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SYNOPSIS: Agronomic soil consistency terms have been evaluated using shear strength as a unit of measure. The Torvane vane shear strength device was employed to measure shear strength on pedogenic profiles developed in several parent materials and on unconsolidated substratas of till. Correlations were then established between the consistency class and shear strength.

The shear device is capable of placing a numerical value on soil consistency classes. Variations in consistency were controlled by soil structure, bulk density, texture and organic matter. The device can easily be carried in the field and can reduce bias in the investigator's consistency estimations.

INDEX DESCRIPTORS: Soil shear strength, soil consistency.

The consistency class assigned to a soil material has, in the past, been dependent upon the judgment and experience of the investigator. Soil consistency is a widely used parameter in the fields of soil genesis, morphology and survey. Previously the soil scientist relied on his keen sense of judgment and sensitivity of his hands. He described the material by how it felt in relation to his preconceptions of ideal parameters. This procedure seemed adequate, for lack of a better method, but was subject to variations caused by passing the knowledge of an experienced hand to the apprentice, thus allowing for considerable bias on the part of the individual. With the advent of an instrument capable of accurately measuring shear strength from soil cores, pits or individual peds in the field, it is possible to place a numerical value on each of the moist soil consistency classes.

The Torvane shear strength device was employed to place a quantitative measure on soil consistency. The vane instrument is devised to measure the resistance to shear of a specific area of soil. Reading in tons per square foot it will account for both the number and degree of binding forces in the soil.

SOIL CONSISTENCY

Soil consistency is that quality of a soil material which resists deformation and rupture. It is controlled by the relative strengths of adhesion and cohesion of the soil mass and is most commonly referred to in terms of friability, stickiness, plasticity, and resistance to shear (Templin, 1947).

The degree and kind of binding forces within the soil mass can be classified into two major groups, one in which the liquid phase administers a surface tension on the contact of the soil particles, adhesion, and another where bridging water between soil particles binds them together by forces of molecular action in very wet conditions, cohesion (Kohnke, 1968).

Many methods of measuring consistency are of value to the agronomist. The most common method now used is a description of the behavior of the material in the hands of the observer, first described by Russell (1928). Many of the terms used to describe consistency have been refined into categories based on the moisture content of the soil. These are air dry, field capacity, or saturated, which are used extensively in the description of soils (Soil Survey Staff, 1952).

The moist soil is noted for its tendency to deform before rupture, break into pieces rather than powder, to cohere together after disturbance, and has a lack of brittleness. The following classes have been devised to define moist consistency: loose, very friable, friable, firm, very firm and extremely firm.

The terms gentle and moderate are arbitrarily dependent upon the strength of the observer and the size of sample being crushed. The larger the sample the more difficult it would be to crush, therefore, a friable piece of soil of considerable size may possibly be classified as firm under the present system. Controlling the area of shear and measuring its resistance will facilitate a valid comparison of the consistency.

The soil mass exhibits a property of resistance to movement under applied force due to the friction and cohesion of the particles. This soil shear resistance has come to be known as shear strength. It can be mathematically expressed by the empirical Coulomb equation, $S = C + N\tan\emptyset$, where S is the shear strength, C is cohesion, N is the normal pressure to the shear surface, and $\emptyset$ is the angle of internal friction (Spangler, 1951).

Civil engineers recognize shear strength as one of the most important properties of the soil and have developed many devices for its field measurement. Most of the types of field shear strength tests can be divided into one of two categories, the vane shear test and the penetration resistance.

The vane shear instrument contains blades which can be pressed into the soil and twisted to form a cylindrically shaped surface of failure. The amount of torque administered to the instrument to cause shear is measure and converted to shear strength by means of the Cadling equation (Wilson, 1963).

The vane shear test has been found to give consistent accurate readings from clays (Skempton, 1948) in the undrained state (Osterberg, 1956). Draining the soil or measuring sand will result in a loss of accuracy to the point where the determinations are no longer justifiable, although sands can be accurately measured using the penetrometer test (Sowers, 1963).

