Geotechnical properties of equestrian riding surfaces

Propriétés géotechniques des surfaces d'équitation

Ryan J. van der Heijden, Department of Civil and Environmental Engineering, University of New Hampshire, USA, rjd286@wildcats.unh.edu
Bruma Morganna Mendonca De Souza, Department of Civil and Environmental Engineering, University of New Hampshire, USA, bm1091@wildcats.unh.edu
William Hawe, Coyote Spring Farm, USA, bill.hawe@me.com
Jean Benoît, Member ICSMGE, Department of Civil and Environmental Engineering, University of New Hampshire, USA, jean.benoit@unh.edu

ABSTRACT: Engineered equestrian surfaces have been gaining popularity and interest among riders, arena and racetrack managers. Unlike natural turf, these surfaces offer the promise of predictable and repeatable performance, safety, and durability under heavy use such as in professional competitions. Most state-of-the-art modern riding surfaces consist of a base of sand to which a wide range of materials are added such as geotextile fabrics and fibers, recycled materials, and binders (water, oil or petroleum compounds). Such materials add cohesion, frictional resistance and shock absorbance to the base sand. In an effort to make evaluation testing more accessible to arena and racetrack owners, research was undertaken to assess various riding surface materials using a direct shear apparatus. The results were used to ascertain if small scale laboratory testing yields an understanding of how the riding surfaces will behave in the field under actual horse loadings. Direct shear testing on various engineered surfaces suggest that the maximum shear strength of a riding surface and the compression/dilation behavior during shearing relate to the many characteristics experienced by horses and riders at the arena.

RÉSUMÉ : La conception des surfaces d'équitation a gagné en popularité et d'intérêt de la part des jockeys, les arénas et les gestionnaires des pistes de course équestre. Contrairement au gazon naturel, ces surfaces offrent la promesse d'une performance prévisible et reproductible, la sécurité, la longévité et la durabilité en usage intensif comme durant les compétitions professionnelles. La plupart des surfaces modernes se composent d'une base de sable de silice de dimensions différentes, à laquelle une grande variété de matériaux sont ajoutés tels que des fibres et des géotextiles, de matériaux recyclés, de vaseline et d'autres liants. Dans un effort pour rendre les tests d'évaluation plus accessible aux propriétaires des arénas, une recherche a été menée pour évaluer divers matériaux de surface d'équitation en utilisant un appareil de cisaillement direct. Les résultats ont été utilisés pour déterminer si des tests à l'échelle du laboratoire donnent une compréhension de la façon dont les surfaces d'équitation vont se comporter dans l'arène sous chargements de chevaux réels. Les résultats des tests de cisaillement direct suggèrent que la résistance au cisaillement maximale ainsi que le comportement pendant le cisaillement se rapportent aux nombreuses caractéristiques éprouvées par des chevaux et des cavaliers dans l'arène.

KEYWORDS: geotextiles, geosynthetics, shear strength, horse, riding surfaces, equestrian surfaces

1 INTRODUCTION

This past decade has seen a surge of interest in engineered riding surfaces. Surfaces are designed to have high performance, increase safety through shock absorption, require less maintenance, and produce more consistent riding characteristics.

Engineered equestrian surfaces are complex systems, and understanding their behavior is an extremely difficult and daunting endeavor. Most state-of-the-art riding surfaces consist of a base of silica sand of varying grain sizes, to which a wide range of materials are added such as geosynthetics, recycled materials, and various fluids as binding and moisture retention agents. Natural silica sand is a desirable material for riding surfaces because of its mineral hardness, resistant weathering, surface roughness and its sub-angular particle shape which increase the overall shear resistance of the material (Premier Equestrian 2014).

Many components can be added to basic sand mixtures in order to achieve the desired characteristics. Pieces of geotextile fabric, small chunks of recycled rubber, and polymer threads and fibers are the most common implements. These materials enhance the overall response of the surface: geotextile fabrics and polymer fibers add shear resistance and help control moisture content fluctuations. Rubber pieces add rebound and help reduce compaction. Chemical treatments and binders add cohesive strength to a surface, control moisture fluctuations, and aid in dust suppression. Water can also be used for binding and dust suppression on natural riding surfaces, such as sand-geotextile mixtures. As a result, these complex engineered riding surfaces are quite expensive.

