*Article*

# An Experimental Comparison of Simple Measurements used for the Characterization of Sand Equestrian Surfaces

**María Alejandra Blanco[1,2,3]*, Raúl Hourquebie[2], Kaleb Dempsey3, Peter Schmitt[3,4] and Michael "Mick" Peterson,[3,4].**

[1] Facultad de Ingeniería y Ciencias Agropecuarias, Pontificia Universidad Católica Argentina. mariablanco@uca.edu.ar
[2] Escuela de Ingeniería y Ciencias Agroalimentarias, Universidad de Morón.rhourquebie@gmail.com
[3] Racing Surfaces Testing Laboratory. pschmitt712@gmail.com; kalebdempsey.rstl@gmail.com; mlpeterson23@gmail.com
[4] Biosystems and Agricultural Engineering, University of Kentucky.
* Correspondence: MAB, MP.

**Simple Summary:** Consistency of equestrian surfaces can contribute to safety and performance. An optimal surface is influenced by the design and material selection as well as maintenance and climate. To improve surfaces the quantitative testing of functional surface properties must expand beyond the current testing at the highest levels of competition. More widespread quantitative measurements would have a positive influence on animal welfare and rider safety. To expand beyond the current top levels of the sport simple tools are required that can be shown to detect relevant changes in construction and maintenance. Our work suggests that the appropriate use of simple devices can help with both quality control of new surfaces and the monitoring of existing surfaces. Performance modifications to the layered surface design and addition of Geotextile were detected using the Going Stick and a simple impact test. These measured results are also influenced by other factors related to the surface condition such as moisture. Caution must be exercised in the interpretation of the results since these tools have not been demonstrated to correlate to either performance or safety of the surface. However, these results are encouraging and provide a justification for future development of this type of equipment.

**Abstract:** Quantitative measurements of performance parameters has the potential to increase consistency and enhance performance of the surfaces as well as to contribute to the safety of horses and riders. This study investigates how factors known to influence the performance of the surface, incorporation of a drainage package, control of the moisture control, and introduction of a geotextile reinforcement, affect quantitative measurements of arena materials. The measurements are made by using affordable lightweight testing tools which are readily available or easily constructed. Sixteen boxes with arena materials at a consistent depth were tested with the Going Stick (GS), both penetration resistance and shear, the impact test device (ITD), and the rotational peak shear device (RPS). Volumetric moisture content (VMC %) was also tested with time-domain reflectometry (TDR). Results obtained using GS, RPS, ITD, and TDR indicate that the presence of the drainage package, moisture content, and geotextile addition were detected. Alterations due to combinations of treatments could also be detected by GS, ITD, and TDR. While the testing showed some limitations of these devices, the potential exists to utilize them for quality control of new installations as well as for the monitoring of maintenance of the surfaces.

**Keywords:** equine; arenas; sand; base layers; portable tools; safety; equine welfare

 doi:10.20944/preprints202107.0663.v1

## 1. Introduction

Recent research has considered the effect of equestrian surfaces on the incidence of injuries [1–4]. In addition the surface also has an impact on the performance of the horse [5, 6]. As a result quantitative measures of surfaces have now been embraced by the International Equestrian Federation (FEI) [7] as well as North America horse racing. The use of quantitative measures is particularly promising in horse racing where the potential exists to link these measures to the extensive epidemiological data available [8–11]. The quantitative measures developed by the FEI initiatives include five different functional properties, firmness, cushioning, rebound, grip, uniformity, and consistency [12]. In order to maintain optimal levels of these functional properties consistent depth of the surface, properly classified sand, consistent moisture control, proper maintenance of the surface and the appropriate selection of materials used for the base and sand additives are generally accepted as having a direct impact on the horse [13–15]. These inputs change the vertical and horizontal deceleration of the hoof and the resulting forces on the limb of the horse.

The construction of surfaces for both training and competition should be based an understanding of equine biomechanics. Therefore, to fully characterize an equestrian surface, it is necessary to replicate both horizonal and vertical loads and use a loading rate that matches the equine athlete. Both the rate and load are important since arena construction materials include unsaturated particulate materials which are in general both nonlinear and strain rate dependent [16]. However, the load and load rate also depend on the riding discipline, activity within the event and the gait. Therefore, it is necessary to identify those portions of each discipline and those portions of each event which are critical to the performance and safety of the athletes [13, 17–19].

While measurement of these parameters with instruments which mimic the loads and speed of the horse are ideal [13, 20, 21], the cost associated with the required instruments presents a significant challenge. Directly reducing the size or speed of the loading is not possible since the speed and size of the equine athlete is fixed. If a correlation between at least some of the critical construction parameters and the measured performance could be determined with smaller tools, then the potential exists to expand use of quantitative measurements to regions where cost is more of an issue. Ideally it would also be possible for these smaller tools to be fabricated locally. The first priority for the instrument should be mobility. A tool that can be easily carried between surfaces for evaluations is more likely to be adopted. Affordability and making use of commercially available data acquisition will also make it easier for these simpler tools to be constructed by the arena builders and owners further increasing the potential for widespread adoption.

### *1.1. Motivation for Horizonal and Vertical Measures*

Two of the functional parameters described by the FEI research, cushioning and firmness, are concerned with the vertical response of the surface. These functional parameters relate to the initial impact and the secondary loading from the mass of the body of the animal dynamically transferring to support from the leg. Shear, the horizontal component of the load on the surface, is in one direction during the first and second impact and then reverses during breakover of the hoof as the surface supports propulsion [13]. Shear resistance affects the extent to which the hoof will slide back and forth or rotate on landing, turning, pushing off, passage, pirouette, or in a sudden brake [22, 23]. Longitudinal traction affects the sliding of the hoof in the horizontal plane when braking in a linear movement. It also affects the resistance of the surface to penetration by the hoof in the form of the angle of the hoof to the ground, during breakover or the penetration of the surface by the inside portion of the hoof in a sharp turn. The limb of the horse rotates about the horizontal axis of the hoof or limb which is resisted by friction between the particles and reinforcing fibers in the equestrian surface [13, 22]. The simplified tools chosen to characterize the surface must include not only vertical loading characteristics but also the shear behavior since these characteristics may not be correlated between surfaces.

 doi:10.20944/preprints202107.0663.v1

*1.2. Proposed Smaller Tools*

To characterize both the vertical and horizontal response of the surface either separate tools are required or tools with more than one axis of measurement are required. For turf surfaces a strain gauge based sensor system, the Going Stick, is widely accepted in Thoroughbred racing [24] and has been proposed as an international standard [25]. This tool measures both penetration resistance and the resistance to shearing of the surface. These two measures are acquired from pushing the device into the surface and then rotating it 45 degrees. It is reasonable to assume that these two motions are related to the impact and propulsion response of the surface, even if the measurements are a direct analog. The peak value of deceleration for a small mass dropped from a low distance is used in some sports applications and is commonly based on ASTM D5874-1 [26]. A rotational shear tester described by ASTM F2333-04, is a surface measurement of rotation unlike the Going Stick which measures the resistance to shear below the surface [25]. Both of the devices associated with the ASTM methods use simple low-cost hardware. It is also possible to make use of simple low-cost data acquisition for both of these devices. Since surface moisture content controls the response of nearly all of these tools a moisture probe based on an older ASTM standard D6565 is also included in the work. In addition to the low cost of the tools described in the three ASTM standards all of them are also easily transportable.

With the exception of the Going Stick the loads used in these measurements is low. This is useful for evaluating the condition of the top layer of the surface and may be important for quality control of the surface installation. In addition, the compaction which results from repeatedly dropping a small mass on the surface will be influenced by additives in the surface and the selection of sand. In fact, the original intent of the device used in the vertical impact is to evaluate the level of compaction and stability of the base materials used for a road or building foundation [27, 28]. While these lightweight devices are generally better suited to describing static loading of the surface and loading by animals much smaller than a horse, they may make it possible to infer the condition of the deeper layers of the track and they are useful for evaluation of each of the layers when surfaces are installed in multiple layers.

*1.3. Other Small Devices*

Other lightweight devices that measure the resistance to penetration by a conical probe have also been investigated for this type of measurement. These devices, normally referred to as penetrometers, can either be devices with a smaller probe which measure dynamic response [29] or large truck mounted devices [30] or the smaller handheld quasi-static devices commonly used in agriculture [31]. Like the Going Stick these devices are sensitive to compaction of the lower layers of the surface and which influence the loading of the limb at higher speeds such as during a gallop or a jump landing. The large dynamic loads under these conditions which are as much as 2.5 times body weight, are significantly influenced by the properties of the deeper layers of the surface [13]. However, since most of these devices are similar to the penetration measure from Going Stick, they would not be expected to add a unique parameter to the study. The Going Stick is a more interesting alternative since it also includes the bending motion or shear as well as the penetration.

Alternative methods to measure rotational peak shear with more sophisticated electronics make those measures more reliable albeit more expensive. Lewis et al. [22] used such a device and found a weak linear relationship between rotational shear measured using the GWTT and longitudinal shear quantified using the OBST. The traction rotational tester described by ASTM F2333-04, didn´t show any relationship with other tools mentioned above but detected differences in surfaces with higher loads. As a result, the simple devices used in this work are evaluated for their ability to make quantitative assessments accessible to more arena builders. It is important to understand the utility of these devices while recognizing the differences in loading between these devices and a horse.

*1.4. Critical Factors*

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

Based on prior work, the effect of moisture content, geotextile addition, and the addition of drainage all influence functional properties of equestrian surfaces [15, 32, 33]. As modification that impact functional properties, and therefore performance, it is also reasonable to assume that they may have an impact on injuries and safety. Using silica sand-based test surfaces lightweight standard measurement tools were used to characterize surfaces with different designs representing surfaces used in a wide range of facilities. While not replicating the full function of the more complex measurement of functional properties, the objective was to investigate the sensitivity of these tools to changes in the design of the arena. These tools can be used for quality control when installing new arenas and may also be helpful when evaluating the consistency of maintenance by users.

