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Design and Development of a Novel Natural Turf Shear Stability Tester

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Abstract

The stability of natural Rugby Union pitches continues to be a recurring problem at all levels of the game. The effects of poor stability are seen when the pitch surface shears under player loading, creating unsightly divots and an uneven and potentially injurious surface. This observed instability is a real concern for many stakeholders, from the groundsmen to the revenue-generating television companies, and is arguably increasing caused by greater popularity of sports, more intensive use of natural turf pitches and advances in player physical conditioning. However, perhaps surprisingly, no objective quantitative mechanical test method currently exists for assessing the shear stability of the natural turf prior to games being played.

This paper presents the findings from a (ongoing) research study into the design and development of a prototype turf stability apparatus (‘Turf Tester’). The key aim was to measure the shearing stability of natural and hybrid turf in order to assess a recurring failure problem. In order to be relatable to sporting performance, this failure imitates conditions to simulate player(s) interaction. The prototype and test method was developed with properties suggested from published papers discussing rugby and agronomists’ experience. It was theorized that there was a potential zone susceptible to failure within the top 100 mm of the sports turf. The position of this zone was variable and depended on pitch construction. The prototype was built to explore this variable failure zone using a 50 mm and 100 mm pin that sheared through the soil when a known load was applied to it. Both the Clegg Impact Hammer (CIH) and the rotational traction (RTD) were suggested to be relatable to penetration and shear stability; however, their relatability to the failure zone was an unknown.

This paper details the background behind the study, the prototype design and principle, the observed failure mechanisms of sports turf, and presents the results of the prototype apparatus trailed on a range of turf constructions at venues used for the 2015 Rugby World Cup. Data was collected at each venue using Labosport’s Scoreplay system detailing full agronomic classifications and a suite of industry standard player performance tests. The combined data from 13 of the venues provided a powerful data set to evaluate and refine the prototype apparatus, providing validity of its conceptual design.

The findings show that the shear tester assessed the upper level of ability of pitches with a 50 mm depth pin and the lower ability with the 100 mm pin. There was some evidence of a relationship to the CIH and RTD, albeit weak, and it was concluded the shear tester was assessing a characteristic of the sport turf not currently measured by standard industry tests currently utilized. The shear tester differentiated between the high stability of the hybrid pitch constructions and the weaker natural pitches. The shear tester rankings for pitch quality also approximated well the ranking from the Scoreplay pitch quality system. Incorporation of the shear tester into routine pitch evaluations could benefit a scoring system approach

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Keywords: Rugby Union; Natural Sports Pitches; Hybrid Sports Pitches, Shear Stability

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1. Introduction

Rugby Union is a physical game that has continuously evolved, creating faster play, increasingly athletic players, and with many technologies improving the game. However, despite all the advancements in player welfare and their personal equipment, it is still common to observe problems with the playing surface used. In particular, low shear stability of natural turf is a recurring problem, and is observed as the surface cutting up under the players’ boots, often in scrums. This is a concern as player safety is potentially

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compromised; furthermore, it creates challenges for groundsmen to rapidly repair the pitch, and is an annoyance for stakeholders as popularity grows for the game and aesthetics are important. Surprisingly, there is no standardized test method for assessing the shear stability of natural turf or hybrid turf systems. Natural turf comprises predominantly clayey soil, some have top-dressing of sand, while hybrid systems have synthetic fibres present to reinforce soil and increase stability. Common hybrid systems are the Desso grassmaster, which injects hundreds of synthetic fibres vertically into the ground to a depth of 200 mm, and stand above the surface to a height of 20 mm, and Fibresand, which has millions of randomly orientated short thin plastic fibres mixed with sand to form a rootzone. A more recent 'hybrid' system is termed 'Mottz', which comprises a 50 mm long-pile (3G) synthetic woven into a permeable mesh backing. Soil is added and natural grass grown that interweaves with the synthetic fibres and through the mesh backing. These systems have been established to improve the durability of the surface and they seem to be successful with many top-flight UK sports venues to accommodate the large number of fixtures and short pitch recovery times.

Rugby players are developing greater body mass, and trends also show them being taller and younger as the game has progressed [1]. An estimate for an upper limit of rugby player mass was reported as approximately 110 kg [1]. When the turf is subjected to the high-sustained forces players can apply through their studded footwear, sudden failure of the turf can be observed (Fig. 1.b). Sustained forces are present in the scrum where players combine to create very high horizontal pushing forces of up to 8.3 kN over periods of several seconds [2,3].

