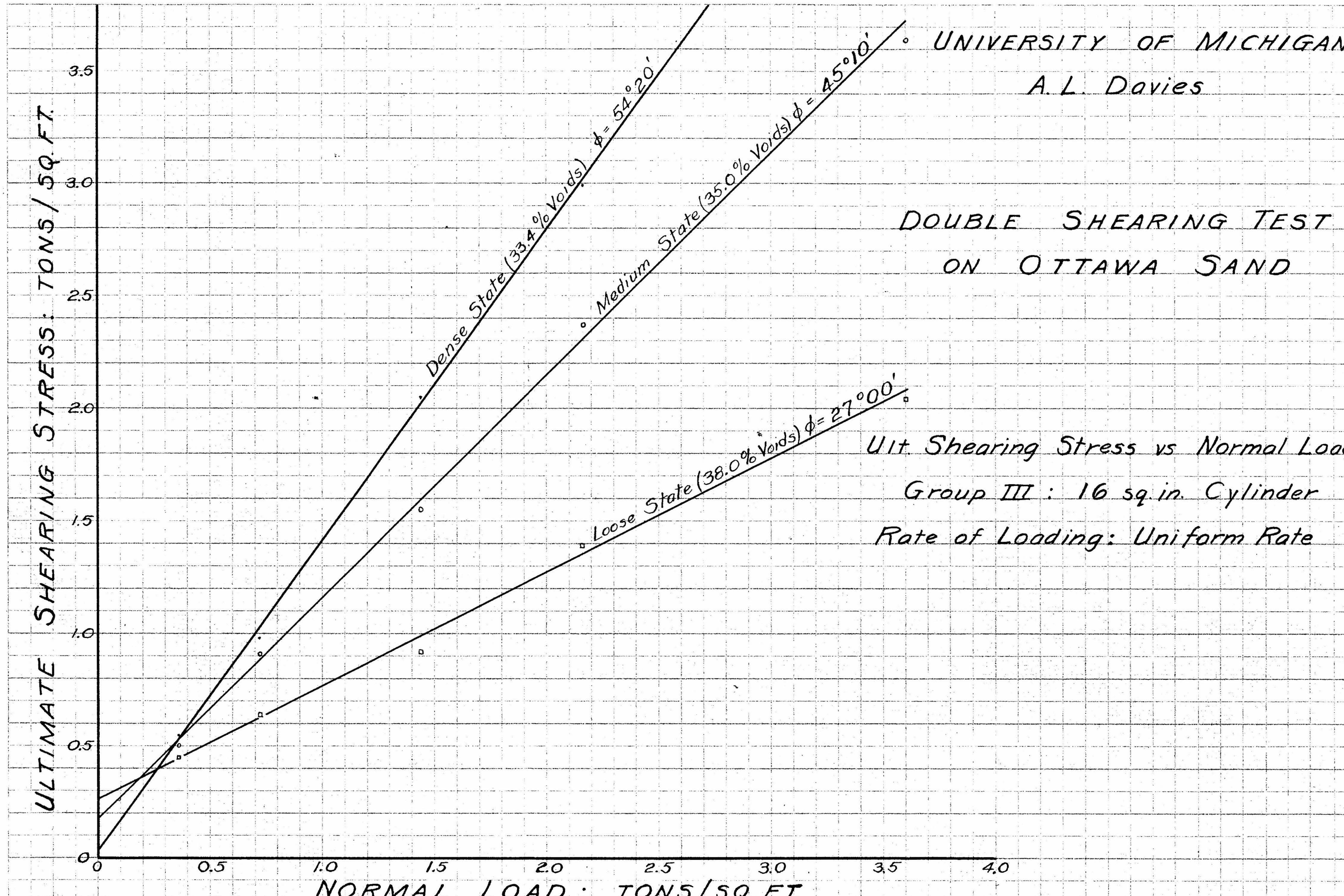
UNIVERSITY OF MICHIGAN

A. L. Davies

DOUBLE SHEARING TEST
ON OTTAWA SAND

ULT. Shearing Stress vs Normal Load
Group II : 1½ sq. in. Cylinder
Rate of Loading: Continuous 3#/min.




UNIVERSITY OF MICHIGAN
A. L. Davies
DOUBLE SHEARING TEST
ON OTTAWA SAND
Ult. Shearing Stress vs Normal Load
Group III : 16 sq. in. Cylinder
Rate of Loading: Uniform Rate
Dense State (33.4% Voids) ϕ = 54°20'
Medium State (35.0% Voids) ϕ = 45°10'
Loose State (38.0% Voids) ϕ = 27°00'
ULTIMATE SHEARING STRESS: TONS/SQ. FT.
NORMAL LOAD: TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Testing Apparatus

Three shear boxes of 60mm x 60mm area were used, mounted on a single frame. The soil samples were about 1/2" thick (counting between the extremities of the plate ribs or fins). The clay samples were confined between indented porous carborundum plates. The normal load was applied to the upper plates through a piston and loading yoke by means of weights suspended directly to that yoke, without any leverage being used. The shearing force could be applied at any desired controlled rate. A water tank connected to the water main and a system of pulleys were used for the purpose. The small friction losses (about 2%) were taken into account. The shearing force was applied to the upper movable part of the shear box by means of lugs located on each side of the box in the vertical plane thru the point of application of the normal load. This arrangement eliminated effects of possible tilting, should the shearing force imperfectly coincide with the shearing plane. A rim around the whole shear box permitted to entirely submerge the sample and the shear box during the whole duration of the test.

PRINCETON UNIVERSITY Prof. G. P. Tschebotareff

Tests on Ottawa Sand

The shearing of dense sand was found to be accompanied by its expansion. The reverse was the case for loose sand.

