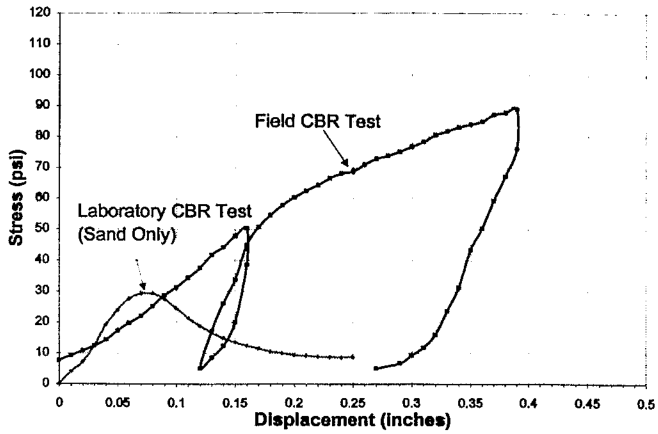


**Figure 2. Laboratory and Field California Bearing Capacity (CBR) tests performed at Michigan State University.**

sand and thatch consolidated approximately 0.12 inches when subjected to a 50-pounds per square inch load. When reloaded, the stress-displacement curve followed the same line back to 50 pounds per square inch stress since the thatch and sand have already 'felt' that stress. Beyond 50 pounds per square inch, the thatch and sand experience new, higher stresses, and will continue to consolidate until the sand begins to fail. Engineers often refer to the load and reload curve as an elastic rebound curve.

A problem associated with testing existing golf putting greens to evaluate the stiffness of the sand root-zone is separating the contributing strength of the root system. Referring to Figure 2, it is clear that the same soil tested in the field with an established root system has significant reserve strength over the same sand tested with no turf. Regardless of where we evaluate the modulus of subgrade reaction in Figure 2, it is consistently greater than that of the sand measured in the laboratory. This suggests that the root system adds strength and stiffness to the elastic and plastic properties of the root-zone sand. This additional strength and stiffness is most likely due to the tensile strength of the root system that reduces local shear failure within the root-zone sand.

Initial findings suggest that golf putting greens can be modeled as an elastic spring that has some stiffness, $k_s$. The stiffness or modulus of subgrade reaction of the root-zone sand increases with higher coefficient of uniformity, $C_u$. The median grain size has no effect on the stiffness of the sand. Field tests show that the stiffness of the green is dependent on soil properties but it also has increased strength and stiffness due to tensile strength contributed by the root structure. The short-term growing season of established root-zones have no effect on the stiffness of the putting green. ⌶

# Methods for Classifying Sand Shape and the Effects of Sand Shape on USGA Specification Rootzone Physical Properties


**The Pennsylvania State University**

*Dr. Charles Mancino*



Start Date: 1996
Number of Years: 2
Total Funding: $38,254


Objectives:

1. *To determine if a simple, inexpensive and quantitative procedure can be used to give a reliable estimate of sand shape without having to examine individual grains.*
2. *Determine the effect of sand shape on the physical properties of rootzone sands and whether particle size distributions of USGA rootzone sands should be modified to account for differences in sand shape.*

A series of experiments were conducted to determine a method for assessing the shape of sand grains in a non-subjective manner. Methods tested in the past have included the direct shear strength method, the rotatable drum method, dense soil angle of repose, and cone penetrometry. These methods have not been capable of separating all classes of sand according to shape. In 1998, sand shape was assessed through computer imaging and analysis, cubical triaxial testing and further evaluation of cone penetrometry.

The use of computer imaging to determine sand shape was performed to compare sphericity ratings for samples of angular, sub-angular, sub-rounded, and rounded sands as calculated by an experienced technician and an image processing and analysis program *ImageTool* is a public domain freeware program. The comparison of measures of sphericity, however, resulted in a low coefficient of determination $R^2$ 0.521. This $R^2$ value is too small to have confidence that the results produced by *ImageTool* and the technician will be similar. The reason for the low values is due to the failure of the software to properly define the edges of the scanned sand grains. The program tends to make the image more angular. Another inexpensive software program, *ArcView*, will be tested next. The *ArcView* package may be able to produce better results using algorithms to generalize or smooth the shape of the grains before analysis.

A cubical triaxial tester was used with the four sands to measure bulk mechanical behavior and how it relates to grain surface texture. The tester showed substantial differences between the sands with the sub-round sand having the best compaction resistance. The angular sand was the most compressible with the round and sub-angular materials being intermediate. In regards to soil strength, at lower pressures the subround sand was strongest while the round sand was weakest. At higher pressure, it was the angular sand and sub-rounded sand with the highest strength. Overall, the sub-round and sub-angular sands had the best combination of compaction resistance and strength.

