Turfgrass and Environmental Research Online

...Using Science to Benefit Golf

Researchers at Michigan State University used engineering techniques to test the bearing capacity (resistance to surface deformation) of various sands used for putting green rootzones. Although the six experimental sands used in the study all fell with USGA guidelines, the sands varied significantly in their ability to resist deformation from applied pressure.

Volume 2, Number 15
August 1, 2003

PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 215 projects at a cost of $21 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

Editor

Jeff Nus, Ph.D.
904 Highland Drive
Lawrence, KS 66044
jnus@usga.org
(785) 832-2300
(785) 832-9265 (fax)

Research Director

Michael P. Kenna, Ph.D.
P.O. Box 2227
Stillwater, OK 74076
mkenna@usga.org
(405) 743-3900
(405) 743-3910 (fax)

USGA Turfgrass and Environmental Research Committee

Agronomic and Engineering Properties of USGA Putting Greens

James R. Crum, Thomas F. Wolff, and John N. Rogers,III

SUMMARY

The goal of this research at Michigan State University was to apply the principles of soils engineering to the issue of ensuring stability of sands used in golf course putting greens. The specific objectives of the research were to: (1) develop six experimental sands that varied in particle size and gradation to represent a range of USGA specifications; (2) determine bearing capacity of the six experimental sands and relate their strength to size and gradation characteristics of the sands; and (3) determine bearing capacity of established putting greens and relate their strength to sand characteristics.

- The bearing capacity tests show the benefits of sands with a high coeffient of uniformity (Cu). The laboratory bearing results show the well-graded sands (i.e., those with grains with a larger range of particle size) were capable of withstanding an ultimate pressure greater than those sustained by uniform sands (i.e., those with grains that were uniform in size).
- Increasing the Cu of intermediate grade sands from 1.8 to 3.0 approximately doubled (from 22 to 42 psi) the laboratory bearing capacity. Increasing the Cu in the fine and coarse grain-sizes of sands also dramatically increased the bearing capacity of the sands.
- The testing conditions in the lab were somewhat different than those in the field. In the lab, there was no layer of turf, organic matter, and roots incorporated in the surface of the soil. Also, in the lab, the sand is contained in a rigid mold that will not allow lateral deformation or strain of the sand. This leads to a well-defined peak stress at failure and a non-ambiguous bearing capacity.

Rootzone specifications for United States Golf Association (USGA) putting greens require greater than 92 percent sand, not more than five percent silt (0.05-0.002 mm), and not more than three percent clay (<0.002 mm) in the soil. Additionally, there must be a minimum of 60 percent coarse and medium sand, not more than 10 percent fine gravel and very coarse sand, not more than 20 percent very fine sand, and not more than 5 percent very fine sand. The resultant rootzone is dominated by macropores (large pores that are air-filled at field capacity) that drain rapidly and maintain large amounts of aeration porosity important for turfgrass growth.

Through practical field-experiences and research, the USGA putting green recommendations have been revised a number of times, but at no time were they drastically changed. They remain the standard by which most golf course architects design and golf course construction companies build their highest-quality golf course putting greens.

Within the engineering literature, high sand content soils are considered cohesionless

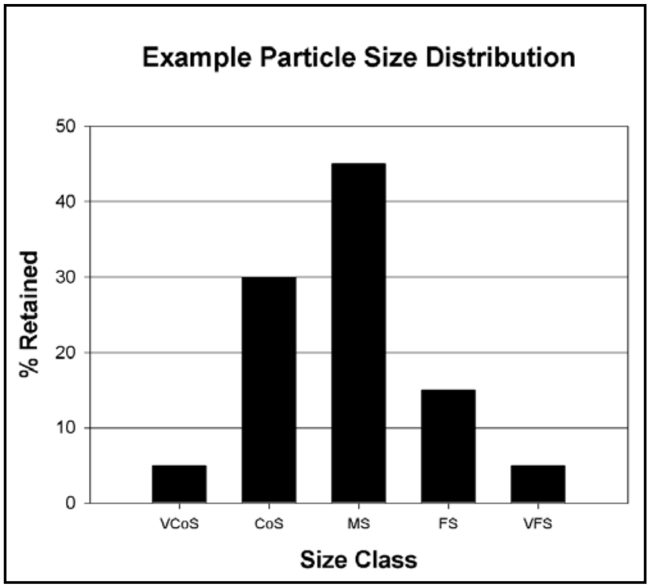


Figure 1. Quantifying particle size distribution of sand uses sieve analysis to segregate sand particles according to grain diameters like the example shown above. The United States Department of Agriculture (USDA) defines five classes of sands based on their particle size: very coarse sand (VCoS, 1.0-2.0 mm diameter), coarse sand (CoS, 0.5-1.0 mm diameter), medium sand (MS, 0.25-0.5 mm diameter), fine sand (FS, 0.10-0.25 mm diameter), and very fine sand (VFS, 0.05-0.10 mm diameter).

JAMES R. CRUM, Ph.D., Professor of Turfgrass Soil Management, THOMAS F. WOLFF, Ph.D., Associate Professor and Associate Dean, College of Engineering, JOHN N. ROGERS III, Ph.D., Professor of Turfgrass Management, Michigan State University, East Lansing, MI.