A typical riding surface system consists of, the riding surface, concussion mats (or compacted stone dust), an angular stone base, and a geotextile layer, all constructed on top of a natural or prepared base grade. This arrangement is depicted in Figure 1. Typically, the overall system thickness is 20 to 25 cm.

The focus of this research was not on the system as a whole, rather on the performance and characterization of the riding surface layer, the top 10 cm engineered component.

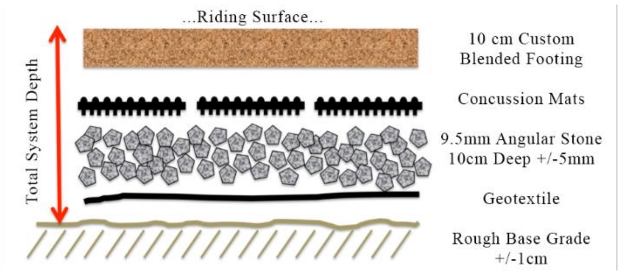

Figure 1. Schematic of the main components of a riding surface system.

The conditions under which riding surfaces are expected to perform are very specific, yet hard to understand. When a horse interacts with a riding surface, it subjects a very specific load sequence upon the surface. Horse loadings vary with the activity (jumping, trotting, or racing, for example). Furthermore, the interaction between the horse hoof and the surface changes within a single stride. There are four general phases of the horse-surface interaction. This complex interaction can be broken down into four main components: touchdown, braking, support, and rollover (Peterson et al. 2012) as shown in Figure 2. Touchdown/braking represents the initial impacts of the horse hoof on the riding surface; the support phase represents when the horse transfers weight onto the supporting hoof; takeoff/rollover is when the horse hoof is pushing off and leaving the riding surface.

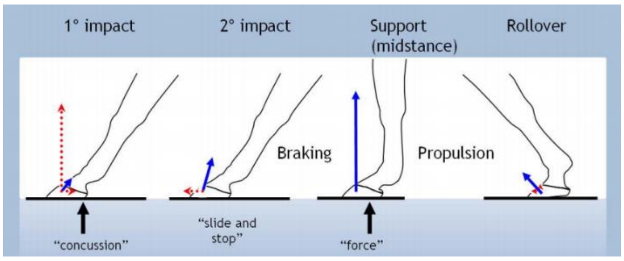

Figure 2. The general phases of the horse-surface interaction. (Adapted from Peterson et al., 2012)

The narrow performance range resulting from the specificity and complexity of the horse-surface interaction presents difficulties with developing and testing riding surfaces.

Much of the evaluation testing work that has been done to date involved attempts to replicate the exact interaction between horse hoof and surface. Equipment such as the Orono Biomechanical Hoof Tester analyze the surface by simulating the action of a horse’s hoof using a mechanical system (Crook and Hobbs 2016). Such advanced testing equipment is very expensive to develop, operate, and use. While it is portable, it is not something that fits in a suitcase, making it an inaccessible tool to many arena owners. Work has been conducted by the Racing Surfaces Testing Laboratory and by the Orono research team to produce a comprehensive database of riding surfaces for comparison by end-users (Racing Surfaces Testing Laboratory 2016). The lab provides testing services that include fiber characterization, impact, permeability, and triaxial shear testing. However, testing is aimed primarily at characterizing the physical composition of a surface and the properties of its individual components. More work remains to be done to assess the performance of the surface system as a whole unit under realistic loadings.

Interest in working with engineered riding surfaces stems from a desire to make testing and information more accessible to competitors, arena and racetrack owners, and to ultimately reduce the amount of uncertainty involved with material design, selection, and maintenance. Currently, there is no inexpensive, simple way to independently verify manufacturer’s claims about the performance and behavior of their riding surface products. The development of a low-cost process that could be used by arena owners to optimize performance would also make manufacturers more accountable for their products, foster competition between manufacturers leading to higher quality and less expensive products.

Based on the phases of horse-surface interaction as well as considerations for horse and rider safety and performance, four main functional properties of horse riding surfaces were investigated during our analysis: impact firmness, cushioning, grip, and responsiveness. Brief descriptions of each term can be seen in Table 1.