STUDY AREA

The sites selected were scattered throughout the northern half of Iowa. The general location of each site can be found in Figure 1. The firm and friable till study was conducted on

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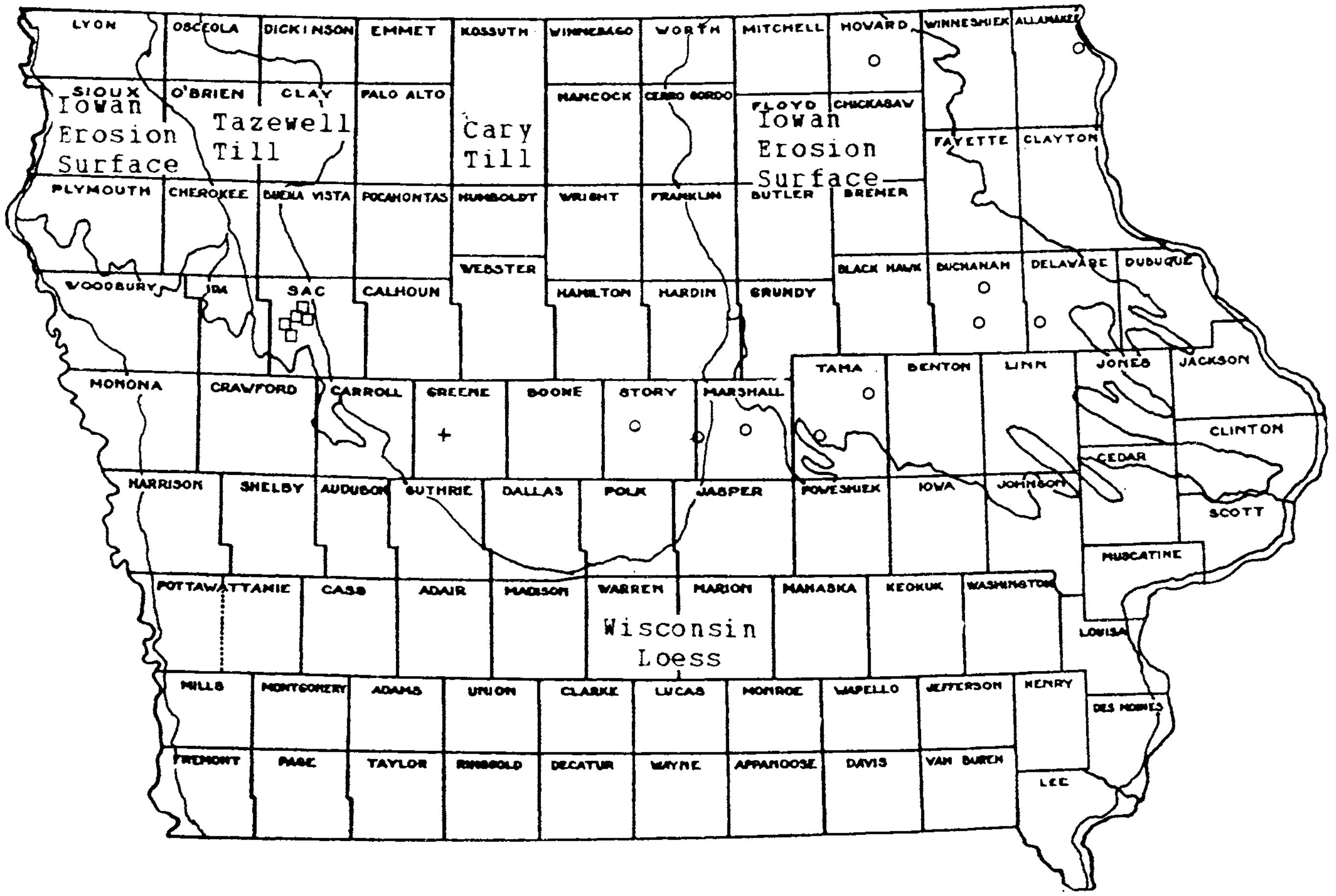

Figure 1. Distribution of geological features and study sites in Iowa.
+ Stratigraphic section at Scranton 3.
O Site locations of modern soils.
□ Firm and friable Tazewell till sites.

the Tazewell till, mantled here by Wisconsin loess. The stratigraphic site (Scranton 3) of Greene County, is a road cut exposing the sequence of four glacial tills with their associated paleosols. The remainder of the sites consist of a selection of the modern soils developed in glacial till, loess and alluvium.