In addition to the tests of the program, tests were carried out on moist sand to determine the effect of bulking on the shearing resistance. It was found to be reduced by about 15% both for very loose and for very dense Ottawa sand when the sand was moistened by about 6% water before being placed in the box. There are indications that if the sand is moistened after it is placed in the box, the opposite effect may be observed, that is the shearing resistance may be increased, presumably due to the action of capillary forces.

Apart from the prescribed manner of loading, tests were also made in the manner usually adopted in our laboratory, that is at a constant rate of application of the shearing force, equal to 1/20 th of the ultimate load per minute. No difference was observed between the results obtained by the two ways of loading when dense sand was tested; this was also the case for loose sand at small normal loads. But loose sand at normal loads over 1.0 tons/sq.ft. gave higher shearing values when loaded at a constant rate. Presumably the application of the shearing force in large increments may facilitate the breaking down of the loose structure of the sand followed by premature shearing.

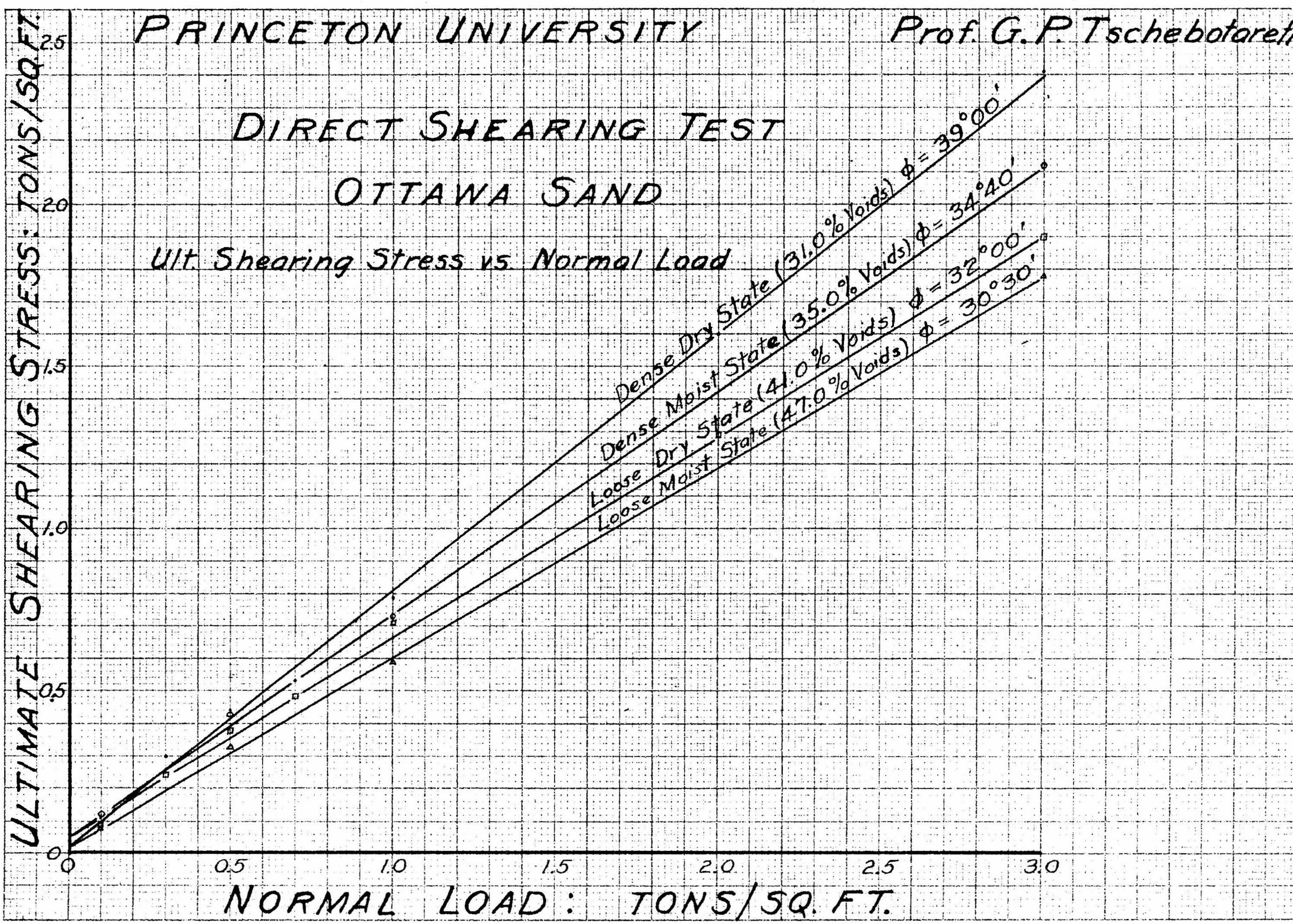
PRINCETON UNIVERSITY

Prof. G. P. Tschebotareff

Tests on Ottawa Sand

Ultimate Shearing Stress.

State of Sand	Porosity	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/Sq.Ft. Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
Dense, Dry	31%	Constant Rate		0.11	0.28	0.42	0.53	0.73	1.60	2.41
do	do	Increment 1/8 Ult.		0.11	0.32	0.46	0.54	0.85	1.60	2.40
		Average	39° 00'	0.11	0.30	0.44	0.53	0.79	1.60	2.41
Dense, Moist	35%	Constant Rate	34° 40'	0.12	—	0.43	—	0.73	—	2.12
Loose, Dry	41%	Constant Rate		0.09	0.24	0.38	0.48	0.77	1.29	1.95
do	do	Increment 1/8 Ult.		0.09	—	0.38	—	0.66	—	1.85
		Average	32° 00'	0.09	0.24	0.38	0.48	0.71	1.29	1.90
Loose, Moist	47%	Constant Rate	30° 30'	0.08	—	0.33	—	0.59	—	1.78