Table 1. Functional properties of equestrian surfaces. (Adapted from Hernlund 2016).

Functional Property	**High-End**	**Low-End**	**Short Description**
Impact Firmness	Hard	Soft	The shock experienced by the horse and rider when the hoof contacts the surface
Cushioning	Deep	Compacted	How supportive a surface is compared to how much it gives when riding on it
Grip	High	Slippery	How much the horse's hoof slides during touchdown, support, and rollover
Responsiveness	Active	Dead	How active or springy the surface feels to the rider

The goal of this research was to ascertain if conventional geotechnical laboratory tests could be used to make educated estimates about the behavior of riding surfaces, and to determine whether these estimates agree with the subjective experiences of riders. To that end, direct shear testing was used to evaluate the shear behavior of the material in terms of strength and volume changes. Other basic tests were also used to determine the composition of each commercial product and evaluate their compactability and responses under loads. An important component to the analysis of the tests was to compare the findings to the way surfaces are generally known to perform and feel under actual use. This would also allow us to assess the integrity of our test methods. By enabling independent verification of surface performance by experienced competition riders, the guesswork associated with surface selection can be reduced. The shear strength appears to be a good indicator of the response of equestrian riding surfaces to the functional properties necessary for safety and optimal performance.

2 METHODS

Testing and analysis was conducted in the Geotechnical Laboratory at the University of New Hampshire, USA. The various testing methods used in this program included sieve analysis, direct shear, and standard Proctor compaction. Only a few of the basic characterization and shear testing results are presented in this paper due to length limitations.

2.1 *Materials Analysis*

Four materials were made available for comparison: Coyote Spring Farm surface (CSF), Attwood Equestrian Surfaces Pinnacle (PNCL), and two proprietary surfaces from Footing First: TravelRight (TR) and TraveLight (TL). CSF is a silica sand mixture with pieces of geotextile fabric and a binding additive. PNCL is a silica sand mixture with geosynthetic fibers and is coated in a viscoelastic polymer (Attwood Equestrian Surfaces, Inc.). TR is a blend of two types of silica sand mixed with rubber crumbs, fibers, and pieces of geotextile fabric (FootingFirst). TL is a silica sand mixture with fibers and pieces of geotextile fabric, designed as the economical version of TR. These materials represent a wide range of mixture composition and properties currently available in the industry.

Sieve analysis was conducted on untreated samples of TL and TR. Samples treated with any petroleum-based additives could not be used for the sieve analysis because full separation of the sand from geotextile fabric pieces could not be achieved. Untreated samples of CSF and PNCL could not be obtained for sieve analysis. Sand sieve analysis revealed that both TR and TL have well-graded particle size distributions according to the

USCS soil classification. Figure 3 shows material separated from the sand mixture of an untreated TL sample.

Figure 3. Different material separated from an untreated TL sample. From left to right: rubber pieces, shredded rubber, fibers, and geotextile fabric pieces. Reference line is 1 cm long.

2.2 *Direct Shear*

Direct shear tests were conducted using a Geocomp Shear Trac II Direct Shear Apparatus (Geocomp Corporation 2016) at normal stresses of approximately 35, 100, 170, 240, and 310 kPa and a horizontal displacement rate of 0.25 cm/min. The normal stresses were selected based on reasonable estimates of loads applied by the horses as they stand, trot, push off and land during jumping. Three tests were conducted for each material at each normal stress. Materials were tested for their maximum shear strength and their compaction/dilation behavior during the shear phase. In addition, the geotextile components of TR were removed and the remaining sand was tested to compare with the material as delivered by the factory.

The shear box measures 10.2 cm on each side, and material was placed to a height of 3.30 cm. Vertical and horizontal displacements as well as vertical and horizontal forces were measured during all phases of the test. Several tests were conducted with varying displacement rates to select an optimum shear rate. It was found that slower tests (0.025 cm/min) were much more stable and resulted in less distortion of the sample, whereas faster tests (0.65 cm/min) led to more distortion of the specimens during shearing. However, displacement rate had no noticeable effect on the maximum shear strength of the samples. Based on these results, a rate of 0.25 cm/min was chosen as a relatively stable and time efficient option. All direct shear tests were conducted in accordance to the specifications outline in ASTM D-3080 (ASTM 2011).

