ENGINEERING PROPERTIES AND MAINTENANCE OF GOLF PUTTING GREENS

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INTRODUCTION

In the first phase of this research project, the primary objective is to apply engineering principles to the study of strength and stability in sand-textured root zones used for golf putting greens. In addition to completing of the literature review, the second year of study allowed us to expand the types of testing. Evaluation of the properties of the six test sands which were generated in the laboratory and designed to simulate possible mix ranges found in USGA specifications was continued. New constraints were incorporated into the testing procedures already in place. The data generated from the modified tests, along with the data previously collected, provided a more detailed picture of the properties crucial for strength and stability. The field testing portion of the study was also begun. This allowed us to compare laboratory test results with real world turf conditions. From this we will be able to begin creating guidelines for achieving desired soil strength.

MATERIALS AND VARIABLES

In order to ensure consistency of the variables which we dealt with in the laboratory, six sands were produced rather than selecting market sands. These sands were made from a commonly available construction sand (MDOT 2NS) which has a wide range of particle sizes. Three different gradations of sands were designed, a coarse, intermediate and fine. Each of these three classifications was again divided into a high coefficient of uniformity (C_u) and a low coefficient of uniformity (C_u). These sands were then given five letter designations for easy clarification. The six sands therefore include $CGHC_u$, $CGLC_u$, $IGHC_u$, $IGLC_u$, $FGHC_u$, $FGLC_u$. The CG, IG or FG stands for either coarse graded, intermediate graded or fine graded. Those sands which have a wider distribution of particle sizes are designated as HC_u which indicates a high coefficient of uniformity while the sands with a more consistent particle size are designated as LC_u indicating a low coefficient of uniformity.

LITERATURE REVIEW

EFFECT OF GRAIN SIZE DISTRIBUTION

In general, the results of sieve analysis for cohesionless soils are presented as grain-size distribution curves. The diameter in the grain-size distribution curve corresponding to 10 % finer is defined as the effective size D_{10} ; 60 % finer is D_{60} . Then, the uniformity coefficient C_u is given as : $C_u = D_{60} / D_{10}$. A higher value of C_u indicates the soil sample is well-graded.

Bishop (1948) tested a full range of cohesionless soils, ranging from sands to gravels and sandy gravels, in shear box tests. Only two samples are of interest here, brasted sand which is a well graded sand of the Folkeston bed ($C_u = 2.5$) and Ham River sand which is a uniform sieved fraction from the Thames Valley gravels ($C_u = 1.3$). It was observed that in the plot of porosity versus friction angle, the curves of two samples were almost parallel. Due to lack of limiting porosities, the effect of C_u is not clear. Chen (1948) investigated the strength characteristics of cohesionless soils by using triaxial compression tests. He concluded that the friction angle of cohesionless soils increases with increasing uniformity coefficient, varying from 26.5° for loose specimens of the well-rounded Ottawa sand to 51.5° for the well-graded gravel.

Koerner (1970) studied the effect of gradation on the strength of cohesionless soils using three single mineral particles (quartz, feldspar and clacite). Gradation was evaluated by varying uniformity coefficient (C_u) from 1.25 to 5. The quartz soils were tested in the saturated and air-dry conditions with both drained and undrained triaxial tests; the feldspar can calcite soils were tested under saturated state using drained triaxial tests. The conclusions from his study are as follows:

(1) The drained friciton angle ($?_d$) for saturated feldspar and calcite soils increase with increasing value of C_u ;

(2) The effect of C_u on the drained friction angle ($?_d$) for both saturated and dry quartz soils is negligible ;

(3) C_u does not affect the undrained friciton angle of quartz soils.

Zelsko et al. (1975) performed triaxial tests using sand materials mainly consisting of quartz grains and the range of C_u values is between 1.2 and 2.0. The similar conclusion with Koerner's study was made that improved gradations have a minor influence on $?_d$ and no influence on $?_f$.

LABORATORY TESTING: DIRECT SHEAR

The direct shear testing device (ASTM D3080) is used to measure the friction angle of a sand. This is done by placing a sample of the sand into a testing block. A shearing stress is then applied to the sample and it is allowed to fail on a horizontal plane. After a series of tests, the friction angle can be plotted and measured for each sand. The strength of a sand is determined by it's friction angle. Larger friction angles coincide with stronger sands. This test is appropriate when testing golf putting green strengths since loading on a golf putting green generates shear stresses and the friction angle determines the maximum shear stress that can be sustained. The direct shear testing performed in the past involved compacted and uncompacted dry sands. Although no putting green is built from dry sand, the testing was necessary to get a better understanding of the behavior of the sands under various controlable parameters.

This year the direct shear testing was extended to moist sands. Testing was performed on these samples under both compacted and uncompacted conditions. A total of over 80 direct shear tests were performed (the tests for each sand were replicated over 12 times) to determine an average value for the friction angle. The moist sands were prepared with a gravimetric water content which corresponded to -0.04 Bars of matric potential. These include moist and dry, compacted and uncompacted samples. The data indicates that the dry and compacted sands have the greatest friction angle. Therefore, those sands are the strongest against resisting shear failure. The moist sands, compacted and uncompacted, have lower friction angles than the compacted or uncompacted dry sands in every case.