The instability of the turf under high shear forces could be induced by a number of factors; these factors may include high moisture, poor grass coverage/health and shallow root establishment. Moisture content in clay soils is more critical to behavior and has a larger effective range compared with sandy soils. Clays retain more moisture and are more susceptible to plastic deformation under load as they become saturated; sand drains water more quickly and relies on inter-particle friction for shear strength. The grass roots help hold the soil together and reinforce it, and it has been shown that roots can improve shear resistance by up to 300% [4]. Therefore, having a full coverage of grass throughout the field with a deep healthy root will aid against shearing of the turf.

It was hypothesized from detailed discussions with specialist sports pitch agronomists and groundsmen that when shear instability occurs the failure zone(s) is typically within the top 100 mm (Fig. 1.a), often where there is a distinct change in the soil properties (e.g. texture, moisture). The depth of the failure zone was considered to be variable in their experience, as a consequence of variations in the construction profile and also the state of the turf–soil system. A related previous study had suggested a rationale for two distinct failure zones [5]: a shallower one in the sward and a deeper one in the sub-soil.

Figure 1. (a) Soil Profile with Distinct Soil Variation (b) Rotational Traction device (RTD) irregular catastrophic failure of sand top-dressed natural pitch (c) Soil profiles: (left) Desso Grassmaster system with synthetic fibres through structure; (right) Sand top dressed natural soil pitch with agglomerated sand in it's structure

At present, there are no specific performance test methods aimed at detecting the potential shear instability of a sports pitch. Several performance test devices have previously been investigated and shown to provide some link to pitch shear stability but none has been routinely utilized in the industry. One such test method, the Going Stick, was successfully developed specifically to assess horse racing track quality or 'going'. A 100 mm long and 21 mm wide plate is inserted into the soil manually and the penetration and resistance to rotation (shear) is measured. It was trialled as a possible tool for sports pitches and assessed against the Clegg impact hammer (CIH) and Rotational Traction device (RTD) [6] on clayey soil based pitch constructions. The CIH measures the impact hardness (via peak deceleration) of the surface using a 2.25 kg mass dropped at a set height (0.45 m). The RTD is a weighted (40 kg) studded disk that is placed on the ground and rotated to record the peak resistance (torque) (Fig. 2.b). The Going Stick penetration resistance showed some correlation with the CIH, and for shear with the RTD torque also. However, a further study [5] evaluated the Going Stick across a wider range of pitch construction types, including natural soil based (Fig. 1.c), Desso Grassmaster (Fig. 1.c), Mottz and Fibresand. The study concluded that the Going Stick was sensitive to variations in shear stability of natural soil constructions, but it showed poor sensitivity or repeatability and less applicability on pitch constructions that utilize a large proportion of sand or reinforcement (hybrid) – and these latter systems are popular for their durability. Clay soils under low normal stress can generate shear strength from suction in the pore water/air interface, and show similar strength whether confined further or not. However, sand as a frictional material reacts differently: when unconfined under low normal stress it can be sheared relatively easily but, when confined, particle friction and resistance to dilation can mobilise much larger resistance to shear. The

Going Stick provides no confinement and consequently measured unexpectedly low shear resistance in high sand content soils. The shear resistance in the sandier soils under a Rugby player is considered to increase though the vertical forces/stresses applied, thus suggesting a need to manufacture a mechanical device that could simulate the rugby related performance more closely.

2. Methodology

2.1. Design of the shear tester prototype and data collection

The prototype shear tester (Fig. 2.a) was developed to include the important factors of how the turf might fail under rugby related player loading. The design was aimed at a simple mechanical test to measure stability up to a depth of 100 mm, be portable, and utilize the operator's mass to create the required confinement in the failure zone (110 kg ideally over a suitable area). It also needed to be easy to use and interpret, and be readily modifiable if required after initial trials.

The prototype works by a simple lever arm principle to rotate a pin through the soil to assess the shear resistance. The initial angle of the arm is set at 52° from the horizontal. Two pin lengths are used, 50 mm and 100 mm, both cylindrical 20 mm in diameter and with a curved 5 mm radius at the base, resembling a (long) rugby stud. The pins are hammered vertically into the ground before the lever arm is released, applying a static force. The two pins lengths were selected to allow investigation of shear stability at depths up to 100 mm.