PROCEDURES

The shear strength of the tills was measured with a Torvane torsional vane shear device (Soiltest, Inc., 1971) with a standard vane (0 to 1.00 tons per square foot). The core was trimmed in 6 inch increments to expose a flat surface perpendicular to the axis. Holding the sample firmly in one hand, the vanes of the Torvane were slowly inserted into the core until they were completely imbedded. Then the handle of the Torvane was turned slowly under a continual even pressure to the point of shear within the material. The shear strength in tons per square foot was read from the dial and recorded. The firm and friable tills were measured with the core method and the remaining readings were obtained in pits and road cuts by inserting the vanes into the material in place.

RESULTS AND DISCUSSION

Shear Strength as a Measure of Till Consistency

The Tazewell till outboard of the Cary in northwestern Iowa was chosen as a control area for this study. Very firm and friable till is prominent in this area. Site selection for these areas was limited to one soil, the Sac on a B slope (2 to 5 percent) to minimize some of the extraneous variables. For these measurements the normal vane (0.0 to 1.00 tons per square foot) was applied and found to be an adequate measure of consistency. The results of the shear strength analysis are graphically portrayed in Figure 2. As can be seen, the friable till is distributed about a mean of 1.35 TSF, and the very firm till is distributed about a mean of 0.93 TSF. The maximum range of the vane used controlled the range of shear strength values obtainable, thus terminating the upper limits of the very firm till shear strengths to 1.00 TSF. The Students t-test was used to statistically compare the tills and soils. It revealed that they are statistically different at the 99% confidence interval. Other statistical manipulations showed high correlations between consistency and shear strength, but none were found with bulk density or for soil moisture.