## 2. Materials and Methods

### *2.1. Study Design*

The design is a two-level experimental design with three factors $2^3$ (Table 1) with two repetitions (sixteen). Details of the construction are shown in Figure 1. Factors are addition of geotextile: where no geotextile is added (G1) and with 2 $\frac{kg}{m^2}$of geotextile chips added to the 10 cm deep surface (G2). The drainage package consists of a geotextile fabric laid over the limestone base, a geomesh layer and another geotextile fabric layer. The geotextile layers are used to avoid saturation of the geomesh with sand. The two conditions for the drainage layer are the absence of a drainage package (D1) and the incorporation of the drainage package (D2). Two gravimetric moisture contents (GMC %) were the lower at 11,16 %± 2.93 GMC (M1) or higher at 21,69 % ± 3,90 GMC (M2).

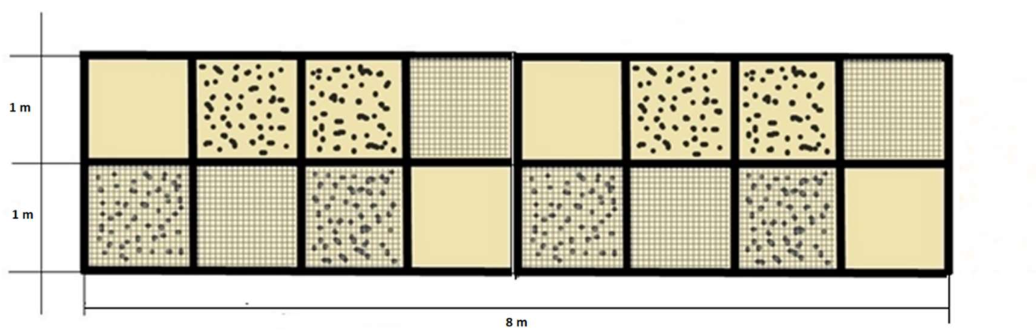


**Figure 1.** Scheme of boxes distribution according to the top cushion material consisting of sand (G1= ) or sand with geotextile (G2= ) over limestone (D1= ) or over drainage package (D2= ) and combinations of both treatments (D2G2= ).

**Table 1.** Description of the $2^3$ experimental designs. geotextile: G1: Without geotextile, G2: with 2 kg/m2; drainage: D1: without drainage package, D2: with drainage package described in methods. moisture: M1: Low gravimetric moisture content (11,16%± 2.93 VMC), M2: High gravimetric moisture content (21,69 % ± 3,90 VMC) or high.

| Factors | | Drainage Package (D) | | | |
|---|---|---|---|---|---|
| | | D1 | | D2 | |
| | | Moisture (M) | | | |
| | | M1 | M2 | M1 | M2 |
| | G1 | D1G1M1 | D1G1M2 | D2G1M1 | D2G1M2 |

| | | | | | |
|---|---|---|---|---|---|
| Geotextile (G) | | | | | |
| | G2 | D1G2M1 | D1G2M2 | D2G2M1 | D2G2M2 |

Sixteen boxes of 1m x 1m x 0.20 m were placed either on a compacted coarse base [34] or on a compacted coarse base with a draining package (Appendix I and II). Boxes were constructed following construction specifications of an equestrian surface manufacturer [35].

The dimensions of the test boxes were selected according to the Boussinesq equation to limit the edge effects [36]. Boxes with similar dimensions have been used by other investigators and are a part of established test protocols [37], [38].

*2.2. Test boxes:*

Eight experiments with two repetitions (sixteen boxes) were set up over a compacted limestone base with a cross-slope of 0,7% (Figure 2). Sand was applied in two layers with each 5 cm layer compacted separately for a total of 10 cm of material over the base. Each layer was compacted using a 4 kg mass dropped three times from a height of 0,30 m onto an area of 0,20m by 0,17m. Compaction was performed in a similar way in all treatments. (Figure 3).

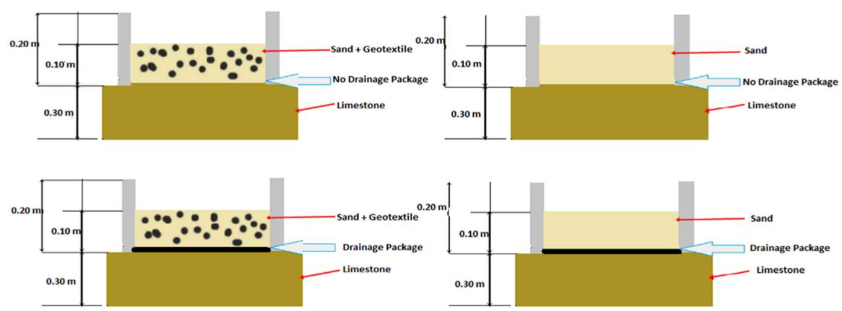


**Figure 2.** Scheme of boxes design including the depth of the top cushion material consisting of sand (G1) or sand with geotextile (G2) over limestone (D1) or over drainage package (D2)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

**Figure 3.** Image of the rammer, 4 kg mass dropped three times from a height of 0,30 m onto an area of 0,20m by 0,17m.

The perimeter of the test boxes was defined by placing 200 cm long concrete tiles with a depth 20 cm and a width of 8 cm around the edge of the plot. The one square meter test boxes were divided by internal walls made with two rows of concrete tiles of 20 cm length, 10 cm depth and 8 cm width which were further reinforced on the outside by identical concrete tiles offset by 10 cm to eliminate gaps between the tiles. Sand was native to the area where the test boxes were located: the Equestrian Training Center of the Solaguayre Farm, in the town of Los Cardales, province of Buenos Aires, Argentina. Geotextile and mesh net were provided by a local equestrian surfaces builder and was consistent with local usage. The sand was tested using sieve and hydrometer tests to be 92,3% sand, 2,6% silt, and 5.1% clay [1]. The particle size distribution of the sand was determined by ASTM D422 [39], silt and clay were test by hydrometer[39]. The geotextile used in the boxes was 100% polyester based on FTIR testing[2][40]. Mineralogy of the sand was determined by X-ray diffraction analysis [41]. The bulk density was determined in accordance with ASTM D698 [42], for both sand and sand with the fiber reinforcement to determine the optimum moisture content for surface compaction (this is further described in the appendix I).

Measurements of the VMC % was done daily on a volumetric basis during compaction using TDR consistent with the ASTM D6870M-19 [43]. The gravimetric moisture content was also determined in the laboratory. Samples were taken from each box, it was weighed and placed in the oven at 65 ° C for 48 hours with a second weight taken for the dried material. The samples were re-weighed, and the moisture content determined [44].

*2.3. In situ measurement of test boxes:*

As described above five in-situ measurements were performed using four measurement tools once the boxes were installed: the Going Stick Penetration (GSP) and Going Stick Shear (GSS) [45], the Impact Test Device (ITD) based on ASTM D5874, [46], the Rotational Peak Shear (RPS) device based on ASTM F2333 [47], and Volumetric Moisture

[1] Testing by Racing Surfaces Testing Laboratory, Lexington, Kentucky

[2] Lab Cor Materials, LLC, Seattle Washington

 doi:10.20944/preprints202107.0663.v1

Content (VMC) which is consistent with ASTM D6565 [43]. The operation and use of each of these devices was consistent with applicable standards described below.

a) The Going Stick Two Axis Sensor Probe:

The Going Stick measures the penetration resistance and the resistance to rotation of the blade in the turf. The penetration shows the resistance to the penetration of the turf by the toe of the shoe and the rotation of the handle is a measure of the shear strength of the surface to a depth of 100 mm which may be related to the rotation of the hoof into the surface and subsequent propulsion force from the horse (Figure 4).

**Figure 4.** Two Axis Commercial Strain-gauge Sensor Probe (Going Stick)

The device has recently been proposed as an international standard measurement tool [45]. In addition to the two distinct measures of penetration and shear the device also calculates an integrated measure of the two measured values which is referred to as "the going index". The going index is commonly used in Thoroughbred racing to describe the surface conditions[49]. The peak force required to press the probe into the surface and the peak torque applied to the handle to rotate the probe to 45 degrees are logged to memory in the device and are then used to calculate the going index. The torque is calculated from the strain gauges located 128 mm from the tip and the calculation of load assumes that the rotation of the device occurs around top of the plate of the probe which penetrates into the surface [49, 50]

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

The shear and penetration load values have also been converted from the measured values from the strain gauges to try to relate to stress applied to the surface by using the area of the penetrating probe and the area of the side of the probe. Because the penetration probe is tapered and the device is not constrained horizontally, the load and torque applied to the top handle of the device has a complex relationship to the stress in the ground. However, making several simplified assumptions allows a load at a reference point to be calculated which gives a reasonable quantifiable value for comparison.

The Going Stick was calibrated in a calibration fixture, with a mass loading the tip and the strain output was then converted to N and Nm for the penetration force and applied torque respectively [49]. The use of a calibration with known loads and measurement locations reported in standard measurement units is consistent with the proposed standard test. The Going Stick software version 2.30 was used which does not average of the values and saves the peak value of penetration and the shear. During the data collection and calibration, the Going stick was set in flat mode.

b) The impact test device (ITD)

The surface hardness and resistance to compaction was measured using a custom impact test device (ITD) based on ASTM D5874-16 (Figure 5). The Clegg hammer is similar to the ITD, however it measures the maximum or the average deceleration of the mass over three to five drops[3]. The ITD, in contrast to the Clegg hammer, measures the deformation of the surface while still using a 2.25 kg mass dropped repeatedly inside a tube at each location from a height of 0.45 m (ITI: Impact Test Index). The principle is based on impact velocity of a falling object with a known energy. The compaction of the surface and orientation of the tube results in variation in the distance traveled by the mass for the Clegg hammer, but the variation in distance is considered in the ITD. Unlike the various static and dynamic designs of penetrometers the displacement on the ITD is measured for a larger impactor than the small square or conical impactors normally used in a penetrometer [31]. In the ITD the distance to the impactor is measured with respect to a reference point at the top of the tube using a low-cost commercial laser distance measurement device[3]. The cost of the system is a fraction of that of the commercial Clegg hammers and if produced locally would be within the means of nearly all arena builders and owners.