The lever arm (Fig. 2) transmits a force to the pin, through mechanical advantage, to attempt to fail the turf. The arm has a mass of 11 kg, and further mass can be added in 5 kg increments at a distance of 0.5 m from the pivot point. The arm is initially supported in the start position (52° to horizontal) by a simple (yellow) latch, which is manually pulled to release the arm. As the force is placed on the pin the soil either offers enough resistance to keep the pin stationary or it starts to yield and the pin moves. If there is no yield in the soil when the arm is released then the test is reset at another point and further mass is applied until failure is observed or mass limit is reached. This pin rotation mechanism aims to represent the rotational movement of a player's forefoot stud during a scrummage. As the player pushes forward, they rotate their foot lifting their heel and applying more force to the front foot. The bend of a player's foot is never greater than 27° [7]. Studies on maximum horizontal pushing force (8.3 kN)[2] suggested a resultant force of 1.04 kN per player applied into the surface.

When falling from 52°, a soil failure was indicated by an angle greater than 27°. This was used because of the physical range of a player and the visual plastic deformity observed in soils trials over this value. Prior to this, the ground was visually unchanged. During failure, a potentiometer measured the angle and the time or rotation (see Fig. 2.b), it was translated into a gradient representing rotation rate for further analysis. The angle and time of failure show a variety of modes of failure during testing. These were defined by the failure speed. Speed was categorized as either 'rapid failure', which quickly reached failure, or 'slow failure', which had some hesitation in reaching failure. Hesitation was likely caused by soil strength, root growth or synthetic structures in hybrids pitches.

The base plate area in contact with the surface was 0.177 m^2. The contact stress is 6 kPa when the operator stands on the base plate, a mass of 110 kg/1079 N is attained. This represents the common weight of the heavier English rugby premier league player [1]. This area of stress may be less than a rugby player would create, but it allows weight to be applied to the device through the technician's feet, without encroaching on the mechanism.

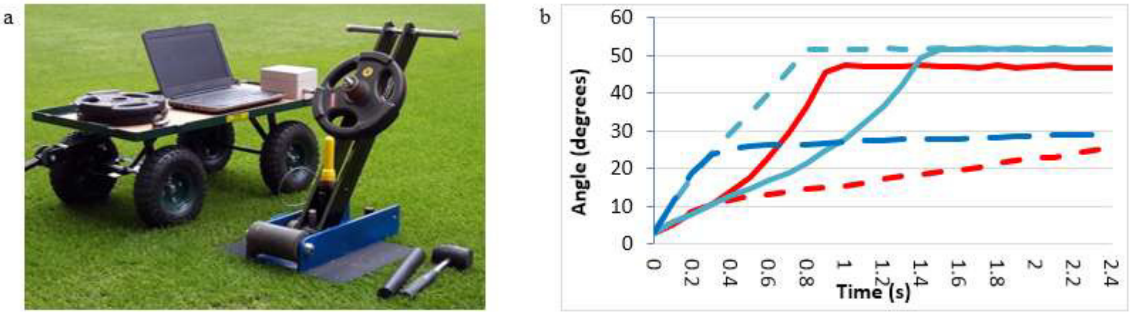

Figure 2. (a) Shear Tester (b) Time vs Angle Shear Tester Graph Example

2.2. Overview of Scoreplay System

Scoreplay is a system created by Labosport International Ltd. It determines an overall score to represent a measure of the 'quality' of natural and hybrid pitches. A combination of agronomy tests (measuring turf health and physical properties) and sports play performance tests (measuring grip and ball bounce, for example) are used to create a percentage rating for pitch quality. Pitches that scored above 85% were rated as excellent quality, between 70 and 75% were rated as good, between 60 and 70% rated as requiring attention and a score below 60% rated as requiring urgent attention. The system was developed to provide feedback to the groundsmen of the match and training venues for the Rugby World Cup (RWC) in England, and involved site visits for a period of 1 year before the competition on hybrid and natural systems. The Scoreplay percentages were compared with the results from the shear tester, with the intention that the outcome might help inform the development of a pitch rating score from the shear tester. In addition, the shear tester results were compared in more detail with those collected from the CIH (hardness measure) and the RTD (peak shear related resistance to studded disc).

3. Results

3.1. Table of Results

Table 1 presents a summary of the results for the shear tester. Each of the 13 pitches tested (10 natural and 3 hybrid) had three positions tested with both the pins. The Table's failure mass represents the positions of failure during testing. The percentage of failures demonstrates the proportion of pitches that succumbed to failure. Gradients indicate fast (lowest) and slow (highest) failures. The natural soil based and hybrid systems percentiles were separated to show any differences in their stability.