USGA Turfgrass and Environmental Research Online 2(15):1-9.
TGIF Record Number: 91782

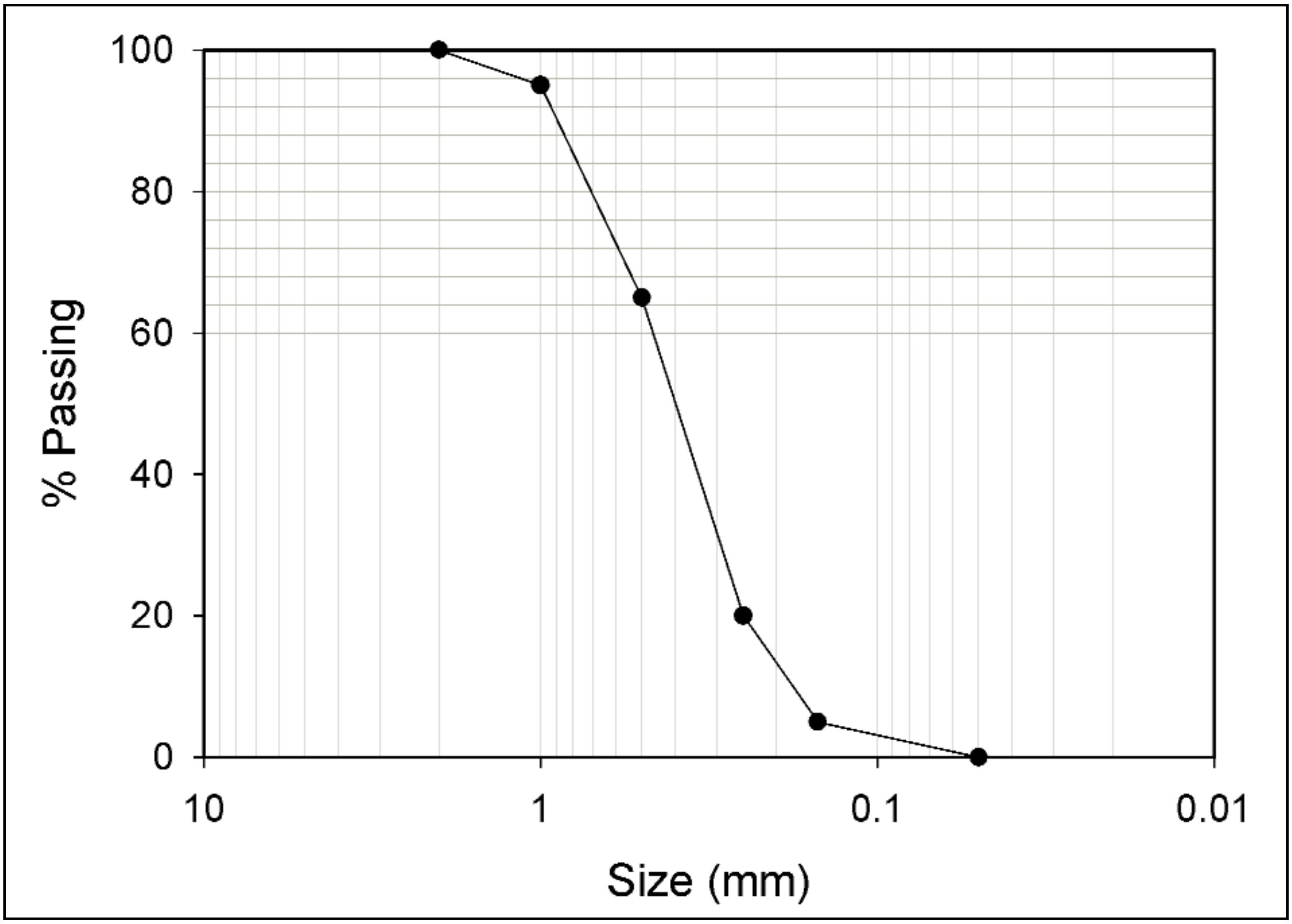


Figure 2. Particle size analyses of sands from sieve analyses can also be expressed as a semi-log graph as shown above which plots the percentage of the sand (by weight) that passes through increasingly finer sieve screens against the base-10 log of the grain diameter (mm). Expressing sand this way allows for the determination of the D_{50} which is the grain diameter value that half the sample is greater than and half the sample is less than.

materials, or materials that do not stick together. High sand content soils must rely on particle-to-particle touching and the friction produced to create a stable surface required for the game of golf. As we have traveled the United States and visited many golf courses, it became apparent that all USGA specification putting greens do not behave alike. Some have strong and stable surfaces and others have surfaces that were difficult to manage because when a load was applied (i.e. foot traffic) deformation occurred. With these observations in mind, we initiated the research reported here.

The goal of this research was to apply the principles of soils engineering to the issue of ensuring stability of sands used in golf course putting greens. The specific objectives of the research were to: (1) develop six experimental sands that varied in particle size and gradation to represent a range of USGA specifications; (2) determine bearing capacity of the six experimental sands and relate their strength to size and gradation characteristics of the sands; and (3) determine bearing capacity of established putting greens and relate their strength to sand characteristics.

Materials and Methods

Laboratory Testing

Laboratory testing focused on the effect of particle size, expressed as median grain size (D_{50}) and gradation, expressed as coefficient of uniformity (CU) on bearing capacity.