The bulk density was significantly higher in the very firm

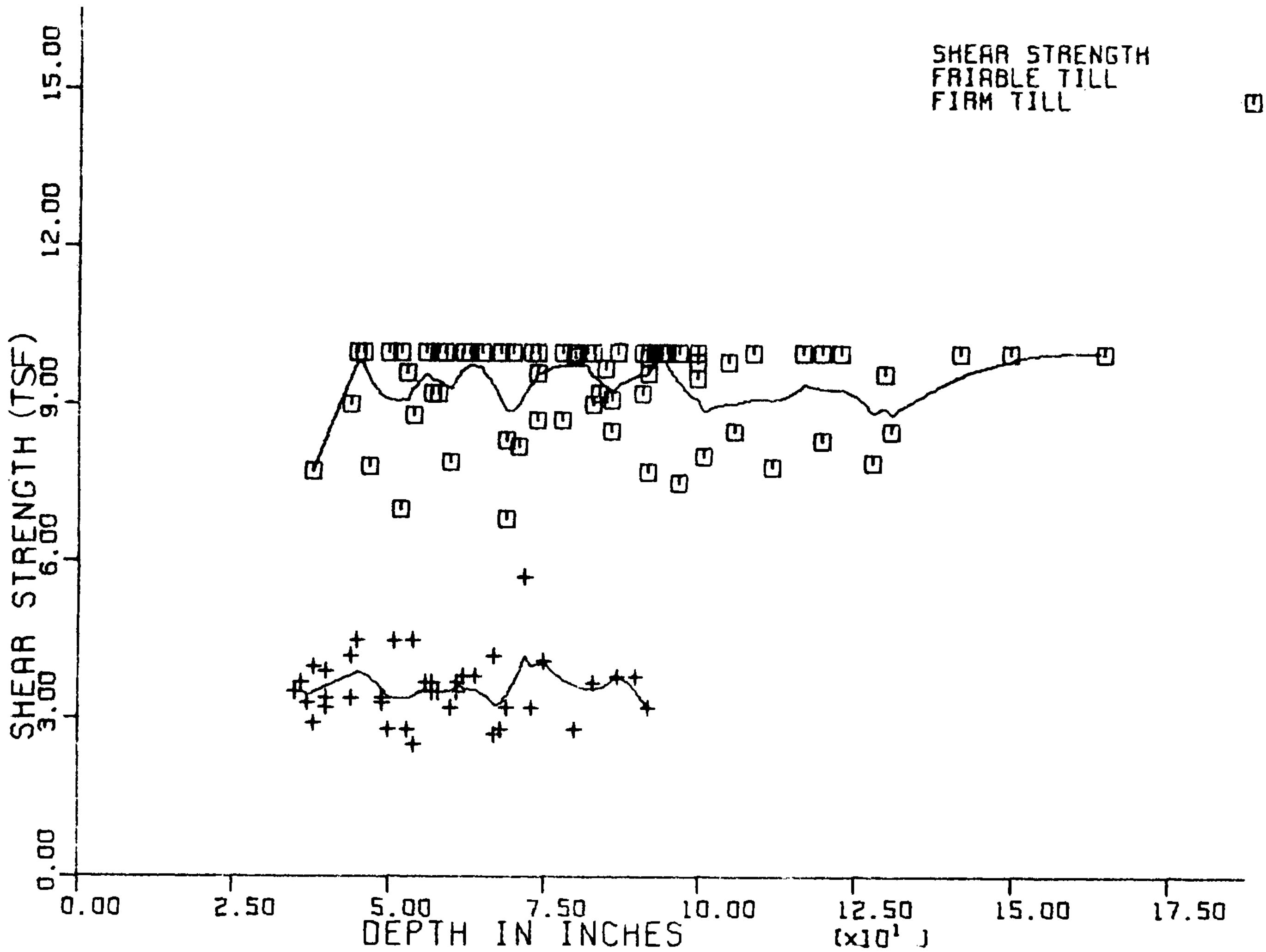

Figure 2. The shear strengths of the very firm and friable glacial tills.

till (1.91 g/cc.) than in the friable till (1.87 g/cc.) with little variation as illustrated by standard deviations of 0.0036 and 0.0099 respectively. The difference in bulk density is probably due to the presence of significantly higher levels of sand and coarse silts in the friable till, with an associated high concentration of clay in the very firm till, giving the friable till a higher geometric mean particle size. The stacking of particles can result in similar bulk densities from both coarse and fine materials, but if clay formation occurred, as it may have in the very firm till, the smaller particles would tend to fill and plug the pores to increase the ratio of solids to pores in a given volume. Another contributing factor was found in those areas where the friable glacial till is found. These areas are underlain by very firm till and have undergone compaction from the overburden of ice and till. Compaction will reduce the total volume of the material, decreasing pore space and increasing bulk density. At each site two samples from each till were sampled and measured to yield a moisture regime from which comparisons can be made to shear strength. Because all of the samples measured were taken midway between field capacity and air dry there was no significant correlation between soil moisture and shear strength. Considering the entire spectrum of soil moisture would reveal a relationship between moisture and shear, since cohesion (C) decreases with increased moisture. Since the samples were at approximately the same moisture content, the total forces of adhesion and cohesion were a function of materials rather than moisture.

Moisture determinations indicated that the very firm till outboard of the friable area maintained a much higher moisture content on an oven dry basis than the friable till. This significant difference was also found in those areas where the well drained friable till was stratigraphically above the very firm till, and is probably caused by an interaction between the greater adhesiveness, bulk density and finer pores of the very firm till associated with the finer texture.

The firm till was much wetter than its friable counterpart. Engineering principles prescribe that shear strength decreases with increasing moisture. No correlation was observed between soil moisture and shear strength over the range of 2.17 to 12.76 percent moisture encountered in this study. We concluded that within the moisture limits prescribed by the