PRINCETON UNIVERSITY
Prof. G.P. Tschebotareff
DIRECT SHEARING TEST
OTTAWA SAND
Ult. Shearing Stress vs. Normal Load
Dense Dry State (31.0% Voids) $\phi = 39°00'$
Dense Moist State (35.0% Voids) $\phi = 34°40'$
Loose Dry State (41.0% Voids) $\phi = 32°00'$
Loose Moist State (47.0% Voids) $\phi = 30°30'$
ULTIMATE SHEARING STRESS: TONS/SQ. FT.
NORMAL LOAD: TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0

U. S. ENGINEER LABORATORY Fort Peck, Montana

Testing Apparatus

All tests were made in a Zanesville type of shear machine. The normal stress was applied in each case in a single increment. The first shearing load increment was applied within 2 minutes after the placement of the normal load. Each increment of load was maintained until there was no further horizontal movement of the shear box due to that load. The criterion for this end-point was a movement of 0.001 inch or less in 1 minute of elapsed time. The indication of failure of the sample in shear was a horizontal movement of 0.1 inch or more due to the addition of an increment of load.

The shear tests were first made according to the standard method used in the Fort Peck Laboratory which differed from the A.S.T.M. method only in the size of the increments of horizontal load used to shear the sample.

It will be noted that, in the A.S.T.M. Method, the load increments are equal to or larger than those in the Fort Peck Method for the values of normal stress greater than 0.1 ton/sq. ft. The size of the increments used in the Fort Peck Method are those usually used in making shear tests at these several values of normal stress. At the conclusion of the tests make according to the Fort Peck Method, the values of ultimate shearing resistance thus found were divided by 8 as suggested in the original instructions to give the approximate size of the increment loading to be used in making the test according to the A.S.T.M. Method.

Conclusions

The general effect of using the larger load increments in the A.S.T.M. Method is to produce a lower ultimate shearing strength for the sample than was found in the corresponding test made according to the Fort Peck Method. This effect can be readily seen by comparing the attached plotted curves for the A.S.T.M. Method with those for the Fort Peck Method.

U. S. ENGINEERING LABORATORY Fort Peck, Montana

Tests on Ottawa Sand

Ultimate Shearing Stress.

1. A. S. T. M. Method

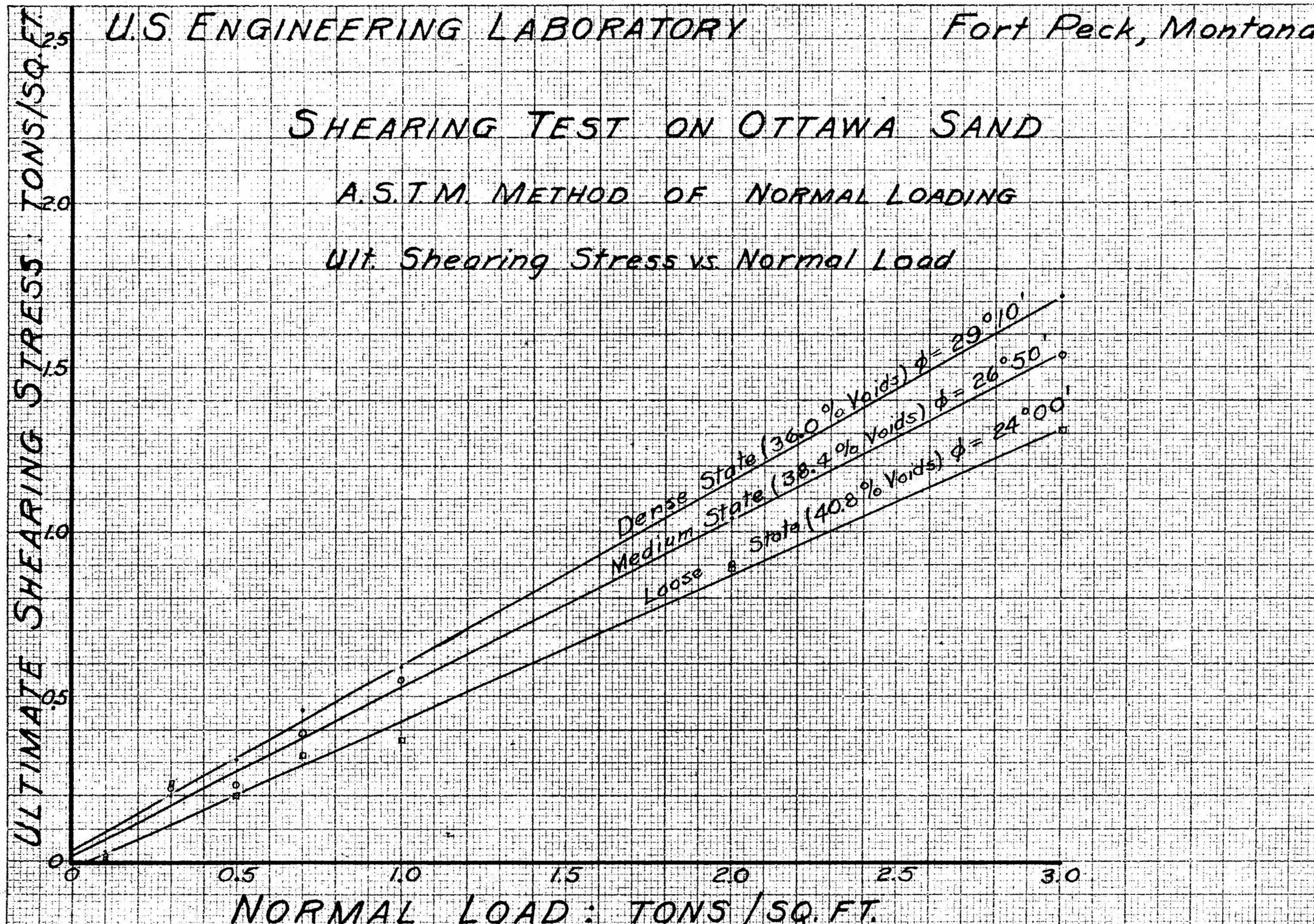
State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/Sq. Ft. — Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
Dense, Dry	36.0%	Increment	29°10'	0.03	0.10	0.31	0.46	0.59	1.04	1.72
Med., Dry	38.4%	do	26°50'	0.02	0.12	0.23	0.39	0.55	0.90	1.54
Loose, Dry	40.8%	do	24°00'	0.01	0.13	0.20	0.32	0.37	0.89	1.31