Table 1. Pitch Shear Failures

Pitch Type	Pin Length	Failure Mass (kg)	% Of Failures	Lowest Gradient	Highest Gradient
Natural Soil Based Systems	50 mm	11	90%	0.342	1.301
		16	10%	0.24	1.348
	100 mm	26	3.5%	1.550	
		36	3.5%	2.380	
		41	10%	0.787	1.882
		56	3.5%	1.308	
		>56	80%	n/a	n/a
Hybrid Systems	50 mm	11	11%	0.788	
		16	45%	0.17	1.334
		21	33 %	0.692	0.84
		26	11%	0.693	
	100 mm	41	11%	1.247	
		51	11%	0.640	
		56	22 %	0.336	0.493
		>56	56%	n/a	n/a

3.2. Pitch rankings

The results obtained from each pitch construction type, soil-based natural (N) and hybrid (H), were compiled into a ranking system (Table 2). The Scoreplay system is presented in percentile scores with the 50 mm and 100 mm pins scores placed in rank. Pitches with the same ranking scored at the same level.

Table 2. Pitch Rankings – comparing the Scoreplay rating with the Shear Tester Prototype

Pitch Type	Scoreplay (%)	50 mm Pin	100 mm Pin
N	97	9	12
H	96	2	11
N	96	8	1
N	94	3	1
N	93	5	1
N	92	6	1
N	92	7	10
N	92	10	1
N	91	11	1
H	90	4	1
H	90	1	1
N	82	12	13
N	68	13	14

3.3. Shear tester relationship to current performance tests

The shear tester results were further compared against the results from the CIH and RTD (as shown in Fig. 3). The Figures show that there appears to be little relationship between the CIH (peak deceleration in g) and the RTD peak torque, for either the 50 mm or the 100 mm pins for the natural or hybrid systems. The best relationship of those selected was the 100 mm pin compared against the CIH

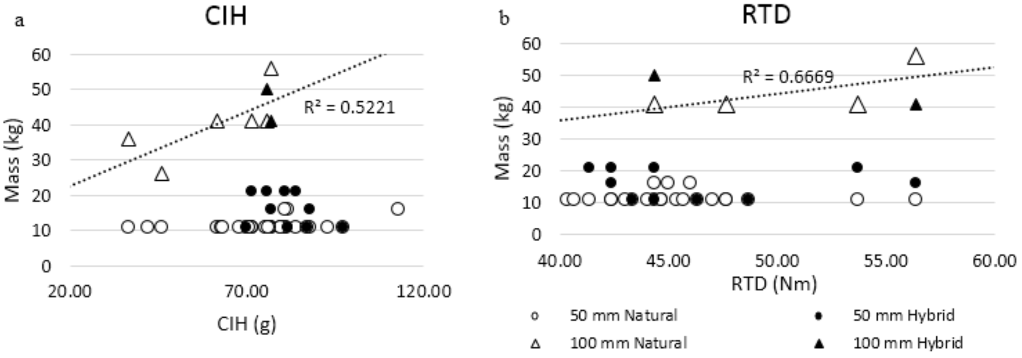

Figure 3. (a) Clegg Impact Hammer (CIH) peak g vs Shear Tester (b) Rotational Traction (RTD) torque vs Shear Tester

4. Discussion

4.1. Prototype success in determining turf stability

The shear tester prototype presented here is an initial attempt at the analysis of a sport turf's shear failure behaviour. The shear resistance was assessed by applying a rotational force to a pin to pushing it through the turf system at a set depth of 50 mm or 100 mm. The key objective was to create a method that could accurately measure the differences in shear stability of different varieties (natural, hybrid) of sports turf. In addition, the prototype's repeatability, practicality, portability and user friendliness were all-important traits also evaluated to ensure the final product would be successful.

The results from each of the pitches given in Table 1 identified a number of outcomes for the assessment of the pitch's construction with the shear tester. It identified that the hybrid systems could survive larger applied mass with both the 50 mm and 100 mm pin. This was as expected because of the inclusion of the synthetic structures designed to reinforce the soil, stabilizing it more than grass alone. These hybrid pitches have been introduced into many top level stadia as they support the soil and poorly established grass which tends to grow in this scenario. Although some hybrid systems failed with the 50 mm pin at the lowest arm mass available, this minority was at a 'slow' failure, which was minimal compared with the 90% failure of natural soil based pitches that failed at a 'rapid' rate at the same level. The hybrid pitch that failed at low mass experienced water-saturated conditions during testing. The 100 mm pin showed a large majority of trials that did not fail with the available mass. However, the natural soil pitches had a higher number of failures at lower masses than the hybrid systems. This indicates that the Desso Grassmaster and the Mottz system are effective in supporting the soil strength and are less sensitive to the variation in the weather conditions present than the natural clay systems.