2.3 *Density*

Controlling the density of the materials during the test was crucial to the integrity of the results, as the shear strength of a material is highly dependent upon its initial density. Due to the nature of the test on these highly compressible materials, two densities were considered: in-place density and test density. The in-place density was the density of the material in the shear box prior to the application of the normal load. The test density was the density of the material after the application of the normal load following initial compression.

Sample test density was set at approximately 1.70 g/cm^3, which is based on in service average density for these types of materials. The density of 1.70 g/cm^3 is significantly lower than for typical soils at 2.70 g/cm^3 because of the low densities components such as rubber and geosynthetics. For some tests, density was purposely altered in order to observe the effect on the material properties and behavior.

3 RESULTS

The direct shear test was used to collect data on two properties of the surfaces: the shear stress during the shear phase and the vertical displacement during the shear phase. A typical test curve is shown in Figure 4.

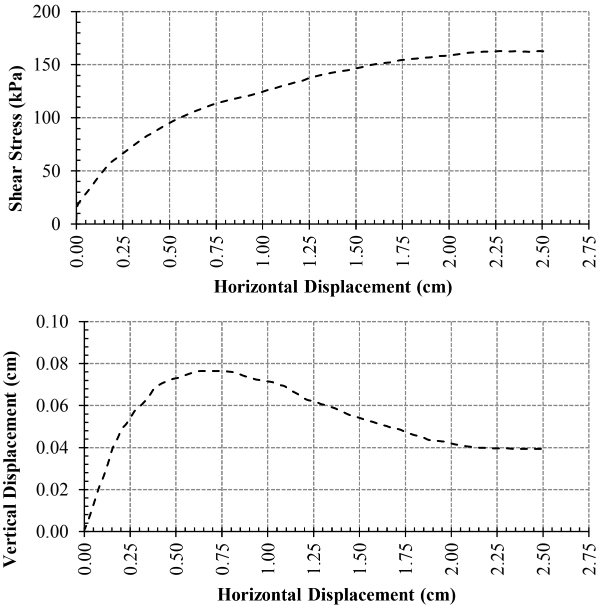

Figure 4. Typical test result of shear stress versus horizontal displacement and vertical displacement versus horizontal displacement, for TR sample.

3.1 *Shear Strength*

The shear strength was taken as the shear stress at 2.5 cm of horizontal displacement, which is the horizontal limit of the Shear Trac II, unless a maximum value was reached prior to 2.5 cm. Samples were used freshly treated or "as delivered" by the manufacturer. Table 2 shows the average maximum shear stress for each material and normal stress. It was found that CSF and TR riding surfaces had the largest shear resistance.

Table 2. Direct shear test results.

Average Shear Strength, 1.70 g/cm^3, 0.25 cm/min

Normal Stress kPa	CSF kPa	PNCL kPa	TR kPa	TL kPa
34	50.3	42.1	42.1	30.3
103	115	90.3	110	92.4
172	175	132	172	126
241	228	178	214	168
310	244	217	265	225

The values from Table 2 were plotted (Figure 5) and linear fits were established. It can be seen that the surfaces show great linearity in the region of normal stresses used in this testing program. The cohesion of the surface was estimated by the intercept of the linear fit line. Linear fit coefficients, cohesion intercepts and friction angles can be seen in Table 3.

Table 3. Linear fit coefficients and cohesion values.

Surface	R^2	C (kPa)	ϕ
TL	0.991	12.5	34
PNCL	0.999	22.5	32
TR	0.992	22.9	39
CSF	0.966	37.5	36