[3] Model GLM 150 c, Bosch Singapore

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

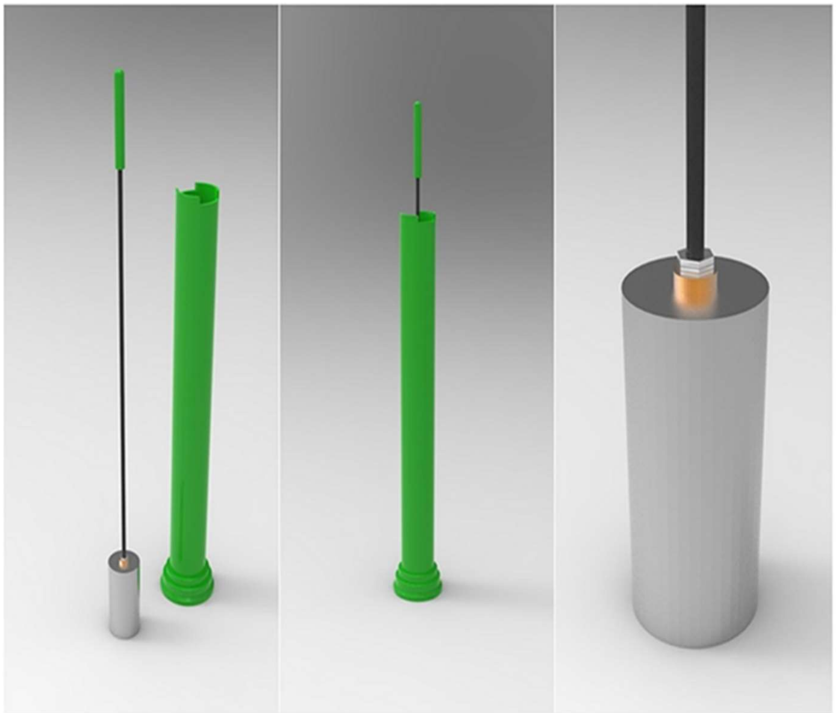

**Figure 5.** Custom impact test device (ITD) built to perform similarly to the device described in ASTM D5874-16.

c) Rotational Traction Tester (ASTM F2333-04).

The rotational shear strength was recorded using a torsional shear tester [47]. The device used is based on a modification of ASTM F2333-04 where the cleats on the disk are replaced by a horseshoe. The device, shown in Figure 6, is used in equine research to address the weaker correlation between rider perception and grip [37] [22]. To pre-set the disk into the surface a 30 kg weight was dropped 0,30 m along a shaft onto a second plate with a size 3 steel studded horseshoe mounted on the bottom of the plate. The horseshoe included two 2,5 cm long cleats which were tapered from 1,35 to 0,50 cm diameter: on its abaxial face. The rotational peak shear (RPS) load was measured with a digital torque wrench with a range of 4-200 NM, and precision of 0,08Nm[4]. To record the failure strength, the torque wrench is turned until it reaches the maximum load while keeping the plate flat on the ground. Five measurements were made for each box. In order to minimize operator variability the same person performed all of the testing which is consistent with best practice [51]

[4] Model ARM602-4, ACDelco,

**Figure 6.** Rotational Traction Tester (ASTM F2333-04)

d) Moisture Probe:

Time domain reflectometry (TDR) is widely used to test volumetric moisture content (VMC %) as one of the primary factors required to achieve a consistent surface. The TDR moisture test probe (Spectrum Field Scout TDR-100 Aurora, IL USA) was used with two measuring rods of 10 cm length. Five sample locations were measured at the inner part of each of the test boxes.

*2.4. Statistical Analysis*

Analysis of variance was performed using commercial statistical analysis software[5]. For comparison of marginal means the t test was performed. Values o $p<0.05$ were considered statistically significant.

It was carried out linear regression analysis between dependent variables and independent variables and Pearson´s coefficients of correlation were calculated to identify the degree of association between dependent variables.

The proposed model for the testing of the boxes is:

$$Y_{ijk} = \mu + D_i + M_j + G_k + (DM)_{ij} + (DG)_{ik} + (MG)_{jk} + (DMG)_{ijk} + e_{ijkl}$$

D: Drainage$_{(1,2)}$ M: Moisture$_{(1,2)}$ G: Geotextile $_{(1,2)}$

## 3. Results

Using the five measurements obtained from four devices the effect of the different treatments of the boxes was shown to be significant for a number of different conditions: drainage (D), moisture (M) and the addition of geotextile (G). Results for each treatment and measurement are shown in table 2 and table 3. Significant effects are showed through f and p value, significant interactions are shown in table 3.

[5] Infostat version 2, Buenos Aires Argentina

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

Linear regression analysis showed in table 4 exhibited that GSS is positively associated with D, ITI is positively associated with D and G, and RPS is also associated with G. Regression analysis showed that p-value of constant for VMC and GSP was not significant. When regression was run extracting independent variables (G and D) for VMC, this was significantly associated with M ($p<0,0021$). Correlations between devices show that GSP is correlated with ITI ($p<0.0011$; P=0.38) and GSP is correlated with GSS ($p<0.0003$; P=0.42) with results shown in table 5.

**Table 2** F and p values of main factors, Moisture, Drainage and Geotextile addition over the five variables (GSP, GSS, ITI, RPS, VMC).

| Variable | Moisture | | Drainage | | Geotextile | |
|---|---|---|---|---|---|---|
| | F | p | F | p | F | p |
| GSP | 0.12 | 0.7307 | 9.68 | 0.0028 | 36.26 | 0.0001 |
| GSS | 0.23 | 0.6343 | 10.39 | 0.0021 | 0.64 | 0.4271 |
| ITI | 5.03 | 0.0284 | 4.75 | 0.0331 | 13.84 | 0.0004 |
| RPS | 0.01 | 0.9356 | 3.59 | 0.0627 | 19.17 | 0.0001 |
| VMC | 252.73 | 0.0001 | 0.28 | 0.5991 | 2.03 | 0.1594 |

Tuckey test Alfa=0,05 p<0,05

**Table 3** F and p values of interactions between factors: moisture x drainage, moisture x geotextile, drainage x geotextile and moisture x drainage x geotextile. over the five variables (GSP, GSS, ITI, RPS, VMC).

| Variable | Interactions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Moisture x Drainage | | Moisture x Geotextile | | Drainage x Geotextile | | Moisture x Drainage x Geotextile | |
| | F | p | F | p | F | p | F | p |
| GSP | 0.27 | 0.6059 | 4.42 | 0.0395 | 2.33 | 0.1319 | 3.09 | 0.0838 |
| GSS | 1.37 | 0.2465 | 0.26 | 0.6111 | 2.80 | 0.0996 | 1.22 | 0.2738 |
| ITI | 1.79 | 0.1860 | 0.01 | 0.9253 | 6.18 | 0.0156 | 2.27 | 0.1372 |
| RPS | 0.18 | 0.6724 | 0.16 | 0.6933 | 0.80 | 0.3754 | 4 | 0.0498 |
| VMC | 0.54 | 0.4668 | 0.01 | 0.9382 | 0.10 | 0.7507 | 0.49 | 0.4865 |

Tuckey test Alfa=0,05 p<0,05

**Table 4** Regression coefficients ($R^2$), constant and signification of each linear model for every variable GSP, GSS, ITI, RPS and TDR.

| Variable | R2 | p | | | | Linear model |
|---|---|---|---|---|---|---|
| | | const. | Moisture | Drainage | Geotextile | |
| GSP | 0.35 | 0.793 | 0.7234 | 0.0076 | 0.0001 | $\hat{y} = 20.43 + 9.83\,x1 + 76.14\,x2 + 155.66\,x3$ |

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

| | | | | | | |
|---|---|---|---|---|---|---|
| GSS | 0.23 | <0.0001 | 0.5877 | 0.0008 | 0.2716 | $\hat{y} = 12.33 - 0.36\,x1 - 2.37\,x2 - 0.75\,x3$ |
| ITI | 0.24 | 0.0194 | 0.1204 | 0.0203 | 0.0002 | $\hat{y} = 0.0046 + 0.0011\,x1 + 0.0016\,x2 + 0.0027\,x3$ |
| RPS | 0.25 | 0.0001 | 0.5638 | 0.0558 | 0.0001 | $\hat{y} = 19.23 + 0.30\,\mathrm{x}1 + 0.99\,\mathrm{x}2 + 2.29\,x3$ |
| TDR | 0.81 | 0.2224 | <0.0001 | 0.6788 | 0.104 | $\hat{y} = -3.04 + 14.88\,x1 + 0.37\,x2 - 1.45x3$ |

*Significant values at p<0,05

**Table 5** Pearson correlation coefficients (P) of each variable GSP, GSS, ITI, RPS and TDR.

| Variable | TDR | | GSP | | GSS | | RPS | | ITI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | p | P | p | P | p | P | p | P | p | P |
| TDR | <0.0001 | 1 | 0.55565 | -0.07 | 0.8792 | 0.02 | 0.6385 | 0.06 | 0.4140 | 0.10 |
| GSP | 0.5444 | 0.07 | 0.0001 | 1,00 | 0.0003 | 0.42 | 0.1690 | 0.17 | 0.0011 | 0.38 |
| GSS | 0.8792 | 0.05 | 0.0264 | -0,27 | 0.0001 | 1 | 0.7407 | -0,04 | 0.2583 | -0,14 |
| RPS | 0.6385 | 0.06 | 0.1744 | 0.16 | 0.7407 | -0,04 | 0.0001 | 1 | 0.2880 | 0.13 |
| ITI | 0.4140 | 0.10 | 0.0011 | 0.38 | 0.2583 | -0,14 | 0.2880 | 0.13 | 0.0001 | 1 |