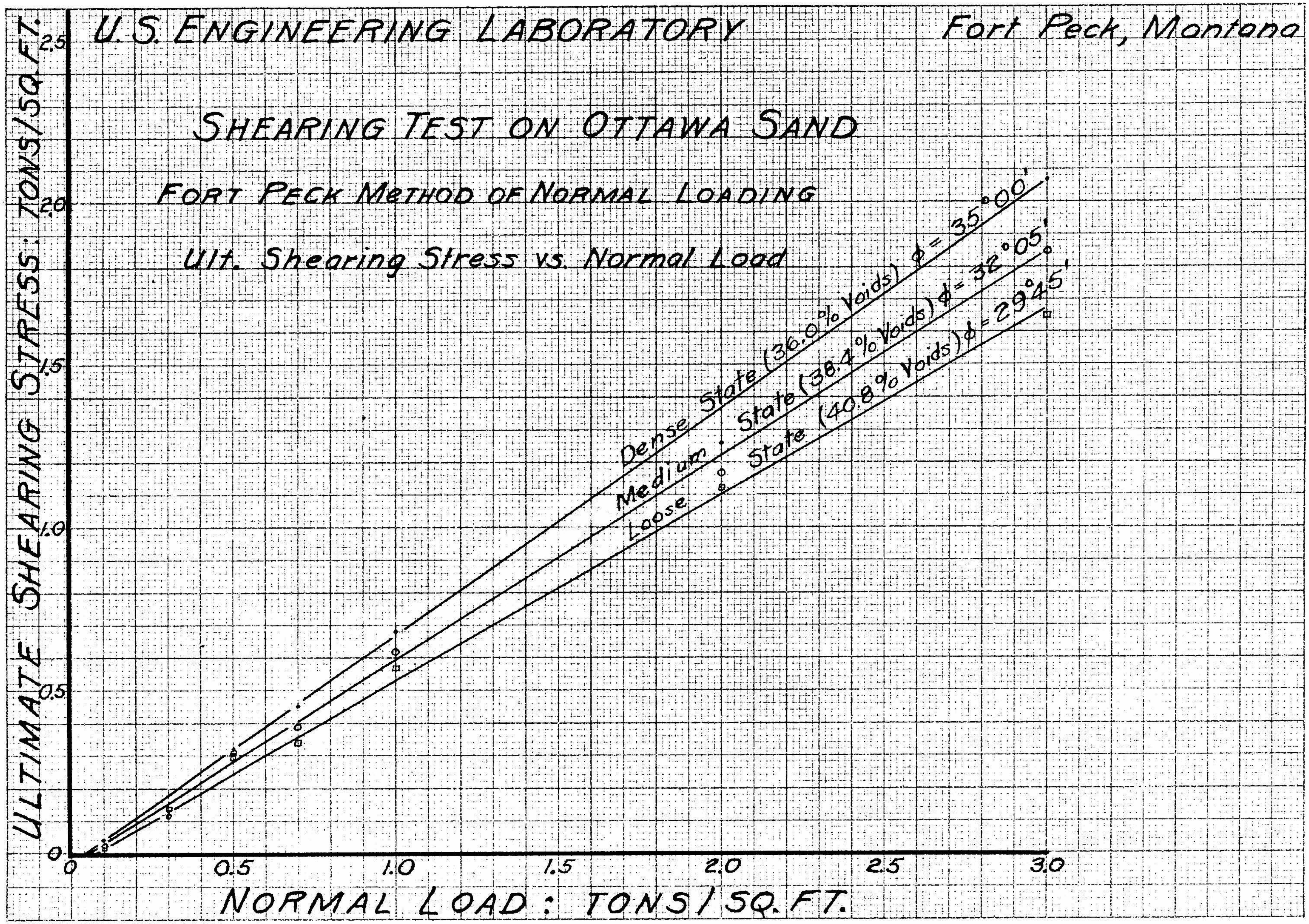
2. Fort Peck Method

State of Sand	Voids	Rate of Loading	ϕ	Ult. Shearing Stress: Tons/Sq.Ft. — Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
Dense, Dry	36.0%	Increment	35°00'	0.04	0.13	0.32	0.45	0.68	1.26	2.07
Med., Dry	38.4%	do	32°05'	0.02	0.12	0.30	0.39	0.62	1.17	1.85
Loose, Dry	40.8%	do	29°45'	0.03	0.14	0.31	0.34	0.57	1.12	1.65

Load Increments

Method	State of Sand	Voids	Size of Horizon. Load Increment: lbs. — Normal Load: Tons/Sq.Ft. 0.1	0.3	0.5	0.7	1.0	2.0	3.0
A.S.T.M.	Dense, Dry	36.0%	2	5	7	10	15	35	40
	Medium, Dry	38.4%	2	5	7	10	15	30	45
	Loose, Dry	40.8%	2	5	7	10	15	25	40
Fort Peck	Dense, Dry	36.0%	5	5	5	10	10	20	20
	Medium, Dry	38.4%	5	5	5	10	10	20	20
	Loose, Dry	40.8%	5	5	5	5	10	20	20


