Investigation of Equestrian Arena Surface Properties and Rider Preferences

by

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A synthetic surface with inconsistent mechanical properties is considered to be a risk factor for injury in horses. Research has been carried out involving the use of surface testing equipment predominantly on race tracks to improve knowledge on surface properties that are implicated in a higher risk of injury. The preference of the rider is also an important consideration and has previously affected the choice of surface. The study investigated the effect of moisture, compaction and drainage on different equine arena sand and fibre surfaces and also the preferences of riders regarding surface properties. A Biomechanical Hoof Tester (maximum load, load rate, range of horizontal acceleration, vertical deceleration, shear modulus and hysteresis), Clegg Hammer (hardness) and Torque Wrench (traction) were used as a suite of mechanical tests to investigate the effects of three different moisture levels (6.83 ± 1.01%, 17.45 ± 0.76%, 21.19 ± 0.9%) and three different surface densities (1.624±0.008 g/cm^3, 1.690±0.016 g/cm^3, 1.705±0.019 g/cm^3) on four equine sand and fibre arena surfaces. In order to test numerous surfaces under the same controlled conditions, eight test boxes (L100cm x W98cm x D20cm) were made, where four surfaces were laid on gravel and four laid on permavoid units, an innovative drainage system. The responses of riders regarding preferred amount of traction and 'way of going' were established using a survey. Traction significantly increased ($P<0.001$) with increasing moisture level however, was not affected by the compaction treatments or drainage type. Hardness and hysteresis were significantly ($P<0.001$) higher at a low moisture content and vertical deceleration was significantly ($P<0.001$) higher at a low and medium moisture content. The surfaces laid on gravel also generated significantly ($P<0.001$) higher values. Maximum load, load rate and shear modulus were significantly ($P<0.001$) lower at a low moisture level. The range of horizontal acceleration was significantly ($P<0.001$) higher when the surfaces had a medium moisture content. The measured variables were significantly ($P<0.001$) higher when the surfaces had a high density except for the shear modulus. The respondents of the survey preferred a 'moderate amount of traction' and a 'firm surface with a bit of give'. The surfaces with a medium (17.45%) to high (21.19%) moisture content when laid on permavoid had the most favourable results when taking into account all of the measured parameters. The low moisture content (6.83%) was associated with a higher energy loss and vertical deceleration on impact with the surface especially when the surfaces had a high density, thereby increasing the risk of injury. The lower maximum loads measured at this moisture content would also have a negative effect on performance. The study has shown that surface properties of different sand and fibre arena surfaces can be altered through not only changing the amount of moisture and compaction but also drainage type and surface composition.

Figures

Plates

Tables

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1.0 LITERATURE REVIEW

1.1 Introduction

Synthetic arena surfaces are widely used throughout the equine industry for training and competition. The surface a horse works on has been documented as a risk factor for injury amongst other variables such as conformation and type of training and discipline (Chateau *et al.*, 2009; Crevier-Denoix *et al.*, 2009; Peterson *et al.*, 2012; Reiser *et al.*, 2000; Riggs, 2010; Robin *et al.*, 2009; Setterbo *et al.*, 2009; Williams *et al.*, 2001). Research on surfaces has been carried out involving the use of horses fitted with devices such as accelerometers and mechanical testing equipment to improve knowledge on how surface properties affect the hoof-surface interaction (Chateau *et al.* 2009; Peterson *et al.*, 2008). The work has predominantly focused on race tracks due to the higher injury rate associated with this discipline (Chateau *et al.* 2009; Peterson *et al.*, 2008; Ratzlaff *et al.*, 1997; Robin *et al.* 2009).

The injuries sustained by three show jumpers at the 2004 Olympic Games in Athens were attributed to the studs used and the resulting surface interaction and has initiated further work on equine arena surfaces. The Fédération Equestre Internationale (FEI) is funding a long term research project led by Dr Lars Roepstorff investigating the influence of surface characteristics on the orthopaedic health of horses (van Weeren, 2010). The published results obtained from different studies have at times been conflicting and inconsistent which is possibly due to differences in experimental design, discipline, analytical approach, injury type and case definitions and therefore further investigations are warranted (Ratzlaff *et al.*, 1997; Setterbo *et al.*, 2011). The development of such research will contribute towards developing an optimal arena surface that combines performance and consistency with safety (Peterson *et al.*, 2012).

1.2 Risk factors for injury

The concern that a surface may be a source of injury in humans arose in the late 1960s when the use of artificial playing surfaces constructed using synthetic or manufactured materials became more popular (Nigg and Yeadon, 1987). The synthetic surfaces were associated with a higher injury rate and negative effects on the locomotor system in comparison with naturally occurring surfaces. The increasing use of artificial surfaces in the equine industry has also been associated with an increase in the occurrence of injuries. Human surfaces have been researched extensively since the work published by Nigg and Yeadon (1987) and a more recent study has shown that injury risks in humans can be reduced and performance enhanced, if training and competition is performed on a suitable surface that meets safety requirements (Swan *et al.*, 2009).

Research conducted on several major racetracks in the United States of America has led to dirt surfaces being replaced with synthetic all weather tracks, which has resulted in a significant reduction in catastrophic breakdown of horses (Peterson *et al.*, 2012; Setterbo *et al.*, 2011). The breakdowns recorded on Arlington race course in the United States of America reduced from 22 in 2006 on a dirt surface to 13 in 2007 when the track had been replaced with a synthetic Polytrack (Liebman, 2007). Synthetic surface properties have shown to be more consistent than dirt in a study by Setterbo *et al.* (2011) which may support why a lower injury rate has been recorded. Dirt surfaces are more dependent on maintenance procedures than synthetic surfaces in relation to keeping the surface properties consistent (Kai *et al.*, 1999; Setterbo *et al.*, 2011). Uneven surfaces with varying moisture content, density and composition result in irregular forces acting upon the horse, which are associated with a greater risk of injury (Kai *et al.*, 1999; Murray *et al.*, 2010a; Ratzlaff *et al.*,1997; Riggs, 2010).

A surface with the ability to remain uniform throughout all climatic conditions is therefore considered essential and an epidemiological study by Murray *et al.* (2010b) suggested a consistent surface appears to have a protective effect against lameness in dressage horses. A sand based surface appeared to be associated with the greatest risk for lameness when used at first and was less prone to cause lameness as the horse continued to work on the surface (Murray *et al.*, 2010a). The reduced risk of injury over a period of time has been attributed to the process of adaptive hypertrophy where the bones and soft tissue within the limbs gradually become conditioned to the interface used. It was of interest however, that Murray *et al.* (2010a) still found at least 77% of British Dressage riders that responded to a survey had a sand based surface. The finding suggests that there are other influential factors when selecting the right arena surface such as finances available which demonstrates that further investigations on controlling and understanding surface properties are warranted.

1.3 Hoof-surface interaction

The equine distal limb is subjected to repetitive shocks and vibrations during the stance phase of locomotion due to rapid deceleration of the limb which transmits shockwaves through the hoof and surrounding structures (Barrey *et al.*, 1991; Chateau *et al.*, 2010; Gustås *et al.*, 2006a). The amplitude of the deceleration peak is partly dependent on the type of surface that the distal limb is colliding with (Gustås *et al.*, 2006a). Large deceleration peaks and high loading rates are experienced within the limb during impact with firm surfaces, which may contribute to subchondral bone damage and increase the risk of injury (Johnston and Back, 2006; Radin 1973; Parkin *et al.*, 2004).

A link between shock and vibration and subchondral bone damage was established by Radin *et al.* (1973) where the knee joints of rabbits stiffened after impulsive loading, which represented changes consistent with degenerative joint disease. Loading has been defined as the vector sum of the external forces and moments acting on a body by Nigg and Yeadon (1987) and more recently, van Weeren (2010) made a similar description of the application of forces to a structure in an equine related research article. The characteristic forces acting on the horse are the ground reaction forces, which are generated by the locomotion activity in combination with the forces exerted by the surface (Brosnan *et al.*, 2009). The ground reaction forces may at times exceed tolerable limits during repetitive loading or directional overloading which will cause micro-trauma and eventually lead to equine musculoskeletal disorders (van Weeren, 2010). The forces and accelerations experienced within the distal limb will also be affected by the point of the stride cycle that the limb is in. A stride cycle consists of a stance phase, followed by a swing phase which can be further subdivided (Figure 1.1, p. 4):

1) Preimpact is the phase immediately before the hoof hits the ground;

2) Impact is the first third of stance during which a ground reaction force is generated which is characterised by prominent peak decelerations and high loading rates (Brosnan *et al.*, 2009; Gustås *et al.*, 2006b). The magnitude of hoof deceleration and ground reaction forces on impact have been found to be significantly affected by the speed at which the horse is travelling (Gustås *et al.*, 2006b; Thomason and Peterson, 2008) and also by the type of surface (Gustås *et al.*, 2006a). The impact can be further divided into primary and secondary impact. The primary impact (Figure 1.1 A) is associated with high accelerations and low forces when the hoof impacts the surface (Thomason and Peterson, 2008). The vertical deceleration is higher than the horizontal deceleration due to the ratio of the forward and downward hoof movement (Gustås *et al.*, 2006b). The horizontal deceleration represents the braking forces of the hoof in order to resist sliding according to Reiser *et al.* (2000). The secondary impact (Figure 1.1 B) is characterised by much higher forces and minimal acceleration when the mass of the horse collides with the leg as it becomes implanted on the ground (Barrey *et al.*, 1991; Thomason and Peterson, 2008);

3) Support (Figure 1.1 C) is initiated when the weight of the body is evenly applied to the leg and the hoof flattens out before continuing to rotate through to the next part of the stance phase (Reiser *et al.*, 2000; Thomason and Peterson, 2008). At this stage, the vertical and horizontal accelerations have diminished and the highest vertical forces are experienced whilst the horizontal forces increase in the latter part of the support phase (Thomason and Peterson, 2008);

4) Breakover or roll over (Figure 1.1 D) occurs when the hoof lifts at the heels and rolls from the ground which causes propulsive forces in the cranial and caudal direction as the horse moves forward (Reiser *et al.*, 2000; Thomason and Peterson, 2008);

5) Post breakover immediately follows where the hoof and digit flex rapidly and forms the start of the swing phase (Thomason and Peterson, 2008).

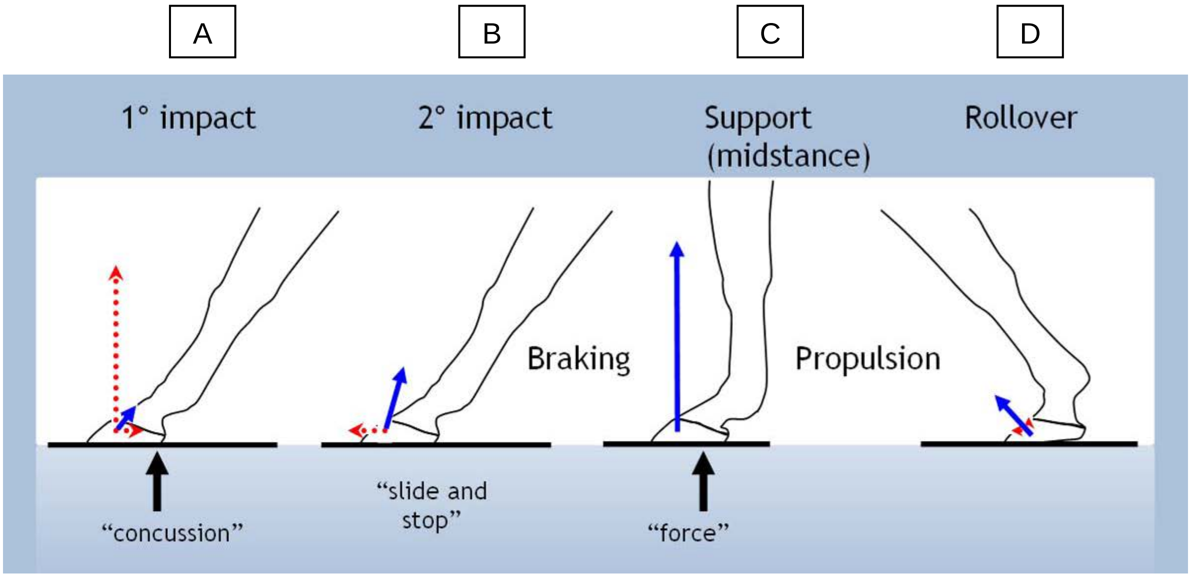

Figure 1.1 Stages of the stance showing the differences in acceleration (red) and ground reaction force (blue) among the stages. When the blue arrow is tilted, it indicates that both vertical and horizontal components of the ground reaction force are present. The arrow shows the direction in which the ground is pushing the horse. Adapted from Peterson *et al.* (2012).

The stance phase appears to be a greater focus in current research when compared to the swing phase. At this stage, the horse will experience high forces and loads that are significantly affected by the surface type and properties (Barrey *et al.*, 1991; Drevemo and Hjertén, 1991; Gustås *et al.*, 2006a; Reiser *et al.,* 2000; Peterson *et al.*, 2008, 2012). The distal limb is structured in such a way so the forces exerted during impact with the ground during natural movement do not exceed tolerable limits.

The physical demands placed on horses whilst being ridden however, can be extensive and the forces may surpass acceptable loads which predisposes the horse to injury.

1.4 Surface types

The surface composition affects the hoof surface interaction and this has been demonstrated by Barrey *et al.* (1991) where impact intensity on a number of different equine surfaces was related to density and composition of the surface. There are many different types of equine surfaces on the market however the manufacture and selection of composition materials have been largely based on empirical evidence and marketing factors (Setterbo *et al.*, 2009). Different surfaces are available for various uses which can be sold as individual components or mixed with additives according to the requirements of the buyer and the intended use of the arena (van Weeren, 2010). The climate is also a major consideration when choosing a surface and variations in the weather throughout the United Kingdom (UK) and across the world means that a surface ideal for one location may be less suitable for another (Riggs, 2010). The base materials used mainly comprise sand, rubber or woodchip (Murray *et al.*, 2010a). The additives can include polypropylene fibres of varying lengths, rubber, fabric pieces and binding polymer which is more commonly referred to as a wax and the entire surface is supported on an engineered foundation or drainage system.

1.4.1 Sand with additives

Arena manufacturers recommend using very fine angular or sub-angular silica sand to provide a firm consolidated surface of approximately 15cm in depth (Andrews Bowen Limited, 2012). Sand, which naturally has low elasticity, is commonly used for arenas and it is thought that the addition of polypropylene fibres and binding polymers adds rebound and reduces compaction (Baker and Richards, 1995; Setterbo *et al.*, 2011).

The use of fibres in a sand based surface appears to have many advantages however, high quality fibres that are dust-free are expensive. The geographical location of the arena may affect the ability to source certain materials and it may only be feasible to utilise surfaces that are locally available. There are many training centres for trotters in France that use sand beaches for training for example due to their close proximity and also because they are considered as good training surfaces specific to competition (Chateau *et al.*, 2010).

The addition of fibres is thought to create a root-like structure and has been shown to increase the stability and drainage of winter games pitches in a study by

Baker and Richards (1995), which is important in areas where there is a high amount of traffic. A synthetic turf surface that contained polypropylene fibre, rubber infill and a shock attenuation pad has also been found to decrease the loading magnitude in certain regions of the foot in comparison to natural grass whilst athletes were playing football (Ford *et al.*, 2006). The change was attributed to the synthetic surface having a lower stiffness and more elasticity than the natural grass, making the synthetic surface a more favourable choice when aiming to reduce the incidence of injuries.

The way in which sand responds to additives is also dependent on particle size, which affects the bulk density, water retention and dustiness of a surface (Barrey *et al.*, 1991). There is currently very limited research on equine sand based surfaces despite the fact that they have been identified as a risk factor for injury (Gustås *et al.*, 2006a; Murray *et al.*, 2010a). Additional studies to educate the industry further on arena construction and reducing the incidence of injury would be extremely valuable.

1.4.2 Other surface types

Rubber and woodchip based surfaces are also in common use within the industry and are usually cheaper to buy than premium sand-based surfaces (Murray *et al.*, 2010a). The high response rate (n=11363) from an arena survey sent to British Dressage members enabled Murray *et al* (2010a) to conclude that 49% of surfaces in use were sand and rubber and 6% were woodchip. The remaining surfaces in use consisted of sand (15%), sand and pvc (13%), wax coated substrate (6%), grass (5%) and the remaining 6% was not specified (Murray *et al.*, 2010a).

The rubber and woodchip can cause problems with the incidence of injury where the consistency of the surfaces reduces if they are not routinely and correctly maintained. The unpredictable surface conditions could negatively influence gait stability and could explain why Murray *et al.* (2010a) suggested that wood chip used as a primary surface increased the occurrence of slipping in horses. A woodchip layer below the primary surface however provides more cushioning by significantly reducing hardness and increasing shock absorbency as found by Drevemo and Hjertén (1991).

1.4.3 Wax

Wax coated sand and fibre surfaces are also offered on the equine market however, this is usually at a premium because the properties allow for long term performance under a variety of conditions (Bridge *et al.*, 2010). Competition centres or arenas in high use often benefit from such a combination. Paraffin wax is commonly used as a binding polymer which has cohesive properties and is usually blended with mineral oil and other additives to stabilise the polymer and optimise melting points and viscosity (Bridge *et al.*, 2010).

The results obtained during the survey by Murray *et al.* (2010a) suggested a waxed surface remains more uniform in a variety of weather conditions than sand and woodchip surfaces and was also thought to contribute to a lower incidence of lameness and injuries. A wax coated surface also required less maintenance to remain stable and suggests that the mechanical properties do not fluctuate as much as an un-waxed surface (Murray *et al.*, 2010a). An all weather waxed track produced more favourable results in comparison to a crushed sand track where loading forces within the distal limb whilst trotting significantly reduced (Chateau *et al.*, 2009; Crevier-Denoix *et al.*, 2009; Robin *et al.*, 2009) Research that will contribute to the development of an affordable surface that remains consistent throughout all weather conditions, when suitably maintained would be a very beneficial addition to the industry (Murray *et al.*, 2010a).

1.4.4 Drainage systems

The drainage is also an essential factor to consider when constructing an arena and will ultimately affect the quality of the footing laid above. An effective system will prevent excess water from gathering and encourage hydraulic conductivity of the substrate which is the ability of the surface to transmit water and therefore drain (Peterson *et al.*, 2010). The surface type and drainage system installed plays a large role on the water holding capacity of a surface where maintaining the correct distribution of air-filled and capillary porosity is essential. Adequate drainage must be installed to ensure the synthetic surface recovers quickly from rainfall however a surface that is too permeable may have a reduced moisture retaining ability during dry periods. The geographical location of the arena is also an important consideration when choosing a drainage system due to the different amounts of rainfall.

Limestone gravel and perforated pipes dug further into the ground are commonly used beneath the surface and a geotextile membrane to aid drainage and more recently specialised drainage systems have been developed such as the Equaflow™ system (Andrews Bowen Limited, 2012) and Ebb and Flow system (Strathoof Managebodems, 2012). The innovative designs allow water to be removed and added to the surface with the use of a storage tank and automatic pump to regulate and maintain the moisture content. The newer drainage systems are costly however and are not widely used at present. The Equaflow™ system was used under the footing at the recent 2012 Olympic Games which may advance its use throughout the industry. Detailed technical guidelines exist on how to construct a sub-base system that is suitable for professional synthetic turf fields (Brock International, 2012). The type of drainage to use within equine arenas has not been substantiated by scientific evidence and is usually installed according to the manufacturer's recommendations.

1.5 Surface Properties

The surface type and drainage system affect the properties of a surface, which will affect the hoof-surface interaction and therefore performance of the horse (Barrett *et al.*, 1997; Burn, 2006; Burn and Usmar, 2005; Ford *et al.*, 2006; Northrop *et al.*, 2012; Peterson *et al.*, 2012). Performance and safety of a substrate represent two of the most important concepts surrounding surfaces and therefore, a combination of properties that creates a surface that is consistent, offers sufficient support to prevent injury and assists in achieving an optimal performance is highly desirable (Baker and Canaway, 1993).

A surface that is considered to assist with an optimal performance of the horse is usually associated with a greater risk of injury whereas a surface that has shock absorbing properties will be of detriment to performance (Chateau *et al.*, 2010; Durá *et al.,* 1999). The balance between safety and performance is highly dependent upon surface properties that relate to variables such as hardness, stiffness, shear resistance, surface density and the ability of the substrate to retain moisture. The mechanical properties have changed under different environmental conditions such as weather and the amount of traffic in studies on human sports surfaces and therefore are an important consideration for equine arena surfaces (Brosnan *et al.*, 2009; Goodall *et al.*, 2005; Spring and Baker, 2006).

1.5.1 Surface hardness

Surface hardness is considered to be a large factor affecting the playing quality of sports surfaces and the risk of injury (Baker *et al.*, 2001; Canaway, 1992; Ford *et al.*, 2006). Surface hardness affects factors such as ball rebound behaviour and player-surface interaction, which has led to extensive studies in order to develop surfaces that provide an optimum performance (Baker *et al.*, 2001; Brosnan *et al.*, 2009; Ford *et al.*, 2006; Goodall *et al.*, 2005; Spring and Baker, 2006). The hardness of a surface is a function of a number of physical properties including stiffness and resilience according to Baker and Canaway (1993) and has been defined by Nigg and Yeadon (1987) as the resistance of a material against penetration of a defined object under defined pressure.

The stiffness of a surface is the ratio of applied force to the amount of deflection of a surface according to Nigg and Yeadon (1987). A material such as concrete would be described as very stiff whereas a surface with low stiffness such as rubber foam would deflect a considerable amount under an applied load and would be considered compliant (Baker and Canaway, 1993). The surface stiffness that is experienced by the horse may vary according to the size and duration of the load. A horse landing after a jump for example would create a much larger load and experience a different hoof-surface interaction in comparison to a Dressage horse performing piaffe that involves a longer stance duration. The resilience is the ratio of the mechanical energy after impact compared to the mechanical energy before impact (Baker and Canaway, 1993; Nigg and Yeadon, 1987). A trampoline for example would be described as a very resilient structure because there is a relatively low amount of energy lost on impact (Baker and Canaway, 1993).

The hardness of a surface has also been identified as a risk factor for injury in horses and consequently, the effects of surface hardness on locomotion of mainly racehorses and trotters has been investigated (Chateau *et al.*, 2009; Ratzlaff *et al.*, 1997). Horses have been instrumented with accelerometers, piezoelectronic transducers and ultrasonic devices to improve understanding on the locomotor forces exerted on different surface types with varying hardness (Chateau *et al.*, 2009; Crevier-Denoix *et al.*, 2009; Ratzlaff *et al.*, 1997; Robin *et al.*, 2009). Only recently, mechanical devices have been used to quantify the effect of arena maintenance on the firmness of a surface (Tranquille *et al.*, 2012; Walker *et al.*, 2012). It is important to develop literature on surface properties measured using testing equipment to provide quantitative baseline data that is not affected by the individual variation of horses.

A softer surface is associated with better shock absorbing characteristics where the forces experienced by the horse are decreased, however it may reduce the efficiency of locomotion (Barret *et al.*, 1997; Chateau *et al.*, 2009). There will be higher demands placed on the musculoskeletal system because the surface is lacking resilience where the ability to absorb the impact mechanical energy is higher (Baker and Canaway, 1993; Brosnan *et al.*, 2009). The propulsion from the elastic energy stored by the tendons within the distal limb will also be lower as a result, which may hasten the onset of muscular fatigue (Barret *et al.*, 1997; Murray *et al.*, 2010a). The effort required from the muscles to achieve the same movement is amplified and consequently increases the risk of injury (Murray *et al.*, 2010a).

The increased effort to sustain the same speed on a more compliant all weather waxed track was reflected in results obtained by a research group from D'Alfort

Veterinary School, France when compared to a crushed sand track (Chateau *et al.*, 2009, 2010; Crevier-Denoix *et al.*, 2009; Robin *et al.*, 2009). A decrease in stride length and an increase in stride frequency were reported in the trotters used. A study by Setterbo *et al.* (2009) conversely found no significant difference between stride frequency and speed whilst investigating ground reaction forces on different surfaces including dirt, synthetic and turf tracks. The sample sizes used for all the studies were small, which may explain the different findings. The surface types used also differed, suggesting that further investigations are warranted on different surfaces being measured under the same conditions.

The shock absorbing characteristics of a compliant surface may also protect the horse from injury. The loads and forces experienced when the distal limb impacts a yielding surface are modulated by spreading the collision over the longest period of time as possible instead of being a nearly instantaneous event (Chateau *et al.*, 2010; Dunlop, 2000; Thomason and Peterson, 2008; Setterbo *et al.*, 2011). The ground reaction forces are consequently reduced. The sequencing of the leg motions in the different gaits and the anatomic adaptations of the horse also increases the time of collision which reduces mechanical stress (Dunlop, 2000; Thomason and Peterson, 2008).

The locomotion of trotters have been documented by Chateau *et al.* (2009) where an all-weather waxed track demonstrated better shock absorbing characteristics when compared with a crushed-sand track. The stance duration was the same on both surfaces however the maximum impact force was experienced sooner on the crushed sand track. Impact forces are forces which reach their maximal magnitude less than 50 milliseconds after first contact with the surface in humans, which demonstrates how quickly the horse is required to dampen the forces (Nigg and Yeadon, 1987). A study on humans by Mcmahon and Greene (1979) however, observed a longer ground contact time on softer surfaces which consequently reduced running speed. The impact time in a small sample of horses (n=4) during a more recent study was also significantly higher on an uncompacted dry sand surface in comparison to wet sand which demonstrates that the load is spread out over a longer period of time (Chateau *et al.*, 2010). The degree of surface compaction appears to be a factor affecting the results between the studies and necessitates further research.

The timing between deformation of the surface under load and when the load is removed is critical and if it is too soon, it will represent additional forces that must be dissipated by the limbs (Ratzlaff *et al.*, 1997). Deceleration of the equine limb during impact is affected by surface type and the amount of deformation. Deceleration on an all weather waxed track was more progressive and significantly reduced by approximately 50% when compared to crushed sand (Chateau *et al.*, 2009). The findings obtained by Crevier-Denoix *et al.* (2009) demonstrated the maximal tendon force and maximal longitudinal braking force also significantly reduced on a waxed track in comparison to a crushed sand track. The soft tissues of the limb will not have been required to dampen as many vibrations on the all weather waxed surface which could explain the lower forces observed. Maximum forces, load rates, maximum accelerations, and tendon forces were also lower for synthetic racing surfaces than traditional dirt surfaces, indicating that engineered surfaces have potential for injury reduction (Setterbo *et al.*, 2009, 2011).

1.5.2 Shear resistance

Shear resistance or traction relates to the frictional forces that are generated in the horizontal plane when the limb impacts the surface. Friction has been described by Medoff (1995) as a combination of mechanical interlocking and adhesion between two interfaces. It is necessary for the horse to apply shear stress to the surface in order to produce traction and therefore a propulsive movement. The cohesive properties of the surface that are affected by other factors such as wax or moisture content will determine the amount of torque or rotational force that the horse will experience whilst travelling on the surface and may create a risk factor for injury (Baker and Firth, 2002; Brosnan *et al.*, 2009; Goodall *et al.*, 2005).

Hoof slip of the leading limb on jump landing, a parameter that is affected by the shear characteristics of a surface has been investigated by Orlande *et al.* (2012) on two arena surfaces with different wax contents (3% and 10%). The higher wax content significantly reduced hoof slip and this was also supported with higher traction values. The surface with 10% wax was considered to be more consistent however and there was also less variation in the jumping technique observed between the horses used (Orlande *et al.*, 2012). Higher friction between the hoof and ground has shown to increase the impact shock, resulting in higher mechanical stress and risk of injury (Gustås *et al.*, 2006a). The degree of traction required to achieve various movements such as turning at speed for show jumping or the pirouette in dressage without being of detriment to the horse has not been reported. The demands being placed on the musculoskeletal system differ according to the discipline of the horse and the amount of traction required may vary which makes it difficult to quantify.

A lower shear resistance could account for the reduced locomotion efficiency observed in horses on an all weather waxed surface compared to a crushed sand track during recent studies (Chateau *et al.*, 2009, 2010; Crevier-Denoix *et al.*, 2009; Robin *et al.*, 2009). The all weather surface was associated with lower forces and decelerations in the horizontal plane which suggests that the crushed sand track may have been firmer and provided more traction. It is possible to reinforce this claim further where Gustås *et al.* (2006a) states that higher friction increases the shockwaves that transmit through the distal limb. A significantly shorter braking duration on the crushed sand surface in comparison to the all weather waxed track could also support the higher amount of shear resistance that the surface offered.

To minimise the effects of the surface properties on the locomotor stresses of the horse, the properties should have low impact forces and accelerations in the horizontal and vertical planes and a relatively low amount of energy lost on impact (Ratzlaff *et al.*, 1997). The impact resistance or hardness of a surface is generally negatively correlated with energy loss when the hoof impacts the surface however, which may prove to be challenging during the selection of a surface. It has also been reported by Setterbo *et al.* (2011) that an ideal, safe surface should have a relatively low energy loss along with low hardness which is correlated with deceleration and is difficult to achieve. The synthetic racing surface used in the study by Setterbo *et al.* (2011) appeared to have both of these qualities however when the surface was under a certain level of compaction.