*Significant values at p<0.05

### *3.1. Going Stick:*

*GSP* was statistically significant for the drainage package (D) and for geotextile addition (G) (Table 2). GSP showed higher values with the second drainage system (D2) and with addition of geotextile chips (G2) as well as being significant for the interaction between moisture content and the geotextile (MG) (Figure 7, Table 3). The treatments M1G2 and M2G2 shown higher penetration values. GSS was statistically significant for drainage package, D1:8,23 ±3.03 and D2: 6.04 ±2.12 (P<0.05).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

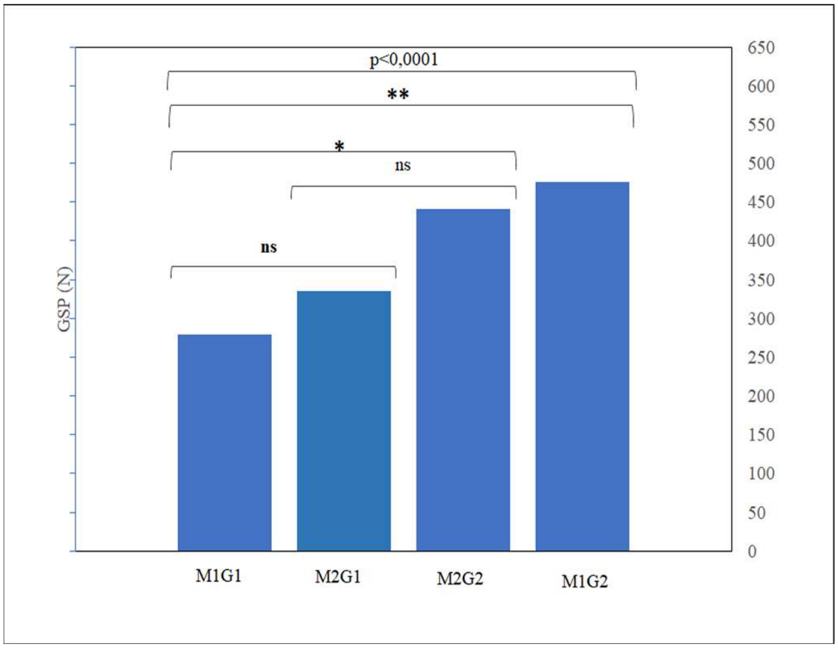


**Figure 7.** Mean of double interaction moisture x geotextile for Going Stick penetration (GSP in N) M 1: GMC was 11.16 % ± 2.93 and treatment; M2: 21.60 % ± 10.90; G1: without geotextile; G2: with 2 kg/m2 of geotextile. The stars indicate significative statistically differences (*). (numbers of stars *, **; *** indicates p value).

### *3.2. Impact Test Device*

The measurements made with the impact test device (ITD) were statistically significant for all three factors and for double interaction of drainage and geotextile (D x G) (Table 2 and table 3, Figure 8). ITD was sensitive to both moistures treatment achieved, M1:0.001209 m ± 0.00316; M2: 0.01316 m ± 0.00314). The displacement was higher when the drainage package is present however the geotextile can lead to similar displacement when the drainage package is absent. When the drainage package is present variation in standard deviation is the lowest of both three other treatments (D1G1: 0.00983±0.00323 vs D1G2:0.01376±0.00304; D2G1:0.01272 ±0.00215; D2G2:0.01472± 0.00278).

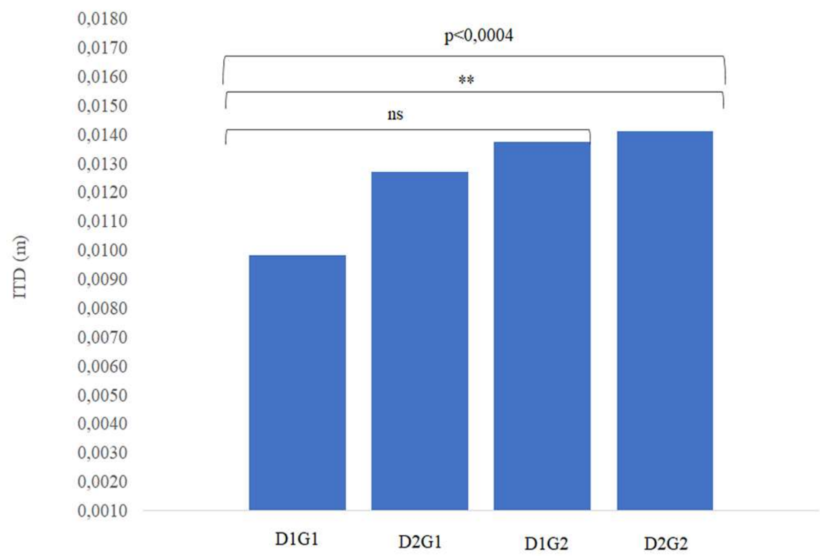


**Figure 8.** Mean of double interaction drainage and geotextile for ITD (m). D 1: no drainage; D2: drainage package; G1: without geotextile; G2: with 2 kg/m2 of geotextile. The stars indicate significative statistically differences (*). (number of stars *, **, *** indicates p value)

*3.3. Rotational Traction of ASTM device:*

The rotational peak shear (RPS) was significant for geotextile addition (G1: 23,57 Nm± 1,85 and G2: 25,86 ±2,16; respectively). Triple interaction of factors Moisture, Geotextile and Drainage package is significant (Figure 9 and Table 3).

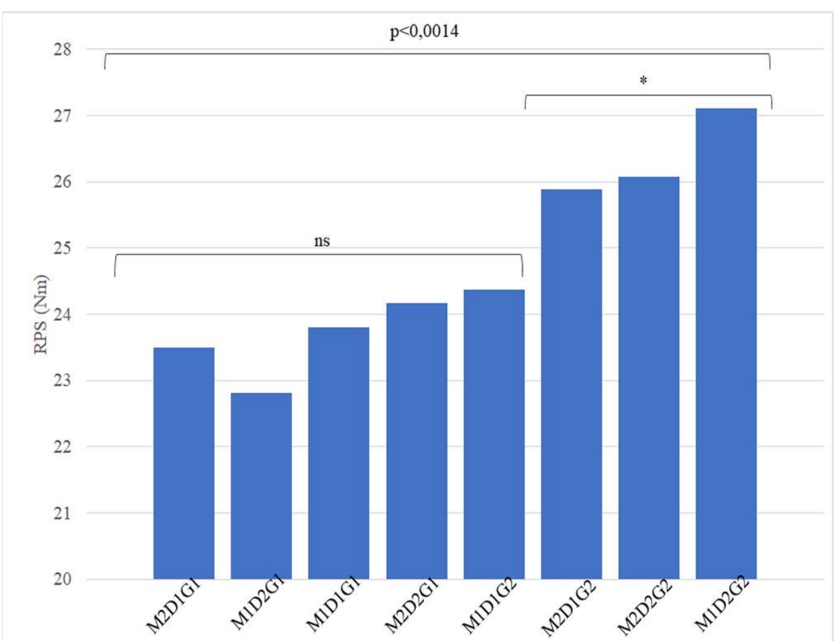


**Figure 9.** Means of triple interaction drainage, moisture, and geotextile for RPS (Nm). D 1: no drainage; D2: drainage package; M1: GMC was 11,16 % ± 2.93 and treatment; M2:

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

21,60 % ± 10,90; G1: without geotextile; G2: with 2 kg/m2 of geotextile. The stars indicate significative statistically differences (*). (number of stars *, **, *** indicates p value).

*3.4. Moisture Probe:*

The Volumetric Moisture Content (VMC %) was significative different for Moisture treatments, M1:10.20 ±2.41; M2:25.08±4.39 p<0.0001 (Table 2). When regression was run extracting independent variables (G and D) for VMC, $R^2$ was 0.80 and was significantly associated with M (p<0,0021) (Table 4).

**4. Discussion**

The aim of this study was to determine the ability to detect the effect of moisture content, geotextile addition, and drainage on an equestrian arena design. The design included silica sand locally sourced in Argentina and a drainage package used as a foundations layer. Testing used readily available devices that could be used to help to maintain consistency during and after construction of the surface.

The GSP was sensitive to different aspects of surface design although GSS was sensitive to one of three factors. Drainage package and geotextile addition effects were detected by GSP. Geotextile addition was mainly detected by GSP. The surface with geotextile had higher GSP, RPS and ITI (311,19 N±105,13 vs 455,97 N±131,87; 23,53 Nm±1,91 vs 25,68 Nm ±2,34; 0,01148 ±0,003 vs 0,01392 ±0,0029; respectively). Although geotextile addition is a widespread practice, a comparison of identical sand without geotextile effects has not been investigated using these type of measurement tools. This data shows that these tools can detect changes that result from the addition of geotextile materials. These attributes may be interpreted related to the firmness and cushioning of the surface.

Although GSS is related to the slide of a longitudinal shear failure of the surface, results indicate that GSS has a weak linear relationship with the use of a drainage package ($R^2$=0,23, 0.001) and could detect differences in longitudinal shear achieved in the experiment when drainage package is present (D1:8,23 ±3.03 Nm; D2: 6.04 ±2.12 Nm). The drainage package consists of two layers of geotextile with a geomesh in the middle, this arrangement has been studied extensively for foundations. This type of so called geocell reinforcement has better performance than other types of geosynthetics due to its three-dimensional structure [52]. For foundations, the soil-reinforcement interface friction is lower than the soil-soil interface friction [53]. This may be the reason for lower longitudinal shear for the D2 treatment.