U.S. ENGINEERING LABORATORY
Fort Peck, Montana
SHEARING TEST ON OTTAWA SAND
A.S.T.M. METHOD OF NORMAL LOADING
Ult. Shearing Stress vs. Normal Load
Dense State (36.0% Voids) φ = 29°10'
Medium State (38.4% Voids) φ = 26°50'
Loose State (40.8% Voids) φ = 24°00'
ULTIMATE SHEARING STRESS TONS/SQ. FT.
NORMAL LOAD: TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0


U.S. ENGINEERING LABORATORY
Fort Peck, Montana
SHEARING TEST ON OTTAWA SAND
FORT PECK METHOD OF NORMAL LOADING
Ult. Shearing Stress vs. Normal Load
Dense State (36.0% Voids) ϕ = 35°00'
Medium State (38.4% Voids) ϕ = 32°05'
Loose State (40.8% Voids) ϕ = 29°45'
ULTIMATE SHEARING STRESS: TONS/SQ.FT.
NORMAL LOAD: TONS/SQ.FT.
0
0.5
1.0
1.5
2.0
2.5
3.0

Procedure

Tests were made with the material in a very loose and very dense state, both dry and submerged. For the series of tests with the material dry, all parts of the shear box and the sand were oven dried. For the submerged series of tests, water placed in the water jacket to produce complete submergence at the shear plane.

The material was compacted in the shear box by tamping it with a small wooden block and hammer before the normal load was applied. After the normal load was applied the piston was vigorously tapped at all corners to vibrate the sand into a more compact mass. Vibration was continued until the vertical dial showed little or no movement. To place the sand loosely in the box for a dry test, it was carefully poured with a spoon. In the submerged runs, the sand was deposited loosely by allowing it to fall through the water

Tests were made at an approximate rate of horizontal movement of 0.0125, 0.050 and 0.200 inches per minute. The rate of horizontal movement was controlled by moving the horizontal jack at a uniform rate. Since the pressure bellows deflected very slightly as the stress was produced, the rate of horizontal movement was not absolutely constant. Normal loads of 0.3, 0.5, 1.0, 2.0, 3.0, 3.5 and 4.0 tons/sq.ft. were used.

Testing Apparatus

The tests were made on the constant strain type of direct shear machine. This device was originally designed by Professor Glennon Gilboy of M.I.T., for the Zanesville Soils Laboratory, and described by him in Engineering News Record, May 21, 1936. The sample is placed in a shear box, 4" x 4", for the tests described in this report, and the box placed in position in the testing machine. Strain is applied at a constant rate to the lower part of the box by a wheel and jack arrangement, while the upper part is restrained from horizontal movement by connections to a yoke bearing against a hydraulic bellows. The actual load applied to the sample becomes a function of the resistance offered to movement along the horizontal plane through the sample between the lower part which is moving, and the upper part which is restrained. The magnitude of this load is indicated by the height of rise of a manometer connected to the bellows. Provision is also made in this device for the application of a vertical load on the sample, so arranged that if the sample tends to expand during the tests, it will not be prevented from so doing, but the vertical load will remain constant.

Summary

The tests indicate that for the compact condition, the submerged material has a slightly larger maximum friction angle than the dry material, while for the loose condition the maximum friction angle is approximately the same for both the dry and submerged material. The tests also indicate that the ultimate friction angle is approximately the same for all four conditions of material, in each of the three rates of horizontal movement.