Sieve analysis of coarse-grained material

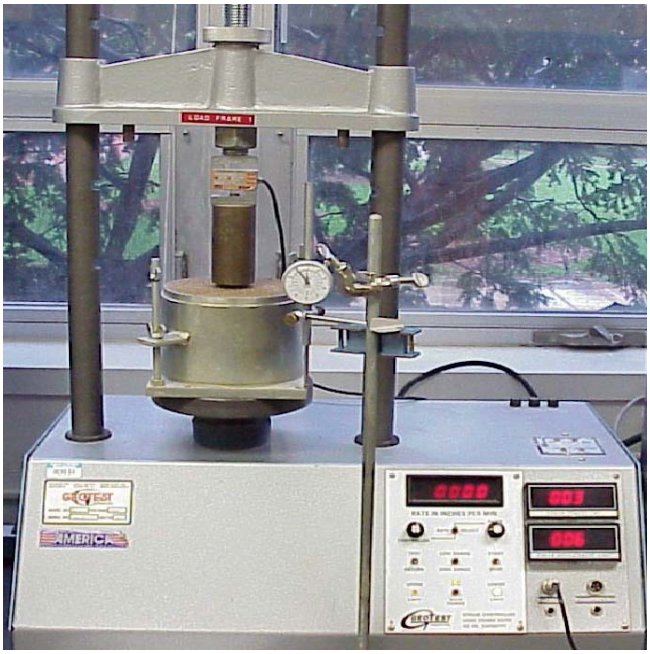


Figure 3. A soil's strength against failure under surface compressive load is termed its bearing capacity. This was directly tested in the lab by developing a modified California Bearing Ratio (CBR) testing device.

(sand, in this case) is generally expressed in two ways: percent retained, and percent passing (or percent finer). The United States Department of Agriculture (USDA) has defined five classes of sands based on their particle size: very coarse sand (VCoS, 1.0-2.0 mm diameter), coarse sand (CoS, 0.5-1.0 mm diameter), medium sand (MS, 0.25-0.5 mm diameter), fine sand (FS, 0.10-0.25 mm diameter), and very fine sand (VFS, 0.05-0.10 mm diameter). The United States Golf Association (USGA) has modified these classes slightly in the FS class range from 0.15-0.25 mm diameter and the VFS class range from 0-05-0.15 mm diameter.

The percent retained in each class is calculated as the proportion of the total weight of the sample that is of the given size class. The percent passing is calculated as the proportion of the total sample weight that is finer, or passes a particular size (i.e. the percent passing a 2-mm sieve). Often both ways of expression are presented as tables and as graphical representation of the data. The graphical representation of the percent retained data appear as histograms (Figure 1) and of the percent passing as semi-log line graphs (Figure 2).

The real usefulness of the semi-log graphical presentations comes in the quantification and calculation of coefficients. For example, to determine the median grain size we would determine the D_{50}, or the diameter (D) at which 50 % is larger and 50 % is smaller. The coefficient of uniformity, Cu, is calculated as D_{60}/D_{10}, or a way to express the shape of the finest 60 % of the percent passing curve. The larger the Cu, the greater the range in particle size and the more well-graded the sand.

Six gradations of sand were prepared for each of three different D_{50} sizes termed fine (FG), medium (MG) and coarse (CG). For each of these sands, two gradations were prepared: a very uniform gradation with a low Cu (LCU) and a more well-graded one with a higher Cu (HCU). In order to ensure consistency, these six sands were produced in the laboratory. These sands were made from a commonly available construction sand (MDOT 2NS) that had a wide range of particle sizes. To prepare the laboratory gradations, the 2NS sand was divided into a number of very narrow gradations by sieving. These were then

Figure 4. MSU researchers adapted a California Bearing Ratio (CBR) testing device for field measurements of putting greens. The CBR device was mounted to a tractor and had a plunger that was pushed into the ground with a jack. A load cell with digital readout measured the force on the plunger. This force was recorded for a set of corresponding vertical displacements of the plunger into the ground, measured by a dial gauge clipped to plunger arm and measured movement relative to a reference beam.