Moisture content is a generally a understood factor in the dynamic properties of equestrian surfaces [15, 33]. In a horse galloping, the hoof exerts compressive and frictional forces through the depth of the cushion. Ratzlaff [33] found that moderate level of moisture was associated with lower levels of impact. In this experiment bulk density achieved for treatments with sand and geotextile addition proved to be lower (Figure 2 and 3, Appendix I). ITD was sensitive to both moisture treatments. The ITD is a measure of the displacement from the top to the bottom of the compaction of the cushion caused by dropping the mass. This compaction is increased at higher values of GMC. The M1 condition for GMC (11,16 % ± 2.93) was outside of the range of the standard curve for the bulk density shown (Figure 3 Appendix I). The result is a very loose sand surface with fewer lubricated pores to facilitate reorientation of the sand particles. The M2 of GMC (21,60 % ± 10,90) results in compaction is which is consistent with the range of the curve of bulk density (Figure 2 and 3 Appendix 1).

Higher ITI (0,01209 m ±0,00316) at M2 of GMC represents the impact being lower at this moisture content. This is consistent with Ratzlaff [33], may also indicate that energy rebound is present. ITI has a positive linear relationship with GSP (P=0.38, p=0.0011).

The effect of geotextile on the response of the surface is related to relative motion between horseshoe and the surface. This resistance result in higher forces during a pivoting movement [28]. The GSP, ITD and RPS have proven to all be sensitive to this effect. The RPS has been addressed in previous work with weaker results [22]. In this paper a sensitivity is shown to the triple interaction of drainage package, moisture content and geotextile addition. Sliding of the hoof on the surface can either occur between the shoe and the surface, or within the material beneath the hoof depending on the characteristics of the surface and the design of the shoe [22]. Moisture content and the existence of the drainage package are thus able to affect the surface response measured by RPS. Shear failure of the surface is detected by both the RPS and GSP measures when geotextile addition is tested, although $R^2$ and P coefficient is not significant. The effective depth of the measurements is different and in fact the peak vertical force over the surface layers may be the controlling factor in these results.

Moisture content, drainage package and geotextile treatments were shown to be significant for ITD. All three factors affected the distance that the drop deformed the arena surface. Moisture and geotextile could achieve the uniformity that the use of the drainage package could not as seen in the higher standard deviation. This result is consistent with the expected influence of the drainage package.

Although increases in GSP could be observed in the combination of moisture and geotextile, the higher GSP showed that moisture has a similar result to the geotextile addition showed by ANOVA. Increases in GSP are higher when geotextile is added (M1G2= 70,3 %, M2G1=19,7 % and M2G2=57,60 %).

The differences in the maximum bulk density of sand with and without geotextile may help with understanding this result. The bulk density varies with the amount of moisture with the maximum bulk density achieved at a specific moisture content. The moisture content where the soil particles are able to reorient while remaining in contact provides the greatest bulk density values. Curves for the bulk density of the sand and the sand with added geotextile showed differences in the moisture content range in which both systems remain stable to compaction (figure 1 and 2 Appendix I). Sand systems get higher bulk densities than sand with addition of geotextile at both VMC% tested (Figure 2 Appendix 1). The VMC% of the bulk density test cover the range of the present experiment (M1= 10.20 % ± 2.41 and M2: 25,08 % ± 4.39 tested with TDR). This may suggest that geotextile addition with the compaction used in this experiment would respond as a low-density depth cushioning system. As Holt et al. [15] reported low density surfaces have lower maximum peak load and lower peak acceleration on impact. In this experiment, hardness was represented by the lower distance achieved by the ITD when M1 was applied (high bulk density). Although resistance to penetration (GSP), is measured as a peak vertical load, the size of the probe and depth of penetration is very different than that of the horseshoe.

The near surface properties measured with the RPS would not be expected to change with the addition of subsurface drainage. However, the drainage package atop limestone may be reducing water flux rate and may also provide a more consistent interface. This lower rate of drainage may cause a more homogenous vertical distribution of water and avoid the loss of water shown by McInnes and Thomas in experimental turfgrass profile designs [54]. In the experimental boxes' double geotextile layer with a mesh plastic was used. These results suggest that the mesh layer does not just serve as a separation layer but may also serve as a subsurface water storage. The mesh layer and the drainage layer may work together to provide more consistent water content both laterally in the boxes and vertically in the profile.

## 5. Conclusions

The effect and the interaction of moisture content, drainage and geotextile was tested with five measurements. Previous studies were confirmed with respect to the effect of moisture and geotextile addition which could both be detected with the simple instruments. The inclusion of a drainage package influenced surface measures such as shear and penetration measured using GS and the ITD. The effect of drainage on surface properties is likely to be related to the presence of both a vertical and horizontal water movement and the subsequent effect on consistency. The ability to test functional properties of the surface may be limited however due to the lower loads and lower load rates. Simpler devices like GS, RPS or ITD may be best suited for quality control process in the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

construction of arenas rather than an evaluation of the suitability of the complete arena for performance and consistency.

The ITD is closely related to methods widely use in sport fields testing[55]. The ITD constructed for this experiment is cost effective and portable which may justify further development. Other tools like the GS may be limited in applicability due to the design complexity and cost. The manufacturers of some subsurface mats used in certain equestrian disciplines such as dressage recommend profiles depths less than 10 cm. The probe on the GS would be too long for use on those surfaces. While none of these devices directly correlate to loading of the limbs of horses or the arena performance, many of the arenas have standard designs which, if properly installed, can provide reasonable functional parameters. As a result, when using these standard designs a simple measurement device may suffice for quality control and can may play a useful role in the development of improved arena surfaces. Future work should consider alternative approaches that are also suited for monitoring the maintenance of the surface to ensure that a high-quality arena will continue to provide consistent performance over time. Type of the Paper (Article, Review, Communication, etc.)

**Appendix I:**

**Table 1** Technical Data Sheet of Geo Mesh (GN 900)

| Technical Data sheet | Standard | GN 900 |
|---|---|---|
| Constituent materials | | HDPE |
| Density | ASTM D 792 | 0,94 $g/cm^3$ |
| Minimun Thickness | IRAM 78004-1 | 5 mm |
| Minimum mass per unit area | IRAM 78002 | 725 $g/cm^2$ |
| Minimum tensile strength (Longitudinal) | IRAM 78012 | 7 kN/m |
| Transmissivity | ASTM D 4716 | 2,5 x $10^{-3}$ |
| Compressive strenght | ASTM D 1621 | 350 kPa |
| Minimun width | - | 2 m |
| Minimun Lenght | - | 50 m |

**Table 2** Technical Data Sheet of **w**oven Geotextile 150 of Polyester

| Technical Data sheet | | | |
|---|---|---|---|
| Constituent materials | 100 % Polyester | | |
| Mechanical Properties | | | |
| Tensile properties Wide width strip method | IRAM 78012 / ASTM D-4595 | | 8 kN/m |
| Deformation | IRAM 78012 / ASTM D-4595 | | 70% |
| Index Puncture Resis-tance CBR | IRAM 78011 / ASTM D-6241 | | 1,3 kN/m |
| Trapezoid Tearing Strength | IRAM 78017 / ASTM D-4533 | | 250 N |

| | | | |
|---|---|---|---|
| Hydraulic Properties | | | |
| Apparent Opening Size of a Geotextile | IRAM 78006 / ASTM D-4751 | | 0,21 mm |
| Water Permeability of Geotextiles by Permit-tivity | IRAM 78007 / ASTM D-4491 | | 2,4 $s^{-1}$ |
| Water Flux | IRAM 78007 / ASTM D-4491 | | 115 $l/s/m^2$ |

**Table 3** Sand description* based on the percentage of sand, silt, and clay in each sample.

| SAMPLE DESCRIPTION | Silicic Sand |
|---|---|
| Sand | 92.3% |
| Silt | 2.6% |
| Clay | 5.1% |

*based on the Wentworth scale of grain size.

**Table 4:** Particle size distribution *.

| SAMPLE DESCRIPTION | Silicic Sand |
|---|---|
| NO. 10 | 0.2% |
| NO. 14 | 0.0% |
| NO. 18 | 0.1% |
| NO. 35 | 1.0% |
| NO. 40 | 0.6% |
| NO. 60 | 13.6% |
| NO. 100 | 70.7% |
| NO. 140 | 5.5% |
| NO. 200 | 0.7% |
| NO. 270 | 0.4% |
| PAN (SILT & CLAY) | 7.4% |
| **OTHER:** | |
| MOISTURE | 3.7% |
| ORGANIC CARBON | 0.7% |

*FEI approved method.

**Table 5** Classification* of sand by comparison of the gravel, sand, silt, and clay distribution of the sample.

| | Grav | Sand | Silt | Clay | |
|---|---|---|---|---|---|

| SAMPLE DESCRIPTION | el | | | | | | | Ratio Med to V. Fine divided by Gravel + Cs. San d |
|---|---|---|---|---|---|---|---|---|
| | Coarse 5 - 12 mm | Fine 2 - 5 mm | Very Coarse 1 - 2 mm | Coarse 0.5 - 1 mm | Ied. To Very Fine 0.05 - 0.5 mm | 0.002 - 0.05 mm | 0 - 0.002 mm | |
| Silicic Sand | | 0.2% | 0.1% | 1.0% | 91.3% | 2.3% | 5.1% | 70.3 |
| | 0.2% | | 1.1 % | | 91.3% | 7.4% | | |

*based on the USDA soil texture classification.