1.5.3 Surface density

A study by Brosnan *et al.* (2009) investigated the effects of compaction on the hardness and traction of a baseball playing surface. A quadratic relationship was reported by Brosnan *et al.* (2009) where greater compaction yielded increases in surface hardness and traction. Traction values represent the peak amount of horizontal force required to initiate movement (Baker and Canaway, 1993; Brosnan *et al.*, 2009). Baker *et al.* (1998) found increases in surface hardness on cricket pitches to be a function of increased soil bulk density, which is defined as the surface mass per unit volume and rises with a higher amount of compaction. Rotational traction measured by Baker *et al.* (1998) was also significantly affected by soil density, which may be due to differences in the size of the air spaces between the surface particles and therefore the degree of shear resistance. The surface density will also be affected by the amount of traffic working over the surface and a suitable maintenance regime should be used to loosen the top surface layer in order to prevent undesirable amounts of compaction.

The presence of organic matter has been found to strongly influence bulk density in a study by Baker *et al.* (1998) and Saffih-Hdadi *et al.* (2009) found organic matter reduced bulk density and consequently the ability of the soil to compact. A similar effect may be expected with the addition of fibres or other additives to a sand based equine surface however this has not been documented. Plastic fibres are commonly added to the soil of many professional football pitches in order to stabilise and strengthen the rootzone (Spring and Baker, 2006).

The addition of polypropylene and polyurethane fibres to a sand and turf football surface has been examined by Spring and Baker (2006) where turf strength had a positive correlation with the amount of fibres added and this was reflected in higher traction values. There was no reference to the amount of surface compaction however. Hardness was found to significantly reduce with an increase in fibre content and possibly demonstrates a lower bulk density according to the findings of Brosnan *et al.* (2009). The surfaces studied by Spring and Baker (2006) and Brosnan *et al.* (2009) were different along with the apparatus used to measure the traction which will have affected the traction values recorded. The results obtained by Saffih-Hdadi *et al* (2009) suggested the susceptibility of a range of soil types to compaction was also found to be affected by moisture content.

1.5.4 Surface Moisture Content

The moisture content of a substrate is considered to be the most important variable to measure because it strongly influences other surface properties (Goodall *et al.*, 2005; Peterson *et al.*, 2008). A level of increase in moisture content improves particle adherence and consequently shear resistance, which provides more stability (Chateau *et al.*, 2010; Murray *et al.*, 2010a; Ratzlaff *et al.*, 1997). There is very limited research on particle adherence when a surface has been saturated, which is when the pore spaces between the particles cannot absorb any more water. A high correlation was found between impact force and moisture content on a race track studied by Ratzlaff *et al.* (1997), which was predominantly medium to very course sand. The outcome suggests that a low (4%) and high (12%) moisture content could be detrimental in terms of injury because these values were associated with higher forces. The mean and peak impact force in the horizontal and vertical planes has been found to be significantly higher on wet beach sand (19%) in comparison to uncompacted, dry beach sand (3%) by Chateau *et al.* (2010), which only support some of the findings of Ratzlaff *et al.* (1997).

A study by Brosnan *et al.* (2009) found conflicting information where a reduction in moisture content was related to an increase in surface hardness of a non-turfed basepath, which is considered to generate higher forces and possibly supports why higher forces were recorded by Ratzlaff *et al.* (1997) at lower moisture contents. The relative density was high when the observations were made by Brosnan *et al.* (2009) and the high hardness values could be explained by an increase in density reducing surface porosity and increasing the particle strength, which decreases soil water infiltration and holding capacity (Saffih-Hdadi *et al.,* 2009). The hardness of skinned infield plots consisting of crushed rock has also been found to be negatively correlated with moisture content by Goodall *et al.* (2005). The water content for the optimum performance of sand surfaces has been suggested to be between 8% and 17% and alterations in this will affect other parameters such as hardness and shear resistance of the surface (Barrey *et al.*, 1991; Ratzlaff *et al.*, 1997). A small variation (5.5%) in moisture content between two beach sand tracks that were used in a study by Chateau *et al.* (2010) was sufficient to cause a significant difference between the peak vertical deceleration at the onset of the stance phase.

The current literature relating to the effects of moisture and surface density on surface properties needs to be strengthened by performing further experiments under field conditions on equine surfaces commonly in use (Chateau *et al.*, 2010). A greater understanding would be gained on possible combinations of moisture and relative density that may be of detriment to the horse in terms of injury and performance. The findings would also inform arena construction and management practices in order to avoid surface properties considered to be unfavourable.

1.6 Current Guidelines

Sports associations have begun to develop safety policies in relation to the suitability and safety of the playing surfaces (Swan *et al.*, 2009). The use of a ground safety checklist for human sports is a mandatory requirement of insurers where factors such as intended use of the surface, frequency of use, unevenness, debris, surface hardness and traction are taken into consideration (Swan *et al.*, 2009). Sports including football, cricket and hockey utilise the checklist because the governing bodies have a duty of care for the health and safety of participants (Swan *et al.*, 2009). Sports hall floors, running tracks, tennis courts, and gymnastic crash mats are more examples of surfaces that are required to exceed minimum shock attenuation criteria established by sports governing bodies and other agencies (Shorten and Himmelsbach, 2002).

Sporting bodies such as the International Association of Athletics Federations (IAAF), Union of European Football Associations (UEFA) and International Hockey Federation (FIH) have laid down specifications for the resilience of playing surfaces. The testing methods in use include the Berlin Athlete and the Stuttgart Athlete which are widely used to determine safety standards for playground surfaces and floors. The standard artificial Berlin Athlete simulates the impact of an 80-90kg person doing a vertical jump and has been accepted as the best practical solution for measuring the shock absorbing properties of a sports surface (Durá *et al.*, 1999). The Stuttgart Athlete was found to be the most precise and accurate method to provide information on the deformation of a surface by Dunlop (2000). A peak deceleration test is another procedure used by many sports governing bodies where the peak value is used to determine the shock absorption of surfaces in relation to the comfort and safety of users (Carré and Haake, 2004).

The Clegg Hammer is commonly used to assess peak deceleration and has been used to assess the hardness of playing surfaces, which is considered to be a good indicator of playing performance and construction profiles (Baker *et al.*, 2001). The most common practice is to establish a minimum strength requirement in terms of Clegg Impact Value (CIV) for specified moisture contents in order to create a single value acceptance/rejection criterion (Clegg, 2012). Studded boot apparatus is also widely used to provide information on the traction of a playing surface because it affects the ability of the player to change direction (Fifa, 2009). There are published performance requirements for games pitches where preferred and acceptable ranges of traction and clegg impact values inform current management regimes for football, rugby and hockey (Baker *et al.*, 2007; Fifa, 2009). The existing standards for the Clegg Hammer were revised by Baker *et al.* (2007) using a different drop mass. The CIVs obtained from a heavier Clegg Hammer mass of 2.25kg was subject to less variation than the lighter mass of 0.5kg which was originally used to create the performance standards (Baker *et al.*, 2001, 2007).

The safety policies are yet to expand across equestrian disciplines in the same magnitude that they have throughout human sports. The rules of horse racing regarding surface safety have been altered however in 2009 (British Horseracing Authority, 2012). It is now a compulsory requirement to take several TurfTrax™ Going Stick measurements per mile for each fixture, which are then published alongside the official going description (British Horseracing Authority, 2012). The Going Stick is a device that provides an objective numerical reading on the penetration and shear resistance of the surface. Research on race track surfaces using other testing methods is predominantly being performed in America. A research team led by Professor Mick Peterson have been using high technology equipment to study the mechanical properties of race tracks (Peterson *et al.*, 2008; Peterson and Mcilwraith, 2008). Some of the properties associated with increasing the risk of injury in race horses have consequently been identified, which enables the best management procedures to be followed.

The research on equine surface characteristics is of great significance yet specified guidelines and policies to ensure a safe working environment are not a compulsory prerequisite and the management of surfaces is based on anecdotal manufacturer's recommendations (Setterbo *et al.*, 2009). The Fédération Equestre Internationale (FEI) regulations for equestrian events at the Olympic Games in 2012 stated that horses must only be trained and compete on suitable surfaces which must be "*designed and maintained to reduce factors that could lead to injuries*" (FEI, 2011, pg5). The FEI (2011) also stated that "*particular attention must be paid to the preparation, composition and upkeep of surfaces*". The exact surface composition and preparation to be used for the different disciplines was not clearly defined and the guidelines provided are potentially open to interpretation.

1.6.1 Athlete Preferences

There is controversy at times between what is considered to be a safe surface and the preference of the athlete regarding surface type. A study by Durá *et al.* (1999) involved asking non-elite sportsmen to jump as high as possible from a 42cm height onto surfaces with varying compliance. The shock absorbing capacity recommendation for a multipurpose indoor surface of 51-53% was considered to be too excessive because the athletes felt it had a negative impact on performance (Durá *et al.*, 1999). A harder surface is negatively proportional to an increase in energy loss, which optimises performance however it increases the risk of injury, which is why the guidelines are installed (Ratzlaff *et al.*, 1997).

Horse racing is another example where conflict has arisen between safety and performance of surfaces used (Liebman, 2007). The newer synthetic tracks, which have reduced the incidence of fatalities are associated with fractionally slower race times and maintenance problems and have caused varied opinions on what is considered to be the best surface for racing (Liebman, 2007; Peterson *et al.*, 2012; Setterbo *et al.*, 2009). The show jumpers at the Greenwich test event in 2011 criticised the all-weather wax surface where the softer going appeared to have a negative impact on the performance of some of the horses (Hart, 2011). There is evidence that the demands of riders at elite level are influencing the type of surfaces used for competition (Hart, 2011). The type of surface to use however is not being substantiated by scientific evidence, which poses a challenge when trying to formulate industry guidelines on equine arena construction (Murray *et al.*, 2010a).

The importance of taking the preferences of football players regarding surface compliance into account has been recognised by Baker *et al.* (2007). A player questionnaire is often used prior to a game in order to determine the most relevant performance limits which may improve acceptance of the current guidelines (Baker *et al.*, 2007). The implementation of safety checklists for human sports may be responsible for the significant decrease in the number of injury related insurance claims recently made (Swan *et al.*, 2009). The equine industry must be made aware of the positive impact the safety guidelines have had on the various human sport associations. The development of equine industry standards on surface properties that take into account the preferences of the rider, will ensure consistency among surfaces under a range of conditions, optimise performance and minimise the risk of injury (Setterbo *et al.*, 2009).

1.7 Surface testing

Sport surfaces have been commonly assessed in an objective manner with respect to technical specifications such as thickness and temperature dependency; cost factors including installation and maintenance; sport functional properties such as hardness, traction and performance and; safety considerations such as measures to prevent injury. The latter two are important aspects to test and consider from a biomechanical point of view. The testing of surfaces requires reliable quantitative information describing the biomechanical and mechanical properties of a surface in order for the research to be of significance to the equine industry (Peterson and Mcilwraith, 2008).

There have been major innovations throughout the last decade in the development of surface testing devices, which allow the quantitative assessment of human sport surfaces (Swan *et al.*, 2009). The mechanical devices have only recently been adapted and developed for use on equine surfaces and they remove the need to use horses during the experimental protocol. The delay in this development could explain the absence of industry guidelines regulating the construction of arenas and specifications on the optimal surface type to enhance performance and reduce the risk of injury (Attwood and Barron, 2009; Peterson *et al.*, 2008; Weishaupt, 2010; Wheeler, 2006; White, 2010). The equipment currently in use for human and equine surfaces do have drawbacks however, and do not always simulate the true forces and accelerations experienced by the limbs on impact (Chateau *et al.*, 2009; Peterson and Mcilwraith, 2008; Ratzlaff *et al.*, 1997; Reiser *et al.*, 2000).

A simple hoof impact model devised by Reiser *et al.* (2000) considers only the vertical loading components of the limb and does not take into account the shear forces in the horizontal plane (Peterson *et al.*, 2012). A track testing device has been developed by Ratzlaff *et al.* (1997) to simulate the impact of the equine hoof so that the dynamic surface properties under different moisture levels relating to force, energy return and impact resistance could be identified. The device however, only calculates the forces and accelerations in the vertical plane when the load cell is dropped onto the surface. The results did however, enable Ratzlaff *et al.* (1997) to establish the trend between force and moisture content of the race tracks studied.

1.7.1 The Clegg Hammer

The Clegg Hammer developed by Dr Baden Clegg in the late 1960s is another example of a drop hammer device which is the most widely used method for measuring the hardness of human sports surfaces (Baker *et al.*, 2007; Clegg, 1976, 2012). The Clegg Hammer along with other drop devices such as penetrometers have low load rates and also only take into account the impact resistance of a surface in the vertical plane. The values obtained with the drop devices are still considered to be useful however, in providing information on the cushion layer and compressive forces of the substrate (Baker and Canaway, 1993; Setterbo *et al.,* 2011).

The relationship between the surface hardness of cricket pitches recorded with different Clegg Hammer drop weights (0.5kg vs 2.25kg) and ball rebound has been investigated (Baker *et al.*, 2001). The results suggested that a heavier hammer of 2.25kg should be used or alternatively the drop height increased to increase the energy of impact and therefore reliability of the readings. The apparatus has also proven to be a useful tool at estimating the strength of compacted soils in a study by Kahn *et al.* (1995). The accelerometer which is rigidly fastened to the hammer allows the deceleration versus time curve upon impact with the soil to be determined and provides information regarding the soil strength or stiffness.

1.7.2 The Torque Wrench

A Torque Wrench or traction apparatus is used to provide information on the traction or shear resistance of a surface and has been commonly used to assess human sports surfaces (Brosnan *et al.*, 2009; Canaway and Bell, 1986). Traction alongside hardness is considered to be frequently linked with injury risk and therefore is an important surface property to consider (Canaway and Bell, 1986). The equipment takes into account the forces experienced in the horizontal plane, however it will not provide acceleration data or the impact forces present in the vertical plane. Results obtained with the apparatus can have a high degree of variability according to the conditions under which data was collected which makes comparisons between studies challenging (Twomey *et al.*, 2011). The traction equipment is consequently used in conjunction with other surface testing devices such as the Clegg Hammer to also provide a wider data set on the mechanical properties of the surface (Brosnan *et al.*, 2009).

The testing devices currently in use undoubtedly improve knowledge on how a surface reacts to various conditions and allow repeatable measurements but as mechanical surface testing devices develop, the equipment must accurately simulate the hoof-surface interaction. The need to measure horizontal forces and accelerations with impact devices has been demonstrated by Gustås *et al.* (2001) because the variables are an important factor in the attenuation of the impact. A more predictive model than those used in previous epidemiological studies (Ratzlaff *et al.*, 1997; Reiser *et al.*, 2000) will enhance further understanding on the optimal surface properties for training and competition. There are important aspects that must be incorporated by the model according to van Weeren (2010) which include 1) the surface characteristics being described comprehensively and unequivocally and 2) the surface being measured reliably and accurately.

1.7.3 The Biomechanical Hoof Tester

The drawbacks of the current models and testing equipment were recognised by Peterson *et al.* (2008). A more advanced, specialised system known as the dual-axis synthetic hoof drop hammer or Biomechanical Hoof Tester has consequently been designed. The device has a hoof-shaped impactor that reproduces the hoof acceleration and force on impact in vertical and horizontal directions which provides realistic quantification of the surface properties under a range of conditions (Peterson *et al.*, 2008). The measured parameters are expected to be related to the performance of the horse and the stage at which the synthetic hoof impacts the ground is one of the most critical phases of the gait cycle and considered a risk factor for injury (Peterson *et al.*, 2012).

It is possible to use the Biomechanical Hoof Tester in a realistic competition environment which will improve the use of the tool if the data can provide relevant information on the properties of surfaces used by many riders. The use of such equipment also removes the inherent variability related to horses and improves the reliability of measurements that can be performed in the field or laboratory environment (Chateau *et al.*, 2009; Gustås *et al.*, 2006a, b; Setterbo *et al.*, 2011). Wide variations in acceleration peaks between successive strides within the same trial have been observed in horses of similar body mass and under the same management practices (Barrey *et al.* 1991; Gustås *et al.* 2004, 2006a, b; Ratzlaff *et al.*, 2005).

There are three published studies to date involving the use of the Hoof Tester where the effect of maintenance including harrowing and watering has been assessed on race track and arena surface properties (Peterson and Mcilwraith, 2008; Tranquille *et al.*, 2012; Walker *et al.*, 2012). The equipment does have drawbacks including cost and the initial set up being time consuming however, once testing commences data can be recorded efficiently. The data set for the Biomechanical Hoof Tester must be developed to improve understanding on how different surface properties affect the hoof-surface interaction.

The current literature on equine arena surfaces involved testing pre-established surfaces where there was a lack of control of testing conditions. The absence of a study which characterises the components of a surface is a significant obstacle to improved performance and safety as stated by Peterson *et al.* (2012). Moisture content and arena usage are large factors that appear to affect surface properties based on the findings of current literature. A study investigating the effects of moisture and surface density of equine arena surfaces under controlled conditions using the testing devices discussed would therefore be a valuable contribution to the industry. A study that also considers the preferences of riders regarding surface properties would also be beneficial to inform management practices. The data obtained on the mechanical characteristics of a surface will improve understanding on conditions influencing the equine locomotory system and how properties can be altered according to rider preferences.

1.8 Aims and Objectives

There are two aims of the study:

Aim 1: To measure the effect of moisture, density and drainage on the mechanical properties of four equine sand and fibre arena surfaces.

Objective 1: Surface testing equipment including a Biomechanical Hoof Tester, Clegg Hammer and Torque Wrench were used to measure the response of the surface to a range of treatments. The surfaces were prepared under three different densities, three moisture contents and also on two different sub-bases including gravel and permavoid.

Aim 2: To establish the preferences of riders regarding surface type and preparation.

Objective 2: The preference of riders regarding surface type and properties was determined with the use of a survey. The survey was available to complete at Myerscough College and also online in order to reach a range of riders across the UK.

The alternative hypothesis for the entire study states there will be a significant change in surface properties under different testing conditions and a significant difference between the preferences of riders according to level and discipline.

2.0 MATERIALS AND METHODS

2.0.1 Ethical Considerations and Health and Safety

The study was approved by the ethics committee (reference number: BuSH 057) at University of Central Lancashire and did not require the use of any horses or animals (Appendix I). Risk assessments (Appendix II) were formulated for the use of all the equipment and every effort was made to ensure the working environment was safe with the lowest risk possible to all the researchers involved. The participants of the arena survey remained anonymous and were able to withdraw at anytime.

2.0.2 Study Design

The study was split into two parts according to the aims; a field based (2.1) and questionnaire based study (2.2). A Biomechanical Hoof Tester simulating equine hoof impact, a Clegg Hammer and a Torque Wrench were used to study the effect of three different moisture contents and three different densities levels on dynamic surface properties, which created nine unique treatments to be applied during the field based study (Figure 2.0.1). Experiments were performed on four different surfaces that were reproduced twice to investigate the effects of a traditional drainage system and permavoid units used for the Equaflow drainage system on surface properties.

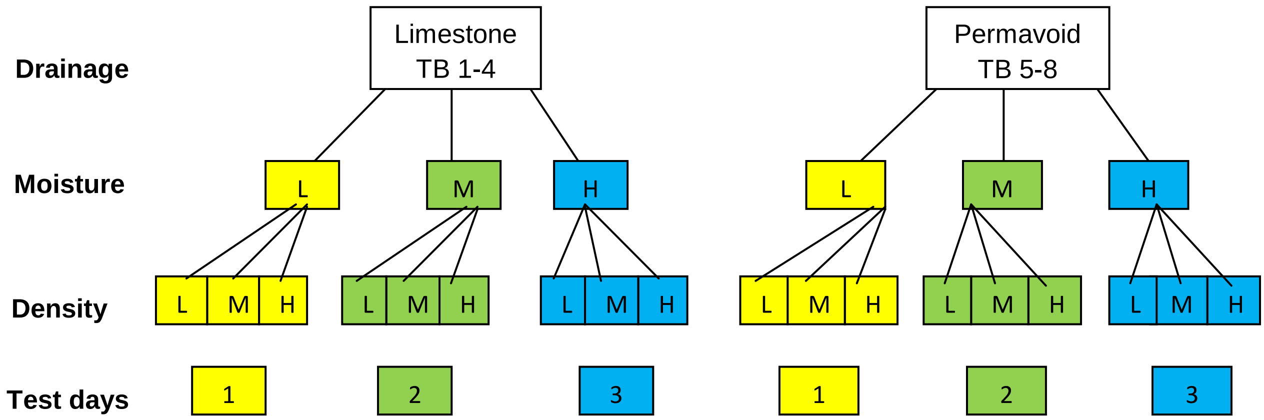

Figure 2.0.1 Study design. L=Low, M=Medium and H=High

The rider preference survey (Appendix III) was constructed for the questionnaire-based study and available to complete online for 11 weeks in order to establish the preferences of riders regarding surface type and preparation.

2.1 Field Based Study

2.1.1 Materials

Synthetic sand and fibre arena surfaces (n=4, 3 waxed and 1 un-waxed) that are currently on the market were used for the study. High quality sub-angular silica sand that is suitable for equestrian use was the main component of all the surfaces and additives included different quantities of polypropylene fibres and binding polymer. A 200g sample of each of the surfaces was separated in order to calculate the composition of the surfaces using the method that has been outlined by Peterson *et al.* (2012) (Appendix IV).

The sand and fibre components were dried in separate pre-weighed trays in the oven at 102˚C for 24 hours after being separated from the binding polymer in order to calculate the moisture content and the actual percentage of sand, fibre and wax. A dried sand sample of 100g was then used to calculate the particle size distribution using the same size sieves as Chivers and Aldous (2003), which included 1mm, 500µm, 355µm, 250µm, 180µm, 150µm, 125µm, 90µm and 63µm.

In order to test a range of surfaces under the same controlled conditions, eight test boxes (L100cm x W98cm x D20cm) were made and situated next to the a research test track at Myerscough College (Plate 2.1.1). The dimensions of the test boxes were selected according to the Boussinesq equation as stated by Das (2008) in order to reduce the boundary effect on the measured parameters. It is expected that the pressure within the surface caused at impact will be less than 2.5% at a horizontal distance that is twice that of the diameter of the impacting device (Das, 2008). The equation assumes circular pressure bulbs under the loaded area and that the surface is elastic however synthetic surfaces are elastoplastic in nature and Setterbo *et al.* (2011) recognised the pressure bulbs on impact are more elliptical where the pressure is concentrated more along the axis of loading. There is little published work surrounding the boundary effects on the values obtained with impact devices and therefore taking the Boussinesq equation into consideration is important.

The surface depth of 15 cm was selected according to the findings of Setterbo *et al.* (2011) where little or no change in the measured parameters would be found if more substrate was to be added. The choice of surface depth is also a recommendation of the manufacturer (Andrews Bowen Limited, 2012). A small Perspex window was installed in the test boxes to allow the researchers to observe any visual changes in the surface properties (Plate 2.1.1). Geotextile membrane was secured to the base of all the test boxes (n=8) prior to installing the surfaces in order to simulate an arena setting.

There were two different types of drainage systems used under the test boxes to determine the effects of hydraulic conductivity on the measured surface properties. The systems included a traditional drainage system, which was situated under test box one to four (Plate 2.1.1), and permavoid units, which were under test box five to eight (Plate 2.1.2). The traditional drainage system consisted of 30mm limestone chipping that had been compacted down with a wacker plate to create a 120mm layer above the levelled earth. A retaining wall was built to prevent the chippings from moving (Plate 2.1.1). The permavoid consists of plastic units with a depth of 85mm and have more commonly been used under pavements to aid drainage (Permavoid Limited, 2012). The units create the main components of an Equaflow™ system and are considered to provide sustainable irrigation and a consistent footing (Permavoid Limited, 2012). The test boxes were filled with 238 kg of the four different types of surface to a depth of 15cm so each surface was prepared in two test boxes to be placed above each of the drainage systems (Table 2.1.1).

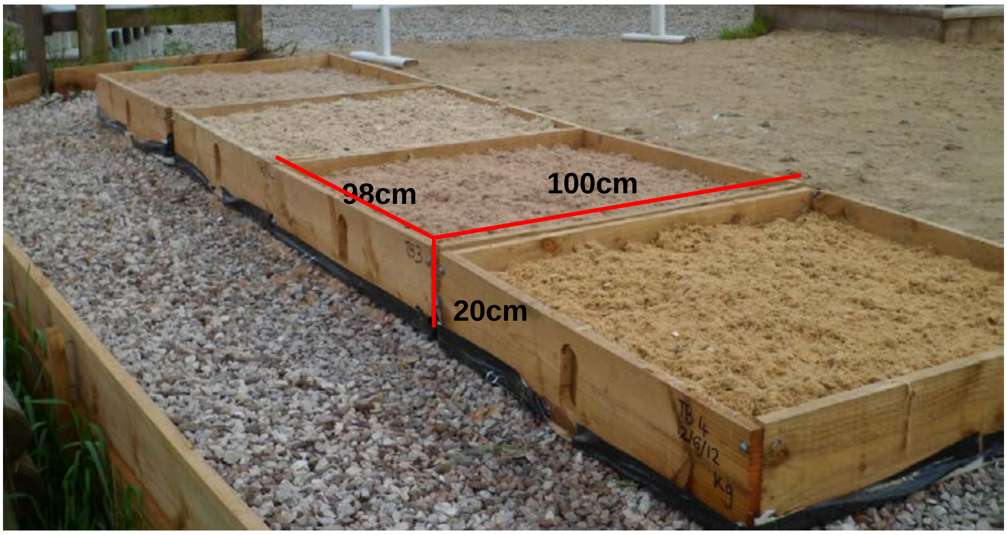

Plate 2.1.1 Test boxes 1-4 situated on top of the limestone chipping. Note the oval Perspex windows installed

Plate 2.1.2 Test boxes 5-8 situated on top of the permavoid units.

Table 2.1.1 Sub-base and surface combinations for the different test boxes.

Test box number	Sub-base and surface combination
1	Gravel, Surface 1 (waxed)
2	Gravel, Surface 2 (un-waxed)
3	Gravel, Surface 3 (waxed)
4	Gravel, Surface 4 (waxed)
5	Permavoid, Surface 1 (waxed)
6	Permavoid, Surface 2 (un-waxed)
7	Permavoid, Surface 3 (waxed)
8	Permavoid, Surface 4 (waxed)

The boxes were filled at 3cm increments, levelled and compacted with an “elephant foot tamper” which is a square weight attached to a long pole to simulate an arena being constructed (Plate 2.1.3). The final 3cm was levelled with a rake but not compacted and this represented the low density in preparation for the protocol to commence. The surfaces were installed and prepared approximately one week prior to the first day of data collection and kept covered with tarpaulin to restrict climatic effects.

Plate 2.1.3 The “elephant foot tamper” being used to compact the first layer of sand.

2.1.2 Developmental and Pilot Work

To validate the use of the surface testing equipment on the test boxes, the suite of mechanical tests were performed on three different equine arenas at Myerscough College prior to data collection. The correct amount of water to add to the surfaces was determined through pilot testing where different volumes of water were added to a surface that had been placed in a test box and was not being used for actual data collection. The volumes were selected in order to achieve three moisture contents that replicated a low, moderate and high amount of moisture. It was important to consider the moisture contents that have been recorded in previous literature which varied from below 1% to above 28% to allow for comparisons (Barrey *et al.*, 1991; Malmgren *et al.*, 1994; Ratzlaff *et al.*, 1997; Setterbo *et al.*, 2011).

To ensure the test boxes were set up correctly, pilot work was carried out during the weeks preceding data collection. The proposed experimental protocol was ran, which helped to refine the procedure and acknowledge any problems that may have been encountered during data collection. To ensure the measurements taken from the test boxes were representational of an actual arena, a similar bulk density to a reference surface was achieved and explains why 238 kg of surface was placed in each box. The bulk density of the reference surface was calculated by digging a hole and measuring the weight of surface and the volume of the hole (Plate 2.1.4). The reference surface was the research test track located at Myerscough College with an up to date waxed sand and fibre that has been used for other published work (Northrop *et al.*, 2012).

Plate 2.1.4 Measuring the bulk density of the reference surface

2.1.3 Experimental Protocol

The moisture content and surface density was controlled throughout the study in order to simulate the effects of climatic rainfall or watering the arena and also the use of the surface respectively. Three test days were allocated for each level of moisture and testing was not performed unless the weather was dry. No water was added on the first day to simulate a low moisture content, ten litres of water were added to each surface on the second test day to replicate moderate moisture and 20 litres of water were added to each surface on the third test day to reproduce a high moisture level. The surfaces were left at least an hour on test day two and three to allow the water to settle and were covered with tarpaulin when possible to reduce the evaporation rate.

The surfaces were prepared with three different densities during each test day to replicate a low, moderate and high amount of traffic on the surface. The surface density is expected to increase with more use. The top 3cm of all the surfaces was raked to replicate a low amount of traffic. The top 3cm layer was compacted down so each area was struck three times with moderate force using the "tamper" to simulate a moderate amount of traffic and five times with maximum force to reproduce a high amount of traffic. The suite of mechanical tests were performed on test box one to four for the different surface densities before moving onto test box five to eight in order to reduce the amount of moisture evaporating throughout the day. A timetable that was used for data collection can be seen in Appendix V.

To quantify the maximum impact force that was being applied to the surface, an accelerometer was rigidly attached to the "tamper" for all of the researchers involved with compacting the surface. The force applied to the surface will have affected the degree of compaction and therefore the results, making it an important factor to consider. Part of the surface was reconstructed before changing the surface density because the weight of the mechanical equipment may have affected the surface properties. The reconstruction involved digging up and re-levelling the top 3cm layer of the surface before the relevant blows were applied to alter the surface density. The test boxes were emptied and re-filled after each test day in order to run the tests again under a different moisture level and to avoid previous testing influencing the results.