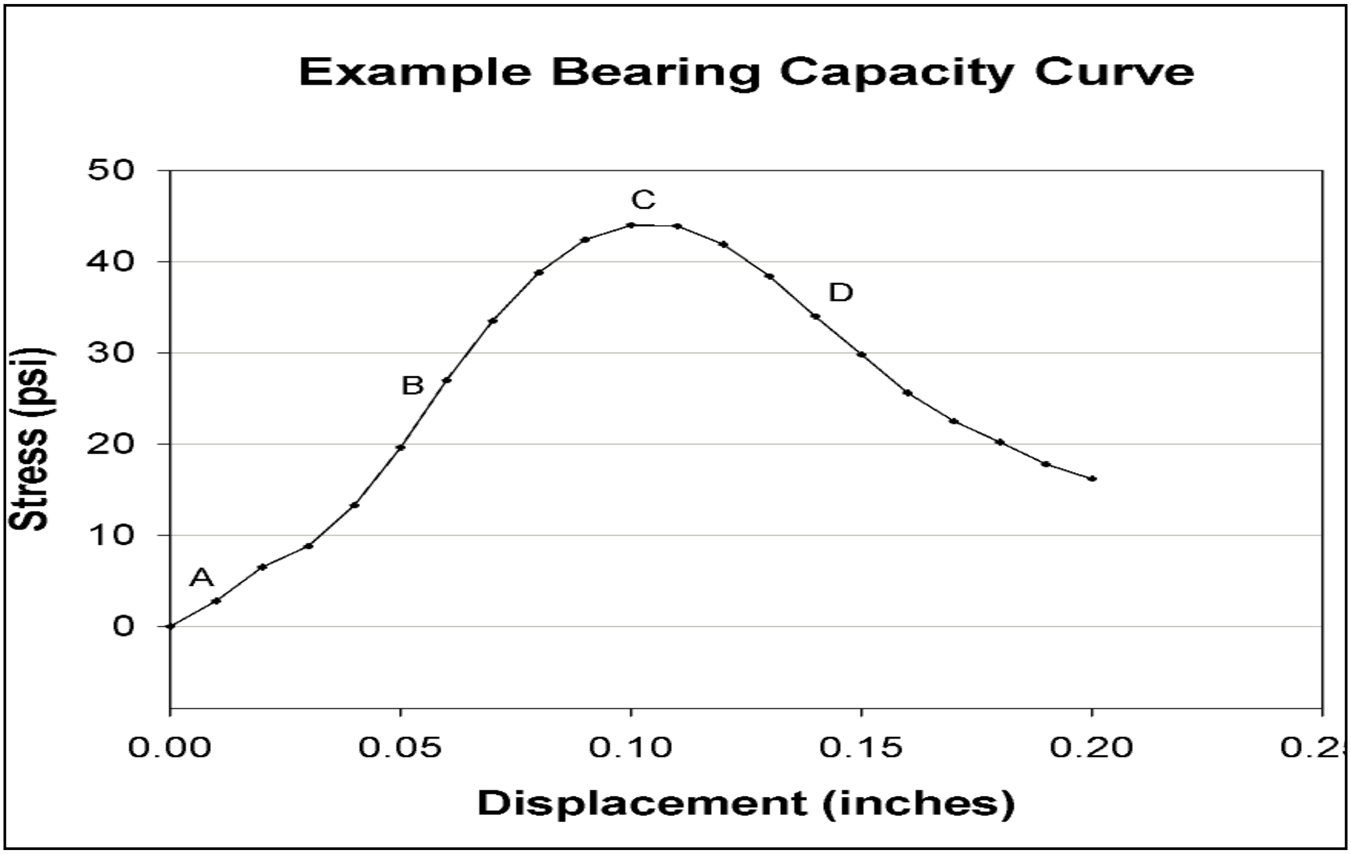


Figure 5. With the California Bearing Capacity technique, the pressure (psi) required to deform the putting green surface was recorded for each 0.01-inch displacement. The initial part of the curve, labeled A, represents the pressure causing initial deformation of the surface layer. It is obvious from the graph that the surface offers little resistance to deformation. The portion of the graph labeled B shows that increasing stresses are developed as the underlying sand-based rootzone deforms under the surface layer. The underlying sand requires significantly greater stresses to produce additional deformation. At point C the sand fails and further displacement occurs with less stress (area D).

recombined to achieve the desired gradations for testing. All six of these test sands were designed to meet the USGA guidelines for golf putting greens.

A soil's strength against failure under surface compressive load is termed its bearing capacity. This was directly tested in the lab by developing a modified California Bearing Ratio (CBR) testing device (Figure 3). This device has a circular plunger with a cross-sectional area of three square inches, which is forced into a sample volume of sand placed in a mold using a load frame.

Sample	**Fine Gravel** (2.0-3.4)	**Very Coarse Sand** (1.0-2.0)	**Coarse Sand** 0.5-1.0)	**Medium Sand** (0.25-0.5)	**Fine Sand** (0.15-0.25)	**Very Fine Sand** (0.05-0.15)	**Cu** (D_{60}/D_{10})	**D_{50}**
	mm							
CGHCU	0	0	70	22	8	0	2.6	0.6
IGHCU	0	0	56	30	10	4	3.0	0.5
FGHCU	0	0	44	30	17	9	3.5	0.4
CGLCU	0	0	82	16	2	0	1.6	0.6
IGLCU	0	0	45	47	5	3	1.8	0.5
FGLCU	0	0	22	61	13	4	1.9	0.3

Table 1. Percent retained data for the six experimental sands

	Sieve Size (mm)						
Sample	**3.4**	**2.0**	**1.0**	**0.5**	**0.25**	**0.15**	**0.05**
CGHCU	100	100	100	30	8	0	0
IGHCU	100	100	100	44	14	4	0
FGHCU	100	100	100	56	26	9	0
CGLCU	100	100	100	18	2	0	0
IGLCU	100	100	100	55	8	3	0
FGLCU	100	100	100	78	17	4	0

Table 2. Percent passing data for the six experimental sands.

A load cell above the plunger displays the force pushing down on the soil sample. The depth the plunger has penetrated into the soil is measured with a dial gauge. Dividing the force by the piston area gives the applied pressure. The bearing capacity, or ultimate pressure which the soil can withstand before it fails corresponds to the peak of the curve and the soil's bearing capacity.

Field Testing

A field CBR device (Figure 4) was adapted from the original California Bearing Ratio (CBR) testing device. The CBR device can be pinned to the three-point hitch or clamped to the loading bucket of most tractors. The device has a plunger that is pushed into the ground with a jack. A load cell with digital readout measures the force on the plunger. This force is recorded for a set of corresponding vertical displacements of the plunger into the ground, measured by a dial gauge clipped to plunger arm and measuring movement relative to a reference beam.

The force measured by the load cell is divided by the area of the load piston to obtain the pressure on the surface of the putting green. This calculation is performed for every increment of