**Table 6** XRD Analysis which shows mineral composition of sand.

| Whole Rock Mineralogy (Weight Percent) | |
|---|---|
| Quartz | 90,6 |
| K-Feldspar | 2,7 |
| Plagioclase | 2,5 |
| Calcite | 0,2 |
| Dolomite | 0 |
| Total Phyllosilicates | 4 |
| TOTAL | 100 |
| | |
| | |
| Phyllosilicate Mineralogy (Relative Abundance) | |
| R0 M-L I/S (90%S)* | 72,5 |
| Illite & Mica | 20 |
| Kaolinite | 5 |
| Chlorite | 2,5 |
| TOTAL | 100 |
| | |
| | |
| Quartz | 90,6 |
| K-Feldspar | 2,7 |
| Plagioclase | 2,5 |
| Calcite | 0,2 |
| Dolomite | 0 |
| R0 M-L I/S (90 % S)* | 2,9 |
| Illite & Mica | 0,8 |
| Kaolinite | 0,2 |
| Chlorite | 0,1 |
| TOTAL | 100 |
| | |

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

| |
|---|
| *R0 M-L I/S (90 % S) - R0 Ordered Mixed-Layer Illite/Smectite<br>with 90% Smectite Layers |
| NOTE: For the two RDE_19002 samples, a minor amount of<br>paraffin wax was present in the samples. |
| The paraffin was not included in the above analytical results. |

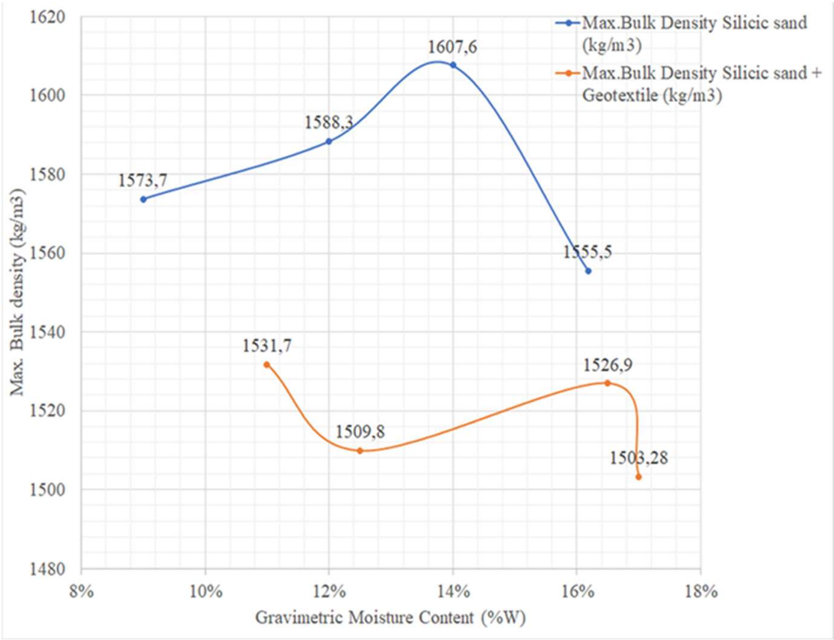


**Figure 1** Bulk density of silicic sand and silicic sand and geotextile addition with gravimetric moisture content (kg/m3[3]).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

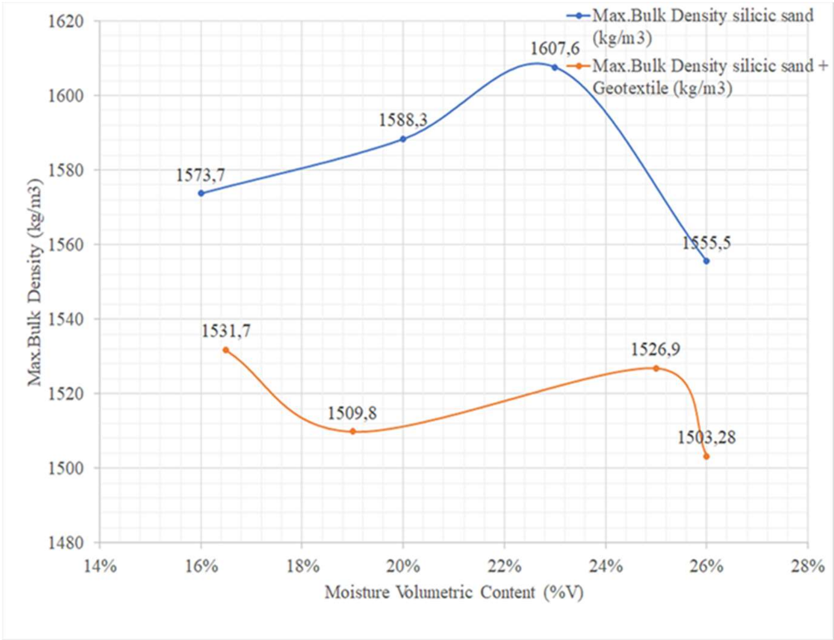


**Figure 2**. Bulk density of silicic sand and silicic sand and geotextile addition (2 kg/m²) with volumetric moisture content (kg/m³).

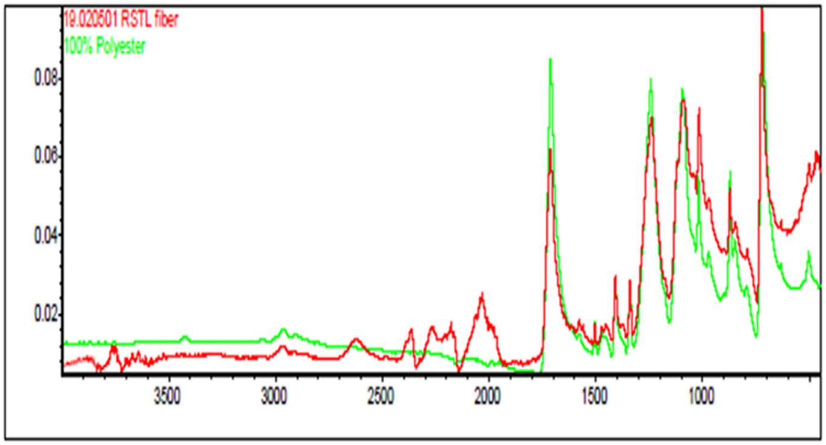


**Figure 3.** FTIR Analysis shows that the fibers are 100 % polyester. Peaks left of 2000 wave numbers are from dust.

**Appendix II:**

**Calibration of Going Stick**

To obtain penetration data in engineering units the Going Stick was placed into a calibration fixture with a 4.5 kN. (1000 lbf) load cell (Omega Engineering, Omegadyne LC101-1K) in line with the measuring tip. Applied loads are shown in Table 1 with the equivalent calibration values from the GSP shown in Table 2 for an average of two Going Stick used. Moments also applied to the probe tip of the clamped Going Stick as shown in Table 3 for the shear calibration to determine the equivalent GSS value. Going Stick values were plotted and a polynomial curve fit are shown in Figure 1. The resulting equation to convert GSP to peak penetration force in Newtons (N)

$$F_p\,(N) = 58.291\ x\ P$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

With $\boldsymbol{R2} = \mathbf{0.9956}$

The GSS value can be converted to peak shear force in Newton-meters (Nm) where $\boldsymbol{\sigma_s}$ :

$$\boldsymbol{F_s(Nm) = 3.3131\ x\ S}$$

With $\boldsymbol{R2} = \mathbf{0.995}$

In the same line, and using theoretical loads, Going Stick values of penetration and shear were plotted, and curve fitted using a linear fit (Figure 1).

**Table 1** The table shows the results from verifying force applied to the Going Stick´s probe tip using the calibration rig for penetration force.

| Applied Load IU (lbf) | Applied Load SI (N) | Force Out Theoretical (N) | Force out measured (N) | Percent Error |
|---|---|---|---|---|
| 4,41 | 19,62 | 69,13 | <59,291 | 14,23 |
| 11,02 | 49,02 | 172,59 | 98,42 | 42,97 |
| 22,05 | 98,08 | 345,63 | 319,51 | 7,56 |
| 33,07 | 147,10 | 518,22 | 527,69 | 1,83 |
| 44,09 | 196,12 | 691,25 | 711,49 | 2,93 |
| 52,51 | 233,59 | 823,12 | 850,83 | 3,37 |
| 55,12 | 245,19 | 863,84 | >889,365 | 2,95 |
| 66,14 | 294,21 | 1036,88 | >889,365 | 14,23 |
| 70,5479 | 313,81 | 1105,82 | >889,365 | 19,57 |

**Table 2.** The table shows the results from varying force applied to the Going Stick´s probe tip using the calibration rig, for engineering mode.

| Calibration Load (IU units) | 4,41 | 11,02 | 22,05 | 33,07 | 44,09 | 52,51 | 55,12 | 66,14 | 70,5479 | lbf |
|---|---|---|---|---|---|---|---|---|---|---|
| Calibration Load (SI units) | 19,62 | 49,02 | 98,08 | 147,10 | 196,12 | 233,59 | 245,19 | 294,21 | 313,81 | N |
| Load at tip (Theoretical) | 69,1 | 172,6 | 345,6 | 518,2 | 691,3 | 823,1 | 863,8 | 1036,9 | 1105,816 | N |
| GS 001 | 16 | 39 | 72 | 106 | 135 | 158 | 167 | 199 | 209 | GS EV* |
| GS 005 | 14 | 34 | 67 | 102 | 135 | 159 | 169 | 202 | 215 | GS EV |
| Average | 15 | 36,5 | 69,5 | 104 | 135 | 158,5 | 168 | 200,5 | 212 | GS EV |
| Flat Penetration | <1 | 1,66 | 5,4 | 8,9 | 12 | 14,35 | >15 | >15 | >15 | GS Value |
| Conversion factor | 4,6 | 4,7 | 5,0 | 5,0 | 5,1 | 5,2 | 5,1 | 5,2 | 5,2 | to N |

*Going Stick Engineering value

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 July 2021 doi:10.20944/preprints202107.0663.v1

**Table 3.** The table shows the results from verifying torque applied to the Going Stick´s probe tip using the calibration rig for shear force.