2.1.4 Sampling Technique

The Biomechanical Hoof Tester

The Biomechanical Hoof Tester or Dual-axis Synthetic Hoof drop Hammer (Figure 2.1.1 and Plate 2.1.5) was first created by Mick Peterson (University of Maine, Orono) for the progression of racing surfaces research and to improve understanding on the hoof interaction with different racing surfaces. The testing device was replicated by the University of Central Lancashire Engineering department in 2011 and funded by the RACES (Research and Consultancy in Equine Surfaces) team which is a collaboration of Myerscough College, the University of Central Lancashire and Anglia Ruskin University. The RACES team use the device to test equine arena surfaces throughout the United Kingdom (UK).

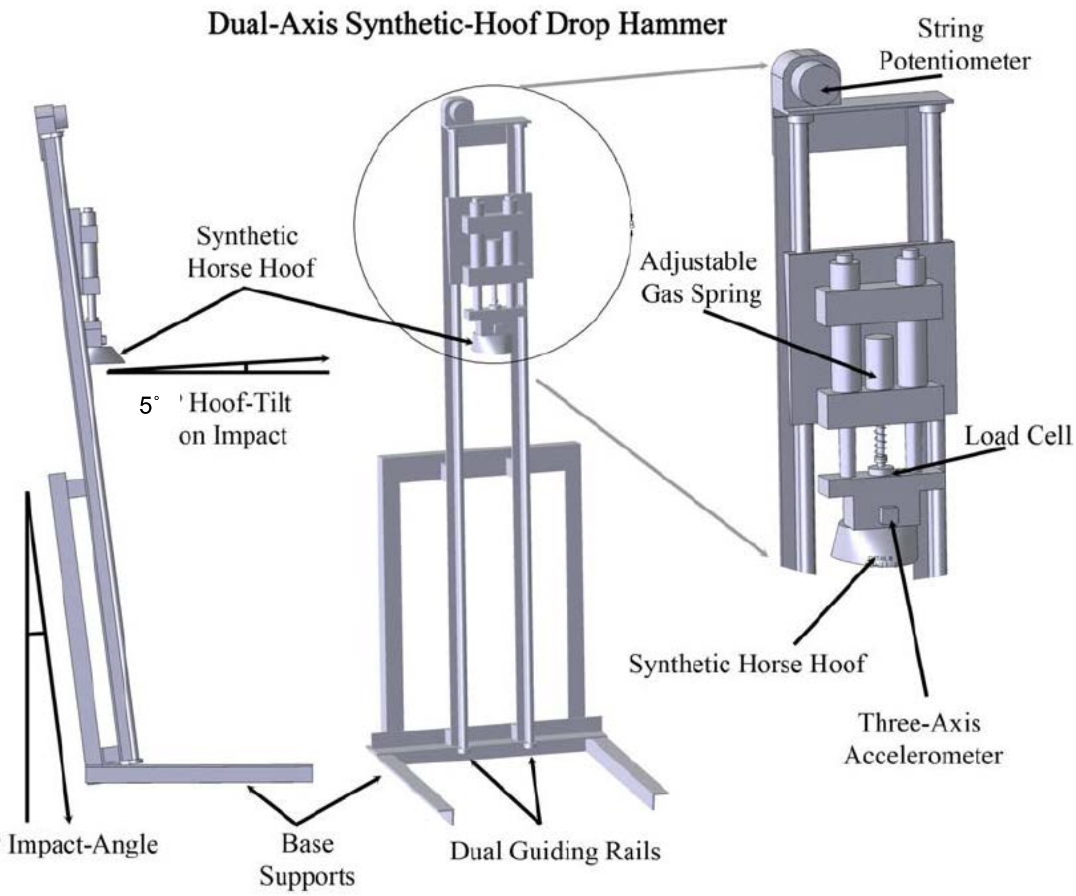

Figure 2.1.1 A surface testing device which shows two axes of motion and the configuration of the instrumentation on the test machine. Extracted from Peterson *et al.* (2008).

The Biomechanical Hoof Tester (Figure 2.1.1 and Plate 2.1.5) is a two axis drop tower type apparatus that impacts a synthetic hoof into the surface at an off set angle of 5˚ from the vertical, which is measured with the use of an inclinometer (Plate 2.1.5). The two non-orthogonal axes of motion allows acceleration and impact force in the vertical and horizontal planes to be calculated when the hoof impacts the surface (Peterson *et al.*, 2008). Gravity acts on the first axes and the long rails on which the hoof and instrumentation slides, generates a force by accelerating a mass of 30kg down the rails (Peterson *et al.*, 2008). A second set of shorter linear rails moves down as a part of the mass attached to the slide that only moves once the hoof is in contact with the surface and is intended to replicate the compliance of the leg. The difference in the angle between the first and second axes of 5˚ forces the hoof to slide forward towards the toe as it impacts the ground and the second preloaded axis is compressed.

The Biomechanical Hoof Tester was dropped three times in the same location and this was repeated four times on each surface for each treatment in order to provide a reliable data set. A study by Peterson and Mcilwraith (2008) and Walker *et al.* (2012) also made three drops with the Biomechanical Hoof Tester when investigating the effects of maintenance on racetracks and arena surfaces respectively. Published data on the readings obtained from the Biomechanical Hoof Tester is limited so it was important to use a similar sampling technique to gain comparable figures.

The vehicle is positioned for the impact site and the feet of the device are lowered and the rails inclined until the inclinometer spirit is level.

Inclinometer which measures the angle of the long rails to the horizontal or vertical.

The magnet is released by pushing a button once all personnel present are in a safe position and the laptop is ready to record the data. The file name is noted down and the raw data is automatically saved in LabVIEW for analysing at a later stage.

The magnet is switched back on and the hoof is lifted by two people, leaving a hoof shaped impact in the surface. The hoof is either dropped again or the feet are lifted to change the impact site.

Plate 2.1.5 The Biomechanical Hoof Tester which has been constructed so that it is possible to mount it to a vehicle in order to change the impact site.

The Biomechanical Hoof Tester data was sampled for two seconds at 2000 Hertz (Hz) using LabVIEW 2010 software and a filter was not required. The formula used in the block diagram of the LabVIEW software to calculate the parameters can be seen in Appendix VI. A threshold of the raw data signals rising above 0.1 volts was used to determine the initiation of impact and the termination of the impact occurred when the signals fell below 0.1 volts again.

The parameters measured included the maximum load on impact and the loading rate. Loading rate was calculated using the following equation:

$$\frac{\boldsymbol{Maximum\ Load - Minimum\ Load}}{\boldsymbol{Time\ from\ minimum\ to\ maximum\ load\ value}}$$

The range of horizontal acceleration which was calculated from the difference between the minimum and maximum values and the maximum vertical deceleration were also recorded. The acceleration data was also used to calculate the shear modulus of the surfaces with the following formula:

$$\boldsymbol{a\,tan}\left(\frac{\boldsymbol{Range\ of\ horizontal\ acceleration}}{\boldsymbol{Maximum\ vertical\ deceleration}}\right) \times \boldsymbol{-1}$$

The hysteresis was also calculated in Excel which is the area under the load-displacement curve. Figure 2.1.2 shows a print screen of the front panel in LabVIEW where all the data was extracted from.

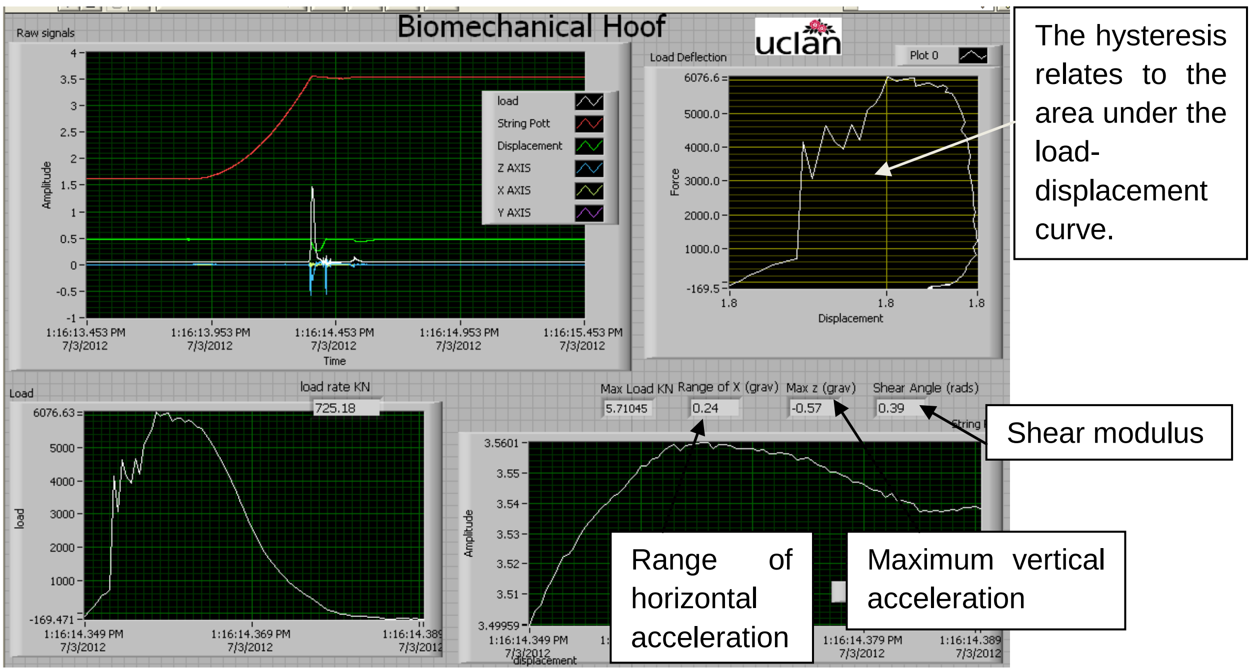

Figure 2.1.2 Front panel image from LabVIEW

The load signal presented as a white line in figure 2.1.3 was affected by noise signals at times (the spike next to the y axis in figure 2.1.3) and was possibly created by an eddy current. The current is a localised electric current induced by a varying magnetic field when the magnet on the Biomechanical Hoof Tester has been released in order to drop the hoof. The eddy current caused the load signal (white line) to trip after the magnet released the synthetic hoof which is shown within the white circle. The data is still obtainable however, the trigger at which the load signal is detected must be raised from 0.1 volts to 0.2 volts in order for all the calculations to be made within the block diagram (back screen which contains all formulae and is shown in AppendixVI) of the Lab VIEW programme. The trigger had to be altered for 120 files that had been affected by noise signals out of a total 864 files whilst extracting data. The Biomechanical Hoof Tester readings needed to be zoomed to prevent this from happening.

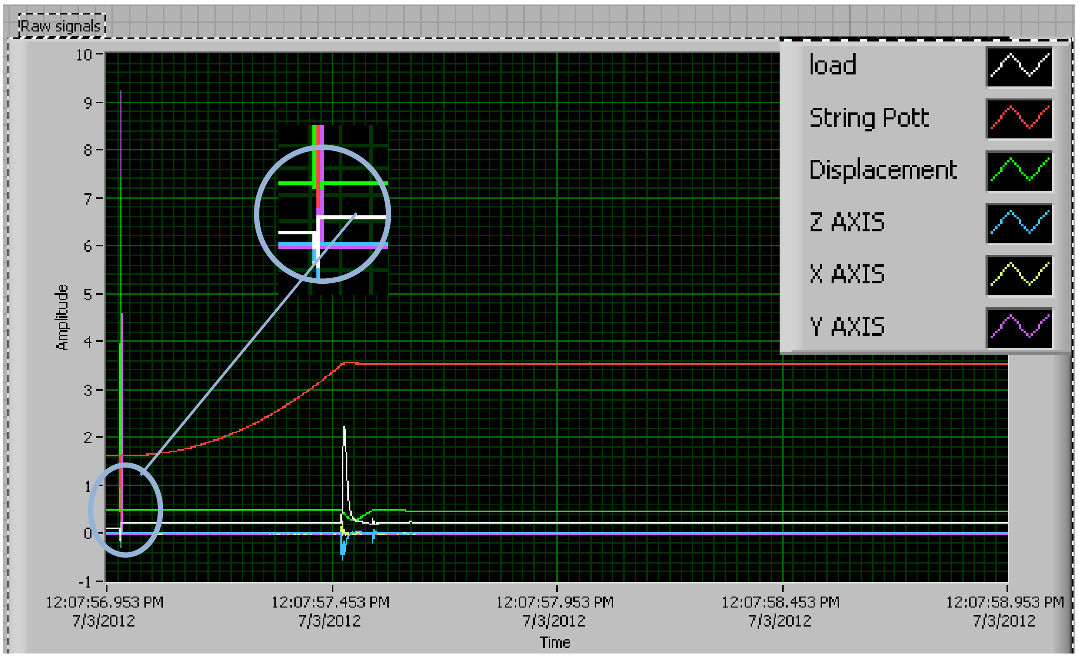

Figure 2.1.3 A print screen from LabVIEW of the raw data signals and noise signal interruption which alters the load signal.

The Clegg Hammer

A 'Medium Clegg Hammer' (Clegg, 1976, 2012) suitable for use on equestrian surfaces was used to measure the hardness of the surface, which has shown to be a good indicator of surface density (Brosnan *et al.*, 2009) (Plate 2.1.6). The medium Clegg Hammer that consists of a 50mm diameter test mass of 2.25 kg was dropped from a fixed height of 0.45m which is defined by a white line on the red weight (Baker *et al.*, 2007). The peak deceleration on impact was displayed in gravities (Clegg, 2012).

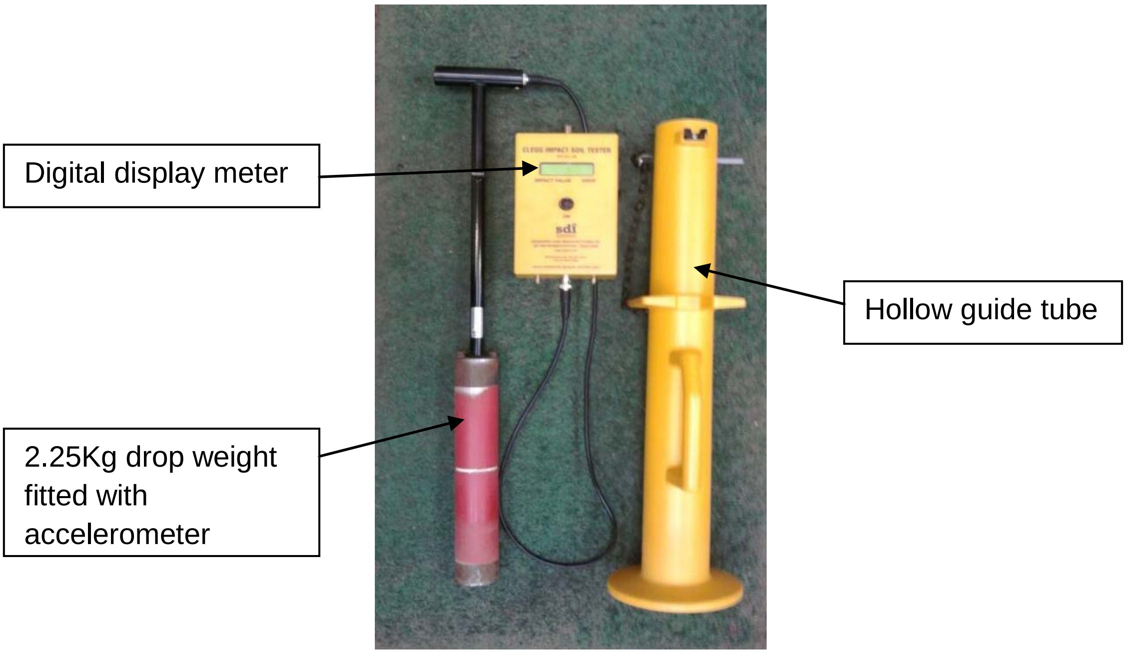

Plate 2.1.6 Clegg Impact Testing device.

The Clegg Hammer was dropped four times in the same location which was the standard protocol adopted by Clegg (1976) and this was also repeated four times for each treatment on all of the surfaces. Higher values demonstrated a higher deceleration on impact and therefore hardness of the tested surface. The same number of drops were also made with a Clegg Hammer in a study by Chivers and Aldous (2003) whilst testing natural turf football surfaces. The method enabled the authors to determine upper and lower values for important playing performance indicators and suggests that the number of repetitions selected for this study were sufficient (Chivers and Aldous, 2003). A Clegg Hammer was also used by Setterbo *et al.* (2011) where five consecutive drops were performed in the same place however the maximum value from the first four drops and residual deformation of the fourth drop were only taken into consideration.

Torque Wrench

A Torque Wrench with a similar design to the traction apparatus used by Canaway and Bell (1986) was used for this study (Plate 2.1.7). A horse shoe with two studs was used instead of a studded disc used by Canaway and Bell (1986) at the base of a 30 kg weight to measure the traction of the surface by dropping the apparatus from a height of 0.2m. The dial was zeroed before the Torque Wrench was pulled with consistent moderate pressure in the horizontal plane whilst supporting the top of the Torque Wrench. A reading was taken when the equipment twisted independently from the surface.

Plate 2.1.7 The Torque Wrench and the studded shoe fitted to the base of the weights.

The Torque Wrench was dropped once in four different locations within the test box for each treatment where higher values represented greater traction or a lower amount of slip. The same person was used to measure traction throughout data collection due to the user having a strong influence on the readings obtained (Twomey *et al.*, 2011). The same sampling method was adopted by Chivers and Aldous (2003) however, the traction was measured with a studded boot apparatus weighing 40 kg which is not fully representational of the Torque Wrench used during this study. There has been no significant association ($P>0.05$) found between the number of areas tested and the sample variance, for synthetic equestrian surfaces assessed during a project by Blundell (2010) which suggests the number of repetitions (n=4) selected for this study were adequate.

Moisture

To establish the exact moisture content of all the surfaces, a sample of 100 grams (g) was taken from each test box after each treatment. A sample was also taken from an approximate depth of 7cm down and at the base, immediately above the membrane to provide information on the moisture content beneath the top surface layer. The sample was dried in an oven at 102 ˚C for 24 hours and weighed again. The moisture content was calculated using the following equation (Rowell, 1994):

$$\boldsymbol{Moisture\ Content} = \left(\frac{\boldsymbol{Moist\ mass - Dry\ mass}}{\boldsymbol{Dry\ mass}}\right) \times \mathbf{100}$$

Other parameters

In addition to the suite of mechanical tests being performed, temperature, humidity and rainfall measurements were recorded in the months preceding and during data collection. Tinytag© temperature and humidity dataloggers were used and have been considered useful in other studies where the loggers recorded one of the most comprehensive sets of dwelling-related temperature data for English homes (Oreszczyn *et al.*, 2006). The dataloggers were sealed within waterproof containers and were programmed to take temperature (n=2 dataloggers on the surface, n=2 dataloggers 10cm beneath the surface) and humidity (n=1 datalogger on the surface, n=1 datalogger 10cm beneath the surface) readings every ten minutes (Tinytag, 2012). Rainwise rain gauges (n=2) were placed near the test boxes in order to calculate rainfall. The amount of precipitation will not have been a large factor influencing the results because the test boxes were covered when possible but may have caused slight condensation underneath the tarpaulin.

2.1.5 Statistical Analysis

The mean and standard error were stated according to moisture level, surface density, drop number (Biomechanical Hoof Tester and Clegg Hammer) and either drainage type (surface 1-4 vs 5-8), surface type (1,2,3,4) or test box number (1-8) for all of the parameters recorded. The range between values was also recorded for each treatment. A General Linear Model was used to look for any significant treatment effects (moisture, density, surface and drainage combination) and the residual values were tested for normality using a Kolmogorov-Smirnov test. Post-hoc analysis was carried out to establish interactions between the test box number and moisture or amount of compaction. Comparisons between treatments were performed using the Tukey method. Values of $P<0.05$ were considered statistically significant. The actual P value was reported unless P was calculated as 0.00, in which case $P<0.0001$ was reported. A non-parametric test was used if the data was not normal. The F values (normally distributed) or H values (non-normally distributed) and degrees of freedom were presented in accordance with the author information pack for the *Animal Behaviour Journal* (2012).

2.2 Questionnaire based study

2.2.1 Rider preferences survey

Surfaces have been assessed through sending out questionnaires to riders previously, which provided valuable information on the relationship between surface type and the incidence of lameness in dressage horses (Murray *et al.*, 2010a). There does not appear to be any other published survey data investigating the type of arena surfaces in use, characteristics of the particular surfaces and also the properties that riders prefer a surface to have.

2.2.2 Pilot work

The web link for the rider preference surveys was forwarded to a small sample (n=10) of equine staff at Myerscough College before the survey was released online to a larger population of the equine industry. There was an opportunity for the respondents to provide feedback at the end on the quality of the questions and whether they were easy to understand. Minor changes to the structure of the questions were necessary before the survey went live to ensure that the questions were appropriately defined.

2.2.3 Experimental Protocol

The rider preference survey (full survey in Appendix III) was available to complete on equine forum pages such as British Dressage, British Showjumping, Horse and Hound, The British Horse Society and other related websites to obtain information regarding the preferences of riders on surface type. A voucher was used as an incentive to encourage participants to complete the survey and the winner was randomly drawn. Closed questions were used to encourage participants to complete the survey.

The questions used are presented in Table 2.2. The questionnaire design was considered in order to avoid biasing the questions and influencing the response of the participants (Brace, 2008). The survey was created using Survey Monkey and it was possible to add question logic so riders that did not ride in the North of England (question 3) were not directed to question 4 for example. Question logic was also used for the non-riders where they were directed to the surface preferences section from question 9. It was important to establish the discipline of the rider in question 2 because it provided information on the requirements of the different types of riders with regards to surface properties. Question 4 allowed the top two preferred arenas in the

North of England to be determined where the surface properties were consequently tested following the end of the survey for another study.

The horse details and training and competition surfaces section (question 5-8) provided an indicator of the demands being placed on the horses, the ability of the rider and possibly their knowledge on how a surface can impact the performance of a horse if training and competition took place on numerous surface types. The questions in the surface preference section (Table 2.2.1) related to the variables that were measured with the surface testing equipment during the field based study. The responses enabled the preferences of riders to be considered when discussing how moisture, compaction and drainage type can manipulate surface properties.

Table 2.2.1 The questions used in the survey.

Question number	Question
	Rider Details
1	Rider or non-rider
2	Rider discipline.
3	Region (s) that the participant rides in.
	Rider Preferences
4	Three preferred equestrian centres in the North of England with a brief explanation.
	Horse Details
5	Level of training and competition.
	Training and Competition surfaces
6	Surface type for training and competition.
7	Training location: indoors or outdoors.
8	The conditions under which the surface provides the best performance.
	Surface Preferences
9	Preferred surface type.
10	Preferred type of ‘going’
11	Preferred surface preparation.
12	Preferred amount of traction

2.2.4 Statistical Analysis

The responses from the survey data were split according to the discipline and level of the rider and visually assessed to understand the preferences of riders regarding surface type and properties. The data was tested for normality using a Kolmogorov-Smirnov test and a chi-squared test for association was used to assess the differences in responses between observed and expected values according to the discipline and level of the rider.

3.0 RESULTS

Results for the study are presented in two parts. The field based study includes the data obtained from the test boxes under different conditions and the questionnaire based study includes the preferences of riders established from the survey data.

3.1 Field based study

Significant differences were found in the surface properties after nine different treatments were applied to all of the surfaces. The exact surface compositions and particle size distribution of the separated sand are presented in tables 3.1.1 and 3.1.2 respectively. Table 3.1.3 presents a description of the surfaces based on the sub-base and composition and should be used as a key throughout the results.

The particle size distribution differed according to surface type (Table 3.1.2). Surface 1 (sand and medium fibre and wax) and 3 (sand and high fibre and wax) consisted of predominantly medium sand (250 -355 µm) whereas the particle size for surface 2 (sand and high fibre no wax) and 4 (sand and low fibre and low wax) was slightly smaller and mainly composed of fine sand (180 -250 µm).

Table 3.1.1 Surface composition.

Surface Composition (%)	Surface 1	Surface 2	Surface 3	Surface 4
Sand	87.33	88.01	83.84	93.84
Fibre/felt	9.60	11.99	12.36	5.15
Binding polymer	3.08	0	3.8	1.01

Table 3.1.2 Particle Size Distribution (%) of each surface calculated using a100g sand sample that had been separated from binding polymer and fibre.

Particle Size category	Sieve Range (µm)	Surface 1 (%)	Surface 2 (unwaxed) (%)	Surface 3 (%)	Surface 4 (%)
Very coarse sand	>1000	0.58	0.04	1.87	0.11
Coarse sand	500-1000	4.25	0.88	2.02	0.25
Medium sand	355-500	13.26	1.93	8.86	1.23
Medium sand	250 -355	33.36	10.88	37.71	8.44
Fine sand	180 -250	24.33	30.61	21.65	30.10
Fine sand	150 -180	15.53	26.01	17.04	29.49
Very fine sand	125 -150	5.15	13.99	5.86	11.53
Very fine sand	90 -125	3.13	10.17	4.26	12.28
Very fine sand	63 -90	0.29	4.55	0.56	5.46
Silt and clay	Base (<631)	0.01	0.95	0.01	1.05

Table 3.1.3 Sub-base and surface combinations for the different test boxes (TB).

Test box number	Sub-base and surface combination
1	Gravel, Sand and medium fibre and wax
2	Gravel, Sand and high fibre, no wax
3	Gravel, Sand and high fibre and wax
4	Gravel, Sand and low fibre and low wax
5	Permavoid, Sand and medium fibre and wax
6	Permavoid, Sand and high fibre, no wax
7	Permavoid, Sand and high fibre and wax
8	Permavoid, Sand and low fibre and low wax

The study was conducted at three moisture contents to replicate a low, medium and high moisture level. The mean ±SE% moisture contents were identified as significantly (F_2=158.47, P<0.0001) different for each level (Table 3.1.4).

Table 3.1.4 Mean (±SE) moisture contents according to moisture level. Different letters denote significant (P<0.0001) differences.

Moisture level	Mean (±SE) moisture content (%)
Low	6.83 ± 1.01 **C**
Medium	17.45 ±0.76 **B**
High	21.19 ±0.90 **A**

The mean moisture contents did not significantly (F_1=3.98, P=0.05) differ between drainage types. The moisture contents recorded in the different test boxes appeared to be consistent except for test box four with a low and medium moisture level, which had a significantly (F_{23}=33.25, P<0.0001) higher moisture content than the other test boxes at the same moisture levels. The actual moisture content of test box four when under a low moisture level was more representative of the moisture contents recorded at a medium moisture level. The data were still considered for test box four due to the moisture content increasing with each moisture level and any interactions between the treatments are presented at the test box level.

There was no significant difference (F_2=1.56, P=0.286) between the moisture content measured at the top of the surface, 75mm beneath the top of the surface and at a depth of 150mm, immediately above the geotextile membrane. Leaving the test boxes for one hour prior to commencing testing appeared to be adequate to allow the moisture to infiltrate throughout the test box. There was also no significant (*F* 2=1.21, P=0.304) change in moisture content when the surface density was changed during each test day. The results suggest that covering the test boxes when not in use was sufficient to reduce evaporation rate.

The change in bulk density according to compaction level is shown in table 3.1.5 and plate 3.1.1 shows surface four with a low density through the perspex window. The bulk density for the low degree of compaction was the initial bulk density of the prepared surfaces (table 3.1.5). The total mean bulk density for all the compactions in each test box is presented in figure 3.1.1. The bulk density is expected to rise with an increase in compaction as long as the weight of the substrate occupying a certain volume stays the same. The mean bulk density according to surface type was significantly (*F* 3=4.37, P=0.007) higher for the sand and low fibre and low wax surface (surface 4) than the sand and high fibre, no wax surface (surface 2). The bulk density of the surfaces when considering drainage type was not normally distributed and a Kruskal-Wallis non-parametric test was used to investigate any differences. The ranked bulk density for the test boxes on the gravel was significantly (*H* 1=8.84, P=0.003) higher overall in comparison to the test boxes on the permavoid.

Table 3.1.5 The mean (±SE) bulk density (g/cm^3) of all the surfaces under different degrees of compaction (The bulk density of the reference surface was 1.6 g/cm^3). Different letters denote significant (*F* 2=11.42, P<0.0001) differences.

Degree of compaction	Mean (±SE) Bulk Density (g/cm^3)
Low	1.62 ± 0.008 **B**
Medium	1.69 ± 0.016 **A**
High	1.71 ± 0.019 **A**

Plate 3.1.1 Test box eight (sand and low fibre and low wax on permavoid) with a low surface density. The double headed arrow depicts the looser top layer, which was compacted down as surface density increased.