Table 1 shows the low and highest gradients, indicating that the failure rates of the turf did not demonstrate any clear variations as mass increased. Natural clay pitches are all near-unique in their construction and are inconsistent because of fluctuating moisture content. The database of pitches would have benefited from a more sensitive range of masses applied to the soil when using the 50 mm pin and greater mass applied when using the 100 mm pin. This would better indicate variation in each pitch and their failure gradients. It would also aid in better determining the factors (i.e. moisture, grass depth, soil texture) that may play a part in the soils shear strength.

The rankings produced in Table 2 suggested only a loose relationship between the two pins and the Scoreplay system. This relationship was most noticeable with the lower Table results. When small margins existed between the Scoreplay percentages (the natural soil pitches of excellent quality), the results were ambiguous with no clear comparison to the shear tester. As most of the pitches were of a similar (excellent) quality this was a hindrance in getting a fully reflective study for the whole range of pitch stability. The fact that only three different hybrid systems were measured compared with ten natural soil-based systems implies that more hybrid fields should be tested. Another key issue is that the shear tester found that the hybrid stadium pitches possessed some of the best stability. This demonstrated that the failure zone can be a problem that is not currently assessed in a quality assessment of the turf. The addition of the shear tester to this study would likely aid in giving the Scoreplay a more reflective answer of the overall pitch quality.

It was noted that after testing was underway that the forces on the pins were different from the predicted range. As stated previously, this was a hindrance in getting sensitive results. However, based on the data achieved from the failure planes, the relationship between the 50 mm pin and the 100 mm pin was considered linear and likely be four times larger.

The relation to other tests methods detailed in Fig. 3 suggest that the CIH showed the best correlation with the shear tester with the 100 mm pin on natural soil pitches. Although mere, the rest of the relationships were poorer with less relation to the 50 mm pin. The CIH is the most relatable, as the properties of clay-based pitches are more dependent on the moisture content. When moisture is low or the clay is compacted then it is harder, requiring more force to shear. The poor relation with the RTD and CIH is a positive factor as it suggests that the shear tester is measuring a property that is currently not collected by performance tests. The shear tester's use could increase the reliability of the Scoreplay system's ability to predict quality. Hybrid systems are currently the gold standard for stability: the Scoreplay system currently undermines this.

The overall mass applied to the surface is 110 kg with the weight of technician and shear tester. The amount of pressure currently applied to the surface is low at 6 kPa. This is a small pressure and although it did show variations in confining and unconfined soil, it should be more reflective of a player's impact on the soil.

4.2. Concept Improvements

The prototype was developed to provide indication of shear stability of pitches. It was designed with simplicity in mind as little was known about the apparent failure zone. This initial testing indicated a number of factors that could be improved in the prototype to produce more precise readings, which are more representative of sporting performance. The main alteration required is the mass of the arm. Weight/mass reduction is needed in order to give sensitivity of failure with the 50 mm pin, while the 100 mm pin requires greater mass on the arm to fully fail soils. Different arms might be used for the two pin lengths.

Another factor that should be considered is decreasing the size of area of the plate on the surface in order to generate a more realistic contact pressure. This modification will reflect the stability more effectively of that applied by a player during a game. In order for this to take place, the prototype needs to be modified to have an area similar to a players two feet (UK average foot size), an area of roughly 0.062 m^2 supporting the 110 kg load.

5. Conclusion

5.1. Findings

The key findings from the study were that the hybrid constructions had a greater stability than natural sports pitches. This was expected because of the addition of synthetic fibres supporting the soil and grass. The shear tester could detect the most stable pitches at 50 mm (with the 50 mm pin) and the poorer pitches at 100 mm (with the 100 mm pin). The shear tester results showed limited relation to the Scoreplay, but this was only evident when there were noticeable differences. The shear tester results also showed a minor relation to the CIH and poorer correlation to the current RTD, suggesting it displayed properties not assessed by current array of performance tests.

5.2. Next Steps

Future works involve laboratory testing the shear tester in controlled soil samples to calibrate the current prototype. Once complete, the prototype can be redesigned to reduce arm weight and provide means of applying more force to the soil. In addition, the footplate area in contact with the ground will be reduced in order reflect more accurately the pressures a player's foot generates. Further field-testing of natural and hybrid systems will be undertaken of pitches of known or expected quality.

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