| Applied Load (Lbf) | Applied Load (N) | Torque Theoretical (N-m) | Torque measured (N-m) | Percent Error |
|---|---|---|---|---|
| 0,00 | 0,00 | 2,68 | 4,07 | 51,90% |
| 0,90 | 4,02 | 5,63 | 7,29 | 29,49% |
| 3,82 | 16,97 | 15,14 | 18,55 | 22,56% |
| 6,16 | 27,42 | 22,81 | 24,57 | 7,74% |
| 8,22 | 36,59 | 29,54 | 30,09 | 1,89% |
| 11,30 | 50,25 | 39,57 | 39,76 | 0,48% |
| 14,84 | 66,01 | 51,14 | 48,04 | 6,06% |

**Table 4.** The table shows the results from varying torque applied along the Going Stick´s probe tip using the calibration rig.

| Calibration Load (IU) | 0,00 | 0,90 | 3,82 | 6,16 | 8,22 | 11,30 | 14,84 | lbf |
|---|---|---|---|---|---|---|---|---|
| Calibration Load (SI) | 0,00 | 4,02 | 16,97 | 27,42 | 36,59 | 50,25 | 66,01 | N |
| App. Torque (Theoretical) | 2,68 | 5,63 | 15,14 | 22,81 | 29,54 | 39,57 | 51,14 | N-m |
| GS 001 | 11 | 20 | 44 | 66 | 85 | 121 | 151 | GS EV |
| GS 005 | 10 | 20 | 46 | 66 | 87 | 121 | 151 | GS EV* |
| Average | 10,5 | 20 | 45 | 66 | 86 | 121 | 151 | GS EV |
| Flat Shear | 1,23 | 2,20 | 5,60 | 7,42 | 9,08 | 12,00 | 14,50 | GS V** |
| Conversion factor | 0,3 | 0.3 | 0,3 | 0,3 | 0,3 | 0,3 | 2,8 | to N-m |

*Going Stick Engineering Value **Going Stick Value

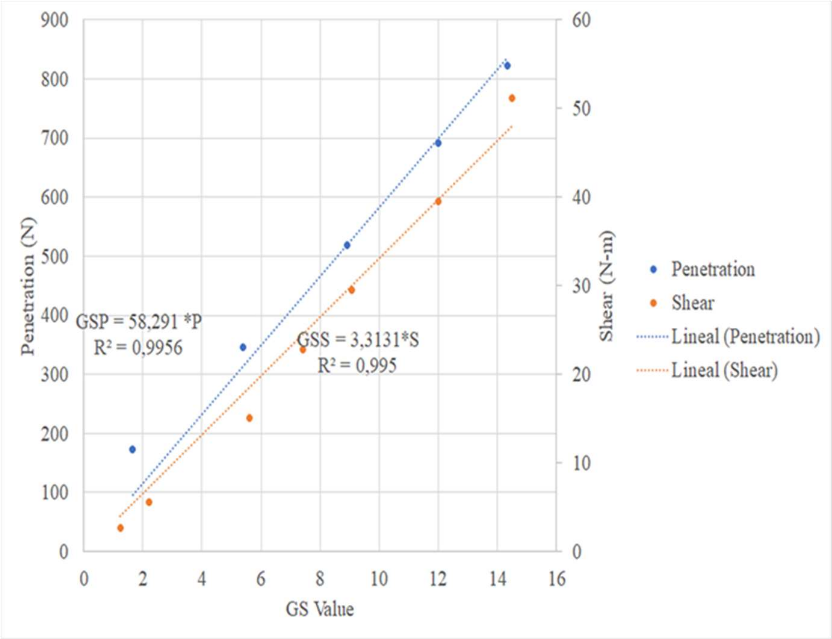


**Figure 1.** Curve fits assuming linearity to determine conversion factor of GS values of penetration and shear.

**Author Contributions:** María Alejandra Blanco, conceived and supervised the study and had substantial inputs into the analysis, all drafts and created the original manuscript preparation. Raúl Hourquebie conducted the field camp data acquisition under supervision, Kaleb Dempsey conducted laboratory analysis of materials and calibration of Going Stick, Peter Schmitt conducted calibration and validation of Going Stick. Michael "Mick" Peterson had substantial inputs into conceptualization, data curation and reviewing the original manuscript of the paper. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by a biennial research project PI3-18-06-MB-005 of the Secretary of Science and Technology from University of Morón, and Racing Surface Testing Laboratory.

**Acknowledgments:** The authors want to thanks to the owners of the equestrian training center Solaguayre for allowing the study to be undertaken on the center, to RSTL for supporting this project, Dr. Marcelo Soria, from the Graduate School of Faculty of Agronomy of the University of Buenos Aires, for his statistician support and Juan José Crespi for supplying and providing technical support for the ITD and RPS.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Egenvall,A.; C.; Tranquille A.; Lönnell C.; Bitschnau A.; Oomen E.; Hernlund S.; Montavon M.; Franko R.; Murray M.; Weishaupt Van R.; Weeren and L.; Roepstorff. Days-lost to training and competition in relation to workload in 263 elite show-jumping horses in four European countries. *Preventive Veterinary Medicine* [online]. 2013, 112(3–4), 387–400. ISSN 01675877. Available at: doi:10.1016/j.prevetmed.2013.09.013
2. Murray,R.C.; J.M.; Walters H.; Snart S.J.; Dyson and T.D.H.; Parkin. Identification of risk factors for lameness in dressage horses. *Veterinary Journal* [online]. 2010, 184(1), 27–36. ISSN 10900233. Available at: doi:10.1016/j.tvjl.2009.03.020
3. Parkin,T.D.H.; P.D.; Clegg N.P.; French C.J.; Proudman C.M.; Riggs E.R.; Singer P.M.; Webbon and K.L.; Morgan. Race- and course-level risk factors for fatal distal limb fracture in racing Thoroughbreds. *Equine Veterinary Journal* [online]. 2004, 36(6), 521–526. ISSN 0425-1644. Available at: doi:10.2746/0425164044877332
4. Hernandez J. Hawkins, D.L. Scollay,M.C.; Race-start characteristics and risk of catastrophic musculoskeletal injury in Thoroughbred racehorses. *Journal of the American Veterinary Medical Association* [online]. 2001, v. 218(1), 83-86–2001 v.218 no.1. Available at: doi:10.2460/javma.2001.218.83