U. S. ENGINEER OFFICE Ithaca, New York

Tests on Ottawa Sand

1. Maximum Shearing Stress.

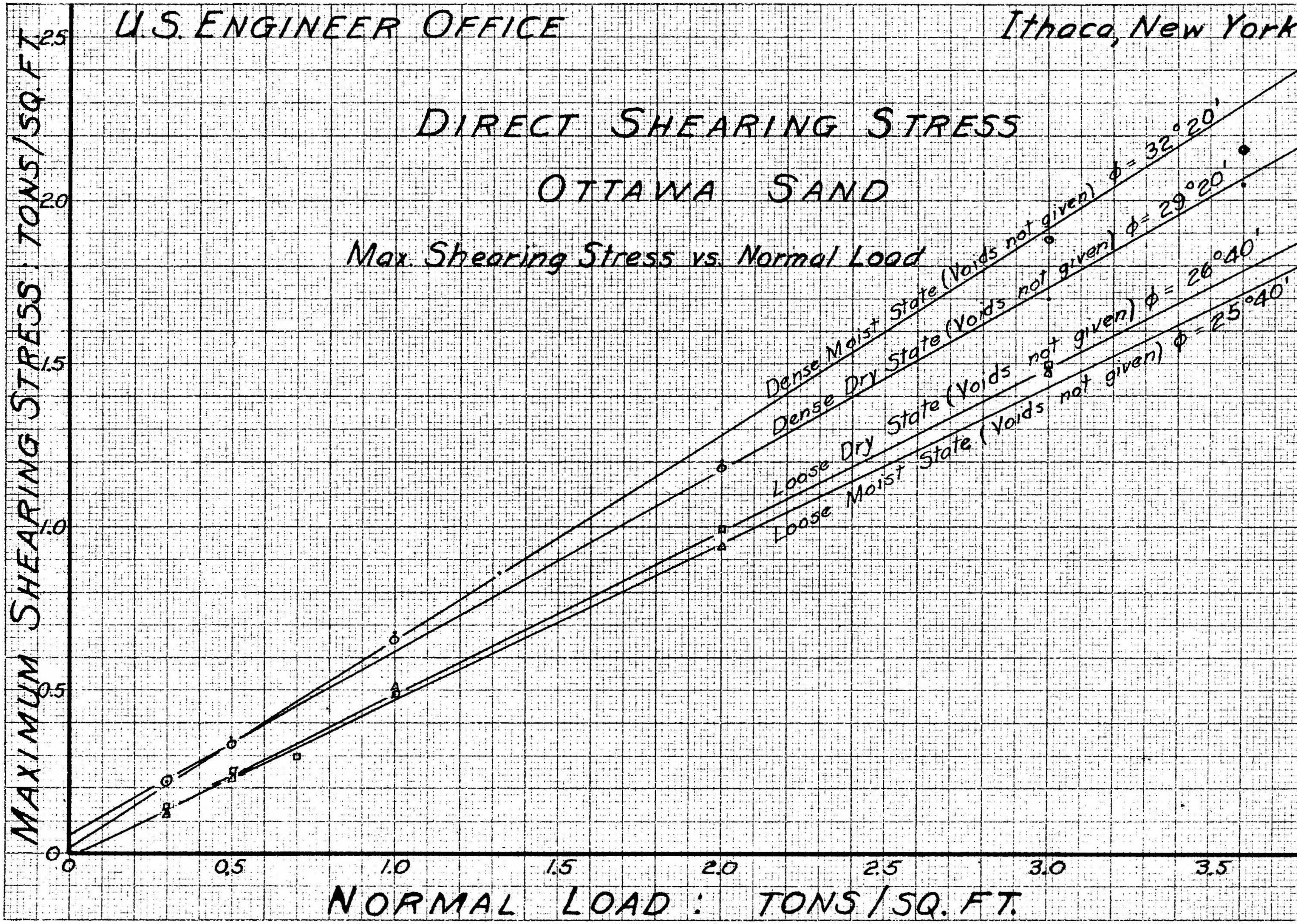
State of Sand	Voids	Rate of Loading	ϕ	Maximum Shearing Stress: Tons/Sq.Ft. Normal Load: Tons/Sq.Ft.								
				0.3	0.5	0.65	1.0	1.32	2.0	3.0	3.5	4.0
Dense Dry	Not given	0.0125"/min		0.25			0.65		1.25	1.83		
		0.05 "/min		0.20	0.33		0.65	0.86	1.16	1.78	2.00	
		0.20 "/min		0.22	0.37		0.70		1.20	1.70	2.10	
		Average	29° 20'	0.22	0.35		0.67	0.86	1.20	1.70	2.05	
Dense Moist	Not given	0.0125 "/min		0.22			0.72			2.02		
		0.05 "/min		0.21	0.34		0.60		1.19	1.82	2.16	
		0.20 "/min		0.24			0.66			1.80		2.61
		Average	32° 20'	0.22	0.34		0.66		1.19	1.88	2.16	2.61
Loose Dry	Not given	0.0125"/min		0.13			0.48		1.06	1.52		
		0.05 "/min		0.14	0.25	0.30	0.49		0.96	1.44		
		0.20 "/min		0.14			0.51		0.95	1.48		1.91
		Average	26° 40'	0.14	0.25	0.30	0.49		0.99	1.48		1.91
Loose Moist	Not given	0.0125"/min		0.12			0.53			1.48		
		0.05 "/min		0.15	0.24		0.50		0.94	1.44		
		0.20 "/min		0.13			0.50			1.53		1.98
		Average	25° 40'	o.13	0.24		0.51		0.94	1.48		1.98

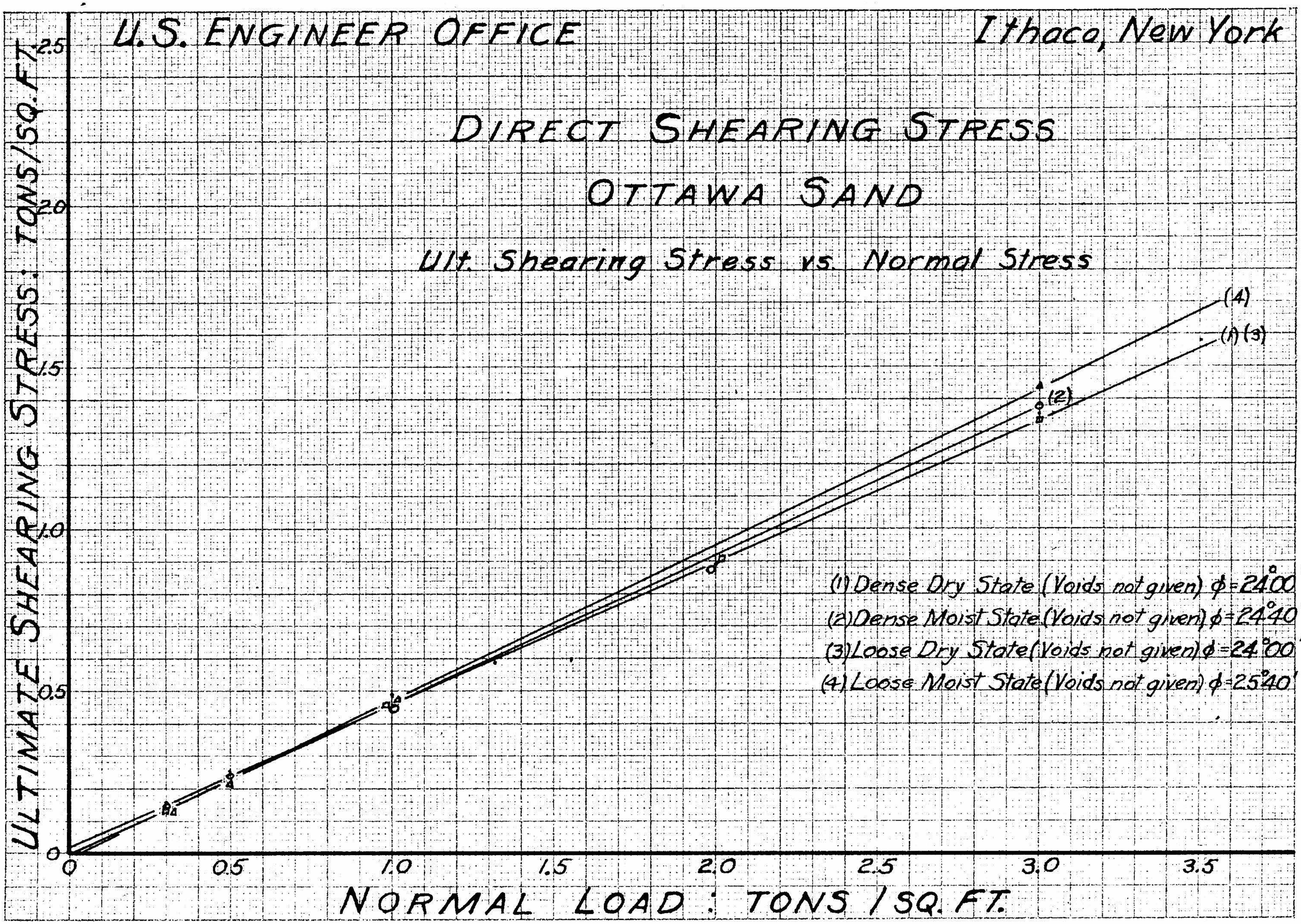
U. S. ENGINEER OFFICE   Ithaca, New York

