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Effects of Compaction on Critical Tractive Forces in Cohesive Soils

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This bulletin reports on Missouri Agricultural Experiment Station research project 43, Terracing.

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Design criteria for open channels have been almost entirely empirical in nature in the past. The tractive force theory, however, presents a theoretical means of evaluating shear at the interface between flowing water and the channel bed material. This shear is the force that causes erosion of the bed material in an open channel. Purpose of this study was to determine the effect of soil compaction on the tractive force required to cause erosion.

Five soils from the state of Missouri were tested in a hydraulic flume located below the 16-acre reservoir at the McCredie Experiment Station. The hydraulic flume was 60 feet long, 2.51 feet wide, and 1.5 feet deep. Two and one-half inches of concrete were poured in the bottom of the flume, except in the test section, where the soil to be tested was placed. This section was located at 30 to 48 feet from the upstream end of the flume. The sides of the flume, at 39.5 to 44.5 feet from the upstream end of the flume, were constructed of clear plexiglas sheets, permitting direct observation of the soil during a hydraulic test. A more complete description of the hydraulic flume and its related apparatus, a discussion of the tractive force theory, and a discussion of the physical and hydraulic tests performed on the soils, were presented Missouri Agricultural Experiment Station Research Bulletin 715.

EQUIPMENT

The equipment used in this study was the same as that described in Research Bulletin 715 except for the following changes.

A false floor was installed ⅝ inch above the bottom of the flume in the test section. The false floor was perforated by ⅛-inch holes drilled on 3-inch centers. This arrangement permitted drainage of the soil sample.

A better arrangement for measuring depths of flow of the water in the flume was also used. These depth measurements were made at 10 points along the flume at 9, 21, 30, 33, 36, 39, 42, 45, 48, and 57 feet from the upstream end of the flume. Hoses were connected to hollow screws countersunk in the sides of the flume. These hoses were connected to piezometer tubes mounted on a rack. This arrangement permitted one observer to make all readings from one position.

SOIL SAMPLES

The soil samples were collected during July and August of 1959. Each sample of soil weighed about 4000 pounds, enough for five to seven hydraulic tests. The soil samples were placed on and covered by polyethylene plastic to keep them from losing moisture. The series name of each soil and the locations and depths of sampling are given below.

Mexico surface soil series. Taken from the top 12 inches of the surface soil one mile east of Kingdom City.

Mexico subsoil series. Taken at a depth of 12 to 18 inches below the surface one mile east of Kingdom City.

Menfro surface soil series. Taken from the top 6 inches of the surface soil one mile west of New Franklin.

Knox surface soil series. Taken from the top 12 inches of the surface soil one mile south of Glasgow.

Knox subsoil series. Taken at a depth of 30 to 48 inches below the surface one mile south of Glasgow.

TEST PROCEDURES

Preparation of Bed Material

Each soil sample was passed through a ¾-inch mesh screen to break up the lumps, mix the soil, and remove foreign material. The amount of soil necessary to obtain a predetermined voids ratio was calculated, weighed, and placed in the flume. A representative sample of about 3 pounds was removed for a moisture content determination. The soil was leveled in the flume by a specially designed template, and compacted using hand tamping tools. The template was used as the compacting progressed in order to obtain a depth of soil of 1.875 inches.

After the compaction process was completed, the soil was saturated by admitting a small amount of water into the flume. A small amount of gravel was placed at each end of the test section to stabilize the bed material. The soil was then allowed to drain approximately 18 hours before the hydraulic tests were performed.

Hydraulic Tests

At the beginning of each test, water was slowly admitted into the flume until a small depth of flow was reached. The piezometers were then primed and checked to make sure they were operating properly.

Flow rate was increased by small increments, and with each increase, loosely bound soil aggregates were dislodged and moved along the bed. At the lower rates of flow, this aggregate movement decreased after a short interval of time. At the higher rates of flow, however, the decrease in aggregate movement did not occur until longer periods of time had elapsed. The flow rate at which the soil aggregate movement did not decrease appreciably with time was considered the point of failure of the bed material. This flow rate was then held constant while all observations needed for calculating the tractive force were made. This value is considered the critical tractive force for the soil under the conditions of test.

At the end of the test the flow was stopped, the bed was allowed to drain, and samples were taken for determination of the voids ratio.

CALCULATIONS

Two equations were used for the calculation of tractive force:

$$T = W D S \qquad (1)$$

$$T = W D \quad [(q^2/gD^3 - 1)\ dD/dX + S] \qquad (2)$$

Where T is tractive force; W, specific weight of water; D, depth of water; S, the slope of the channel bed; q, discharge per unit channel width; g, acceleration of gravity; and dD/dX, change in depth per unit length of channel. Equation (1) was used if uniform flow was occurring in the flume, and equation (2) was used if non-uniform flow was occurring in the flume.

DATA AND RESULTS

Physical Properties of the Soils

Physical properties determined for the soils were: Specific gravity, liquid limit, plastic limit, plasticity index, dispersion ratio, mean particle size, and percent clay. Results of the physical tests of the soils are summarized in Table 1.