LABORATORY TESTING: BEARING CAPACITY

A more direct measure of a soils strength against failure under surface compressive load is its bearing capacity. This can be directly tested in the lab with the Modified California Bearing Ratio (CBR) testing device (ASTM 1883). This device has a small plunger which is forced into a sample volume of sand. A load cell is attached to the plunger and records the force being used to push down on the soil sample. The depth the plunger has punctured into the soil can then be measured to determine the amount of force necessary to cause failure within a soil. The ultimate pressure which the soil can withstand before it fails is designated by the peak of the test graph. The bearing capacity test was run approximately 290 times on the sand samples under all types of conditions. The trends of the bearing tests coincided quite closely with those from the direct shear tests. The sands prove to have higher strengths under dry conditions as opposed to moist. (All sands were compacted for the bearing tests)

The bearing capacity tests also show the benefits of sands with a high coefficient of uniformity (C_u). As the graph shows, the well graded sands were capable of withstanding an ultimate pressure on the order of 45 psi. The poorly graded sands under the same conditions could only withstand pressures up to 25 psi. This is below the tire pressure found in some golf course maintenance vehicles and indicates that a golf putting green may suffer deformation during normal servicing. It should be reiterated that although these sands display such a wide variety between their ultimate bearing capacities, they all fall within USGA gradation specifications and would be considered acceptable sands for golf putting green construction.

FIELD TESTING

In cooperation with the Michigan Turfgrass Foundation, the design and construction of the field testing device was completed this year. This allowed for the initiation of the field testing phase. The field testing device is designed to model the laboratory California Bearing Ratio (CBR) testing device. The field device is mounted to a three point hitch which can be found on the back of most tractors. The device has an adjustable diameter plunger which is forced into the ground. The load cell which is attached to the plunger measures the force which is being applied as the surface of the ground is penetrated. This force is recorded along with the corresponding vertical displacement which has taken place.

Initially the testing device was used on plots at MSU's Hancock Turf Research Center. Sample plots included USGA turf samples, Prescription Athletic Turf (PAT) and thin rye grass in native soils. These tests went well, so correspondence with golf courses and athletic field superintendents was begun to set up testing dates at other sites. The first off-campus test took place at Hillsdale College football field. The field was constructed with dune sand which is recognized for its uniformity of size and shape; the field has experienced problems with poor strength. The testing was completed in one day and went well. As expected, Hillsdale College's football field showed a lower ultimate bearing capacity than the other turf grass tests performed at the Hancock Research facility. Another distinction between the laboratory and field tests is that the laboratory tests have a definite failure point were the curve peaks out and then begins to drop off. The field tests on the other hand, have an abrupt turn where they switch from a sharp rise to gradual slope. Both of these differences are apparently attributed to the root zone which is present in the field tests. The root zone increases the strength of the soil. It also helps to provide reserve strength after it has failed due to loading. Although the root zone is difficult to simulate in the laboratory environment, comparison of the two test procedures is still beneficial. Soil samples from the field test sights were analyzed to determine their soil gradation. From this a coefficient of

uniformity (C_u) and grain size (D_{10}) can be determined. (D_{10} is commonly used in engineering classifications and represents the maximum diameter of soil particles from a particular mix which makes up the bottom 10% of the soil sizes) These values can then be compared with the sample sand which was developed for the laboratory tests. Field samples which
were well graded or had a high coefficient of uniformity (C_u) performed better than those which were low. It compares the percent of each particular grain size found within the mixture. The thick gray lines indicate the maximum and minimum acceptable gradations by the USGA. Those sands with a *lower* coefficient of uniformity (C_u) and *steeper* slope, such as the Hillsdale College soil, produce a poorer bearing capacity. This verifies that previous hypothesis and laboratory information was correct.

More in-depth analysis of the field testing results has also allowed us to expand the study to engineering behavior which may be more specific to the needs of the golf course. If the soil is likened to a spring, it behaves as a very stiff spring under low loads, and a much softer spring as it nears failure. In engineering terms, it is a "nonlinear" spring; different from the linear steel springs commonly encountered. The spring properties are inportant in predicting engineering behavior. Once the soil nears and then passes it's failure point it loses it's stiffness and deforms very easily.

The three field tests present very close stiffness values for the corresponding loading. Additional field testing will invariably produce results with more variance.

FINDINGS

Based on engineering principles, the research up to this point has allowed us to conclude many things about what parameters are most beneficial for obtaining a desirable sand mixture. Certain trends have been established which will be beneficial for golf course superintendents who wish to choose a sand mixture in order to attain desired properties. As the coefficient of uniformity (C_u) is *increased*, the ultimate bearing capacity is also *increased*. This is exactly as expected and directly coincide with the previously sited literature review. On the other hand, as the grain size (D_{10}) *decreased* the ultimate bearing capacity *increased*. Together these trends indicate that the broader the particle size distribution in a sand mixture is, and the smaller the particles within that broadly distributed mixture are, the more capable the sand will be to support greater loads.

SUMMARY

The second year of research has allowed for extensive laboratory testing. This has made it possible to test the strengths of sands under numerous controlable parameters. Tests included the direct shear test and the California Bearing Ratio (CBR) tests. From these tests we were able to determine that although small amounts of water may cause some apparent cohesion within a sand, drier more-well compacted sands withstand a greater load before failing. In addition the initial phase of field testing was begun and has already produced significant amounts of information. It was possible to directly relate the field test results with the laboratory tests. From this, the previous hypothesies could be confirmed and new questions could be generated. The testing has shown us that a soil will be able to carry a greater load without failure if it is comprised of soil particles which cover a wide range of sizes. In addition, the smaller the minimum sized particles in this wide range of sizes are, the greater load the sand will be able to carry. Through the tests it has also been found that for most soils within the root zone, once a large enough load has been applied to cause a given deformation, very little increase in loading is needed to casue further failure of the soil. All of this information points to the fact that significant variations in the bearing capacity and resistance to deformation can be found among similar sands even thought they are all within USGA specifications.

The increased number of field tests which will be possible in the future will make it possible to further analyze the most crucial soil parameters for affecting strength. Once this is accomplished, guidelines will be developed so that superintendents will be able to design a sand mixture which will produce the exact results which they desire while still falling within USGA specified guidelines.