Tests on Ottawa Sand

2. Ultimate Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Ultimate Shearing Stress: Tons/Sq.Ft. Normal Load: Tons/Sq.Ft.							
				0.3	0.5	1.0	1.32	2.0	3.0	3.5	4.0
Dense Dry	Not given	0.0125"/min						0.89	1.36		
		0.05 "/min		0.15	0.25	0.50	0.59	0.89	1.35	1.54	
		0.20 "/min		0.17		0.48		0.89	1.34	1.63	
		Average	24° 00'	0.16	0.25	0.49	0.59	0.89	1.35	1.58	
Dense Moist	Not given	0.0125"/min							1.41		
		0.05 "/min		0.15	0.24	0.45		0.88			
		0.20 "/min		0.15					1.35		
		Average	24° 40'	0.15	0.24	0.45		0.88	1.38		
Loose Dry	Not given	0.0125"/min						0.86	1.32		
		0.05 "/min		0.14		0.45		0.94	1.33		
		0.20 "/min		0.14		0.47			1.38		
		Average	24° 00'	0.14		0.46		0.90	1.34		
Loose Moist	Not given	0.0125"/min									
		0.05 "/min		0.14	0.23	0.48					
		0.20 "/min		0.12		0.46			1.44		1.88
		Average	25° 40'	0.13	0.23	0.47			1.44		1.88


U.S. ENGINEER OFFICE
Ithaca, New York
DIRECT SHEARING STRESS
OTTAWA SAND
Max. Shearing Stress vs. Normal Load
Dense Moist State (Voids not given) φ = 32°20'
Dense Dry State (Voids not given) φ = 29°20'
Loose Dry State (Voids not given) φ = 26°40'
Loose Moist State (Voids not given) φ = 25°40'
MAXIMUM SHEARING STRESS: TONS/SQ. FT.
NORMAL LOAD: TONS/SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5


U.S. ENGINEER OFFICE
Ithaca, New York
DIRECT SHEARING STRESS
OTTAWA SAND
Ult. Shearing Stress vs. Normal Stress
(1) Dense Dry State (Voids not given) ϕ=24°00'
(2) Dense Moist State (Voids not given) ϕ=24°40'
(3) Loose Dry State (Voids not given) ϕ=24°00'
(4) Loose Moist State (Voids not given) ϕ=25°40'
(4)
(1) (3)
(2)
ULTIMATE SHEARING STRESS: TONS/SQ. FT.
NORMAL LOAD: TONS / SQ. FT.
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

U. S. DEPT. OF INTERIOR Washington, D.C.

Grain Size Analysis of Ottawa Sand

The specifications required sand that would pass #20 and be retained on #30 seives respectively. The Engineering Laboratory uses #16 and #32 seives because these more closely approximate the upper and lower boundaries of "coarse sand" according to the National Park Service grain size identification. It is believed that the material meets the specifications even though the specified seives were not used.

The sample was first thoroughly oven dried at 105 C following which it was placed in the Rotap. After 5 mins. the sieves were removed and material in each seive brushed lightly to remove any finer particles that might remain. The portion on each seive was then oven dried, cooled, and weighed. The initial and final total sample weights checked within less than 0.01%.

Testing Apparatus

The shear apparatus of the Engineering Laboratory differs in some respects from the apparatus used by M.I.T., the Corps of Engineers, and others. The following is a brief description:

Size of sample - 2.5 ins. in diam., 1 in. in thickness

Shear Box - Upper section rigidly supported on base. Lower section moves on ball bearings.

Testing Apparatus (Cont'd)

Bearing - Two tool steel raceways attached to base; both V groove. Raceways on bottom of moveable section of box, V groove on one side, plane on the other.

Normal Load - Fixed increments supported by yoke and saddle. Yoke and saddle form first increment. Load transmitted to sample from yoke by means of ball bearing and bearing plate.

Horizontal Load - 1.5 cu. ft. container, water load. Container counterbalanced by weight suspended from rear of moveable section of shear box. Increments corrected for mechanical losses in the machine.