## Layers in Golf Green Construction

**Sports Turf Research Institute**

*Dr. Stephen Baker*

Start Date: 1996
Number of Years: 2
Total Funding: $28,778

Objectives:

1. *To examine particle migration from the rootzone layer into underlying gravels of increasing size in situations where no intermediate layer is present.*
2. *To assess the effects of different intermediate and drainage layers on moisture retention in the rootzone layer.*
3. *To review the particle size criteria for the selection of intermediate layer and drainage layer materials.*

**Particle Migration** is being examined for two contrasting rootzone materials placed directly over ten drainage layer gravels of varying sizes. The two rootzones are an 85:15 mix of medium sand and sphagnum peat and a 70:30 mix of medium-coarse sand and peat. Five of the gravels are rounded and the other five are angular. The $D_{15}$ size values range from 2.2 mm to 5.6 mm. Gravel sizes were selected so that, in theory, no migration would occur from the rootzone into the gravel for the finer gravels but the risk of particle migration into the coarser gravels was high. Each profile is receiving 3000 mm of simulated rainfall before particle migration is examined.

A technique was developed to examine whether migration has occurred at the interface of the rootzone layer and the gravel (Figure 3). The profile is stabilized using plaster of Paris. This is then impregnated with an araldite resin containing fluorescent dye. When the resin has hardened, the profile can be sectioned and photographed under ultra-violet light. This will enable examination of pore-space blockage within the gravel due to particle migration from the rootzone.

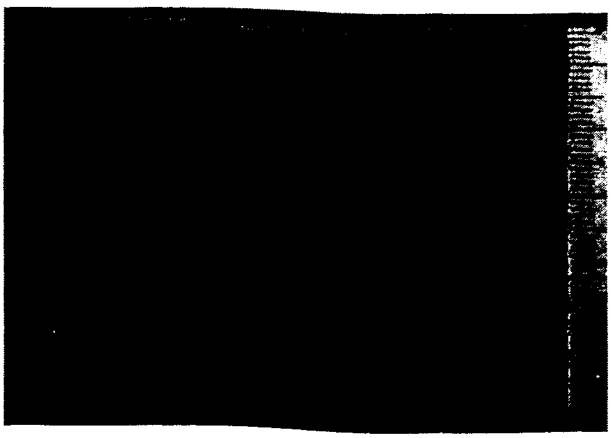

**Figure 3. Cross section of intermediate sand layer above the gravel layer observed under UV light.**

**Moisture Profiles.** The vertical distribution of moisture within the profiles discussed above is being measured after 48 hours of gravitational drainage to examine whether variations in the in type of gravel influence moisture retention in the profile.

In a separate study, the influence of particle size of the intermediate layers on moisture retention within an 80:20 sand/peat rootzone has been examined. The underlying gravel was predominantly a 6 to 9 mm material while the intermediate layer was based on 1 to 4 mm grit but with increasing proportions of medium (0.25-0.5 mm) and coarse sand (0.5-1.0 mm). Moisture profiles were assessed after saturation followed by 48 hours gravitational drainage.

Increasing proportions of coarse and medium-coarse sand had significant effects on the moisture content of the intermediate layer. For example volumetric moisture content increased from 7.5 percent when the 1 to 4 mm. grit included no sand to 18.4 percent when 50 percent coarse sand was added to the grit. However, no strong relationships were found between the composition of the intermediate layer and moisture retention with the rootzone. These data suggest that it should be possible to increase the proportion of material between 0.25 mm and 1 mm in the intermediate layer without a significant reduction of water retention in the rootzone. However, the work on moisture profiles directly over a gravel base must be completed before firm recommendations are made.

## Understanding the Hydrology of Modern Putting Green Construction Methods

**The Ohio State University - OARDC**

*Dr. Edward McCoy*

Start Date: 1996
Number of Years: 5
Total Funding: $100,000 (co-funded with the GCSAA)

Objectives:

1. *Examine the effects of rootzone composition and putting green construction method on water drainage and redistribution within the profile.*
2. *Examine the effects of rootzone compostition, soil depth and degree of water perching on turf water use and irrigation management.*
3. *Examine long-term changes in physical, biochemical and microbiological properties of the rootzone; and relate these changes to the long-term hydrologic behavior of modern putting green designs.*