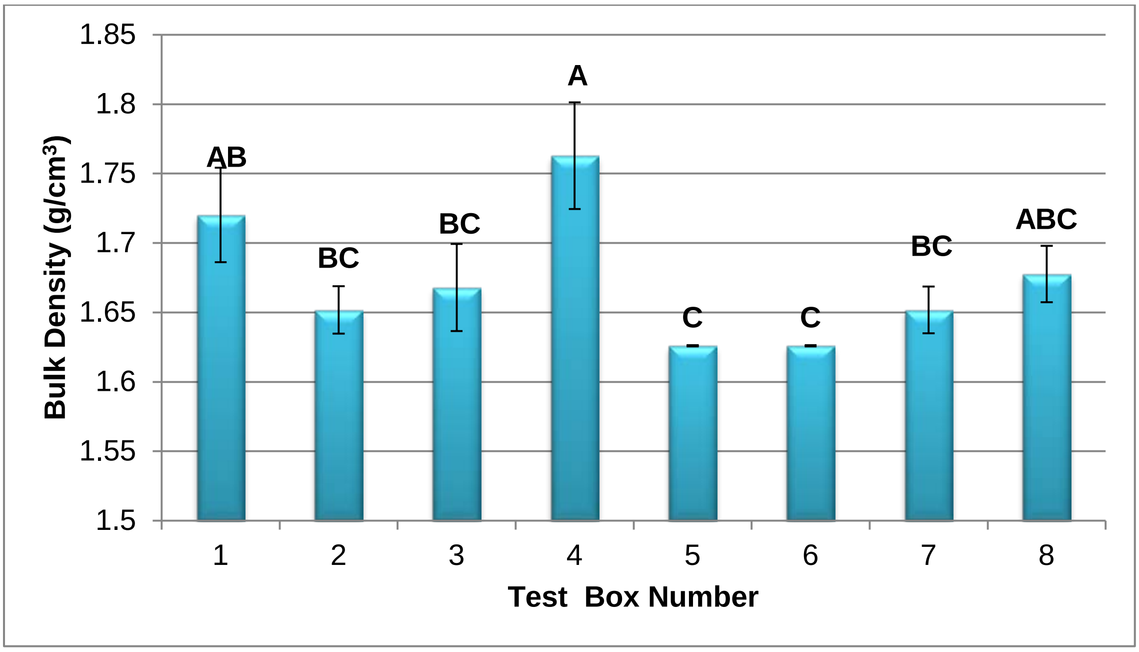

Figure 3.1.1 The mean (±SE) bulk density (g/cm^3) of the surfaces in each test box. Different letters denote significant (F 7=5.11, P<0.0001) differences.

3.1.1 Maximum impact force used to compact the surfaces

The maximum impact force used by the researchers to create a medium and high surface density is presented in Figure 3.1.2 The maximum force used to create the medium bulk density was significantly (F 3=99.51, P<0.0001) lower than the force used to create the high bulk density. There was no significant (P>0.05) difference between the force used on the gravel and permavoid drainage systems. It was not possible to use the same person to compact the surfaces throughout data collection due to the physical demands involved with using the 'tamper'. There was no significant difference between the maximum force used by four researchers except for one person where a significantly (F 3=30.5, P<0.0001) lower amount of force was used to compact the surfaces. The researchers compacted all of the surfaces throughout the entire study and therefore the reduced amount of force used by one person will have been applied for all treatments and not become a factor affecting the results.

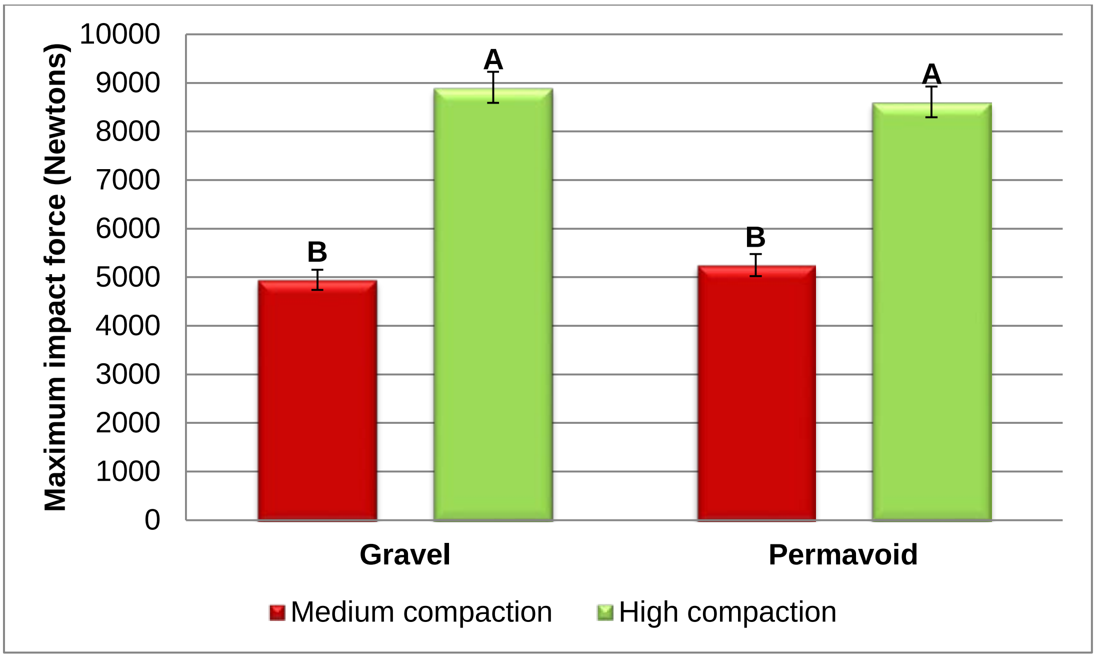

Figure 3.1.2 Mean (±SE) maximum impact force used by all the researchers to compact the surfaces to create a medium and high surface density. Different letters denote significant (P<0.0001) differences.

There was no significant (H 2=1.86, P=0.395) difference in the humidity levels and also rainfall amount on all of the test days because testing was not performed if it was raining. There was no significant (F 1=0.64, P=0.423) difference between the air temperature measured below and above the surface on each day however day 3 of data collection was significantly (F 2=40.24, P<0.0001) warmer than day 1 and 2 (Table 3.1.6).

Table 3.1.6 Mean (±SE) air temperature above and below the surface during data collection. Different letters denote significant (P<0.0001) differences.

Day	Moisture level		Temperature below the surface (ºC)	Temperature above the surface (ºC)
1	Low moisture	**B**	18.678 ± 0.302	18.488 ± 0.276
2	Medium moisture	**B**	19.157 ± 0.291	18.497 ± 0.171
3	High moisture	**A**	20.156 ±0.271	21.552 ± 0.319

3.1.2 Traction

Traction values significantly (F 2=240.99, P<0.0001) increased as moisture content increased and there was a significant (F 14=2.26, P=0.007) interaction between the two parameters (Figure 3.1.3). Table 3.1.7 presents the mean (±SE) traction values according to moisture content and where the significant differences lie between the test boxes. The main interaction appeared to be with test box 5 at the high moisture level. Test boxes 1, 2, 6 and 7 may also be responsible for the significant interaction at the high moisture level and test box 8 at the low moisture level. The sand and low fibre and low wax surface (TB 4 and 8) generated significantly (F 3=9.90, P<0.0001) higher traction values than the sand and medium fibre and wax surface (TB 1 and 5) and the sand and high fibre, no wax surface (TB 2 and 6) and the sand and high fibre and wax surface (TB 3 and 7) had significantly (F 3= 9.90, P<0.0001) higher traction values than the sand and medium fibre and wax surface (TB 1 and 5). There was no significant (F 2=0.38, P=0.684) change in traction for the different surface densities. The sub-base had no significant (H 1= 0.98, P=0.323) effect on the traction values obtained.

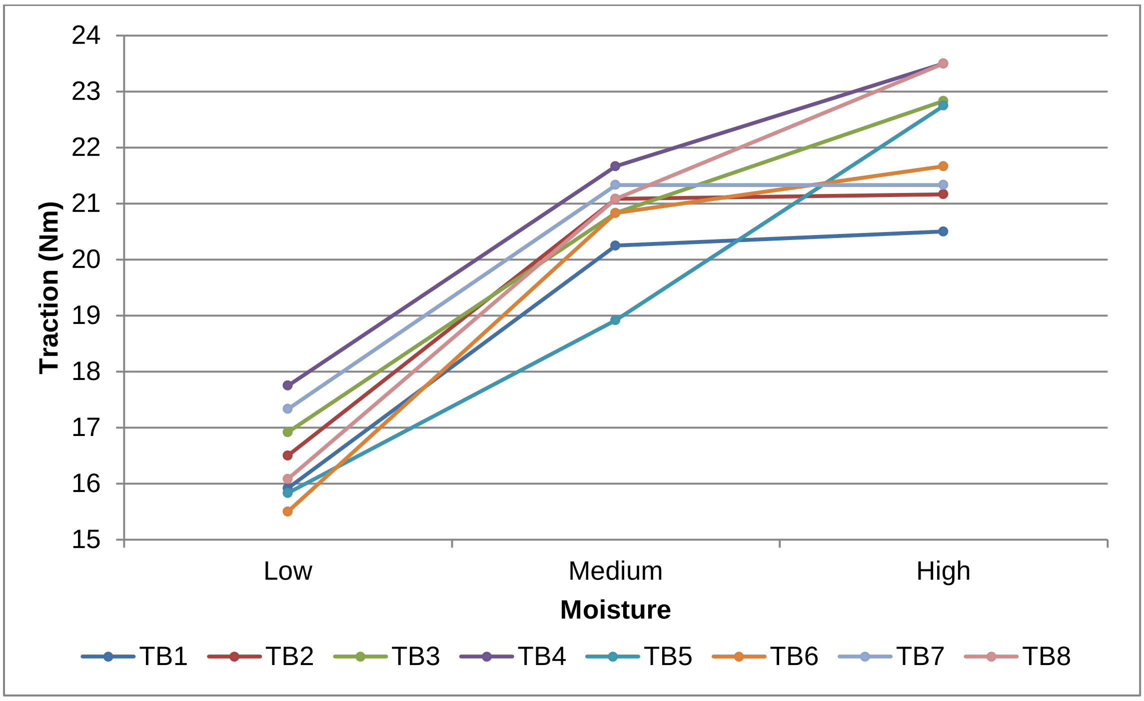

Figure 3.1.3 Interactions between mean traction values for moisture level and test box number.

Table 3.1.7 Mean (±SE) traction according to test box and moisture content. The different letters denote significant (*F* 23=24.87, P<0.0001) differences between all the values.

Mean (±SE) Traction								
Low Moisture (Nm)			Medium Moisture (Nm)			High Moisture (Nm)		
Box			**Box**			**Box**		
4	17.8 ± 0.45	**DEF**	**4**	21.7 ± 0.58	**AB**	**8**	23.5 ± 0.70	**A**
7	17.3 ± 0.56	**EF**	**7**	21.3 ± 0.36	**ABC**	**4**	23.5 ± 0.58	**A**
3	16.9 ± 0.61	**EF**	**8**	21.1 ± 0.62	**ABC**	**3**	22.8 ± 0.49	**AB**
2	16.5 ± 0.42	**EF**	**2**	21.1 ± 0.60	**ABC**	**5**	22.8 ± 0.39	**AB**
8	16.1 ± 0.23	**F**	**6**	20.8 ± 0.51	**ABC**	**6**	21.7 ± 0.56	**AB**
1	15.9 ± 0.60	**F**	**3**	20.8 ± 0.39	**ABC**	**7**	21.3 ± 0.70	**ABC**
5	15.8 ± 0.46	**F**	**1**	20.3 ± 0.51	**BCD**	**2**	21.2 ± 0.41	**ABC**
6	15.5 ± 0.58	**F**	**5**	18.9 ± 0.66	**CDE**	**1**	20.5 ± 0.34	**BC**

3.1.3 Surface hardness

The Clegg values recorded during the first drop were not significantly (F 2=1.68, P=0.188) affected by the moisture level for any of the surfaces. The medium and high surface density made the surface significantly (F 2=80.61, P<0.0001) harder during the first drop in comparison to the surfaces with a low density (Figure 3.1.4). The surfaces laid on the gravel generated significantly (F 1= 36.83, P<0.0001) higher hardness readings on the first drop than the surfaces installed on the permavoid sub-base. Surface four (Sand and low fibre and low wax) in test box 4 and 8 had significantly (F 3= 8.98, P<0.0001) higher first drop values when compared to surface one, two and three. At the test box level, test box 1-4 and test box eight were significantly (F 7= 10.37, P<0.0001) harder on the first drop than the remaining test boxes (Figure 3.1.4).

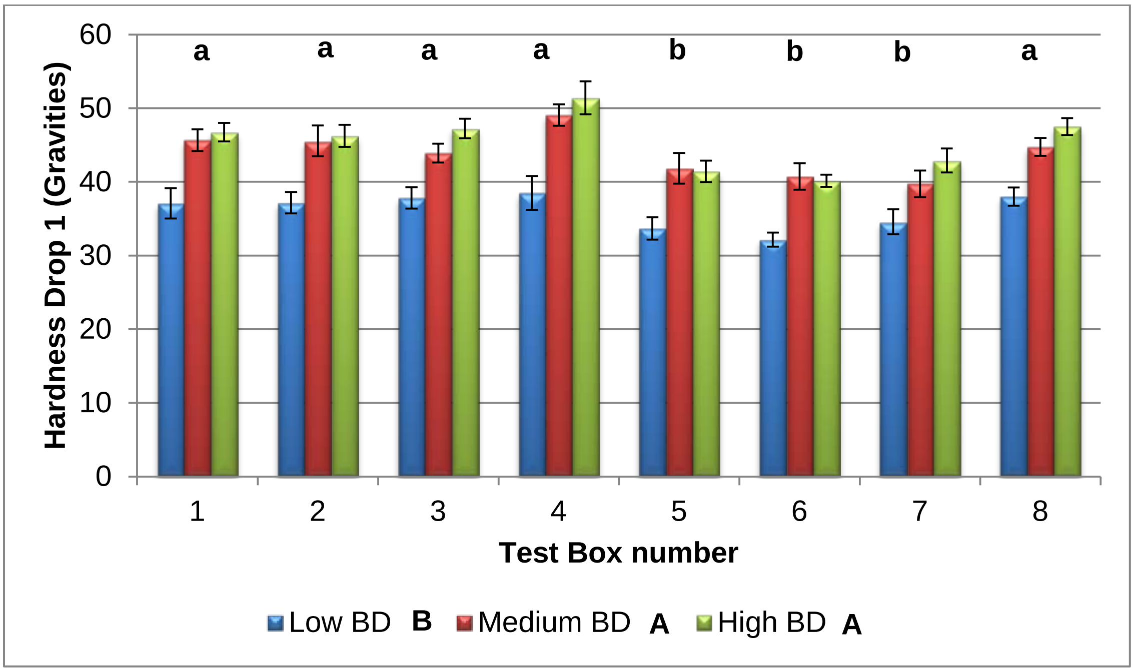

Figure 3.1.4 Mean (±SE) hardness values for the first drop of the Clegg Hammer according to test box number and bulk density (BD). Different letters (A, B) denote significant (P<0.0001) differences between the surface densities. Different letters (a, b) denote significant (P<0.0001) differences between test boxes.

The moisture content significantly altered the fourth drop reading of the Clegg Hammer where the surfaces under a low moisture content were significantly (F 2=13.05, P<0.0001) harder than the surfaces under a medium and high moisture level. The surfaces significantly (F 2=138.18, P<0.0001) increased in hardness with increasing bulk density (Figure 3.1.5). The significant (F 7=26.58, P<0.0001) differences in the fourth drop hardness values according to test box number are presented in figure 3.1.5.

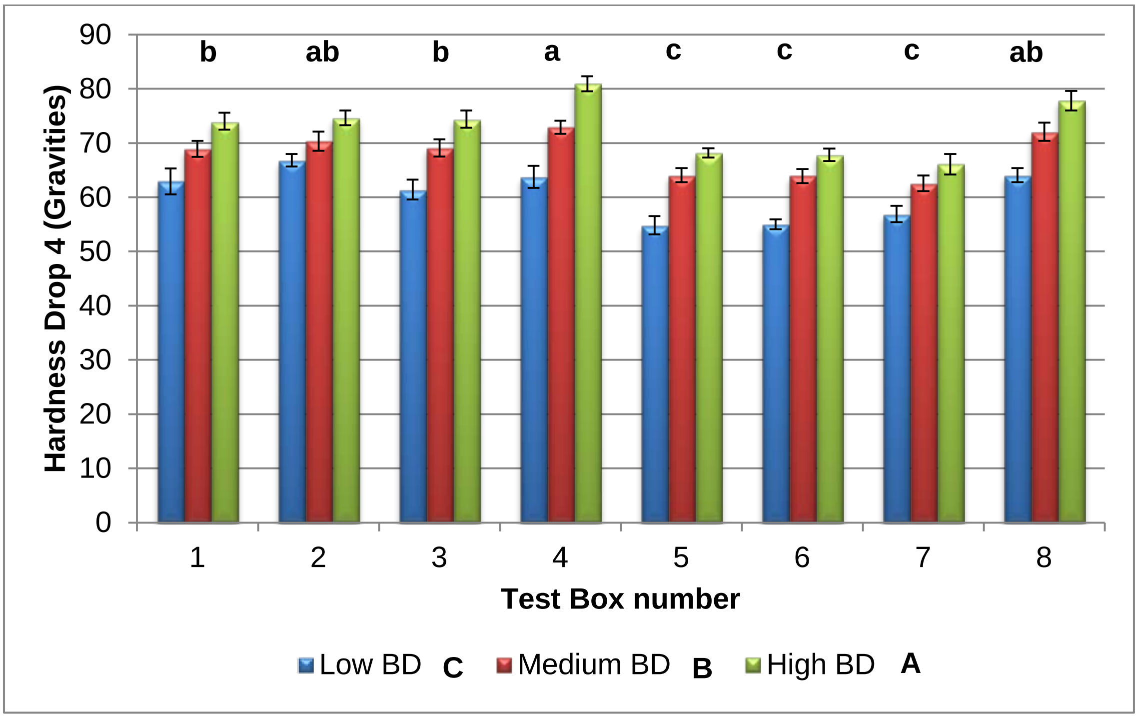

Figure 3.1.5 Mean (±SE) hardness values for the fourth drop of the Clegg Hammer according to test box number and bulk density (BD). Different letters (A, B, C) denote significant (P<0.0001) differences between the surface densities. Different letters (a, b, c) denote significant (P<0.0001) differences between test boxes.

The difference in hardness values between drop one and four were significantly (F 2=27.95, P<0.0001) higher when the surfaces had a low moisture content in comparison to the medium and high moisture contents. The range in hardness from the first to the fourth drop also significantly (F 2=21.16, P<0.0001) altered according to the bulk density where a higher range in hardness values were recorded whilst the surfaces had a high density.

The difference in hardness values between drop one and four was considered when the moisture contents and bulk densities were combined (Figure 3.1.6). Significant (F 8=12.31, P<0.0001) differences were measured between the combined treatments where the low and high bulk densities and the low moisture content generated the largest range (Figure 3.1.6). The test boxes with a medium bulk density and a medium moisture content and test boxes with a low and medium density with a high moisture content appeared to have the lowest hardness range.

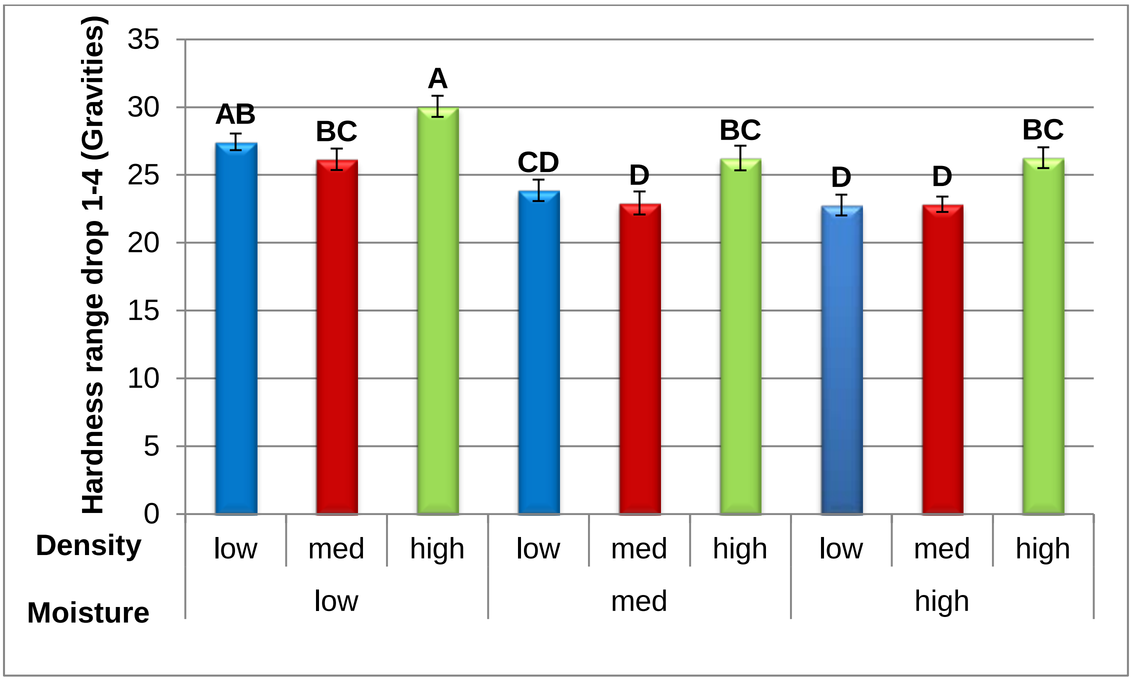

Figure 3.1.6 The mean (±SE) range in hardness values from drop1-4 according to moisture and bulk density. Different letters denote significant (P<0.0001) differences between the combined treatments.

The surfaces laid on the gravel generated a significantly (F 1=8.63, P=0.004) greater range in hardness values overall than the surfaces installed on the permavoid sub-base. Surface four (Sand and low fibre and low wax) had a significantly (F 3=8.33, P<0.0001) greater range in hardness values from drop one to four than surface one (sand and medium fibre and wax) and three (sand and high fibre and wax) and surface two (sand and high fibre, no wax) had a significantly (P<0.0001) greater range than surface three. The range in hardness values significantly (F 7=7.51, P<0.0001) altered according to test box number which is shown in figure 3.1.7. Table 3.1.3 on p.41 presents the sub-base and surface combinations for the different test boxes.

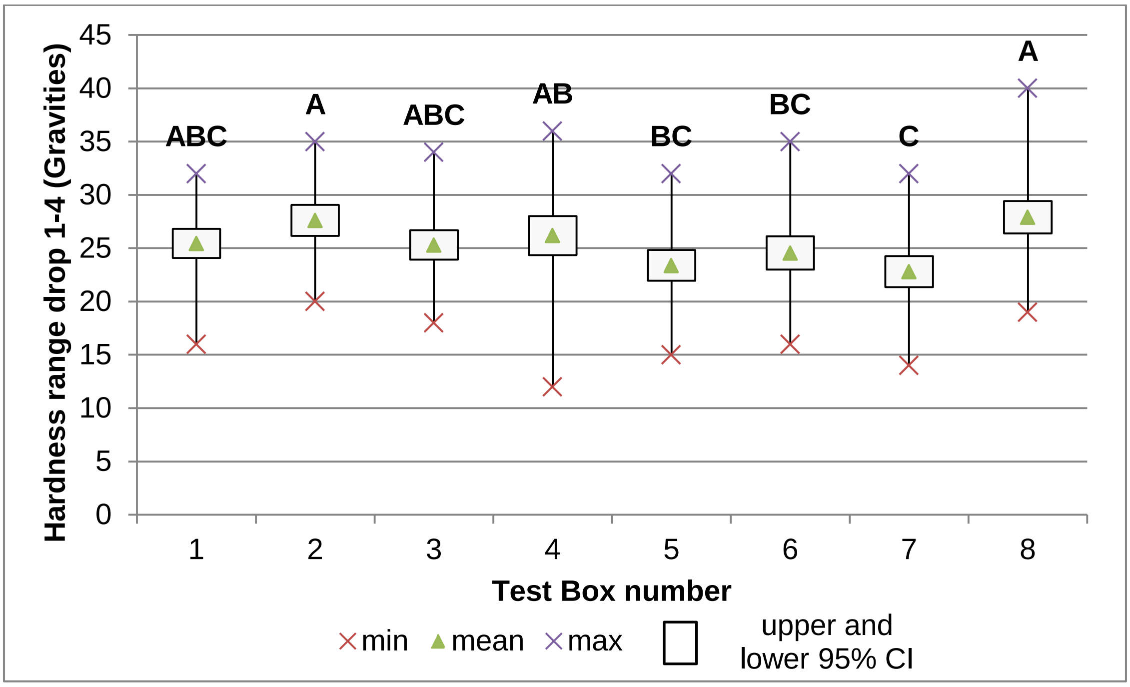

Figure 3.1.7 The range in hardness values from drop 1-4 obtained from the different test boxes for all the treatments applied. Different letters denote significant (P<0.0001) differences between the mean values (green triangle marker).

Test box four that was laid on gravel and contained surface four created the hardest values for drop one of the Clegg Hammer whilst under a medium or high density. Surface one, two and three that were laid on permavoid (test box 5-7) and under a low density generated the lowest first drop hardness values. Test box four also generated the hardest values for drop four of the Clegg Hammer when the surface had a low moisture content and was under a high density. Surface one, two and three that were laid on permavoid (test box 5-7) whilst under a low degree of compaction with a medium or high moisture level generated the lowest fourth drop hardness values.

Surfaces under a low moisture level with a high bulk density and installed on gravel generated the highest range between drop one and four of the Clegg Hammer. Test box eight, which was on permavoid, also generated a high range in hardness values, which could be due to surface type because surface four installed in test box four and eight was associated with a higher range. Test box seven which was placed on permavoid and contained surface three appeared to have the lowest range in hardness values.

3.1.4 Maximum Load on impact

The moisture content significantly (F_2=42.87, P<0.0001) affected the maximum load values recorded with the Biomechanical Hoof Tester. A medium and high moisture content created significantly (P<0.0001) higher maximum load values than when the surfaces had a low moisture content. Surface density significantly (F_2=435.30, P<0.0001) altered the maximum load on impact where the values significantly (P<0.0001) increased with each degree of compaction.

The maximum load was considered when the moisture contents and surface densities were combined (Figure 3.1.8). Significant (F_8=131.48, P<0.0001) differences were found between the treatments where the surfaces with a high density and medium or high moisture content generated the highest values (Figure 3.1.8). The lowest values were measured when the surfaces had a low density regardless of moisture content and also with a medium density and a low moisture content (Figure 3.1.8). The maximum load significantly (F_2=727.44, P<0.0001) increased with each drop number. It is important to note that the maximum load for the third drop was at times lower than the value recorded for the second drop however, this does not appear to affect the significance of the overall results.

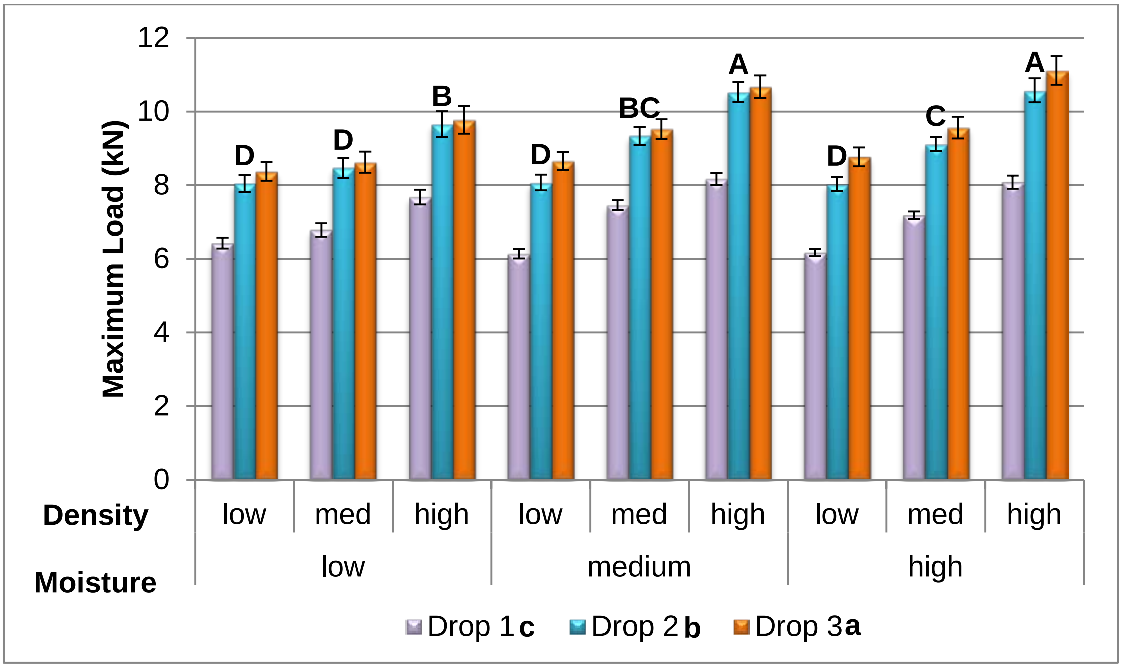

Figure 3.1.8 The mean (±SE) maximum load for the different drop numbers according to moisture level and bulk density. Different letters (A, B, C, D) denote significant (P<0.0001) differences between the combined treatments. Different letters (a, b, c) denote significant (P<0.0001) differences between drop numbers.