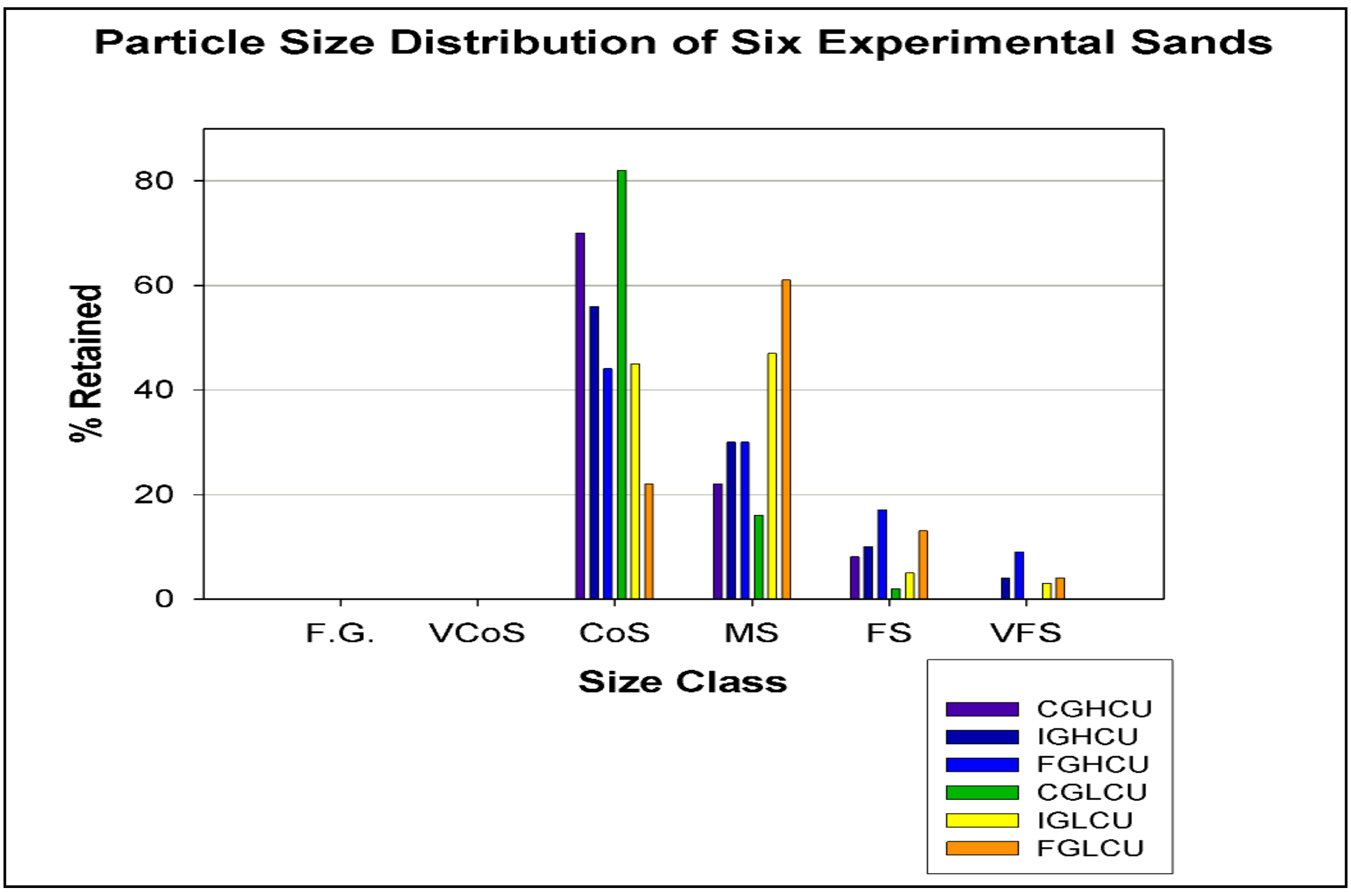


Figure 6. Particle size distribution of the six experimental sands used in the Michigan State University study classified by particle size group (i.e., fine gravel, very coarse sand, coarse sand, medium sand, fine sand, and very fine sand)

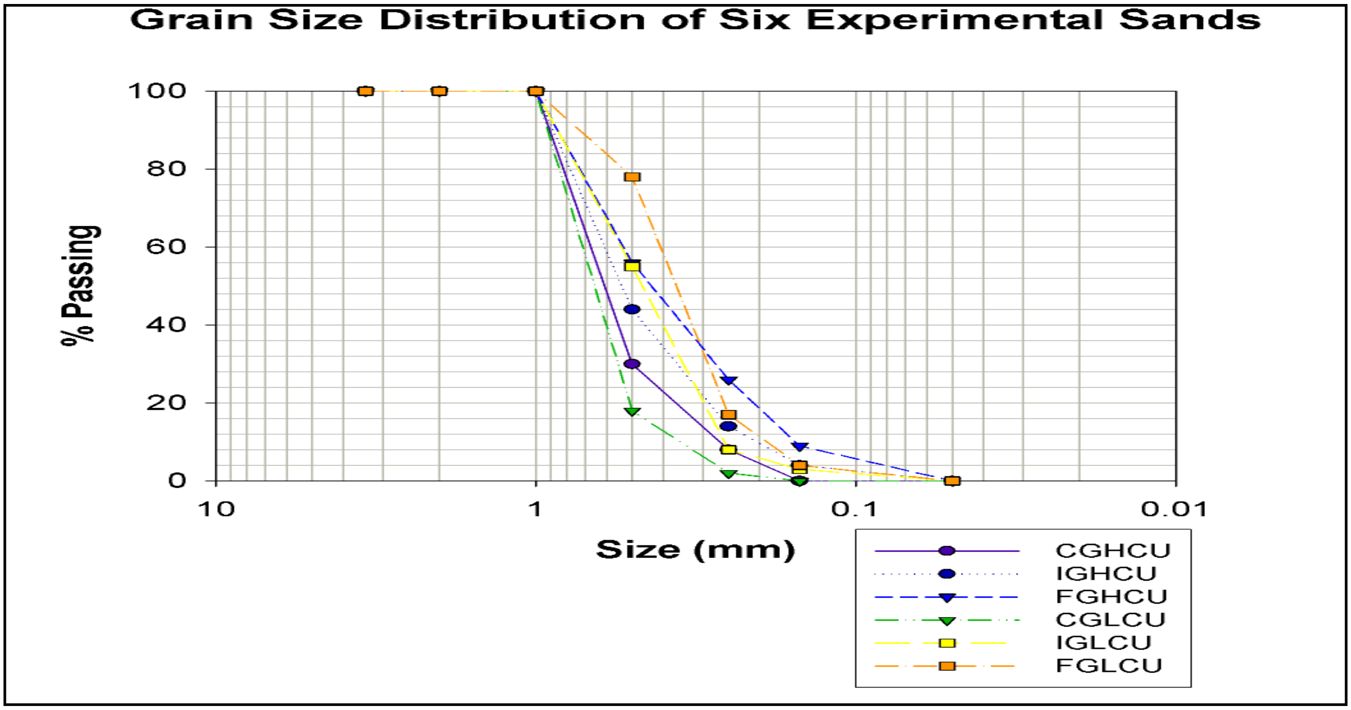


Figure 7. Grain size ditribution of the six experimental sands used in the Michigan State University study expressed as the percent of the sand sample that passes through various sieve sizes (mm).