The various elements were designed to accomplish certain results. First, the bottom section of the box was made moveable instead of the top section as is more usual in order to eliminate all loads from the sample with the exception of that due to one half the sample thickness, and to eliminate the necessity of adjusting the space between sections after the sample is in place. The container and water for the horizontal loading was used for several reasons. The first was reduction of cost of the device. Another is the elimination of the possibility of setting up excess loads due either to dropping fixed increments or resting on a beam. Since the increment flows by a siphon from a reservoir set

Testing Apparatus (Cont'd)

on a scale the load can be applied by a single operator who need not look away from the horizontal dial during the loading since he can obtain the net from the scale after the load is applied. The increment is usually determined by the rate of dial movement which is set up rather than by definite weight intervals. Moreover, the apparatus permits continuous loading at any reasonable rate desired.

The sample is permitted to come to complete rest after normal loads are applied. When horizontal load increments are applied the sample is permitted to stand until movement of the dial is less than 0.00025 ins. in two or three minutes. Actual shearing load is determined from the stress-strain plotting.

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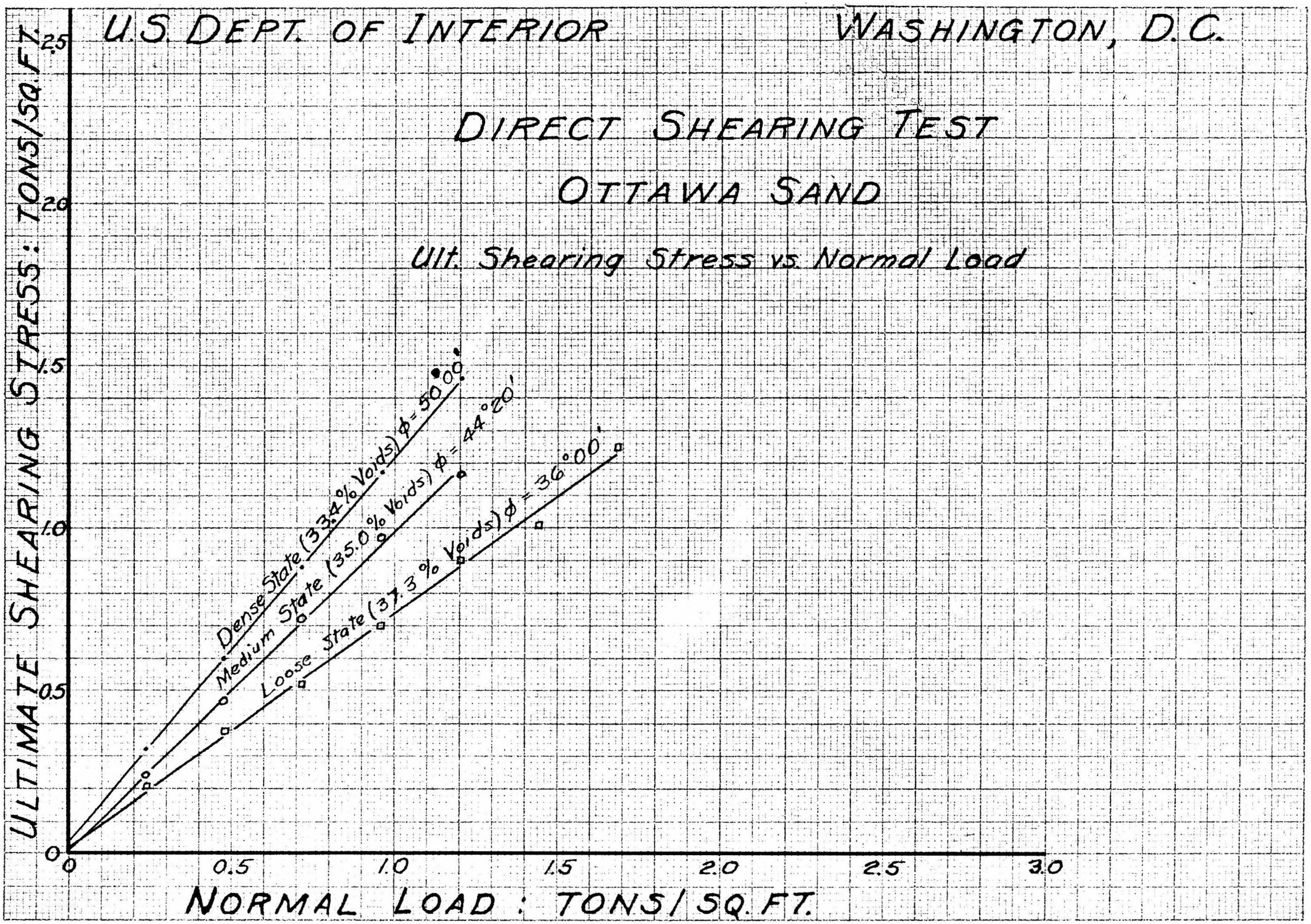
Tests on Ottawa Sand

Ultimate or Maximum Shearing Stress

State of Sand	Voids	Rate of Loading	ϕ	Shearing Stress: Tons/Sq.Ft.						
				Normal Load: Tons/Sq.Ft.						
				0.234	0.476	0.718	0.960	1.203	1.445	1.687
Dense Dry	33.4%	Increment	50°00'	0.32	0.60	0.88	1.17	1.46		
Medium Dry	35.0%	do	44°20'	0.24	0.47	0.72	0.97	1.17		
Loose Dry	37.3%	do	36°00'	0.21	0.38	0.52	0.70	0.90	1.01	1.25


U.S. DEPT. OF INTERIOR
WASHINGTON, D.C.
DIRECT SHEARING TEST
OTTAWA SAND
Ult. Shearing Stress vs Normal Load
Dense State (33.4% Voids) ϕ = 50°00'
Medium State (35.0% Voids) ϕ = 44°20'
Loose State (37.3% Voids) ϕ = 36°00'
ULTIMATE SHEARING STRESS: TONS/SQ.FT.
NORMAL LOAD : TONS/SQ.FT.
0
0.5
1.0
1.5
2.0
2.5
3.0