Hydraulic Tests of the Soils

The summarized data from the hydraulic tests of the soils, the voids ratio determinations, and the moisture content determinations are presented in Table 2.

TABLE 1-PHYSICAL PROPERTIES OF THE SOILS TESTED

Soil	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	Dispersion Ratio	Mean Particle Size in Millimeters	Percent Clay
Mexico Surface	2.64	36.0	32.0	4	17.9	.0119	22.0
Mexico Subsoil	2.68	59.4	42.0	17.4	15.7	.00166	61.2
Menfro Surface	2.64	29.8	24.5	5.3	43.5	.0197	17.5
Knox Surface	2.65	35.0	31.0	4	24.9	.0203	14.0
Knox Subsoil	2.69	41.0	28.0	13	32.6	.0184	24.2

TABLE 2-DATA FROM HYDRAULIC TESTS OF THE SOILS

Test Number	Soil	Depth of flow (ft.)	$\frac{dD}{dx}$*	Slope of Channel (ft./ft.)	Critical Tractive Force (lbs./ft.^{2})	Voids Ratio	Soil Moisture Percent
1	Mexico Surface	.420	0	-.002	.0524	1.14	19.2
2	Mexico Surface	.343	-.0005	-.002	.0532	1.32	20.1
3	Mexico Surface	.355	-.0003	-.002	.0507	1.37	18.6
4	Mexico Surface	.196	-.0007	-.002	.0329	1.74	19.5
5	Knox Surface	.131	+.0002	-.002	.0147	1.37	12.4
6	Knox Surface	.099	+.0002	-.002	.0111	1.55	12.0
7	Knox Surface	.136	-.0003	-.002	.0195	1.25	20.3
8	Knox Surface	.104	+.0003	-.002	.0111	1.20	20.9
9	Knox Surface	.093	0	-.002	.0116	1.32	18.3
10	Knox Subsoil	.093	-.0002	-.002	.0128	1.43	16.2
11	Knox Subsoil	.164	0	-.002	.0205	1.22	23.0
12	Knox Subsoil	.136	-.0008	-.002	.0236	1.15	23.4
13	Knox Subsoil	.095	-.0003	-.002	.0136	1.61	17.9
14	Knox Subsoil	.081	-.0002	-.002	.0111	1.61	20.0
15	Knox Subsoil	.079	-.0003	-.002	.0113	1.60	15.5
16	Mexico Subsoil	.357	-.0002	-.002	.0489	1.53	26.2
17	Mexico Subsoil	.327	0	-.002	.0408	1.70	20.8
18	Mexico Subsoil	.302	+.0002	-.002	.0340	1.64	20.4
19	Mexico Subsoil	.263	0	-.002	.0329	1.65	19.6
20	Mexico Subsoil	.235	-.0003	-.002	.0337	1.83	7.8
21	Menfro Surface	.302	0	-.002	.0377	1.57	10.6
22	Menfro Surface	.324	-.0003	-.002	.0410	1.30	4.4
23	Menfro Surface	.451	+.0002	-.002	.0508	1.01	18.3
24	Menfro Surface	.401	+.0002	-.002	.0452	1.09	17.8
25	Menfro Surface	.424	0	-.002	.0529	1.12	15.9

*Change in depth of flow in feet per foot of channel length.

Critical Tractive Force Related to the Voids Ratio and to the Soil

Purpose of this study was to determine the effect of compaction of the channel bed material on critical tractive force. The voids ratio was used as the measure of compaction of the bed material. It was found that a linear relationship existed between voids ratio and critical tractive force for each soil tested. Figure 1 shows this linear relationship for each soil.

The method of least squares was used to determine the line best fitting the data for each soil. The equations of the lines of best fit were of the form, $T_c = a - be$, where a and b are constants. The slopes of the lines of best fit are all negative. The equations for these lines are given in Table 3.

The results indicate that the critical tractive force varies with the soil. For example, at a voids ratio of 1.5 the critical tractive force for the Knox surface soil was 0.013 and for the Mexico subsoil, 0.046. This indicates that approximately four times as much force is required to erode the Mexico subsoil as is required to erode the Knox surface soil.

Results also indicate that the effect of compaction on the critical tractive force varies with different soils. For example, with an increase in the voids ratio of 0.3 the critical tractive force for Knox surface soil decreased by 0.002, whereas for the Menfro surface soil this decrease was 0.007.

TABLE 3-LINEAR RELATIONS BETWEEN VOIDS RATIO AND CRITICAL TRACTIVE FORCE FOR SOILS TESTED

Soil	Equation
Mexico Surface	$T_c = .0970-.0357e$
Mexico Subsoil	$T_c = .1052-.0402e$
Menfro Surface	$T_c = .0775-.0262e$
Knox Surface	$T_c = .0250-.0085e$
Knox Subsoil	$T_c = .0430-.0191e$

CONCLUSIONS

The linear relationship between the voids ratio and the critical tractive force for each soil tested indicates that the critical tractive force varies directly with the degree of compaction.

Results of this study also indicate that the critical tractive force varies with the soil.

FIGURE 1—CRITICAL TRACTIVE FORCE VERSUS VOIDS RATIO