vertical displacement. Force is recorded at every 0.01 inch of displacement for consistency. The pressure at each 0.01-inch displacement is plotted versus the vertical displacement as shown in Figure 5. The initial part of the curve, labeled A, represents the pressure causing initial deformation of the surface layer. It is obvious from the graph that the surface offers little resistance to deformation. The portion of the graph labeled B shows that increasing stresses are developed as the underlying sand-based rootzone deforms under the surface layer. The underlying sand requires significantly greater stresses to produce additional deformation. At point C the sand fails and further displacement occurs with less stress (area D).

Study Results

The percent retained and percent passing data for the six sands used in this experiment are detailed in Tables 1 and 2 and Figures 6 and 7. Each of the sands falls within USGA specification guidelines, but represent the extremes allowable for median size and distribution. Our expectation was the sands with poor gradation (low Cu) would have lower ultimate bearing capacities than the sands with more well-graded distributions of sand sizes. Sands with poor gradation do not have the internal frictional forces required to make them strong. Sands that are well graded have frictional forces produced by smaller particles fitting within the voids of larger particles.

The bearing capacity tests show the benefits of sands with a high Cu (Figure 8). The laboratory bearing results show the well-graded sands (FGHCU, IGHCU, and CGHCU) were capable of withstanding an ultimate pressure greater than those sustained by the uniform sands. For example, the fine-grained high Cu sand has an ultimate bearing capacity of approximately 44 pounds per square inch (psi), as compared to an ultimate bearing capacity of approximately 23 psi for the coarse-graded low Cu sand. The higher Cu sands have nearly double the bearing capacity as the low Cu sands. 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.