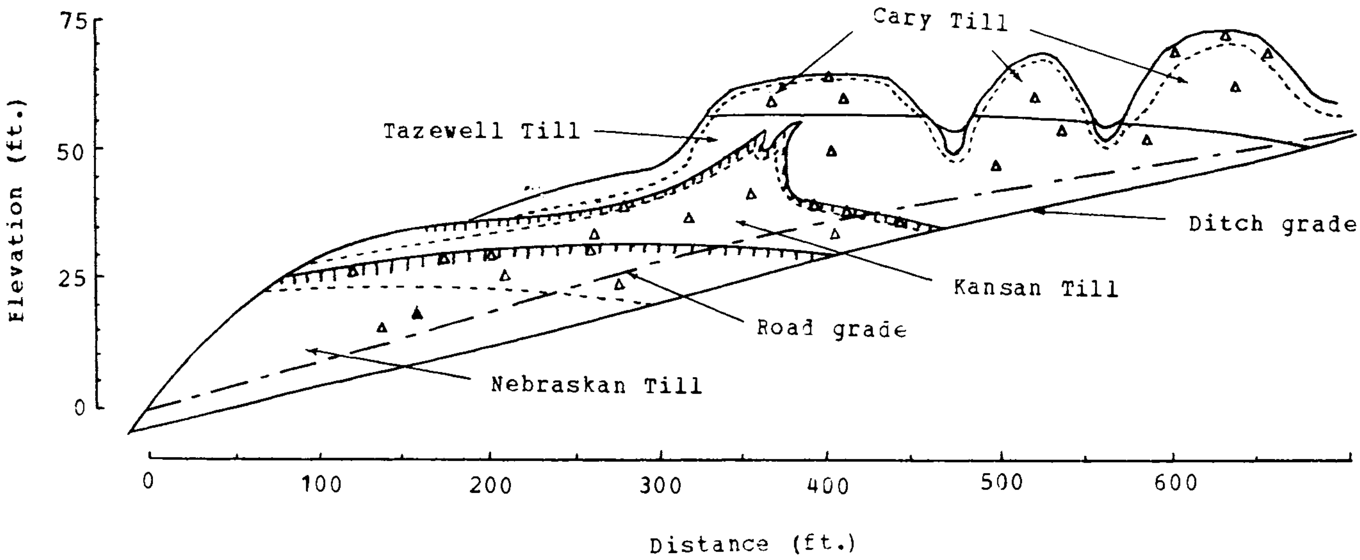

Figure 3. Cross section of the stratigraphic site at Scranton 3, including four glacial tills and their associated paleosols.

Soil Survey Manual for moist consistency the Torvane is capable of measuring shear strength to the accuracy required to indicate trends in materials.

Definite physical differences have been noted between these tills, in addition to several chemical variations. Statistically significant differences were found in the sand, silt and medium clay size fractions. The sand sized particles, under this moisture condition, will offer only limited degrees of adhesion and cohesion to the soil mass. Therefore, the greater the percentage sand in the friable till the lesser the shear strength and the more friable the consistency. Silt was also greater in the friable till. When concentrated in the coarse and very coarse fractions, these silts would reflect properties of soil cohesion similar to the sand and contribute to the lower consistency values of the friable till. The clay in a soil material constitutes the greatest force of cohesion. Generally clay particles have a high surface area and account for the greatest number of ion exchange sites in a mineral soil. Each of these properties contributes to the cohesiveness between the soil particles. The percent medium clay being eight percent greater in the firm than in the friable till was perhaps the strongest difference noted between the two tills. The residual and alluvial medium clay of the very firm till was responsible for its higher bulk density. This results in reduced total pore space with an associated enhancement of smaller pores, accounting for the poorly drained condition in which the very firm till was found.

The calcium and magnesium carbonates were found to be statistically significant between the two tills. These carbonates will precipitate on the soil particles to form a strong bond between them. The carbonate concentration is greater in the firm till and can be said to produce some of the resistance to shear in the soil.

Modern Soils

The B horizons of 11 different soils of northeastern Iowa were compared in consistency and shear strength. At each site four shear strengths were obtained and the consistency estimated according to the procedure described by the Soil Survey Manual (Soil Survey Staff, 1952). From this it was possible to place statistical parameters on the influence of parent material and the value of the Torvane for measuring consistency in genetic horizons.

TABLE 1. SHEAR STRENGTH OF THE MATERIALS AND CONSISTENCY TERMS TESTED.