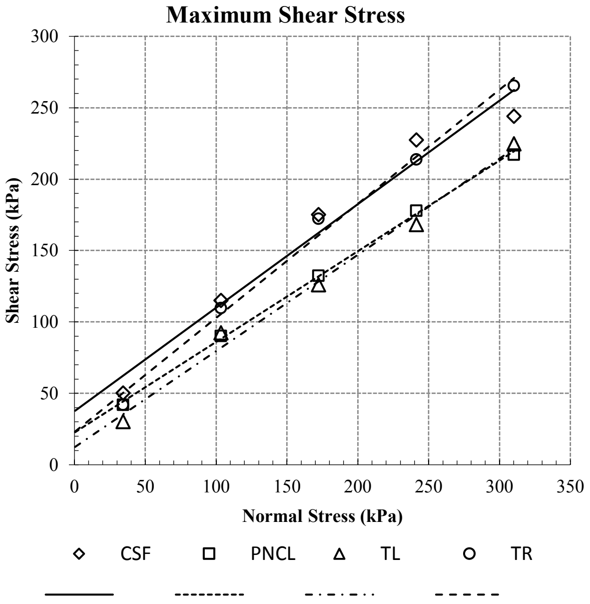

Figure 5. Average shear strength of test surfaces. Linear fits were used to estimate cohesive strength

Figure 5 shows that the results fall within a relatively narrow band although not insignificant in terms of shearing resistance when considering the contributions of apparent cohesion and friction angle. For these test conditions at a consolidated density of 1.70 g/cm^3 and a moisture content of about 2% for the CSF and less than 1% for the others, the CSF material gave the highest apparent cohesion while TL had the lowest. Some of the results indicated that with age (1 year following treatment), CSF increased in friction resistance translating into a higher grip. The Pinnacle sample showed the lowest friction value but a similar apparent cohesion to TR.

3.2 *Compaction and Dilation*

Vertical displacement during the shear phase was an important component of the analysis. Vertical displacement is a manifestation of a change in volume, and therefore density, of a sample during the shear phase. In the graphs produced, a positive vertical displacement indicates compaction (reduction of sample height). Figure 6 shows a comparison of the vertical behavior of the four materials.

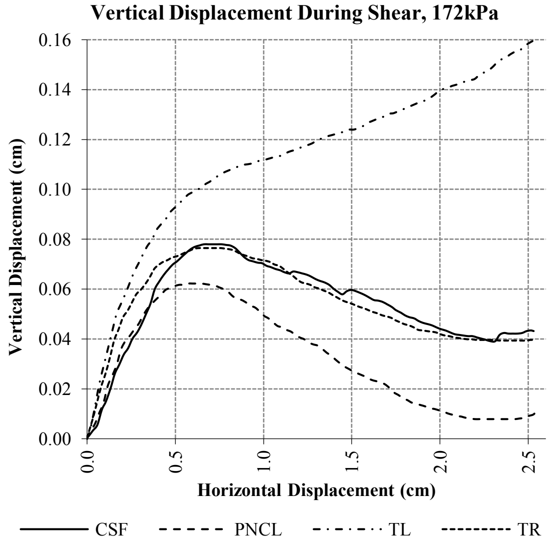

Figure 6. Vertical displacement during the shear phase.

Higher initial compaction can be seen initially for all materials until a peak in vertical displacement is reached for all materials except TL. Following the peak, dilation can be seen in CSF, PNCL, and TR as a decrease in vertical displacement. Note that TL has continually increasing vertical displacement and thus does not dilate and react back against the load.

4 DISCUSSION

The four main functional properties of the surfaces, impact firmness, cushioning, grip, and responsiveness, were investigated. Shear strength was used to characterize grip and cushioning. Vertical displacement behavior was used to characterize impact firmness, cushioning, and responsiveness by looking at peak displacement and dilation behavior. A summary of the surface characterization can be seen in Table 4.

Table 4. Surface Characterization

Surface	CSF	PNCL	TL	TR
Impact Firmness	Soft	Soft	Hard	Soft
Cushioning	Deep	Deep	Compacted	Deep
Grip	High	Slippery	Slippery	High
Responsiveness	Alive	Alive	Dead	Alive

Several other direct shear tests were conducted to evaluate the effect of moisture content on the shear resistance by varying the moisture from about 0.5% to 8% and 12%. Results for TR untreated showed a corresponding increase in apparent cohesion along with a decrease in friction angle from 35 to 31 degrees. The materials were also tested without their geosynthetics to evaluate the strength contribution from simply having silica sand.

Overall, the results suggest that careful combination of natural sand and synthetic components can be evaluated using conventional geotechnical tests. Such understanding should lead to better characteristics and at a lower cost.

5 ACKNOWLEDGEMENTS

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