5. Hernlund,E.; A.; Egenvall S.J.; Hobbs M.L.; Peterson A.J.; Northrop A.; Bergh J.H.; Martin and L.; Roepstorff. Comparing subjective and objective evaluation of show jumping competition and warm-up arena surfaces. *Veterinary Journal* [online]. 2017, 227, 49–57. ISSN 15322971. Available at: doi:10.1016/j.tvjl.2017.09.001
6. Peterson M.L., Reiser, R.F. II, Kuo, P.H. , Radford, D.W. , McIlwraith,C.W..; Effect of temperature on race times on a synthetic surface. *Equine veterinary journal* [online]. 2010, v. 42(4), 351-357–2010 v.42 no.4. Available at: doi:10.1111/j.2042-3306.2010.00072.x
7. Hernlund,E.; *Sport Surfaces in Show Jumping*. 2016. ISBN 9789157686107
8. Georgopoulos,S.P.; and T.D.H.; Parkin. Risk factors associated with fatal injuries in thoroughbred racehorses competing in flat racing in the United States and Canada. *Journal of the American Veterinary Medical Association* [online]. 2016, 249(8), 931–939. ISSN 1943569X. Available at: doi:10.2460/javma.249.8.931
9. Georgopoulos,S.P.; An investigation of equine injuries in Thoroughbred flat racing in North America. *Journal of the American Veterinary Medical Association*. 2017.
10. Georgopoulos,S.P.; and T.D.H.; Parkin. Risk factors for equine fractures in Thoroughbred flat racing in North America. *Preventive Veterinary Medicine*. [online]. 2017, 139((Pt.B)), 99–104. ISSN 1943569X. Available at: doi:10.2460/javma.249.8.931
11. Peterson,M.; W.; Sanderson N.; Kussainov S.J.; Hobbs P.; Miles M.C.; Scollay and H.M.; Clayton. Effects of racing surface and turn radius on fatal limb fractures in thoroughbred racehorses. *Sustainability (Switzerland)* [online]. 2021, 13(2), 1–16. ISSN 20711050. Available at: doi:10.3390/su13020539
12. Hobbs, S. J., Northrop, A.J,Mahaffey,C.,Martin, J.H., Clayton, H.M., Murray, R., Et al.; Equestrian Surfaces – a Guide. *Fei publication*. [online]. 2014. Available at: www.fei.org/fei/about-fei/%0Apublications/fei-books
13. Thomason,J.J.; and M.L.; Peterson. *Biomechanical and Mechanical Investigations of the Hoof-Track Interface in Racing Horses* [online]. April 2008. ISSN 07490739. Available at: doi:10.1016/j.cveq.2007.11.007
14. Setterbo, Jacob J., Chau, Ann, Fyhrie, Patricia, Hubbard, Mont, Uphadyaya Shrini K., Symons Jenifer E.,S.S.; Validation of a Laboratory Method for Evaluating Dynamic Properties of Reconstructed Equine Racestrack surfaces. *PLoS ONE* [online]. 2012, 7(12), 1–14. Available at: www.plosone.org
15. Holt,D.; A.; Northrop A.; Owen J.; Martin and S.J.; Hobbs. Use of surface testing devices to identify potential risk factors for synthetic equestrian surfaces. In: *Procedia Engineering* [online]. B.m.: Elsevier Ltd, 2014, p. 949–954. ISSN 18777058. Available at: doi:10.1016/j.proeng.2014.06.160
16. Goncu,F.; *Mechanics of Granular Materials : Constitutive Behavior and Pattern Transformation*. 2012. ISBN 9789461913418.
17. Clayton,H.M.; Comparison of the stride kinematics of the collected, medium, and extended walks in horses. *American Journal of Veterinary Research*. 1995, 56, 849–852.
18. Merkens, H.W., Schamhardt, H.C., van Osch, G.J.V.M., van der Bogert,A.J.; Ground reaction force analysis of Dutch Warmblood Horses at canter and jumping. *Equine Exerc.Physiol.* 1993, 3, 128–135.
19. Clayton,H.M.; and S.J.; Hobbs. A review of biomechanical gait classification with reference to collected trot, passage and piaffe in dressage horses. *Animals* [online]. 2019, 9(10), 1–19. ISSN 20762615. Available at: doi:10.3390/ani9100763
20. Mahaffey,C.A.; M.L.; Peterson J.J.; Thomason and C.W.; McIlwraith. Dynamic testing of horseshoe designs at impact on synthetic and dirt Thoroughbred racetrack materials. *Equine Veterinary Journal* [online]. 2016, 48(1). ISSN 20423306. Available at: doi:10.1111/evj.12360
21. Mahaffey,C.A.; M.L.; Peterson and L.; Roepstorff. The effects of varying cushion depth on dynamic loading in shallow sand thoroughbred horse dirt racetracks. *Biosystems Engineering* [online]. 2013, 114(2), 178–186. ISSN 15375110. Available at: doi:10.1016/j.biosystemseng.2012.12.004
22. Lewis,K.; A.J.; Northrop G.M.; Crook J.; Mather J.H.; Martin D.; Holt H.M.; Clayton L.; Roepstorff M.L.; Peterson and S.J.; Hobbs. Comparison of equipment used to measure shear properties in equine arena surfaces. *Biosystems Engineering* [online]. 2015, 137, 43–54. ISSN 15375110. Available at: doi:10.1016/j.biosystemseng.2015.07.006
23. Claußen,G.; R.; Dürselen B.; Krone and E.F.; Hessel. Evaluation of the Factors Influencing the Rotational Shear Resistance of Horse Riding Arena Surfaces (Technical and Field Investigations). *Journal of Equine Veterinary Science* [online]. 2019, 74, 95–102. ISSN 07370806. Available at: doi:10.1016/j.jevs.2018.12.002
24. Godfrey,N.; Everything you ever wanted to know about the smelly stuff. *Horse Racing News* [online]. 2017, (Racing Post), 1–8. Available at: https://www.racingpost.com/news/everything-you-ever-wanted-to-know-about-the-goingstick/260234
25. ASTM International. *WK73697 Proposed Standard Test Method for Assessing Physical Resistance in Turfgrass Equine Surfaces* [online]. 2020. Available at: doi:10.1520/XXXXX-XX
26. American Society for Testing and Materials. ASTM D5874-16. Standard Test Methods for Determination of the Impact Value (IV) of a Soil. [online]. 2016. Available at: doi:10.1520/D5874-16
27. Mohajerani,A.; H.; Kurmus L.; Tran C.; Maha Arachchillegedar M.; Mirzababaei and A.; Arulrajah. Clegg impact hammer: an equipment for evaluation of the strength characteristics of pavement materials, turf, and natural and artificial playing surfaces: a review,. *Road Materials and Pavement Design* [online]. 2019. ISSN 21647402. Available at: doi:10.1080/14680629.2018.1502092
28. Twomey,D.M.; S.; Ullah and L.A.; Petrass. One, two, three or four: Does the number of Clegg hammer drops alter ground hardness readings on natural grass? *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology* [online]. 2014, 228(1), 33–39. ISSN 17543371. Available at: doi:10.1177/1754337113501300
29. American Society for Testing and Materials. ASTM D6067 / D6067M-17, Standard Practice for Using the Electronic Piezocone Penetrometer Tests for Environmental Site Characterization and Estimation of Hydraulic Conductivity [online]. 2017. Available at: doi:10.1520/D6067_D6067M-17

30. American Society for Testing and materials. ASTM D3441-16, Standard Test Method for Mechanical Cone Penetration Testing of Soils [online]. 2016. Available at: doi:10.1520/D3441-16
31. ASABE STANDARDS. S313.3. Soil cone penetrometer. 2010, 1999.
32. Ratzlaff,M.H.; M.L.; Hyde D.; V. Hutton R.A.; Rathgeber and O.K.; Balch. Interrelationships between moisture content of the track, dynamic properties of the track and the locomotor forces exerted by galloping horses. *Journal of Equine Veterinary Science* [online]. 1997, 17(1), 35–42. ISSN 07370806. Available at: doi:10.1016/S0737-0806(97)80456-X
33. Ratzlaff,M.H.; P.D.; Wilson D.; V. Hutton and B.K.; Slinker. Relationships between hoof-acceleration patterns of galloping horses and dynamic properties of the track. *American Journal of Veterinary Research* [online]. 2005, 66(4), 589–595. ISSN 00029645. Available at: doi:10.2460/ajvr.2005.66.589
34. Dirección Nacional de Vialidad. Norma de ensayos. VN-E5-93 Compactación de suelos [online]. 1993, (March), 1–14. Available at: https://www.monografias.com/trabajos107/compactacion-suelos-mecanica-suelos/compactacion-suelos-mecanica-suelos.shtml#bibliograa
35. Sports Arenas S.A. Grass and Horses by Sports Arenas. *Grass and Horses* [online]. 2020. Available at: https://grassandhorses.com/
36. Das,B.M.; Advanced Soils Mechanics. *Advanced Soils Mechanics.* Third Edit. 2008, 567.
37. Northrop,A.J.; S.J.; Hobbs D.; Holt E.; Clayton-Smith and J.H.; Martin. Spatial Variation of the Physical and Biomechanical Properties Within an Equestrian Arena Surface. In: *Procedia Engineering* [online]. B.m.: Elsevier Ltd, 2016, p. 866–871. ISSN 18777058. Available at: doi:10.1016/j.proeng.2016.06.288
38. Setterbo,J.J.; A.; Yamaguchi M.; Hubbard S.K.; Upadhyaya and S.M.; Stover. Effects of equine racetrack surface type, depth, boundary area, and harrowing on dynamic surface properties measured using a track-testing device in a laboratory setting. *Sports Engineering* [online]. 2011, 14(2–4), 119–137. ISSN 13697072. Available at: doi:10.1007/s12283-011-0073-4
39. American Society for Testing and Materials. ASTM-D422-63 (2007)e2. Standard Test Method for Particle-Size Analysis of Soils. 2007, (Reapproved), 1–8. ISSN <null>.
40. American Society of Testing and Materials. ASTM F3416-21, Standard Guide For Using Fourier Transform Infrared Spectrometry to Evaluate Synthetic Equine Surface Components, ASTM. 2021.
41. ASTM. Commitee on Sports Equipment. Working paper (69498) Method for Performing Whole Rock and Clay Fraction XRay Diffraction Standard Test Method for Performing Whole Rock and Clay Fraction XRay Diffraction (XRD) on Equine Surfaces. F08.28. 2021.
42. American Society for Testing and Materials. ASTM D 698-07. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort ( 12 , 400 ft-lbf / ft 3 ( 600 kN-m / m 3 ). *The Annual Book of ASTM Standards*. 2007, 3, 1–11.
43. American Society for Testing and Materials. ASTM D6780/D6780-19. Standard Test Methods for Water Content and Density of Soil In situ by Time Domain Reflectometry (TDR). [online]. 2019. Available at: doi:10.1520/D6780_D6780M-19
44. International Organization for Standarization. *ISO 17892-1:2014. Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content.* 2014
45. ASTM. Commitee on Sports equipment. Working paper (73697) Assessing Physical Resistance in Turfgrass Equine Surfaces. F08-28. 2021.
46. American Society of Testing and Materials. ASTM D5874-16, Standard Test Methods for Determination of the Impact Value (IV) of a Soil [online]. 2016. Available at: doi:10.1520/D5874-16
47. American Society for Testing and Materials. ASTM F2333-04(2017). Standard Test Method for Traction Characteristics of the Athletic Shoe-Sports Surface Interface. [online]. 2017. Available at: doi:10.1520/F2333-04R17
48. American Society for Testing and material. Standard Test Method for Water Content and Density of Soil In situ by Time Domain Reflectometry (TDR), ASTM D6780 / D6780M-12. [online]. 2012. Available at: www.astm.org
49. Dufour,M.J.D.; and C.; Mumford. GoingStick ® technology and electromagnetic induction scanning for naturally-turfed sports surfaces . *Sports Technology* [online]. 2008, 1(2–3), 125–131. ISSN 1934-6182. Available at: doi:10.1080/19346182.2008.9648463
50. Mumford,C.; The optimization of going management on UK racecourses using controlled water. 2006, 297.
51. Blundell,E.; The effects of dressage competitions on the mechanical properties of a synthetic equestrian arena surface. 2010.
52. Dash,S.K.; Effect of Geocell Type on Load-Carrying Mechanisms of Geocell-Reinforced Sand Foundations. *International Journal of Geomechanics* [online]. 2012, 12(5), 537–548. ISSN 1532-3641. Available at: doi:10.1061/(asce)gm.1943-5622.0000162
53. Juran, I., Guermazi, A., Chen, C.L. and Idder,H.H.; Modelling and simulation of load transfer in reinforced soils: Part 1. *Int. J. Numer. Anal. Methods Geomech.* 1988, 12(2), 141–155.
54. Rose-Harvey,K.; K.J.; McInnes and J.C.; Thomas. Water flow through sand-based root zones atop geotextiles. *HortScience* [online]. 2012, 47(10), 1543–1547. ISSN 00185345. Available at: doi:10.21273/hortsci.47.10.1543
55. Caple,M.; I.; James and M.; Bartlett. Spatial analysis of the mechanical behaviour of natural turf sports pitches. *Sports Engineering* [online]. 2012, 15(3), 143–157. ISSN 13697072. Available at: doi:10.1007/s12283-012-0097-4