Parameter	Mean	Std. Dev.	Range
	Tazewell Control Sites		
Friable	0.356	0.062	0.319
Very firm	0.935	0.081	0.320
	Modern Soils		
Very friable	0.098	0.093	0.249
Friable	0.281	0.154	0.240
Firm	0.676	0.243	0.400
Very firm	0.960	0.089	0.080
Alluvium	0.398	0.423	0.979
Loess	0.244	0.102	0.300
Till	0.359	0.089	0.269
Peat	0.111	0.109	0.239
	Stratigraphic Section		
Friable	0.463	0.114	0.310
Firm	0.677	0.146	0.370
B2 hor. Cary	0.407	0.070	0.230
Cary till	0.649	0.112	0.450
Tazewell till	0.853	0.123	0.500
Y-S paleosol	0.599	0.119	0.480
Kansan till	0.779	0.176	0.529
Aftonian pal.	0.482	0.105	0.459
Nebraskan till	0.619	0.132	0.350

The results (Table 1) indicate that the shear strength values are different between materials and that the values are dependent on the moist consistency class of the soil. Each consistency class was differentiated from the other in shear strength at the 95 percent level.

This relationship of shear strength to the established consistency classes is reflected in the very friable, friable and firm soils. As the firmness of the soil increased the standard deviation and range also increased, except in the very firm till. This is due to the difficulty in separating the midrange consistencies in the field, where those soils having the extreme consistencies, such as very friable and very firm were more distinctly recognized by touch. The mean shear strength of each consistency was patterned in increments of two, from one term to another, with the exception of the friable which seemed to be separated by a wider range. From this basis it can be predicted that shear strengths less than 0.20 should be considered very friable, from 0.20 to 0.50 friable, 0.50 to 0.80 as firm, 0.80 to 1.00 as very firm, and greater than 1.00 should be extremely firm for most natural soils.

The values given in this section are uniformly lower than that of the firm and friable till. The reason for this is that the till, being massive, is lacking the zones of weakness between the peds which are normally associated with a well structured soil. With most soil structure the consistency is taken on the mass of the horizon rather than the peds alone. This includes the alluviated clay, water and large pore spaces between the aggregates, each of which will increase the friability of the soil.

The parent materials of the soils showed both uniformities and inconsistencies. The loess, till and alluvium derived soils showed no significant difference in shear strength or consistency based on the mode of transportation and deposition of material. But all are mineral soils. The peat, an organic soil, displayed properties very much to the contrary of the alluvium and loess, but not the till. The peat differs from the mineral soils, in that it generally has a higher microbial activity, higher moisture holding capacity, lower bulk density, soft and easily broken particles, and is fibrous, each contributing to the low shear strength.

Comparing the statistical data of the parent materials indicates a relatively even distribution of shear strength values for the loess, till and peat. The alluvium deviated from the others due to the variation in particle sizes which can be found in alluvial material. From this the conclusion can be made that shear strength is a measure of soil consistency in a soil material regardless of the type of parent material or the type, grade, and class of the present soil structure.

Stratigraphic Section

The stratigraphic section of storied materials was taken at Scranton 3 where each of the Nebraskan, Kansan, Tazewell and Cary glacial tills can be found with their associated paleosols (Figure 3). Four sites were randomly selected from each till and paleosol to be analyzed for shear strength and the estimated consistence. At each site 5 shear strengths were obtained from the soil in site.

At this location only friable and firm materials were encountered, they both gave shear strengths comparable to their associated moist consistency class of the other types of samples. The mean shear strength of the friable material was somewhat higher than the same class in the other materials, but remaining within the range of the proposed scheme.

Each of the materials showed little difference in consistency with the exception of the Tazewell which seemed to be firmer than the others. This is possibly due to a higher bulk density and clay content than the other tills.

CONCLUSIONS

The Torvane CL - 600 was able to accurately measure soil consistency to such a degree that it is possible to place a numerical value on each of the parameters described for moist consistency. From the shear strengths obtained for each class, statistical differences were found between each one to at least the 95% confidence interval. This is a further quantitative measurement which can be used to characterize soils and aid in their identification and separation.

For moist consistency the following shear strength parameters will be proposed for each term (Table 2).

TABLE 2. SHEAR STRENGTH LIMITS FOR EACH OF THE MOIST CONSISTENCY TERMS

Consistency	Mean	Shear Strength (TSF)
Very Friable	0.089	0.0-0.2
Friable	0.367	0.2-0.5
Firm	0.676	0.5-0.8
Very Firm	0.940	0.8-1.0
Extremely Firm	1.00	1.0

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