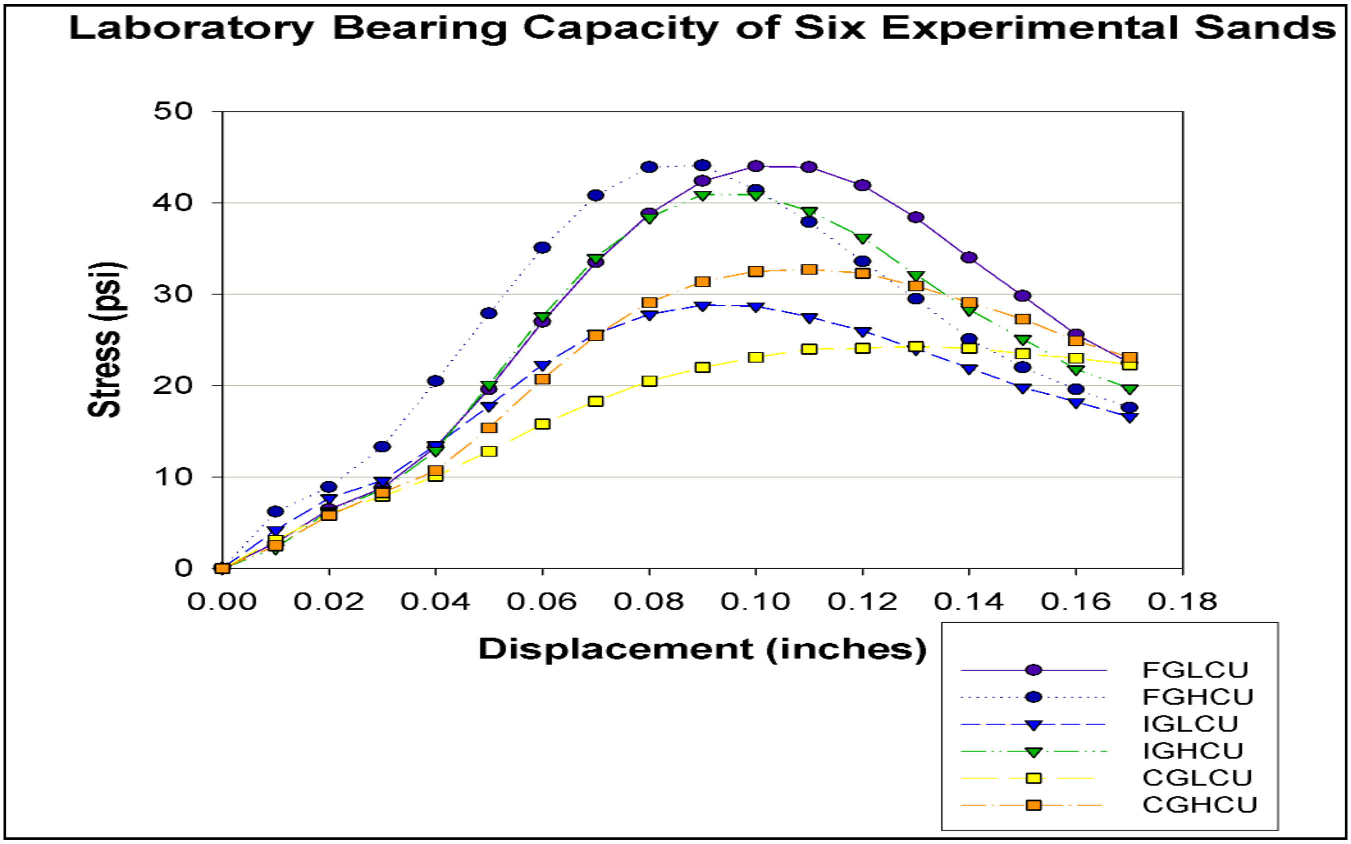


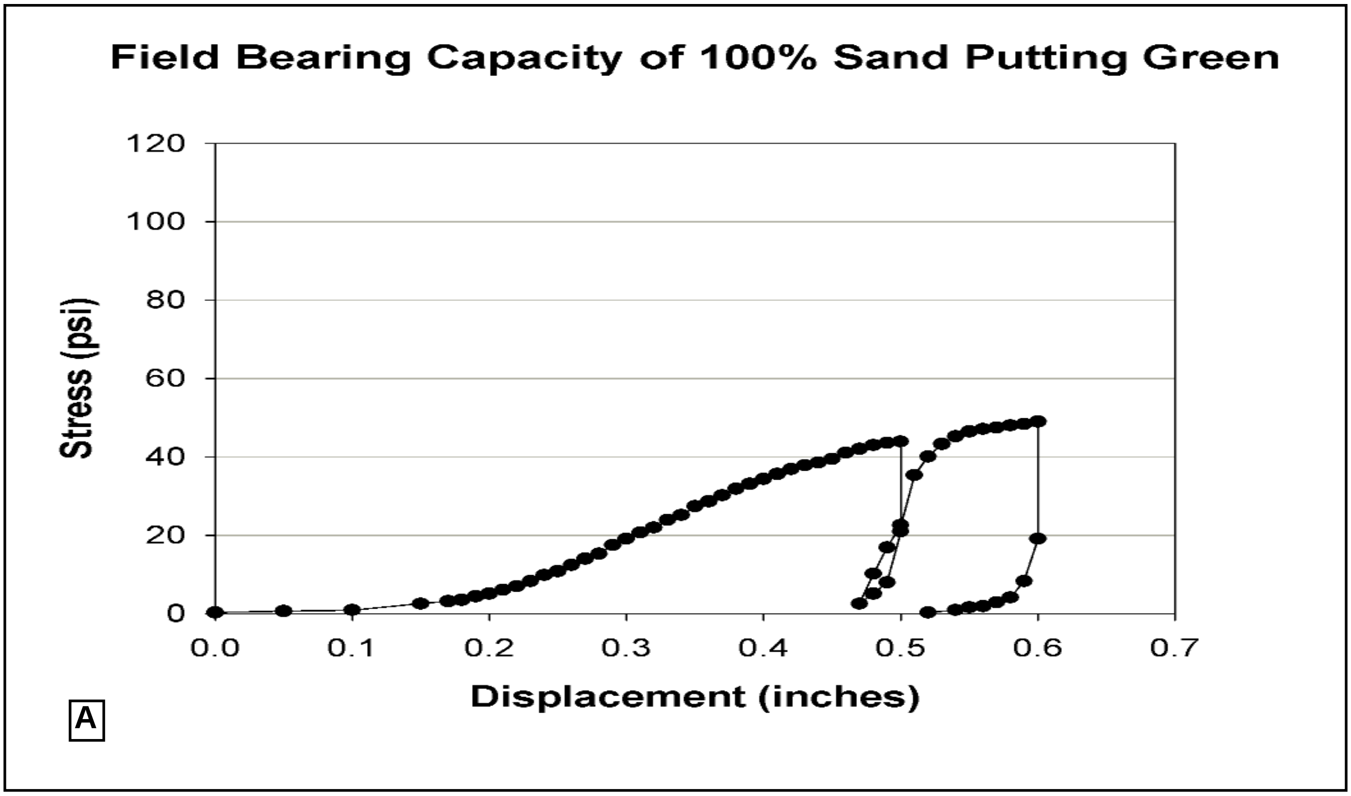
Figure 8. Bearing capacity curves of six experimental sands used in the Michigan State University study. The data show that well-graded sands (i.e., sands that contain a broader range of particle size) are capable of greater greater bearing capacity (i.e., resistance to surface deformation) than sands that have grains that are more uniform in size. Sands with poor gradation do not have the internal frictional forces required to make them strong. Sands that are well graded have frictional forces produced by smaller particles fitting within the voids of larger particles.

Comparison of Field Bearing Tests and Laboratory Bearing Tests

The testing conditions in the lab were somewhat different than those in the field. In the lab, there was no layer of turf, organic matter, and roots incorporated in the surface of the soil. Also, in the lab, the sand is contained in a rigid mold that will not allow lateral deformation or strain of the sand. This leads to a well-defined peak stress at failure and a non-ambiguous bearing capacity. In the field, the surface layer applies a tensile confinement that allows significant deformation to occur at increasingly greater pressures on the sand without producing a well-defined peak stress at failure. Also, in the field, the sand-based rootzone can strain or deform somewhat laterally, similarly reducing the tendency to exhibit a peak.

The sand-based rootzone does not reach a distinct failure point because of the tensile confinement applied by the surface layer filled with organic matter and roots. Also, the rootzone material has the freedom to deform laterally and redistribute the pressure to the adjacent soil. Although the field and lab tests are not exactly equivalent, it is noted that the lab results tend to act as upper and lower limits, bracketing the field results.