Significant interactions were found between the maximum load values for the different moisture levels (F 14=6.28, P<0.0001) and test box number (Figure 3.1.9). Table 3.1.8 presents the mean (±SE) maximum load according to moisture content and where the significant differences lie between the test boxes. Significant interactions were also found between the surface densities (F 14=7.88, P<0.0001) and test box number (Figure 3.1.10). Table 3.1.9 presents the mean (±SE) maximum load according to bulk density and where the significant differences lie between the test boxes. It is important to note that the values recorded for the different treatments appear to be split according to the drainage type where the surfaces laid on gravel generated higher values (TB1-4: gravel, TB5-8: permavoid). The maximum load range for all of the drops combined according to the different treatments is presented in figure 3.1.11 and demonstrates that the range was higher for all treatments on the surfaces laid on gravel.

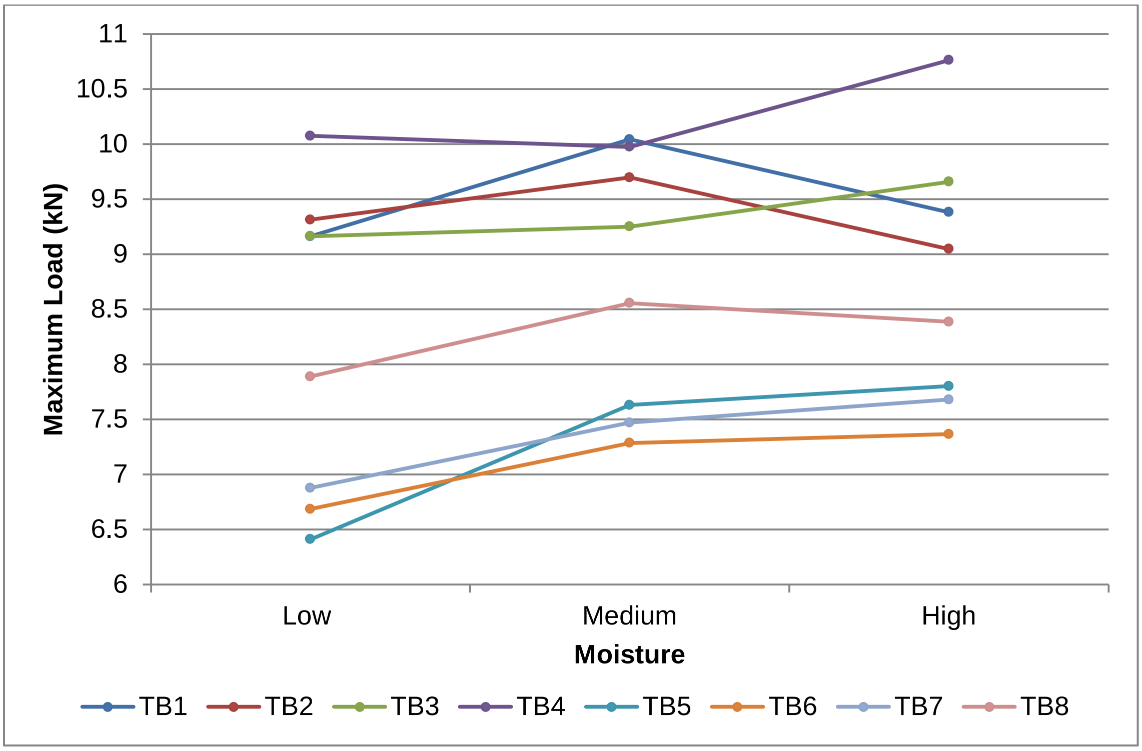

Figure 3.1.9 Interactions between mean maximum load values for moisture level and test box number.

Table 3.1.8 Mean (±SE) maximum load according to test box and moisture content. The different letters denote significant (F 23=90.06, P<0.0001) differences between all the values.

Mean (±SE) Maximum Load								
Low Moisture (kN)			Medium Moisture (kN)			High Moisture (kN)		
Box			**Box**			**Box**		
4	10.08 ± 0.314	**AB**	**1**	10.04 ± 0.320	**AB**	**4**	10.76 ± 0.442	**A**
2	9.31 ± 0.251	**BCD**	**4**	9.98 ± 0.358	**AB**	**3**	9.66 ± 0.354	**ABCD**
3	9.16 ± 0.268	**BCDE**	**2**	9.70 ±0.265	**ABC**	**1**	9.38 ± 0.327	**BCD**
1	9.16 ± 0.267	**BCDE**	**3**	9.25 ± 0.264	**BCD**	**2**	9.05 ± 0.319	**BCDEF**
8	7.89 ± 0.126	**DEFG**	**8**	8.56 ± 0.205	**CDEFG**	**8**	8.39 ± 0.178	**DEFG**
7	6.88 ± 0.115	**HI**	**5**	7.63 ± 0.233	**GHI**	**5**	7.80 ± 0.210	**FGH**
6	6.69 ± 0.089	**HI**	**7**	7.47 ± 0.193	**GHI**	**7**	7.68 ± 0.206	**GHI**
5	6.41 ± 0.139	**I**	**6**	7.29 ± 0.167	**GHI**	**6**	7.37 ± 0.141	**GHI**

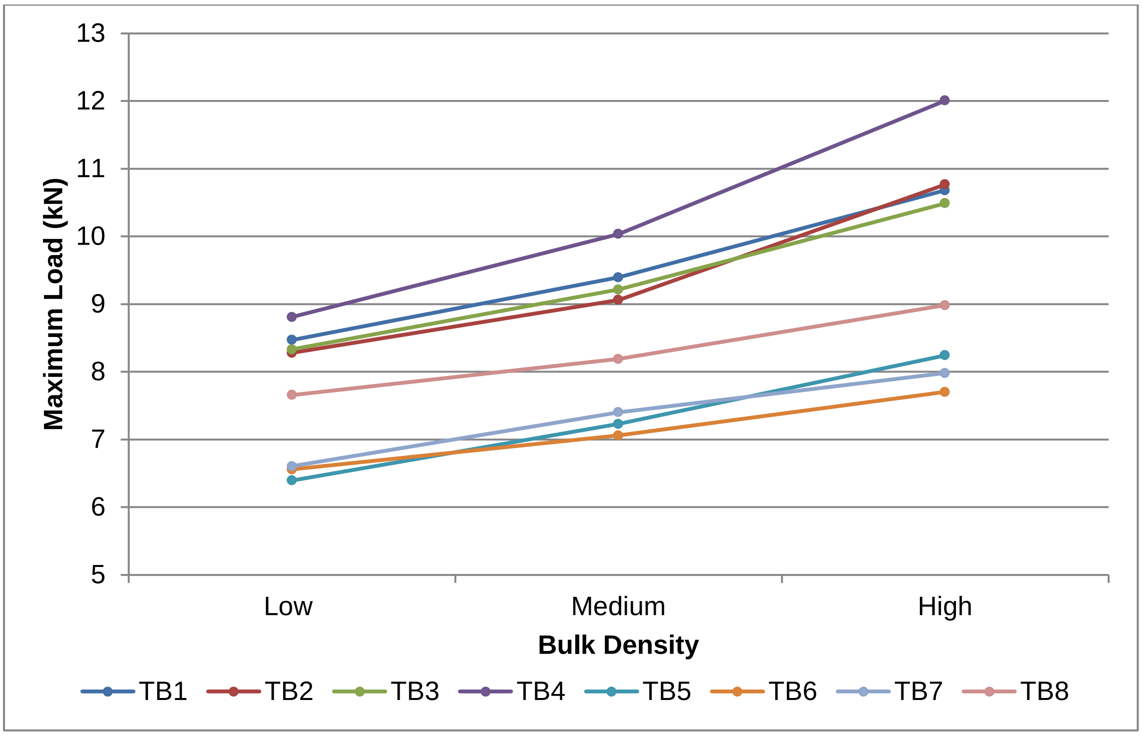

Figure 3.1.10 Interactions between the mean maximum load values for the different bulk densities and test box number.

Table 3.1.9 Mean (±SE) maximum load according to test box and bulk density (BD). The different letters denote significant (*F* 23=117.25, P<0.0001) differences between all the values.

Mean (±SE) Maximum Load								
Low Bulk Density (kN)			Medium Bulk Density (kN)			High Bulk Density (kN)		
Box			**Box**			**Box**		
4	8.81 ± 0.294	**EFGH**	**4**	10.03 ± 0.266	**BCD**	**4**	12.01 ± 0.353	**A**
1	8.47 ± 0.262	**EFGHI**	**1**	9.39 ± 0.270	**CDE**	**2**	10.77 ± 0.222	**B**
3	8.33 ± 0.241	**EFGHIJ**	**3**	9.22 ± 0.240	**DEF**	**1**	10.68 ± 0.280	**B**
2	8.28 ± 0.241	**EFGHIJ**	**2**	9.06 ± 0.2	**DEFG**	**3**	10.49 ± 0.292	**BC**
8	7.66 ± 0.133	**IJKLM**	**8**	8.19 ± 0.153	**FGHIJ**	**8**	8.98 ± 0.173	**DEFG**
7	6.61 ± 0.132	**LMN**	**7**	7.40 ± 0.154	**IJKLMN**	**5**	8.24 ± 0.210	**FGHIJ**
6	6.56 ± 0.101	**MN**	**5**	7.23 ± 0.197	**JKLMN**	**7**	7.98 ± 0.180	**GHIJK**
2	8.28 ± 0.241	**N**	**6**	7.06 ± 0.119	**KLMN**	**6**	7.70 ± 0.141	**HIJKL**

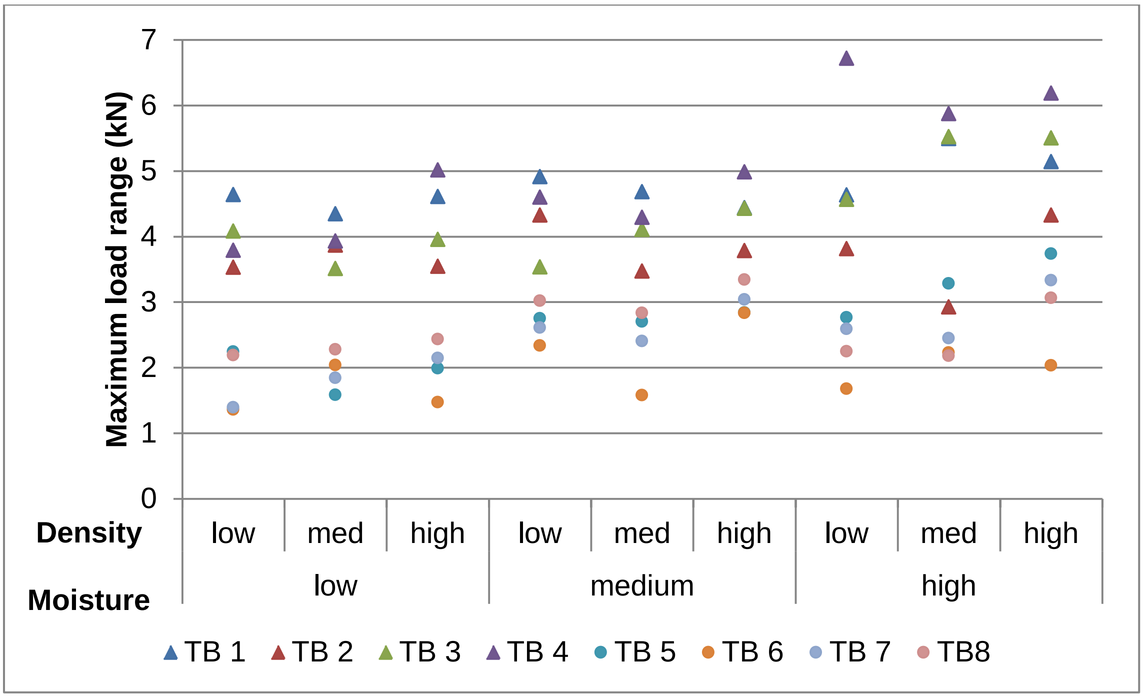

Figure 3.1.11 The range in maximum load values obtained from each of the test boxes for all of the treatments.

3.1.5 Load rate

The load rate was extracted from LabVIEW as shown in Figure 3.1.12. The load-time graphs in figure 3.1.12 A and 3.1.12 B demonstrate a low and high loading rate respectively where the incline from the minimum to the maximum value is more gradual in figure 3.1.12A

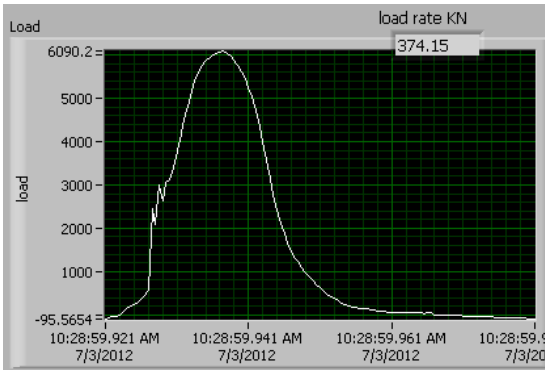

Figure 3.1.12 A

A Load- time graph obtained during the first drop of the Biomechanical Hoof Tester when TB 1 had a low moisture content and low bulk density.

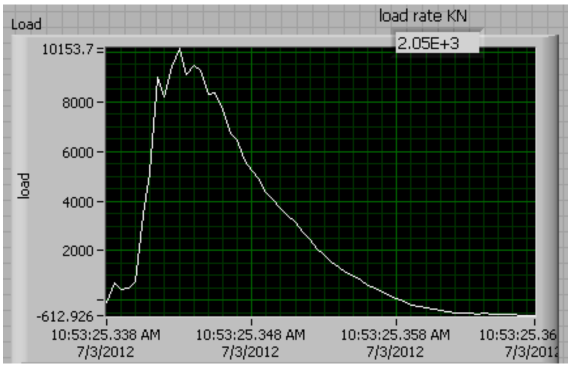

Figure 3.1.12 B

A Load- time graph obtained during the third drop of the Biomechanical Hoof Tester when TB 4 had a low moisture content and low bulk density.

The moisture content significantly (F 2=89.14, P<0.0001) affected the loading rates where the medium moisture level generated a significantly (P<0.0001) higher load rate than the high moisture content, which was significantly (P<0.0001) higher than the low moisture content. The load rate significantly (F 2=224.96, P<0.0001) increased with an increase in surface density.

The load rate was considered when the moisture contents and surface densities were combined (Figure 3.1.13). Significant (F 8=86.73, P<0.0001) differences were found between the different treatments and appeared to be very similar to the differences in the maximum load values where the surfaces with a high density and a medium or high moisture content generated the highest values on the third drop (Figure 3.1.13). The lowest values were observed when the surfaces had a low degree of compaction at all moisture levels and also with a medium density and low moisture level for the first drop. The load rate significantly (F 2=546.18, P<0.0001) increased with each drop number.

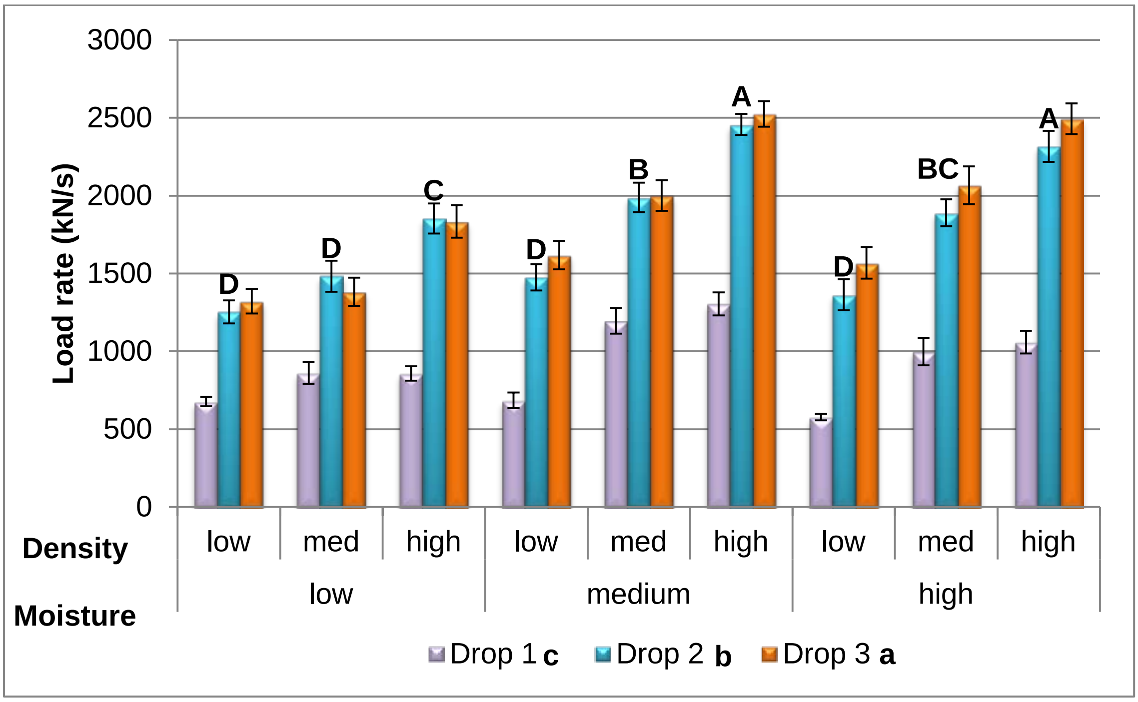

Figure 3.1.13 The mean (± SE) load rate for the different drop numbers according to moisture level and bulk density. Different letters (A, B, C, D) denote significant (P<0.0001) differences between the combined treatments. Different letters (a, b, c) denote significant (P<0.0001) differences between drop numbers.

Significant interactions were found between the load rates for the different moisture levels (*F* 14=4.96, P<0.0001) and test box number (Figure 3.1.14) where more interactions were observed at the low moisture level. The surface type (TB 1 and 5: surface 1, TB 2 and 6: surface 2, TB 3 and 7: surface 3, TB 4 and 8: surface 4) appeared to have a larger impact on the load rate values recorded for the different moisture levels than drainage type. Table 3.1.10 presents the mean (±SE) load rate according to moisture content and where the significant differences lie between the test boxes. There was no significant (*F* 14=1.37, P=0.159) interaction between surface density and test box number. The load rate range for all of the drops combined according to the different treatments is presented in figure 3.1.15. The treatment combinations that created a greater range in loading rates included a high surface density with a medium or high moisture content.

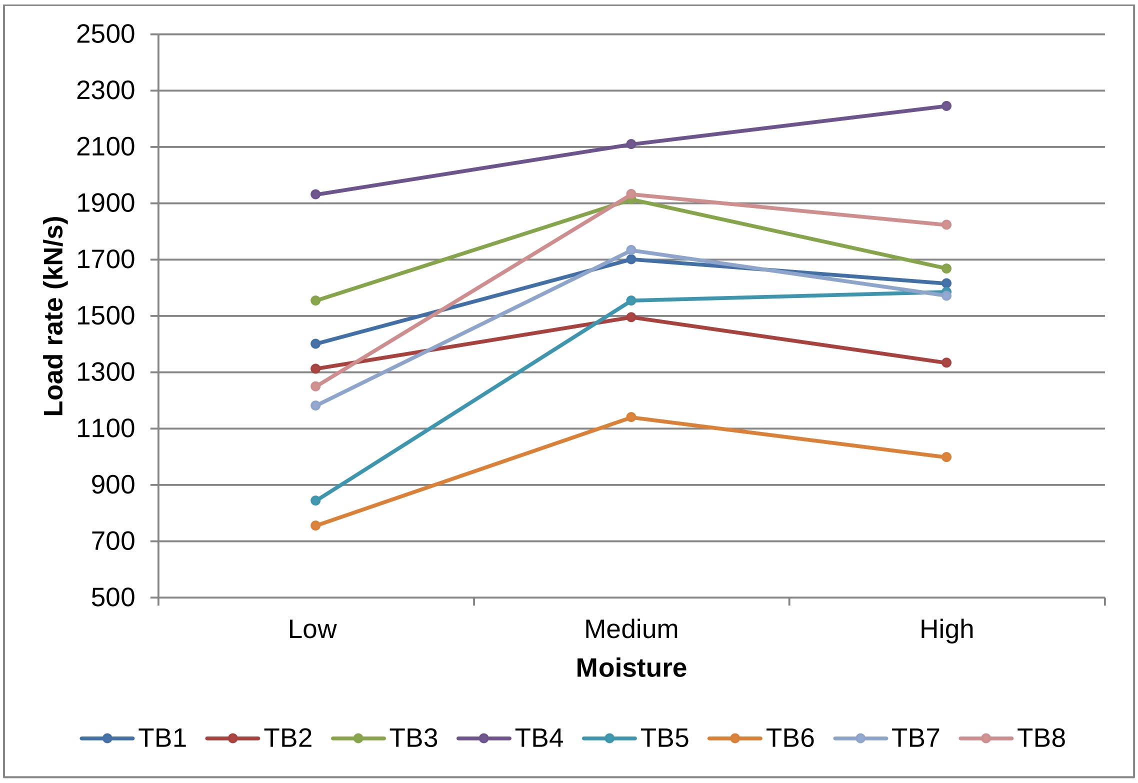

Figure 3.1.14 Interactions between mean load rates for moisture level and test box number.

Table 3.1.10 Mean (±SE) load rate according to test box and moisture content. The different letters denote significant (*F* 23=36.06, P<0.0001) differences between all the values.

Mean (±SE) Load rate								
Low Moisture (kN/s)			Medium Moisture (kN/s)			High Moisture (kN/s)		
Box			**Box**			**Box**		
4	1931 ± 116	**ABC**	**4**	2109 ± 145	**AB**	**4**	2245 ± 149	**A**
3	1554.1 ± 93.2	**DEFGHI**	**8**	1932 ± 130	**ABC**	**8**	1823 ± 149	**BCD**
1	1400.7 ± 85.5	**FGHIJK**	**3**	1914 ± 111	**ABC**	**3**	1668 ± 121	**CDEFG**
2	1312.5 ± 64.8	**HIJKL**	**7**	1733 ± 110	**CDE**	**1**	1615 ± 119	**CDEFG H**
8	1249.7 ± 85.1	**IJKL**	**1**	1701 ± 109	**CDEF**	**5**	1585 ± 123	**DEFGH**
7	1181.8 ± 91.1	**JKL**	**5**	1554 ± 111	**DEFGHI**	**7**	1571 ± 134	**DEFGH I**
5	844.1 ± 60.5	**MN**	**2**	1494.9 ± 79.1	**EFGHIJ**	**2**	1333.4 ± 90.5	**GHIJK**
6	755.9 ± 21.3	**N**	**6**	1140 ± 106	**KLM**	**6**	998.2 ± 81.5	**LMN**

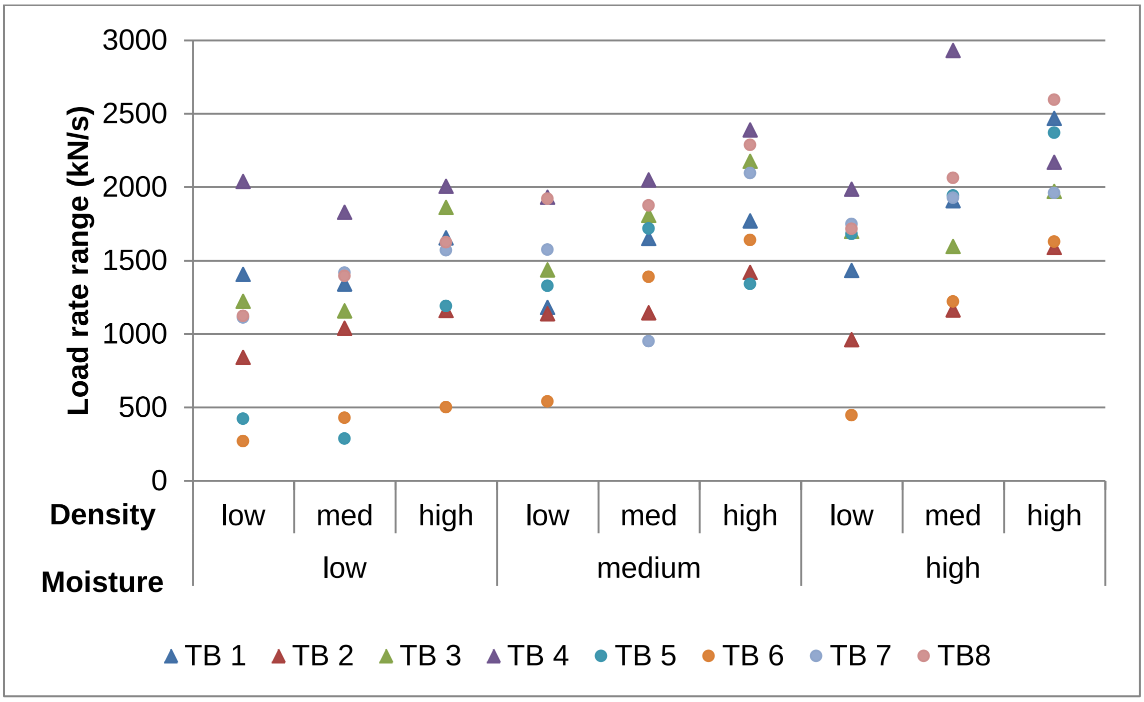

Figure 3.1.15 The range in load rate values obtained from each of the test boxes for all of the treatments.

3.1.6 Range of horizontal acceleration

The range of horizontal acceleration was significantly (*F* 2=24.63, P<0.0001) higher when the surfaces were under a medium moisture content than under a low and high moisture content. There were significant (*F* 2=3.35, P=0.036) differences between the ranges in horizontal acceleration for the different surface densities where low densities generated significantly (P=0.036) lower values.

The range of horizontal acceleration was considered when the moisture contents and bulk densities were combined (Figure 3.1.16). Significant (*F* 8=7.49, P<0.0001) differences were found between the different treatments where the medium moisture level appeared to create the highest values (Figure 3.1.16). The significant differences suggest the moisture level had a larger effect on the values than the surface densities. The range of acceleration recorded on drop number 1 was significantly (*F* 2=27.18, P<0.0001) lower than drop 2 and 3.

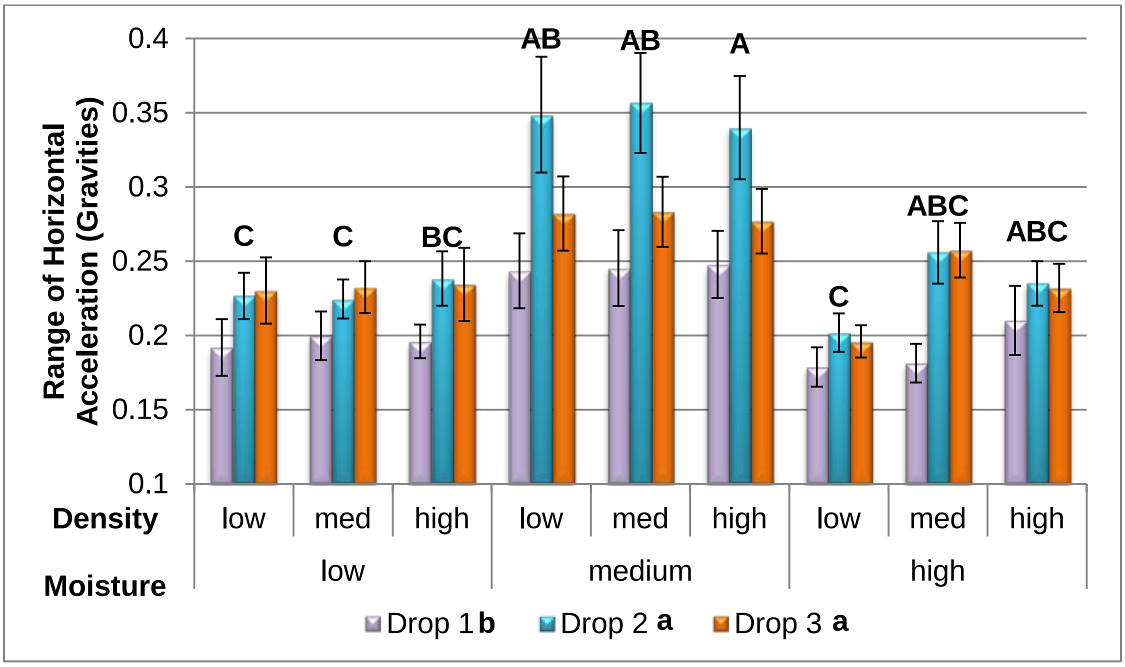

Figure 3.1.16 The mean (± SE) range of horizontal acceleration for the different drop numbers according to moisture level and bulk density. Different letters (A, B, C) denote significant (P<0.0001) differences between the combined treatments. Different letters (a, b) denote significant (P<0.0001) differences between drop numbers. The significant differences relate to transformed data (Range of x transformed using 1/(x^0.5)).

Significant interactions were found between the range of horizontal acceleration for the different moisture levels (F 14=2.20, P=0.007) and test box number where more interactions appeared to occur at the high moisture level (Figure 3.1.17). Table 3.1.11 presents the mean (±SE) range of horizontal acceleration according to moisture content and where the significant differences lie between the test boxes. There was no significant (F 14=0.81, P=0.662) interaction between surface density and test box number. The horizontal acceleration range for all of the drops combined according to the different treatments is presented in figure 3.1.18. The lowest range of horizontal acceleration was also associated with a lower range in all the values recorded and as the range of horizontal acceleration increased, the range in values increased and differences between test boxes became more apparent.

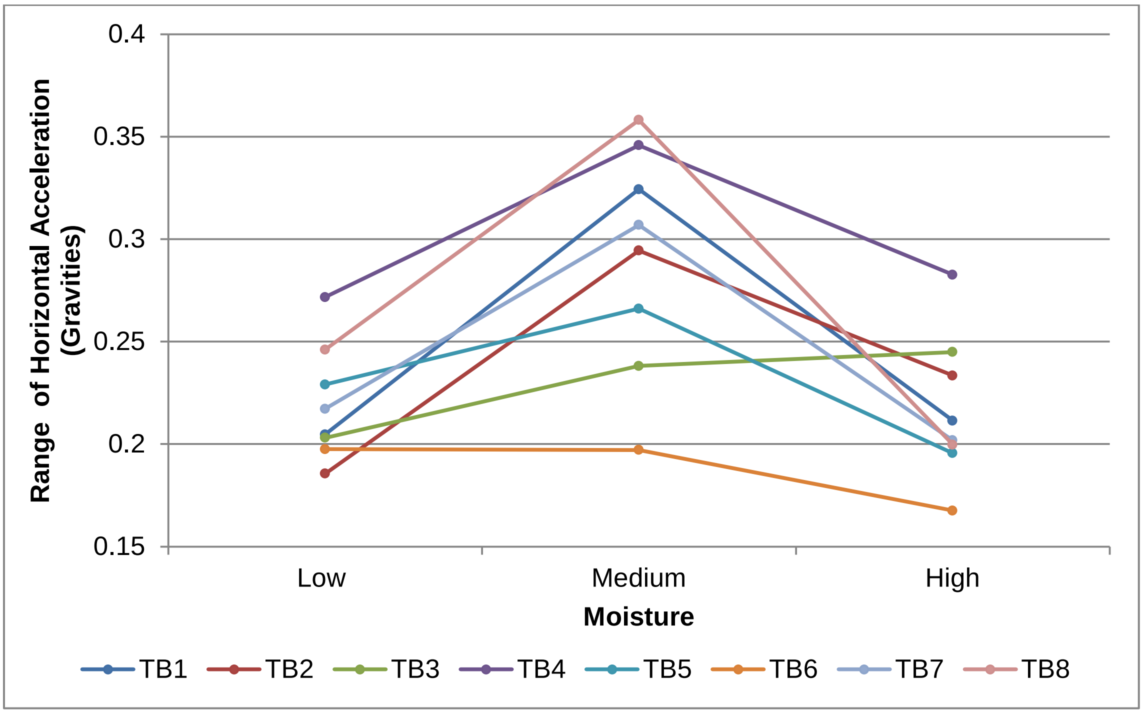

Figure 3.1.17 Interactions between mean ranges of horizontal acceleration for moisture level and test box number.

Table 3.1.11 Mean (±SE) range of horizontal acceleration according to test box and moisture content. The different letters denote significant (*F* 23=6.9, P<0.0001) differences between all the values.

Mean (±SE) Range of horizontal acceleration								
Low Moisture (Gravities)			Medium Moisture (Gravities)			High Moisture (Gravities)		
Box			**Box**			**Box**		
2	0.19 ± 0.011	**AB**	**6**	0.2 ± 0.018	**AB**	**6**	0.17 ± 0.011	**A**
6	0.2 ± 0.014	**ABC**	**3**	0.24 ± 0.017	**BCDEF**	**5**	0.2 ± 0.013	**ABCD**
1	0.2 ± 0.015	**ABCD**	**5**	0.27 ± 0.023	**BCDEF**	**8**	0.2 ± 0.013	**ABCD**
3	0.24 ± 0.019	**ABCD**	**2**	0.29 ± 0.032	**BCDEF**	**7**	0.2 ± 0.012	**ABCD**
7	0.2 ± 0.012	**ABCD**	**7**	0.31 ± 0.03	**CDEF**	**1**	0.21 ± 0.012	**ABCDE**
5	0.2 ± 0.013	**ABCDE**	**1**	0.32 ± 0.025	**EF**	**2**	0.23 ± 0.016	**BCDEF**
8	0.2 ± 0.013	**BCDEF**	**4**	0.35 ± 0.03	**F**	**3**	0.24 ± 0.019	**BCDEF**
4	0.28 ± 0.023	**DEF**	**8**	0.36 ± 0.032	**F**	**4**	0.28 ± 0.023	**DEF**

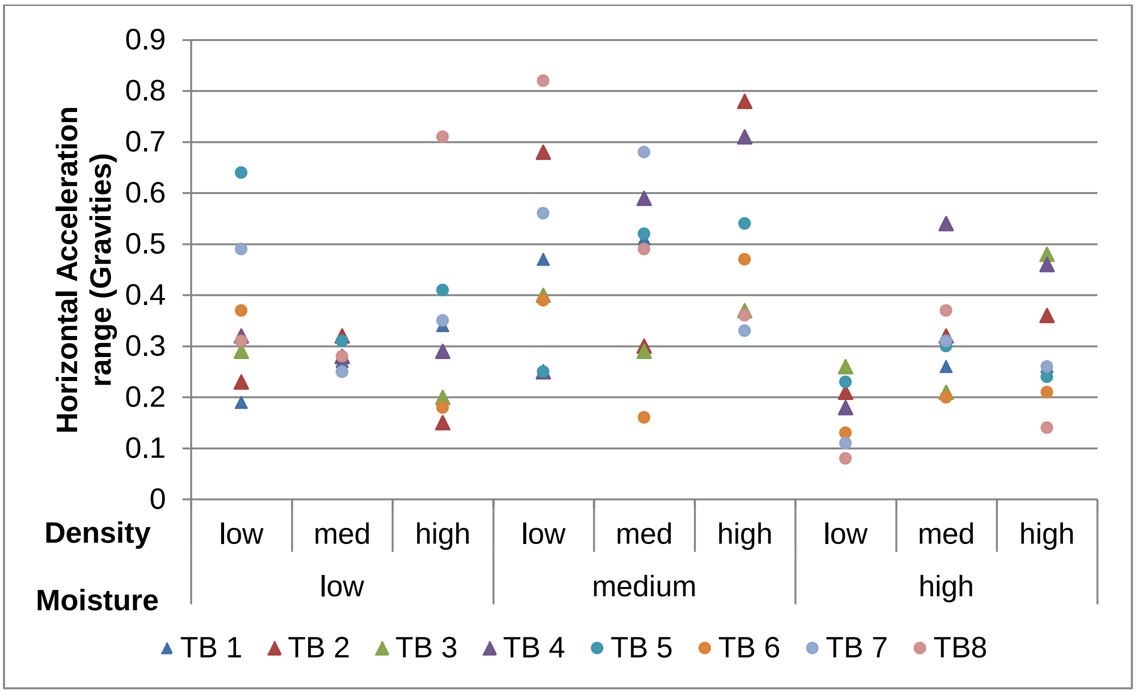

Figure 3.1.18 The horizontal acceleration range obtained from each of the test boxes for all of the treatments.

3.1.7 Maximum vertical deceleration

The maximum vertical deceleration was significantly (*F* 2=31.77, P<0.0001) higher on the surfaces with a low and medium moisture level than the surfaces under a high moisture level. The maximum vertical deceleration significantly (*F* 2=216.38, P<0.0001) increased with an increase in surface density, which was the same trend as the maximum load and load rate values. The surfaces laid on gravel (test boxes 1-4) generated significantly (*F* 1=26.95, P<0.0001) higher maximum vertical decelerations than the surfaces installed on permavoid (test boxes 5-8).

The maximum vertical deceleration was considered when the moisture contents and bulk densities were combined (Figure 3.1.19). Significant (*F* 8=41.70, P<0.0001) differences were found between the different treatments where the high bulk densities caused a higher vertical deceleration on drop 2 and 3 regardless of moisture content. The lowest values were recorded on the first drop of the Biomechanical Hoof Tester when the surfaces had a low density, especially when the surfaces had a high moisture content. The maximum vertical deceleration recorded on drop number 2 and 3 was significantly (*F* 2=219.69, P<0.0001) higher than drop 1 which is the same finding with the range of horizontal acceleration values.

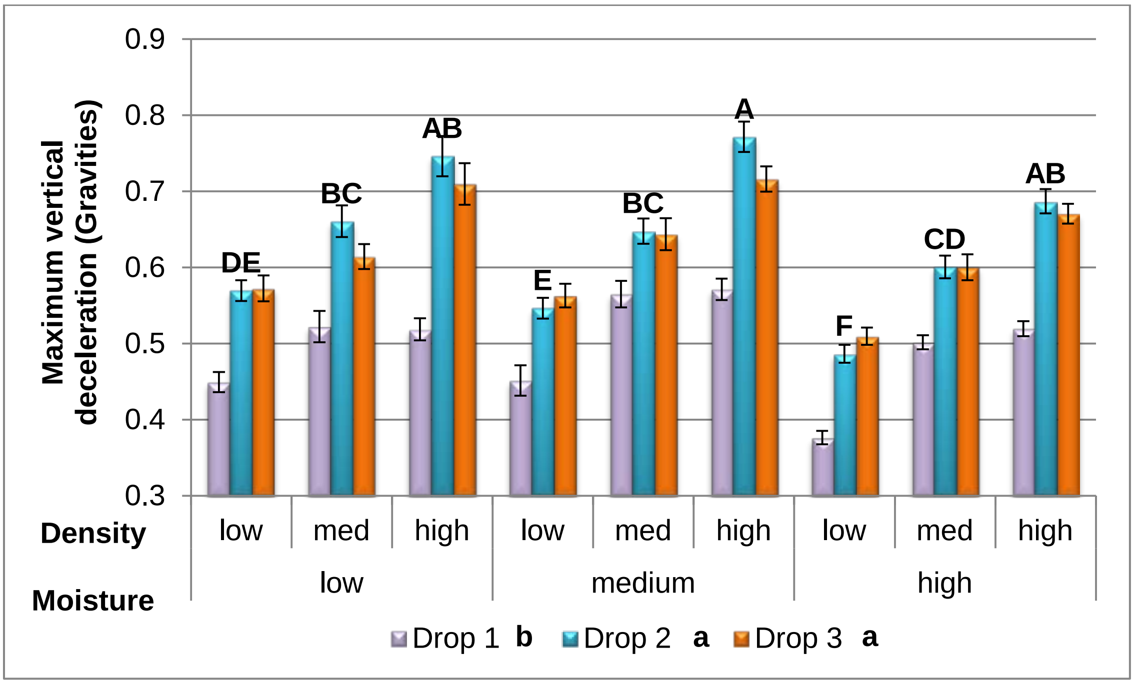

Figure 3.1.19 The mean (± SE) maximum vertical deceleration for the different drop numbers according to moisture content and bulk density. Different letters (A, B, C, D, E, F) denote significant (P<0.0001) differences between the combined treatments. Different letters (a, b) denote significant (P<0.0001) differences between drop numbers. The significant differences relate to log transformed data.

A significant interaction was found between the maximum vertical deceleration for the different moisture levels (*F* 2=9.33, P<0.0001) and the two drainage types at the high moisture level (Figure 3.1.20). There was no significant (*F* 2=1.17, P=0.312) interaction between surface density and drainage type. The maximum vertical deceleration range for all of the drops combined according to the different treatments is presented in figure 3.1.21.

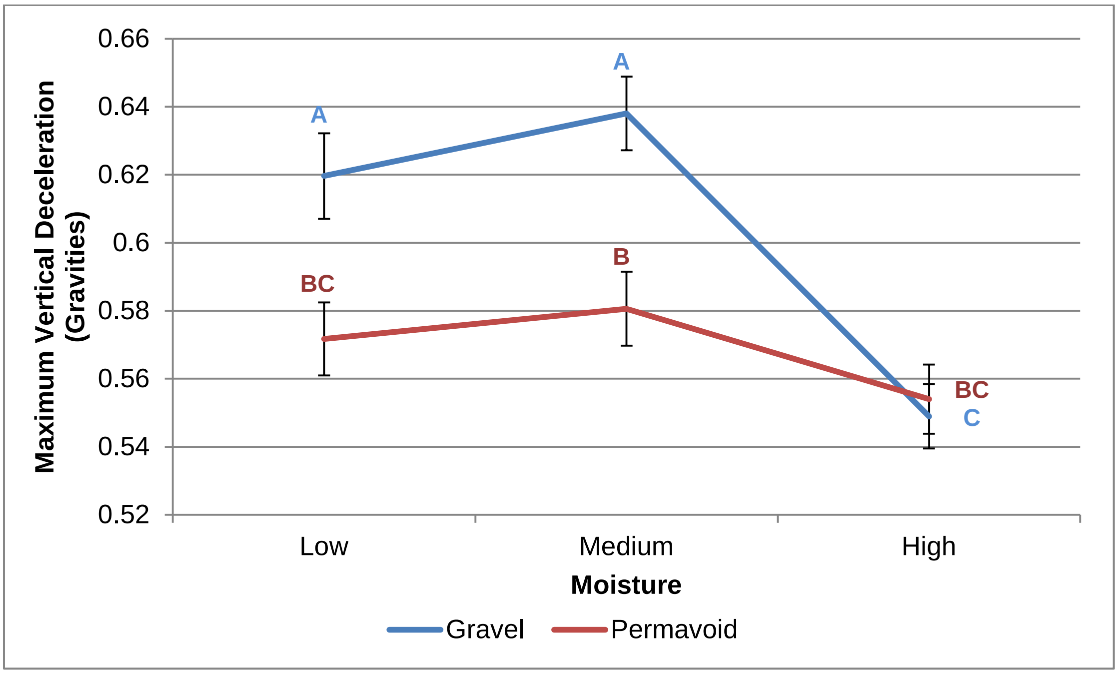

Figure 3.1.20 Interactions between mean (±SE) maximum vertical deceleration for moisture level and drainage type (Gravel =TB1-4, Permavoid =TB5-8). Different letters denote significant (*F* 5=22.22, P<0.0001) differences between the different moisture levels applied and drainage type. Letters underlined are shared with other test boxes.

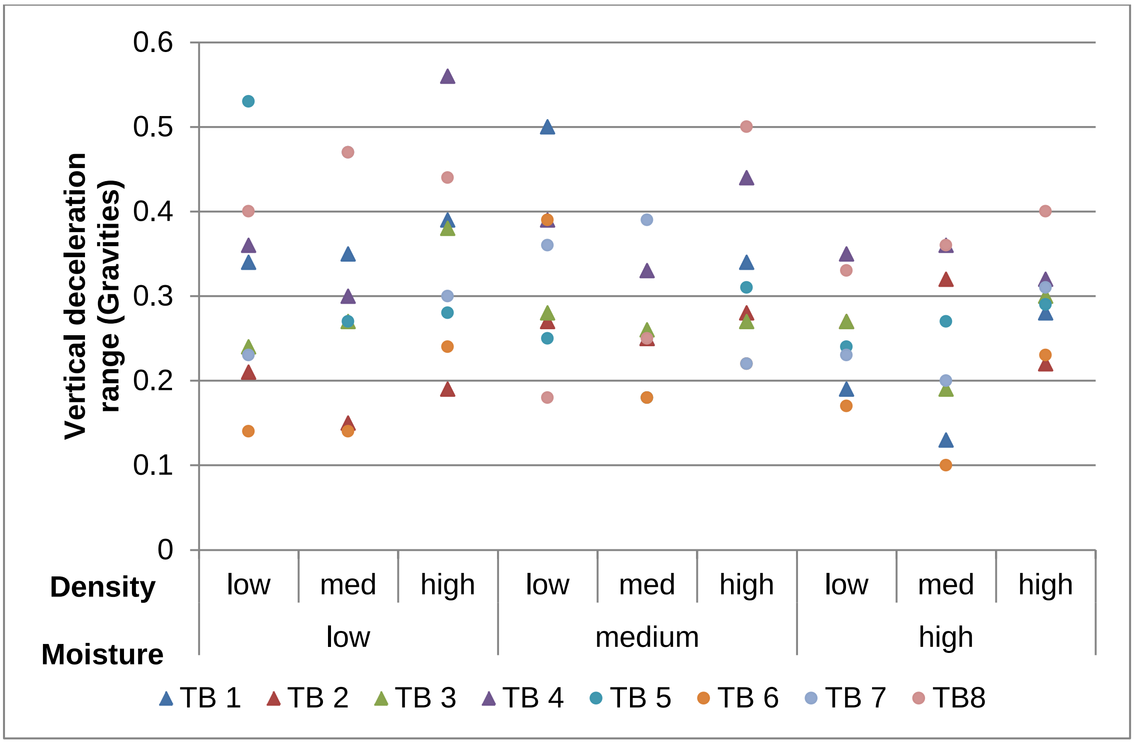

Figure 3.1.21 The range in maximum vertical deceleration values obtained from each of the test boxes for all of the treatments.

The correlation between the vertical deceleration and the surface hardness readings obtained with the Clegg Hammer was also studied. All of the drops were considered for the vertical deceleration and drop 2, 3 and 4 were considered for the Clegg Hammer readings to equalise column lengths and also because the first drop of the Clegg Hammer tested the immediate top layer. The values were then compared according to moisture content and bulk density where a significant (P<0.0001) positive correlation was found for all the treatments. The *R* value was higher for the high surface densities regardless of moisture content. The low moisture and high density combination showed the most significant (F1=108.72, P<0.0001) correlation, which was also when the surfaces were found to be the hardest (Figure 3.1.22).

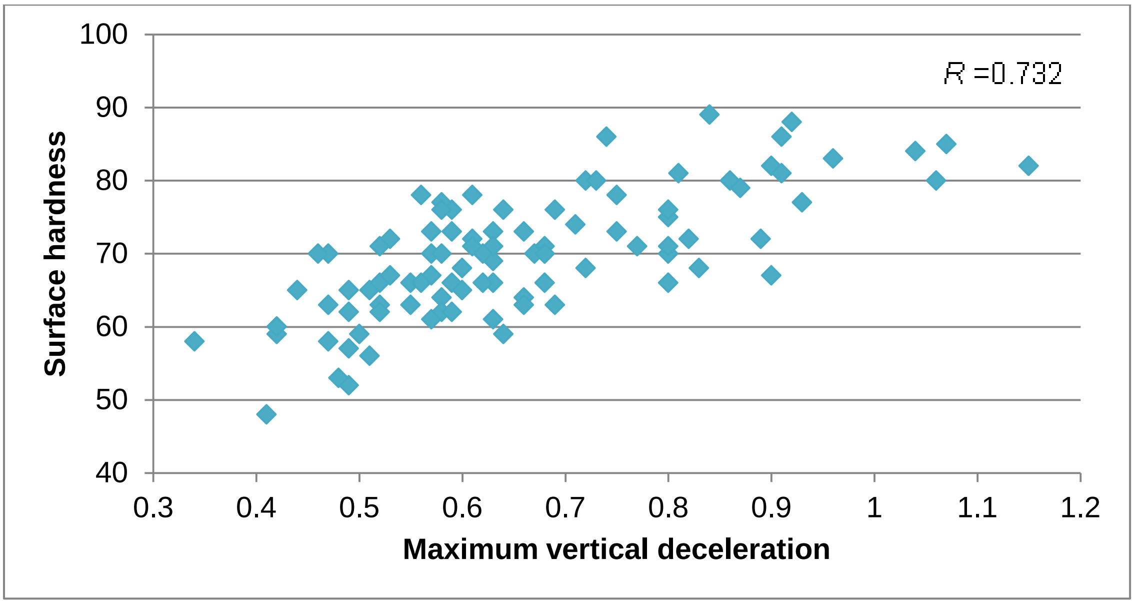

Figure 3.1.22 Correlation between surface hardness recorded with the Clegg Hammer (drop 2, 3, 4) and maximum vertical deceleration recorded with the Biomechanical Hoof Tester (drop 1, 2, 3) for the low moisture and high surface density.

3.1.8 Shear Modulus

The shear modulus data were non-normal and a Kruskal-Wallis test was used to determine any significant differences. There were significant (H 2=26.84, P<0.0001) differences between the different moisture levels where the shear modulus was lower when the surfaces had a low moisture content (Figure 3.1.23). There were also significant (H 2=31.76, P<0.0001) differences between the different bulk densities where the shear modulus reduced with increasing density (Figure 3.1.23). There were no significant (H 2=2.27, P=0.322) differences between the shear modulus values for the different drop numbers (Figure 3.1.23). The shear modulus range for all of the drops combined according to the different treatments is presented in figure 3.1.24.

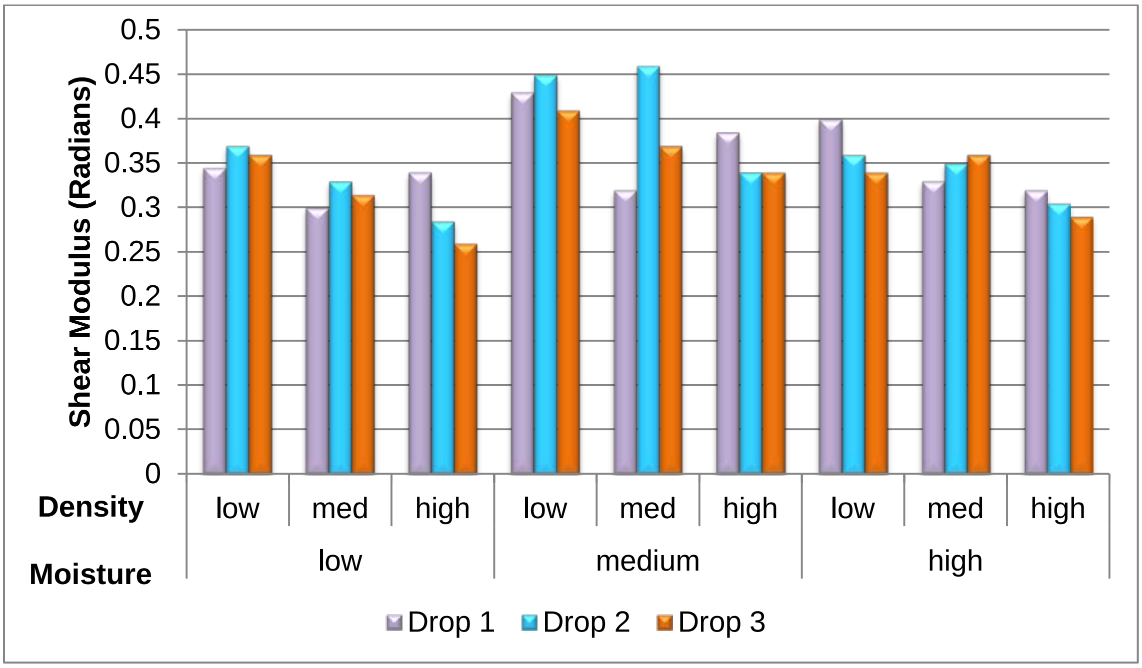

Figure 3.1.23 The median shear modulus of the surfaces for the different drop numbers according to moisture content and surface density.

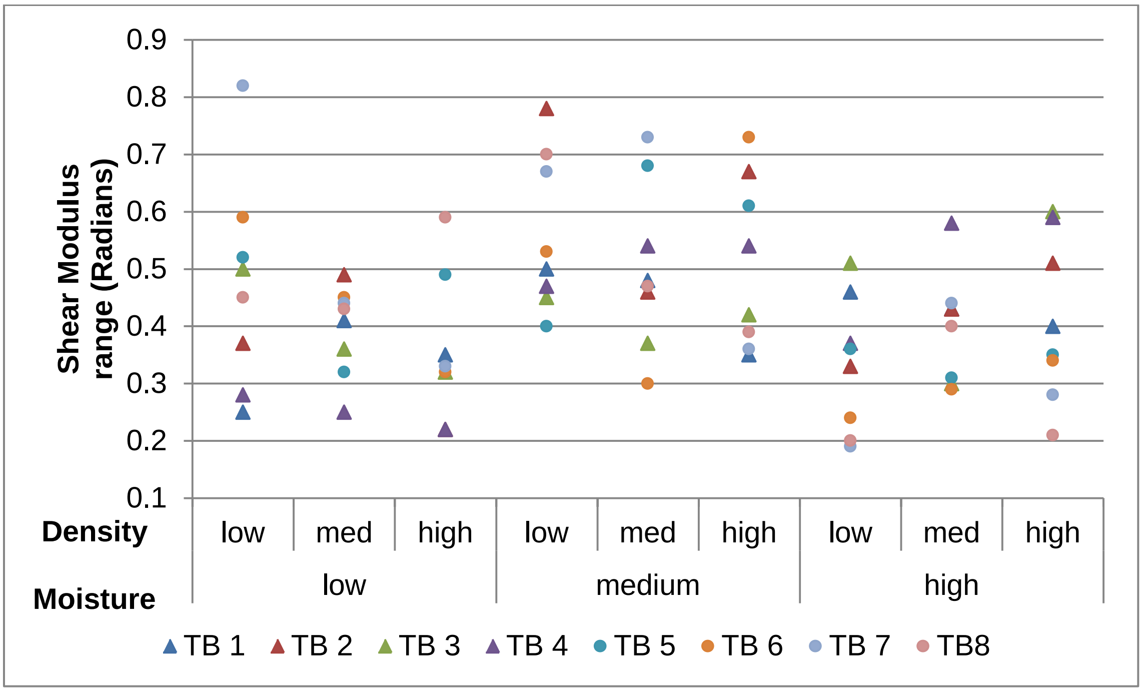

Figure 3.1.24 The range in shear modulus values obtained from each of the test boxes for all of the treatments.

3.1.8 Hysteresis

The hysteresis relates to the area under the load-displacement curve and reflects the energy lost on impact with the surface. The higher values were associated with higher forces and a smaller displacement, which represent a greater amount of energy lost on impact. The lower values were associated with lower forces and a higher displacement and represent a lower amount of energy lost on impact. The moisture level significantly (F 2=18.19, P<0.0001) affected the hysteresis where the low moisture content significantly (P<0.0001) increased the energy loss on impact in comparison to the medium and high moisture level. Surface density significantly (F 2=83.46, P<0.0001) altered the hysteresis where the low and medium densities significantly (P<0.0001) reduced energy loss when compared to the high density.

The hysteresis was considered when the moisture contents and bulk densities were combined (Figure 3.1.25). Significant (F 8=26.43, P<0.0001) differences were found between the different treatments where the surfaces with a high density and low moisture content generated the highest energy lost on impact (Figure 3.1.25). The lowest energy loss was created when the surfaces had a low or medium density with a medium or high moisture level. The energy loss on impact was significantly (F 2=70.53, P<0.0001) lower on drop one than drop two and three, which was the same finding with the maximum vertical deceleration and range of horizontal acceleration.

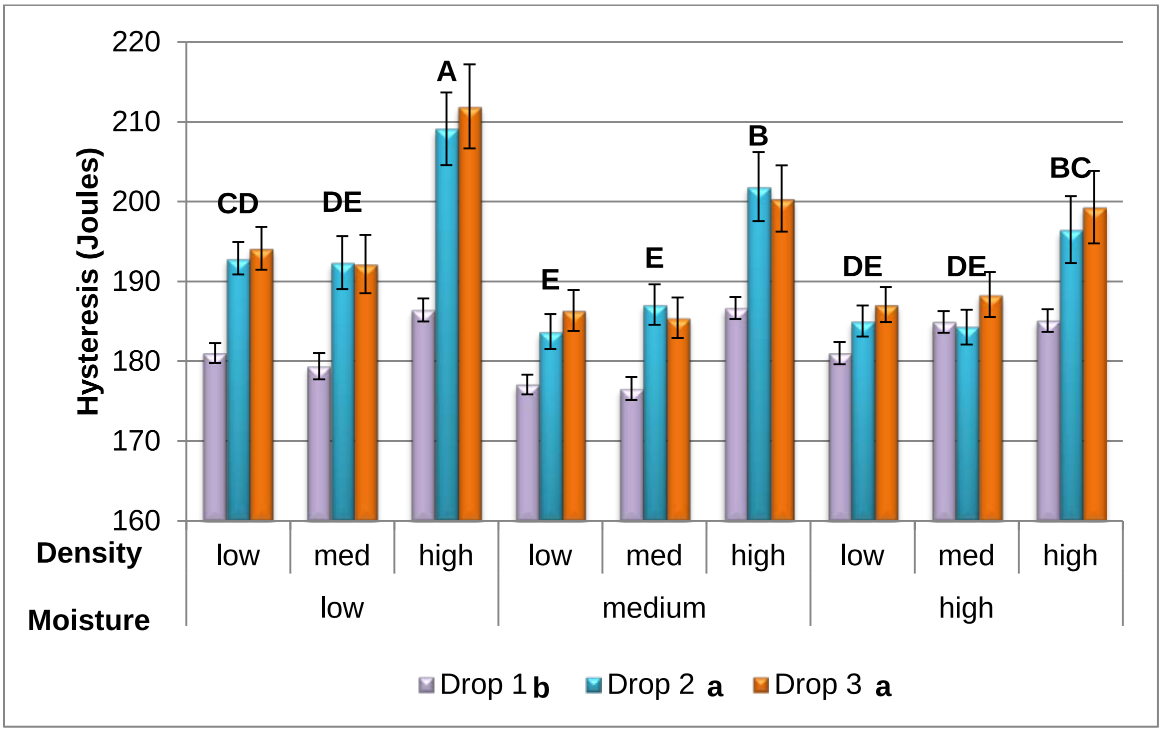

Figure 3.1.25 The mean (± SE) hysteresis for the different drop numbers according to moisture content and bulk density. Different letters (A, B, C, D, E) denote significant ($P<0.0001$) differences between the combined treatments. Different letters (a, b) denote significant ($P<0.0001$) differences between drop numbers.