It is also shown that the slope of the pressure-displacement curves, or rate at which the pressure increases with increasing displacement, is highest for the confined lab bearing test and lowest for the field bearing test. The high rate of increase in pressure due to increasing displacement for the confined lab test occurs because the sand is confined from both lateral deformation (due to the rigid mold) and vertical deformation (due to the applied surcharge). The rootzone material is allowed to deform laterally, thus lead-



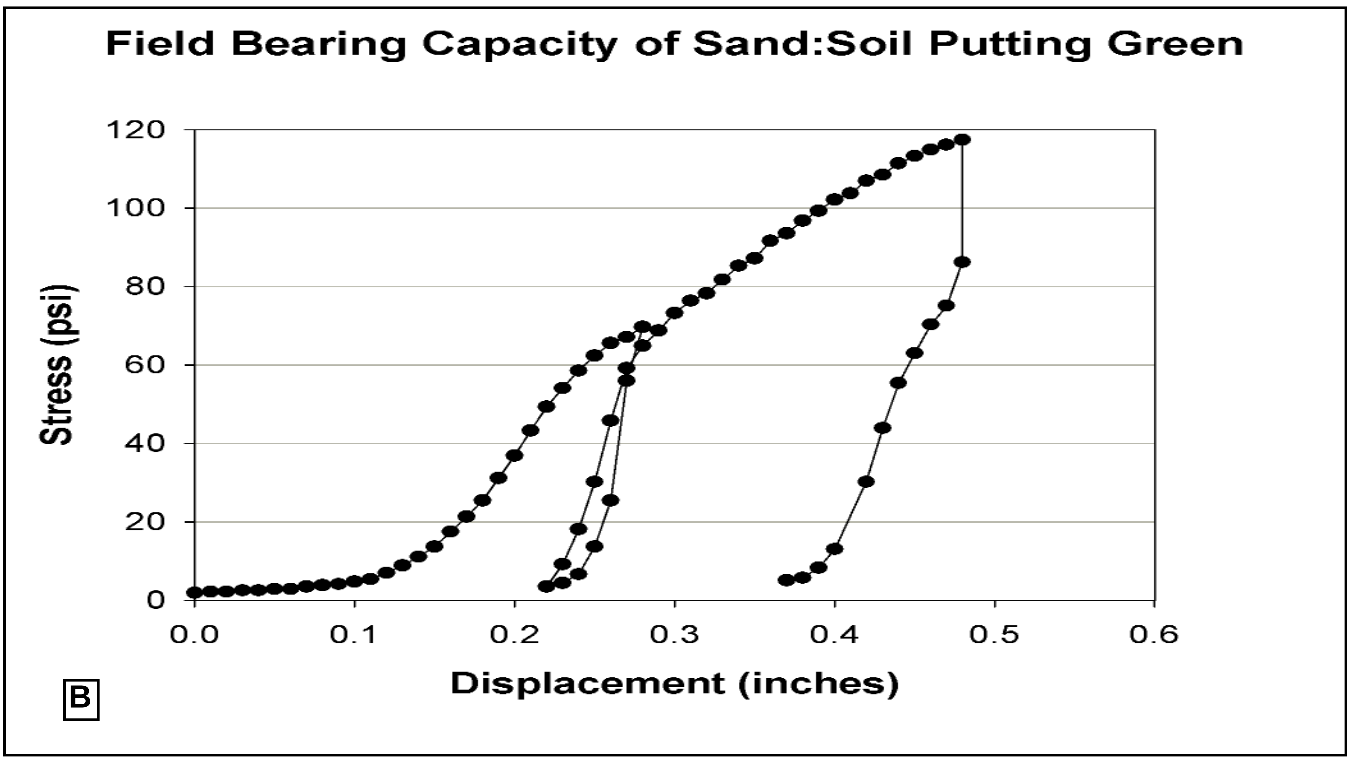


Figure 9. Bearing capacity curves for newly (two- to four-months-old) established golf putting greens constructed of 100 % sand (A, top chart, IGHCU) and of a mixture of IGHCU sand and 10% sandy loam textured topsoil (B, bottom chart). With the addition of soil, a rootzone mixture with a higher Cu is produced. Results show a much higher bearing capacity than was seen from the six experimental sands. Qualitatively, it is easy to see and feel the sand:soil rootzone is firmer and stronger than the 100 % sand rootzone. Data suggest the latter has a bearing capacity on the order of twice as high as the 100 % sand rootzone.

ing to its lower rate of increase in pressure due to increasing displacement.

Figure 9 displays bearing capacity curves for newly (two- to four-months-old) established golf putting greens constructed of 100 % sand (IGHCU) and of a mixture of IGHCU sand and 10% sandy loam textured topsoil. In general, the 100 % sand bearing capacity curves in the field and in the laboratory compare well, but in the field, there is no lateral confinement and no distinct maximum bearing capacity like under laboratory conditions.

With the addition of soil, a rootzone mixture with a higher Cu is produced. In fact, our results show a much higher bearing capacity than was seen from the six experimental sands. Qualitatively, it is easy to see and feel the sand:soil rootzone is firmer and stronger than the 100 % sand rootzone. Our data suggest the latter has a bearing capacity on the order of twice as high as the 100 % sand rootzone.

To date we have not done enough field testing on a wide enough range of rootzones to develop bearing capacity criteria for what might be "too soft" or "too hard" for golf putting greens. We plan to continue this work and collect field bearing capacities from a wider variety of soils and putting greens to begin characterizing the strength properties of sandy rootzones.

Summary

Particle gradation greatly influences the engineering properties of high sand content soils. In our studies, increasing the Cu of intermediate grade sands from 1.8 to 3.0 approximately doubled (from 22 to 42 psi) the laboratory bearing capacity. Increasing the Cu in the fine and coarse grain-sizes of sands also dramatically increased the bearing capacity of the sands.

Acknowledgements

We would like to thank the United States Golf Association, Green Section and the Michigan Turfgrass Foundation for their generous support of the research reported in this publication.