Significant interactions were found between the hysteresis for the different moisture levels (F 14=7.02, $P<0.0001$) and test box number (Figure 3.1.26). Table 3.1.12 presents the mean (±SE) hysteresis according to moisture content and where the significant differences lie between the test boxes. Significant interactions were also found between the hysteresis for the different surface densities (F 14=11.16, $P<0.0001$) and test box number (Figure 3.1.27). Table 3.1.13 presents the mean (±SE) hysteresis according to bulk density and where the significant differences lie between the test boxes. It is important to note that the values recorded according to moisture content and bulk density are split according to the drainage type (TB 1-4: gravel, TB 5-8: permavoid) the surface is laid upon where the energy lost on impact was higher on gravel. The hysteresis recorded for the different surface densities (Figure 3.1.27) in the test boxes laid on permavoid (TB 5-8) appeared to be more consistent and suggests that drainage type rather than surface type was a greater influence on the results. The hysteresis range for all of the drops combined according to the different treatments is presented in figure 3.1.28. The surfaces with the highest hysteresis readings generally had the largest range.

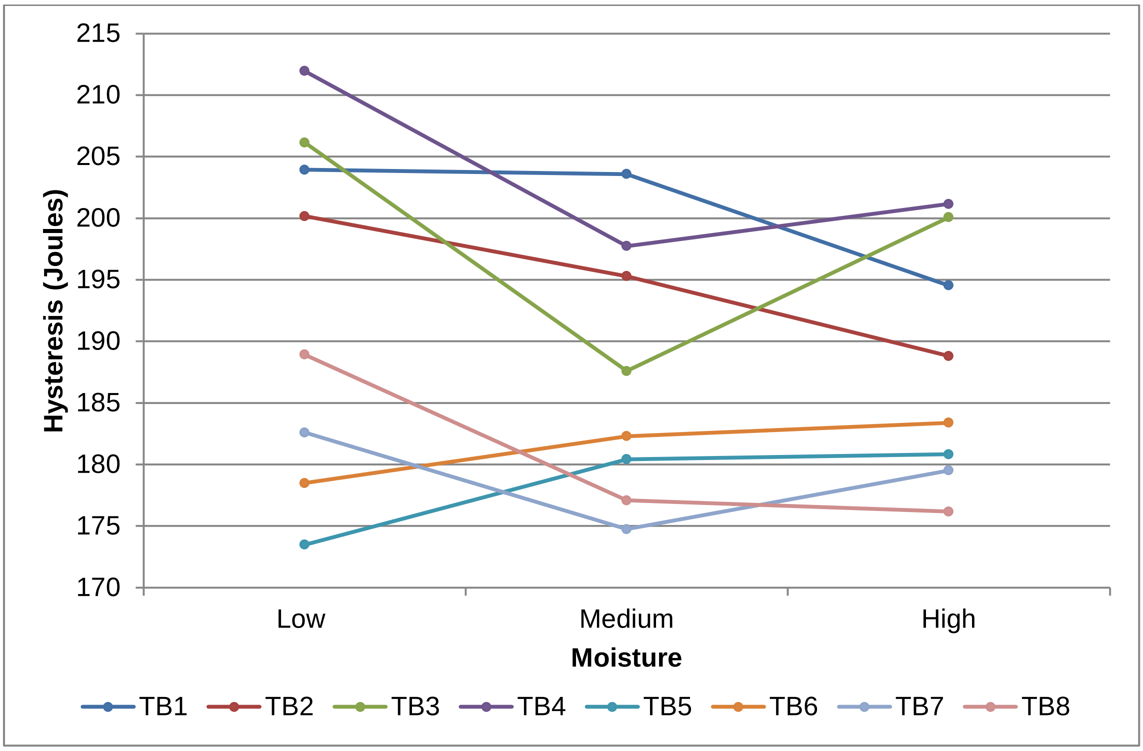

Figure 3.1.26 Interactions between mean hysteresis for moisture level and test box number.

Table 3.1.12 Mean (±SE) hysteresis according to test box and moisture content. The different letters denote significant (*F* 23=30.50, P<0.0001) differences between all the values.

Mean (±SE) Hysteresis								
Low Moisture (Joules)			Medium Moisture (Joules)			High Moisture (Joules)		
Box			**Box**			**Box**		
4	212 ± 4.44	**A**	**1**	203.6 ± 3.26	**ABC**	**4**	201.2 ± 4.22	**BC**
3	206.2 ± 3.29	**AB**	**4**	197.3 ± 3.4	**BCD**	**3**	200.1 ± 2.34	**BC**
1	203.9 ± 2.85	**ABC**	**2**	195.3 ± 2.88	**CD**	**1**	194.5 ± 1.96	**CD**
2	200.2 ± 3.29	**BC**	**3**	187.6 ± 2.37	**DEF**	**2**	188.8 ± 2.28	**DE**
8	188.9 ± 1.08	**DE**	**6**	182.3 ± 1.24	**EFG**	**6**	183.4 ± 1.18	**EFG**
7	182.6 ± 0.9	**EFG**	**5**	180.4 ± 1.57	**EFG**	**5**	180.8 ± 1.64	**EFG**
6	178.5 ± 1.19	**EFG**	**8**	177.1 ± 1.45	**FG**	**7**	179.5 ± 1.66	**EFG**
5	173.5 ± 1.74	**G**	**7**	174.7 ± 1.9	**G**	**8**	176.2 ± 1.7	**G**

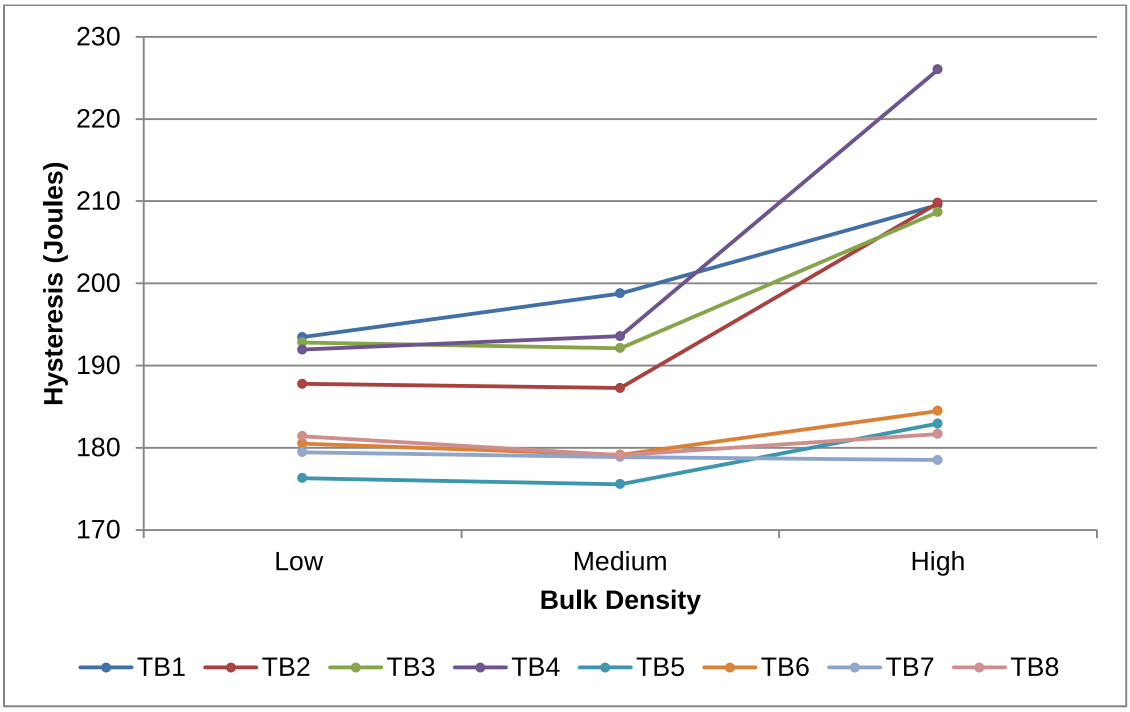

Figure 3.1.27 Interactions between mean hysteresis for the different bulk densities and test box number.

Table 3.1.13 Mean (±SE) hysteresis according to test box and bulk density (BD). The different letters denote significant (*F* 23=41.12, P<0.0001) differences between all the values.

Mean (±SE) Hysteresis								
Low BD (Joules)			Medium BD (Joules)			High BD (Joules)		
Box			**Box**			**Box**		
1	193.5 ± 2.03	**DEF**	**1**	198.8 ± 2.31	**CD**	**4**	226 ± 4.15	**A**
3	192.8 ± 1.83	**DEF**	**4**	193.6 ± 3.09	**DE**	**1**	209.6 ± 3.25	**B**
4	191.9 ± 2.17	**DEFG**	**3**	192.1 ± 2.75	**DEF**	**2**	209.8 ± 3.04	**B**
2	187.8 ± 2.08	**EFGH**	**2**	187.3 ± 1.86	**EFGH**	**3**	208.7 ± 3.32	**BC**
8	181.4 ± 1.76	**HI**	**6**	179.1 ± 1.5	**HI**	**6**	184.5 ± 0.91	**EFGHI**
6	180.5 ± 1.09	**HI**	**8**	179.1 ± 1.4	**HI**	**5**	182.9 ± 1.46	**FGHI**
7	179.5 ± 1.57	**HI**	**7**	178.9 ± 1.26	**HI**	**8**	181.7 ± 1.97	**GHI**
5	176.3 ± 1.59	**I**	**5**	175.6 ± 1.89	**I**	**7**	178.5 ± 1.98	**HI**

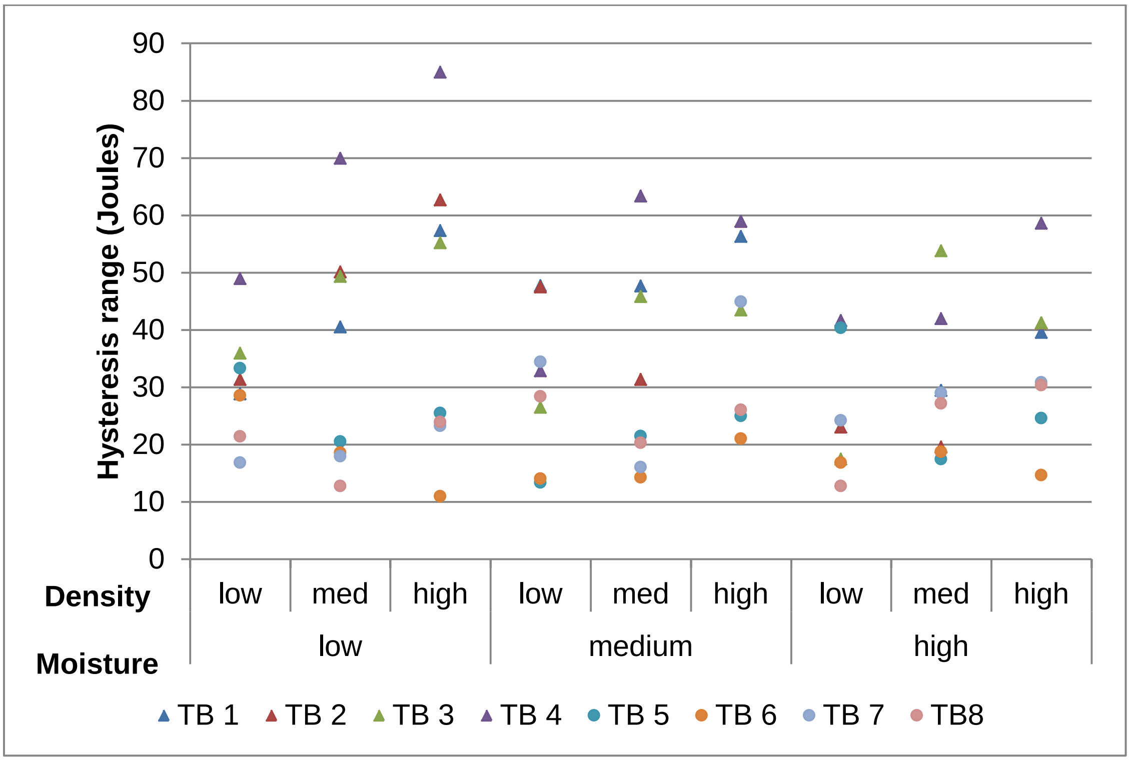

Figure 3.1.28 The range in hysteresis values obtained from each of the test boxes for all of the treatments.

The load-displacement curves for test box 1 (Sand and medium fibre and wax on gravel) and 5 (Sand and medium fibre and wax on permavoid) are shown in Figure 3.1.29. The readings were taken on the first drop of the Biomechanical Hoof Tester for the three surface densities and the three graphs demonstrate the effects of the different moisture contents (A, B, C). The curves appear to alter according to drainage type where the sand and medium fibre and wax surface on permavoid was associated with higher deformations and lower forces, creating a smaller area under the curve and therefore a lower amount of energy lost on impact. The same surface on gravel was associated with a larger area under the curve and demonstrates that a higher energy loss would occur on impact.

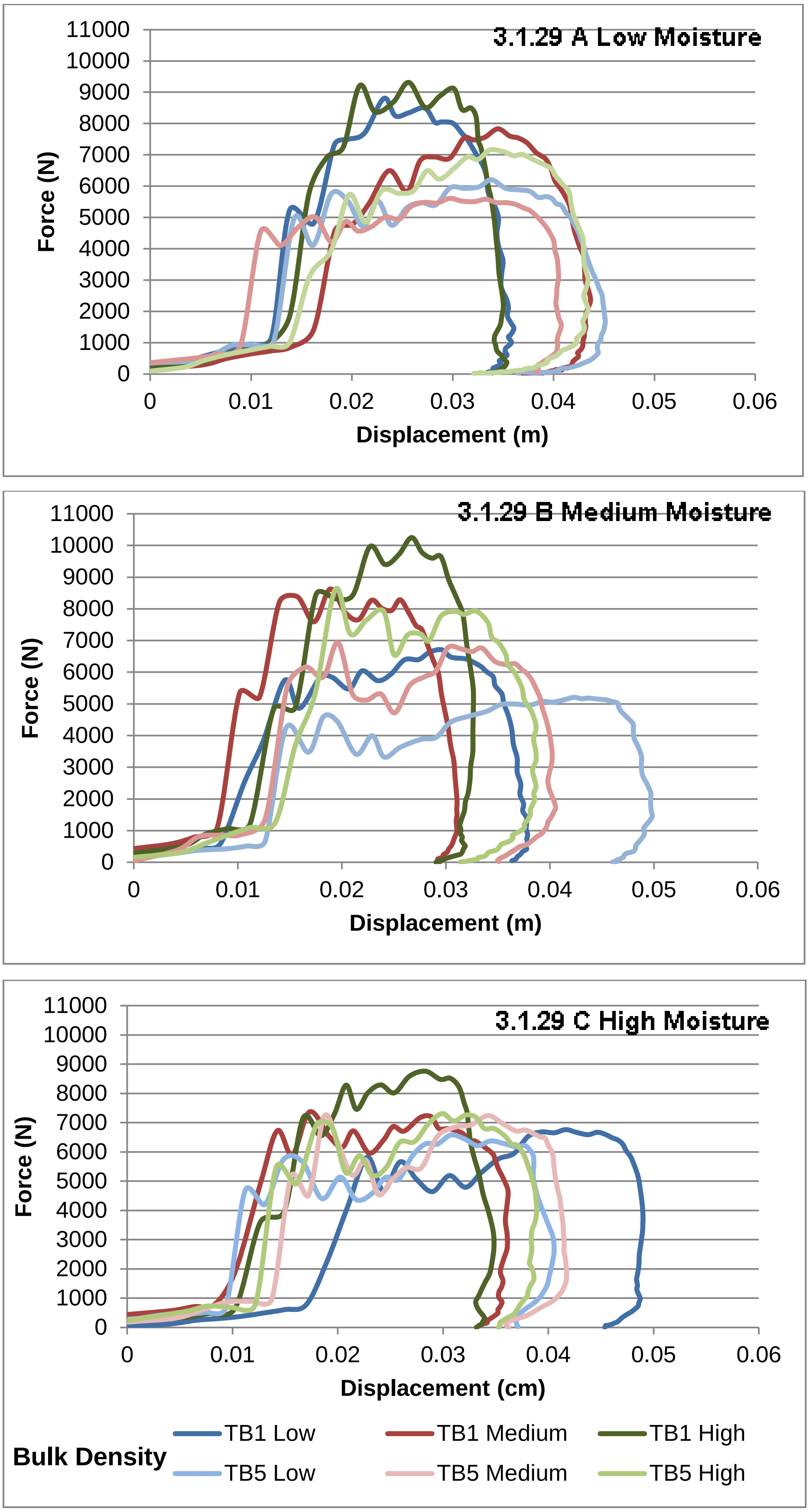

Figure 3.1.29 Load-displacement curves for TB1 and TB5 according to moisture content and bulk density recorded during the first drop of the Biomechanical Hoof Tester.

3.1.9 Summary of results

The main findings from the field based study according to treatment effects on the measured parameters are presented in table 3.1.14.

Table 3.1.14 Summary of the main findings for how the parameters were affected by the moisture contents and surface densities.

Parameter assessed	Main findings	Significance level
Torque Wrench		
Traction p. 45	-Increased with increasing moisture level. -The surface density did not significantly affect traction.	P<0.0001 P=0.684
Clegg Hammer		
Hardness p. 47	**Drop 1:** -The moisture level did not significantly affect surface hardness. -Medium and high bulk densities made the surface significantly harder in comparison to the surfaces with a low density. **Drop 4:** -The surfaces with a low moisture content were significantly harder than the surfaces under a medium and high moisture level. -The surfaces significantly increased in hardness with increasing bulk density. **Range from drop 1-4:** -Significantly greater for a low moisture level than medium and high moisture levels. -A greater range was recorded whilst the surfaces had a high density.	P=0.188 P<0.0001 P<0.0001 P<0.0001 P<0.0001 P<0.0001
Biomechanical Hoof Tester		
Maximum load p. 51	-A high and medium moisture level created significantly (P<0.0001) higher load values than the low moisture level. - The maximum load significantly increased with each increase in bulk density.	P<0.0001 P<0.0001
Load rate p. 55	-A medium moisture level generated a significantly higher load rate than the high moisture level which was significantly higher than the low moisture content. -The load rate significantly increased with each increase in bulk density.	P<0.0001 P<0.0001
Range of horizontal acceleration	-Significantly higher when the surfaces were under a medium moisture level than under a low and high moisture level.	P<0.0001

p. 58	-Significantly lower when the surfaces had a low density.	P=0.036
Maximum vertical deceleration p. 61	-Significantly higher on the surfaces with a low and medium moisture level than with a high moisture level. -Significantly increased with an increase in each bulk density.	P<0.0001 P<0.0001
Shear modulus (Kruskal-Wallis) p. 64	-Significantly lower when the surfaces had a low moisture level. -Shear modulus reduced with increasing bulk density.	P<0.0001 P<0.0001
Hysteresis p.66	-The low moisture level created significantly higher values than the medium and high moisture levels. -Low and medium surface densities generated significantly lower values than a high density.	P<0.0001 P<0.0001

3.2 Questionnaire based study

The responses (n=342) from the rider preference survey were split initially according to the discipline of the riders (Figure 3.2.1). Dressage is a discipline where the horse is ridden through a series of movements in order to test the obedience, suppleness and balance of the horse. Show jumping involves the horse being jumped over a series of fences or obstacles. Eventing has three phases which includes Dressage, Show jumping and a Cross Country phase where the horse must work over varying terrain and obstacles and requires stamina and confidence. The 'other' disciplines that have been specified in the survey included showing where the conformation and movement of the horse are assessed, endurance and general leisure riding. Not all of the answers were completed by some of the participants, possibly because they did not feel a question was relevant to them. For example a rider who does not compete may not have completed a question regarding competition surfaces. The responses for all the other questions that the particular respondents completed were considered.

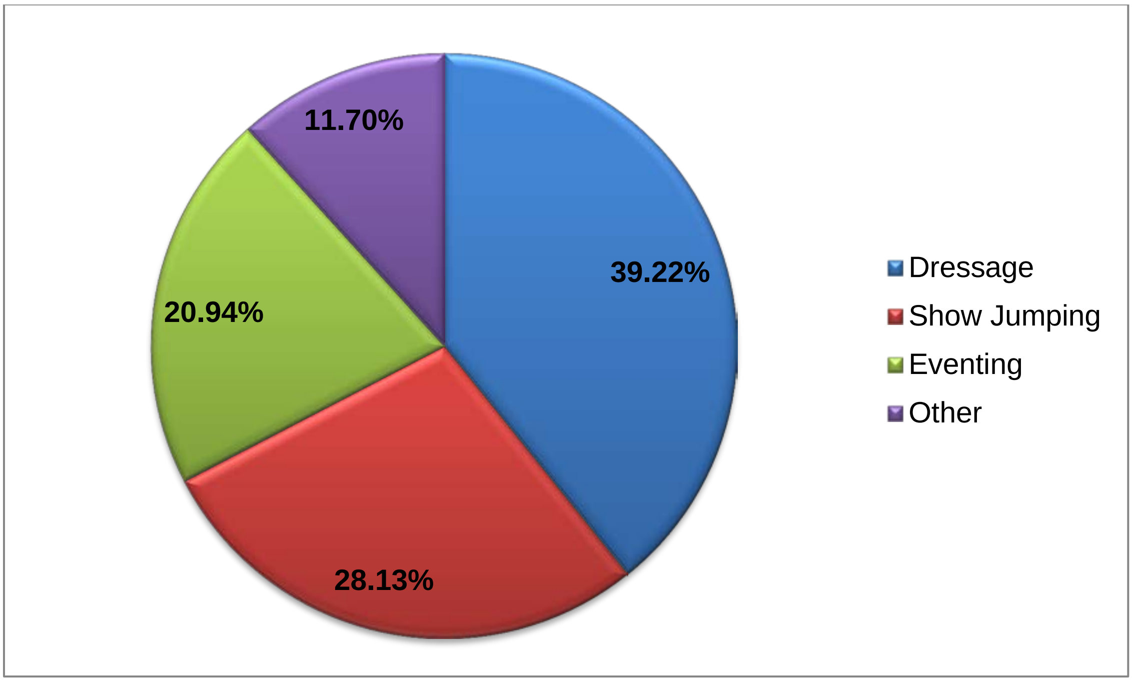

Figure 3.2.1 Proportion of riders from the different disciplines responding to the survey.

The riders were also categorised according to the level that their horse was competing at. The technical moves required at higher levels can be expected to have a greater degree of difficulty where a horse completing a canter pirouette or a course of 1.20 metre fences at professional level will be affected by the surface type more than a novice horse completing more basic movements. It is therefore assumed that riders competing at a higher level will be more aware on how a horse interacts with the surface (Murray *et al.*, 2010a). Table 3.2.1 shows how the different levels were determined. The proportion of riders at the different levels is a good reflection of the actual population where fewer riders make it to the higher levels. It is important to note that not all of the respondents provided information on the current level of competition of the horse however their responses were still included under a 'no level stated' category.

Table 3.2.1 Different level of riders and how they were categorised according to competition level.

Level	**Competition level**
1 (Novice) (n=52)	British Dressage – Intro and Prelim Unaffiliated Show Jumping, Eventing and Showing
2 (Intermediate) (n=90)	British Dressage - Novice and Elementary British Show Jumping - British Novice (90cm) British Eventing (BE) – BE80, BE90
3 (Advanced) (n=44)	British Dressage – Medium British Show Jumping – Discovery (1.00m) and Newcomers (1.10m) British Eventing (BE) – BE100 and Pre-novice County level Showing
4 (Professional) (n=21)	British Dressage – Advanced Medium – Grand Prix British Show Jumping – Foxhunter (1.20m) British Eventing (BE) – Novice and Intermediate, CCI 1* FEI 2**

3.2.1 Preferred amount of Traction

A question was constructed for the rider preference survey to establish the amount of traction that riders prefer. The discipline of the rider did not significantly (*F* 3=2.64, P=0.113) affect the choice of preferred amount of traction. A moderate and large amount of traction was the most popular choice, however there was no significant (X^2 8=0.7095, P>0.05) association between the level of rider and the preferred amount of traction selected (Figure 3.2.2). All of the riders who preferred a small amount of traction (n=3) also preferred a softer 'way of going'.

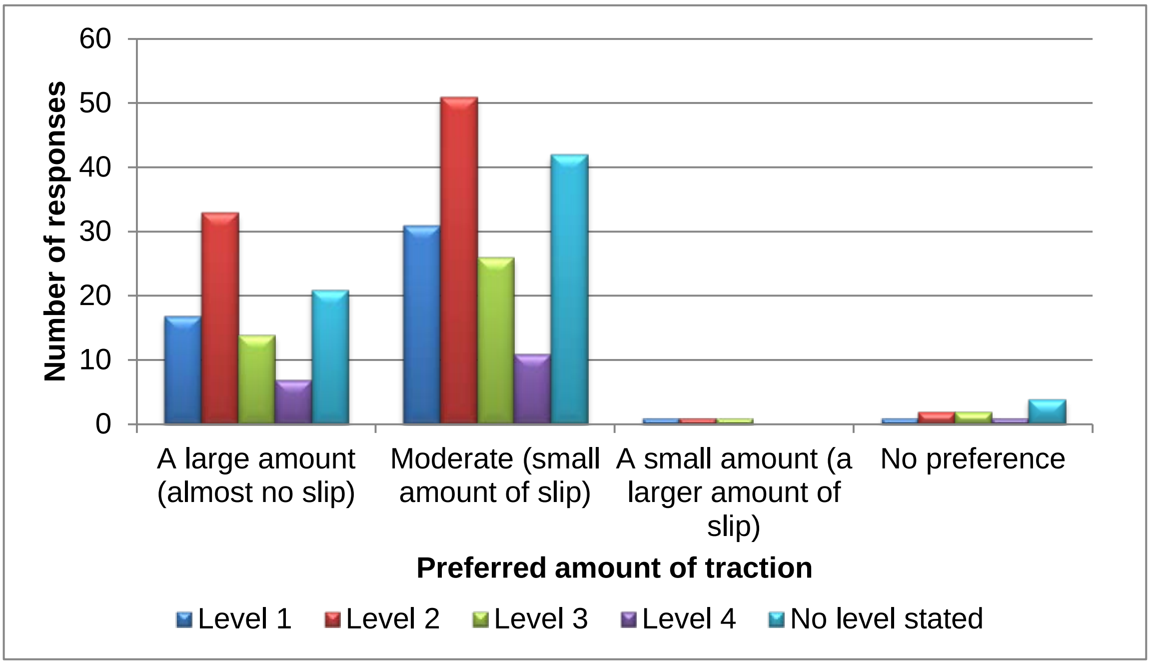

Figure 3.2.2 The number of responses relating to the preferred amount of traction a surface provides.

3.2.2 Preferred way of going

A question was constructed for the rider preference survey to establish the 'way of going' that riders prefer which relates to surface hardness that was measured in the test boxes during the field based study. The discipline of the rider did not have a significant (*F* 3=2.58, P=0.092) effect on the choice of preferred 'way of going'. The most popular preferences included 'firm with a bit of give' and 'a softer surface with a bit more give' however there was no significant (X^2 8=14.217, P>0.05) association between the answers selected and the different levels of rider (Figure 3.2.3). It is still important to note that more level 1 riders preferred a softer surface with a bit more give than a surface that is firm and offers a bit of give. The technical movements required of a level one horse and rider combination are expected to be easier than the other levels, suggesting that the way in which a softer surface affects performance is not yet apparent.

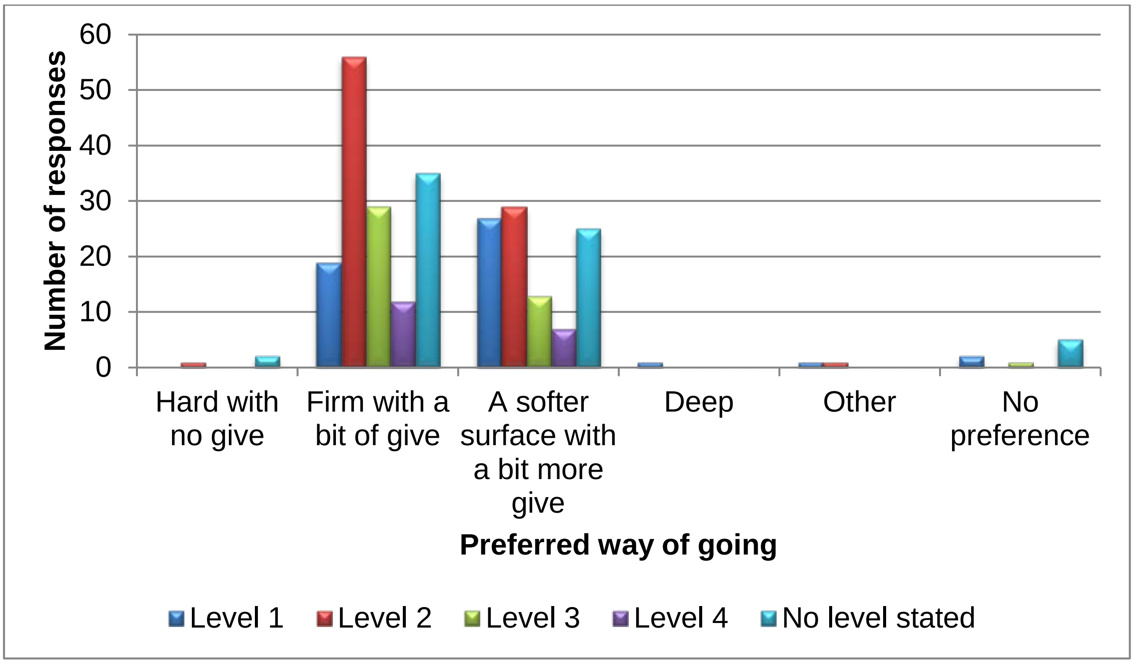

Figure 3.2.3 The number of responses relating to the preferred way of going a surface provides.

The participant that selected 'deep' (n=1) as a preferred way of going participates in Dressage and Eventing and appeared to train and compete on a wide variety of surfaces. The level one participant that selected 'other' (n=2) for their preferred way of going participates in Show Jumping and specified that they want the surface to 'bounce' with no give however they did not specify a preferred surface type to ride on. The other respondent selecting 'other' was considered to be a level 2 rider who trains and competes in Dressage and Show Jumping on a variety of surfaces and stated they prefer a firm surface that allows 'some longitudinal slip' and 'good going on grass is the best'.

3.2.3 Training, competition and preferred surfaces

A question was constructed for the rider preference survey to establish the surface types used for training and competition and also the preferred surface type to ride on (Figure 3.2.4).

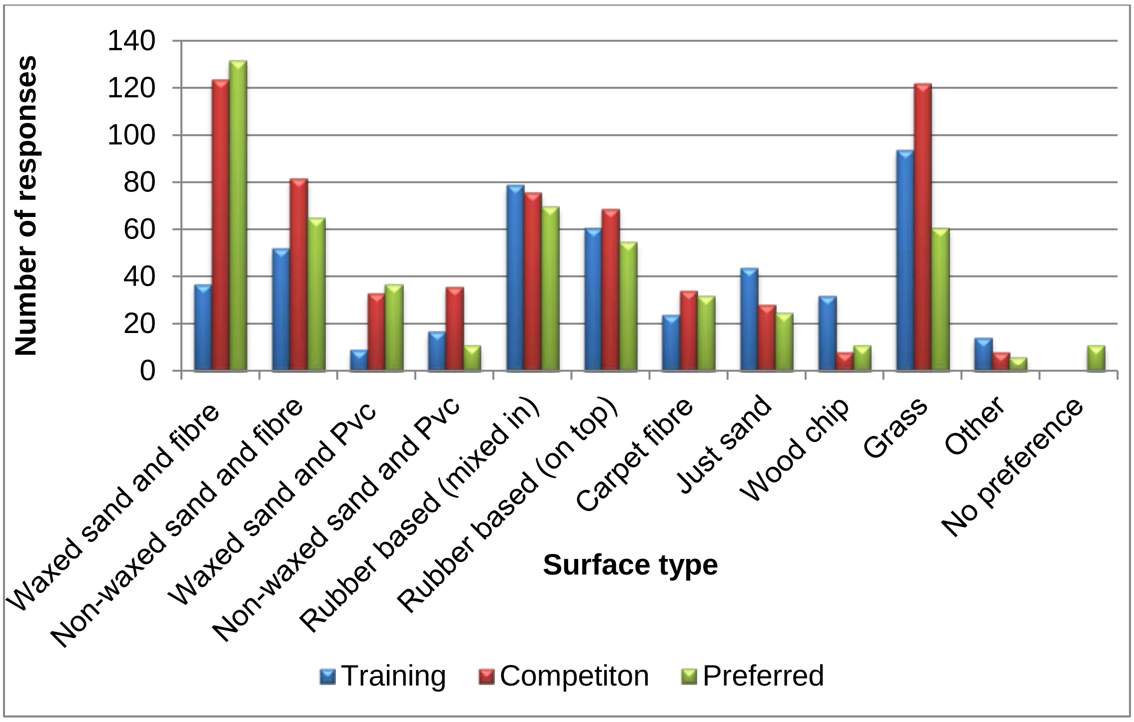

Figure 3.2.4 Training, competition and preferred surface types of the riders who responded to the survey.

There was a significant (X^2 22=157.754, P<0.0001) association between the surface type according to training, competition and preferred surface (Table 3.2.2).

Table 3.2.2 Chi-square test (X^2 22=157.754, P<0.0001) for the training, competition and preferred surface types. **Observed** and **expected** values and **chi-square contributions** are presented.

Surface	Training	Competition	Preferred	Total
Sand and Fibre with wax	37 84.84 26.976	124 113.61 0.950	132 94.55 14.832	293
Sand and Fibre non wax	52 57.62 0.548	82 77.16 0.304	65 64.22 0.010	199
Sand and PvC with wax	9 22.87 8.416	33 30.63 0.183	37 25.49 5.194	79
Sand and PvC non wax	17 18.53 0.127	36 24.82 5.041	11 20.65 4.512	64
Rubber based (mixed in)	79 65.15 2.944	76 87.24 1.449	70 72.61 0.094	225
Rubber based (on top)	61 53.57 1.031	69 71.73 0.104	55 59.70 0.370	185
Carpet fibre	24 26.06 0.163	34 34.90 0.023	32 29.04 0.301	90
Just sand	44 28.09 9.016	28 37.61 2.456	25 31.30 1.269	97
Wood chip	32 14.77 20.109	8 19.77 7.011	11 16.46 1.810	51
Grass	94 80.21 2.372	122 107.40 1.983	61 89.39 9.016	277
Other	14 8.11 4.283	8 10.86 0.752	6 9.04 1.020	28
No preference	0 3.19 3.185	0 4.27 4.265	11 3.55 15.637	11
Total	463	620	516	1599

The expected values for the non-waxed sand and fibre and carpet fibre surface were very similar to the observed values. The expected values for a waxed sand and fibre surface were higher for a training surface and lower for the competition and preferred surface which was a similar finding with the waxed sand and Polyvinyl chloride (PvC) granules surface. The non-waxed sand and PvC surface is used more often than expected for competition and a lower number of respondents preferred the surface than expected. The rubber based surfaces, just sand and woodchip are used for training more often than expected and the observed values for competition and preferred surface type are lower than expected. There was a similar finding with grass however it was expected that grass was used less for competition than the observations made. It is important to note however that the grass surface is the only natural occurring surface that riders could choose from and the remaining surface types were all synthetic. The higher response rate seen for some of the training surfaces may be affected by other factors such as finances available to construct the arena or other facilities available that encourage a particular client to use a yard.

The responses for 'other' surface types were looked at in more detail where some of the respondents stated they prefer to ride on surfaces manufactured by specific companies. Sand and flexiride which is carpet and foam laid on top of sand was also a preferred surface and one respondent stated that any surface that is not too deep or hard would be ideal. The 'other' types of training and competition surfaces included sand mixed with carpet fibre, cushion ride which is made from wood fibre, Martin Collins clopft pre-mixed surface, ash and flexi ride. The respondents that did not have a preferred surface type were predominantly riding at a level one standard according to the categories in table 3.2.1 (p.75).

There may be other factors that affect the preferred amount of traction, 'way of going' and surface type such as the training surfaces used and the way in which it may aid or hinder the performance of the horse. Figure 3.2.5 shows the number of riders who train indoors or outdoors and in which conditions the surface provides them with an optimal performance on their horse.

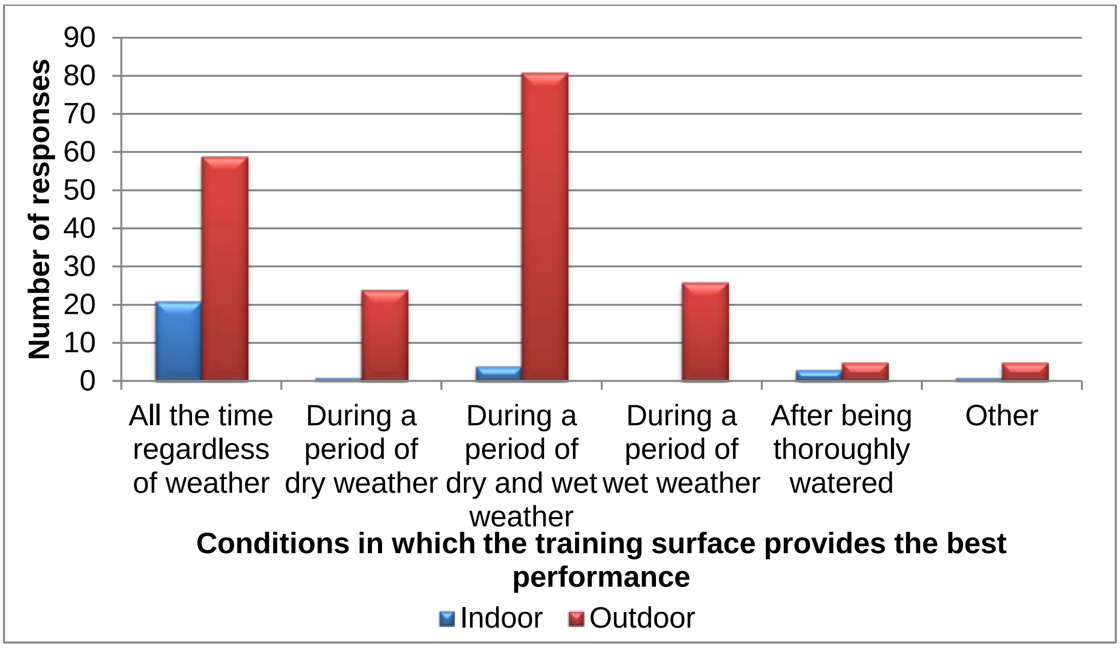

Figure 3.2.5 The number of riders who train indoors (n=30) or outdoors (n=200) and in which conditions the surface provides them with an optimal performance on their horse.

There was a significant (X^2 4=27.606, P<0.0001) association between the conditions in which an arena provides the best performance and whether the arena is indoor or outdoor (Table 3.2.3).

Table 3.2.3 Chi-square test (X^2 4=27.606, P<0.0001) for the conditions in which the indoor or outdoor training surface provides the best performance. **Observed** and **expected** values and **chi-square contributions** are presented.

Condition	Indoor	Outdoor	Total
All the time regardless of weather	21 10.36 10.936	59 69.64 1.626	80
During a period of dry weather	1 3.24 1.546	24 21.76 0.230	25
During a period of dry and wet weather	4 11 4.458	81 74 0.663	85
During a period of wet weather	0 3.37 3.366	26 22.63 0.501	26
After being thoroughly watered	3 1.04 3.725	5 6.96 0.554	8
Total	29	195	224

The expected values for indoor arenas providing the best performance all the time regardless of weather conditions and also when the arena had been thoroughly watered were lower than observed and were higher than observed for the outdoor arena. Expected values for the indoor arenas performing the best in a period of dry weather, in a period of dry and wet weather and in a period of wet weather were all higher than the observed values whereas the outdoor arenas exposed to the same conditions had higher values than expected. Environmental conditions are more easily controlled within an indoor arena in comparison to outdoor arenas however it can also pose a problem if the arena is not managed correctly and the moisture content fluctuates.

The respondents selected ‘other’ as an option for various reasons including arenas being affected by extremes in weather conditions such as snow or torrential rain and irregular maintenance but provide an optimal performance for their horse in all other conditions. A respondent stated their arena performed best when it was as wet as possible without standing water and another participant prefers their arena when it has been harrowed followed by rainfall.

3.2.4 Summary of Results

The main findings from the questionnaire based study according to rider preferences regarding surface type and properties are presented in table 3.2.4.

Table 3.2.4 Summary of questionnaire results.

Factor	**Most popular selection**
Traction	Moderate
Way of going	Firm with a bit of give
Surface type (training)	Grass (higher than expected)
Surface type (Competition)	Waxed sand and fibre surface (higher than expected)
Surface type (Preferred)	Waxed sand and fibre surface (higher than expected)
Conditions in which the surface performs best (indoor)	All the time regardless of weather
Conditions in which the surface performs best (outdoor)	During a period of dry and wet weather

4.0 DISCUSSION

The aims of the current study were to measure the effect of moisture, density and drainage on different equine sand and fibre arena surfaces and to establish the preferences of riders regarding surface properties. The alternative hypotheses were supported where a significant change in surface properties under different testing conditions and differences in the preferences of riders were found. The three different moisture contents and three surface densities caused significant alterations in the traction, hardness and measurements recorded with the Biomechanical Hoof Tester. There are indications that drainage layer and surface type also affected the readings obtained.

4.1 Traction

The different moisture contents significantly affected traction where traction increased with an increase in moisture level. There appeared to be a larger difference in the surface traction between the low and medium moisture contents than between the medium and high moisture contents, possibly because there was a larger difference between the actual moisture contents recorded for the low and medium moisture levels. Surface one (sand and medium fibre and wax) on permavoid (test box 5) showed the greatest rise in traction when the surfaces had a high moisture content.

At lower moisture contents, the sand particles move easily against each other, possibly resulting in the surface giving way more readily against the force of the Torque Wrench and implies why lower traction was recorded at lower moisture contents (Murray *et al.*, 2010a). Higher moisture contents increase the particle adherence and stability of the surface and that would explain why traction rose as moisture content increased in this study (Murray *et al.*, 2010a). The optimum water content for sand has been suggested to be between 8% and 17% where alterations in this have affected other properties such as the hardness and energy lost to the surface at hoof impact (Barrey *et al.*, 1991; Ratzlaff *et al.*, 1997).

Alterations in water content in this study have also demonstrated that it is possible to change the traction of a surface. Surface four (sand and low fibre and low wax) laid on the gravel (TB 4) had consistently higher traction values, which could be explained by a higher moisture content being measured on this combination throughout the study. The particle size of the surface will also affect the moisture retention of the surface where smaller particles have previously shown to hold more moisture (Baker and Firth, 2002). The particle size analysis performed during this study revealed that surface four and the sand and high fibre, no wax surface (surface 2) had a smaller particle size and could explain why surface four held a higher moisture content. Surface two was un-waxed, which will have affected the cohesive properties and may explain why higher moisture contents and traction values were not recorded on this substrate.

The surface density and sub base type did not have a significant effect on the traction. The higher degree of compaction reduced the pore spaces between the sand particles, reflected by a higher bulk density and traction values may have been expected to rise due to less movement between particles occurring. A medium and high compaction of a non-turfed basepath has yielded greater traction values in comparison to a low degree of compaction (Brosnan *et al.*, 2009). Moisture contents were measured but not controlled in the study by Brosnan *et al.* (2009). It was evident that moisture had a larger effect than bulk density during this study.

The traction of sand based greyhound tracks increased with increasing moisture content and density in a study by Baker and Firth (2002). The traction apparatus used was adapted to represent the dimensions of an average greyhound footprint and weighed 30kg, which is the same as the current study and could explain some of the similarities between the results. The effects of the base layer, which included gravel or sandy loam soil on traction were small and suggests that the top layer of the surface has the greatest impact on traction (Baker and Firth, 2002).

Traction has also shown a strong positive response to increasing the rate of Alginure, applied to a sand based football surface in a study by Canaway (1992). Alginure is a water retentive product and its addition increased traction values from 28Nm to 39Nm when the sports surface was being supplied with 25mm of water every week. An increase in moisture, also increased static friction of skinned infields used for baseball and softball in a study by Goodall *et al.* (2005) however, there were no clear trends between moisture content of different soils and traction values. The static friction and traction was measured using a similar apparatus to Canaway and Bell (1986) however it was modified with two plates that held four baseballs and steel baseball cleats respectively. The moisture contents used for the study included 10%, 14% and 18% and the bulk density of the different soils ranged from 1.57-1.70 Mg m^{-3} (Goodall *et al.*, 2005). The different soils tested included silt loam, loam, coarse sandy loam, loamy sand and loamy coarse sand, which had larger particle sizes than the surfaces used for this study. The traction values of 22.8-29.2Nm were also comparable to the higher values recorded during the current study and so the different particle sizes and apparatus used could be a relevant explanation for the variation in the trends between moisture and traction.

The traction of natural turf football pitches did not appear to alter according to moisture content, which varied from approximately 8% to 50% in a study by Baker (1991). The traction was measured using a 45 kg studded disc apparatus (Canaway and Bell, 1986) and varied from approximately 14 Nm to 51 Nm, which were considerably higher than the readings taken during this study. The heavier weight of the traction apparatus and the presence of sward will have been critical in raising the values. The traction was more dependent on the amount of ground cover than moisture content and Goodall *et al.* (2005) stated that plant root systems increase tensile strength and therefore surface traction.

Adding fibres to supplement the strength and quality of sand rootzones improved stability and traction when compared with unreinforced sand (Baker and Richards, 1995). The mean gravimetric moisture content varied from 3.2% to 15.9% however there was no clear relationship between traction and moisture content (Baker and Richards, 1995). A similar finding was obtained by Spring and Baker (2006) where turf strength increased with more polypropylene fibres, which was reflected by higher traction values however, no relationship again was identified between moisture (20.8-31.1%) and traction (41.4-64.7Nm). Surface type and composition appears to have a larger impact on the traction values recorded in studies on human sports surfaces in comparison to moisture content. There is no other published literature on the traction of equine arena surfaces measured using similar apparatus to this study, making comparisons between studies a challenge at present.

Moisture content, surface type and the weight and style of the traction apparatus have affected the values obtained in the different studies. The reliability between testers measuring traction was also a significant factor affecting the readings in a study by Twomey *et al.* (2011) where values ranged from 15.2Nm to 21.1Nm between users regardless of experience on the same area. The low reliability identified by Twomey *et al.* (2011) was also attributed to a lack of control and quantification of the speed in which the device is rotated and may have differed between the studies. The range may appear small however it was sufficient to cause significant differences between treatments in this study. The large variability could greatly alter the significance of recorded values and consequently the same tester was used to measure traction throughout this study.

Most of the riders who responded to the survey preferred a surface that offered a ‘moderate amount of traction (small amount of slip)’ and there was also a notable sample who preferred a ‘large amount of traction (almost no slip)’. The choice of the rider may have been affected by a recent competition where the horse performed well.

An insecure footing, offering little grip will negatively influence performance and affect the confidence of horse and rider, which explains why very few riders (n=3) selected a low amount of traction. A surface with too much traction conversely, will pose a serious risk to the horse in terms of injury (Gustås *et al.*, 2006a).

It is not possible to quantify the exact degree of slip that riders prefer from the results of this study however, it provides baseline information that can be considered in the future during arena construction and management. If a rider wishes to increase the grip or traction of a surface, they should initially consider increasing the moisture content or maintaining an optimum moisture content for that surface. It is important to note that there was a maximum mean moisture content of 21.19% and further studies must be carried out to establish the moisture content that generates the highest traction values before particle adherence is exceeded and begin to separate when saturated. The recommendation can only be made for waxed and unwaxed sand and fibre surfaces at present and future work on different equine arena surfaces would be valuable.

<u>4.2 Hardness</u>

Surface hardness was assessed by the first drop, fourth drop readings and difference between the respective drops of a 2.25 kg Clegg Hammer and were studied more closely. The first drop provided information on the top layer of the surface whereas the fourth drop values showed changes in the substrate once it had been compacted slightly with the 2.25 kg Hammer. It is important to consider the drop number of the Clegg Hammer separately because the treatments had a different effect according to whether the top layer or more compacted layers were being tested. Drop one values have shown to be misleading however, they are an important consideration when subsequent drops are also reported (Setterbo *et al.*, 2011).

The first drop readings were not significantly affected by the different moisture contents however a medium and high surface density created harder surfaces than the low density. The bulk density for the medium and high degree of compaction was similar and possibly supports why there was no change observed in surface hardness of the top layer between the respective densities. The hardness values increased with each drop of the Clegg Hammer, which was a similar finding to Setterbo *et al.* (2011) who compared a synthetic and dirt race track.

The fourth drop readings were significantly affected by the moisture content where the surfaces under a low moisture content were significantly harder, which demonstrates that moisture is a factor affecting hardness below the top layer of the surface. The fourth drop also identified an increase in hardness with each compaction level and suggests that this drop is more sensitive to detecting changes in surface density. The top layer of a maintained arena surface is generally compacted down after its first use and therefore the fourth drop readings potentially relate to surfaces that have been used post maintenance.

The drainage system has been shown to have a significant effect on surface hardness for all of the Clegg Hammer drops where TB 1-4 on gravel and TB 8 on permavoid were harder than TB 5-7 on permavoid. Surface four (sand and low fibre and low wax in TB 4 and 8) generated consistently higher hardness values regardless of drainage type, which is possibly related to having a higher bulk density compared to the other surfaces. The smaller particle size of surface four may have also improved the compactability of the surface and further supports why a higher bulk density was measured.

The addition of polypropylene and polyurethane fibres to winter games pitches has been shown to affect the ability of the surface to compact and significantly reduce hardness values (Spring and Baker, 2006). The sand and low fibre and low wax surface (surface four) in this study had a lower fibre rate than the other surfaces and the findings of Spring and Baker (2006) could support why this surface was associated with significantly higher hardness values. The presence of fibres made winter games pitches harder in a study by Baker and Richards (1995), which conflicts with this study and Spring and Baker (2006). The justification of Baker and Richards (1995) was a higher fibre content increased hydraulic conductivity making the surfaces more freely draining and low moisture levels more readily achievable. The surfaces that held a lower moisture content in this study also had a lower overall bulk density suggesting that a higher bulk density of a surface with a smaller proportion of fibres was more likely to increase hardness.

The bulk density of all the surfaces laid on gravel was also higher, indicating more compaction and may explain why higher surface hardness values were recorded on the sub-base. The maximum force applied to simulate a medium and high degree of compaction however, was the same for the surfaces laid on gravel and permavoid. The results suggest that the surfaces on permavoid are less susceptible to compaction possibly because the units deflect some of the force applied, creating a lower bulk density. The findings indicate that the drainage type and therefore the way in which the surfaces were compacted had the largest impact on the hardness readings.

Sand-based greyhound race surfaces were laid over gravel and soil in a study by Baker and Firth (2002) and were consistently harder on gravel, suggesting that the stiffness of the sub-base can alter the surface properties. Moisture content and bulk density also had a significant effect on the hardness where values increased as the sand became drier and denser, which supports the results of this study (Baker and Firth, 2002). The moisture contents measured were higher than this study however, the hardness readings obtained with a lighter (0.5 kg) Clegg Hammer were comparable. Hardness values were also very dependent on moisture content measured on a turf racetrack where the highest hardness values were obtained at lower moisture contents (Baker *et al.*, 1999). The moisture contents recorded however, were much higher, varying from 23-51%. It would be interesting to establish whether hardness continued to reduce at higher moisture contents prior to saturation in future investigations.

Moisture content was the primary influence on surface hardness of baseball skinned infields, which are sand based surfaces (Goodall *et al.*, 2005). Hardness decreased as moisture increased, which was a similar finding to this study at comparable moisture levels (10%, 14% and 18%). There were fewer differences in hardness readings according to the amount of compaction at higher moisture contents, which was attributed to the ability of the soils tested to drain freely (Goodall *et al.*, 2005). The amount of compaction was altered in a different manner with a vibratory plate compactor and the bulk density was recorded according to the surface type and soil particle size and could explain the different findings to this study.

Compaction treatments were applied with a Brinkman traffic simulator to three different baseball surfaces in a study by Brosnan *et al.* (2009) including a non-turfed basepath, natural turfgrass and synthetic turf with varying infill depths. Increasing levels of soil compaction yielded increases in surface hardness. Synthetic surface type also influenced the results where no infill generated the highest readings. The moisture content was not controlled and a quadratic relationship was found between plots receiving medium and high compaction treatments measuring lower in soil moisture content than plots receiving the low compaction treatment (Brosnan *et al.*, 2009). The increasing bulk density may have reduced the air space left for moisture to occupy and possibly reduced the moisture content, explaining why the hardness increased. The moisture content in this study did not significantly alter with a change in surface density, possibly because the surfaces were tested within three hours of water being applied. The low moisture and high compaction treatment combination however, did generate the highest hardness readings.

The riders who responded to the survey prefer a 'firm surface with a bit of give', which could be achieved by reducing the moisture content and increasing the amount of compaction depending on the original condition of the surface. The difference between the first and fourth drop was significantly higher during this combination in comparison to any of the other treatments. The difference between the drops provides information on the bulk density of the surface with successive drops of the Clegg Hammer and higher differences could pose a risk for injury because it would not supply a consistent footing for all horses working over that particular combination (Murray *et al.*, 2010b). The surfaces laid on permavoid, although associated with softer surfaces, significantly lowered the range in hardness values and suggests that a surface installed on a permavoid sub-base would provide a more uniform surface. The different levels of moisture, bulk density, drainage and surface type have all influenced the surface hardness in this study. There was a strong interdependence between the variables as suggested by Goodall *et al.* (2005), which poses a challenge that must be addressed when trying to create a consistent surface.

4.3 Maximum Load and Load rate

The maximum load recorded using the Biomechanical Hoof Tester was greater when the surfaces had a medium and high moisture content. Maximum load for three test boxes did however reduce from medium to high moisture contents. A study by Chateau *et al.* (2010) involved attaching a dynamometric horseshoe to the fore hoof of four trotter horses that were working on beach sand with varying moisture contents and depths (Firm wet sand:19%, Deep wet sand: 13.5%, Deep dry sand:3%). The results indicated that deep dry sand surfaces reduce the impact force in both vertical and horizontal directions during landing, which is comparable to this study (Chateau *et al.*, 2010). The observations made by Chateau *et al.* (2010) and during this study suggest that the distal limb is subjected to reduced mechanical stress during the initial part of the stance phase on drier surfaces.

A high correlation between vertical force and moisture content of a dirt race track was identified by Ratzlaff *et al.* (1997) where the trend line created an inverted bell shape with the lowest forces associated with a moderate moisture content (6-10%). The study involved testing the surface, which was mainly medium to coarse sand with six horses fitted with piezoelectric transducers and a track testing device at lower moisture contents (approximately 2%) than this study (6.83%), which could explain the different findings (Ratzlaff *et al.*, 1997). The results contradict the observations made by Chateau *et al.* (2010) at lower moisture contents however, the racing surfaces tested by Ratzlaff *et al.* (1997) were harrowed and more compact. Further research would be required to observe the maximum load on surfaces with a lower moisture content. The conditions under which testing took place were also more variable than for this study, which could have affected the results where humidity and temperature ranged from 24-91% and 37-94ºF respectively (Ratzlaff *et al.*, 1997).

The horse must experience a relatively high maximum load during the support phase of the stride in order for the cost of locomotion to be efficient (Figure 1.1 C, p.4). The maximum load was also considered in terms of body weights where one body weight approximately equates to a 500kg horse. The bodyweights recorded during the first drop of the Biomechanical Hoof Tester on surfaces with a low degree of compaction varied from 1.25 - 1.31 bodyweights whereas 2.18 – 2.27 bodyweights were recorded on the third drop when the surfaces had a medium or high moisture content and a high degree of compaction. The vertical force exerted by all four limbs of horses galloping at speeds of 15.5-16.5m/s was up to 93% body weight (Ratzlaff *et al*., 1997). The total forces recorded from the shoes fitted with piezoelectric transducers were less than the body weights of the horses (Ratzlaff *et al*., 1997). This was expected since forces exerted on the 3 transducers represented only a small proportion of the forces exerted on the entire hoof (Ratzlaff *et al*., 1997). It has also been stated that the maximum load at midstance may reach 2.4 times the bodyweight of the animal at a racing gallop (Witte *et al*., 2004). The exact maximum load for optimum performance before being too damaging to the horse is yet to be quantified however arena surfaces that create more than two bodyweights should be avoided.

The maximum load and loading rates measured using a Biomechanical Hoof Tester on a waxed sand and fibre surface were lower before watering, which is a routine management practice for some surfaces (Walker *et al.*, 2012). The exact moisture contents recorded were not presented in the conference proceedings and make detailed comparisons difficult. A longer stance duration was observed by Chateau *et al.* (2010) when horses worked over sand holding the lowest moisture content (3%) and demonstrates the load generated on impact being spread out, which may reduce the risk of concussive injuries. Low moisture had a negative impact on stride parameters however, possibly because the going was considered to be deep and may also increase the risk of strain related injuries (Chateau *et al.*, 2010). All of the surfaces in this study had a higher load rate when holding a medium moisture content although not always significant. Surface four (sand and low fibre and low wax) on gravel (TB 4) however, had consistently higher readings and increased linearly with each moisture level. The actual moisture contents recorded in test box four were significantly higher throughout the study, which was possibly due to the smaller particle size and suggests why a different trend was observed. Controlling moisture content in an outdoor arena in the United Kingdom poses a significant challenge and could explain why most riders who responded to the survey found their surfaces provided the best performance during periods of dry and wet weather. The moisture content is possibly being regulated by short periods of rain and dry weather and suggests that surface properties are being maintained. The findings may be of more use to indoor arena management at present.

Maximum load and loading rate increased as bulk density increased, a trend also shown by surface hardness. The increase in maximum load and load rate in conjunction with each drop of the synthetic hoof also demonstrates that as the surface becomes more compact with repeated use, a horse would be expected to experience higher loads over a shorter period of time. A study by Peterson and Mcilwraith (2008) has also found higher loads using the same apparatus in areas of high traffic and also where machinery is stored on a racetrack. A greater number of horses ridden on a surface per levelling or maintenance has been identified as a risk factor for lameness in a survey-based study by Murray *et al.* (2010a) where the maximum loads would be expected to rise with increase in use according to the results of this study.

The results obtained by Kai *et al.* (1999) postulate that the trajectory of the resultant forces acting on the hoof become more irregular on a surface that has already been used than on a harrowed surface and could explain the increased risk of lameness found by Murray *et al.* (2010a). Harrowing is considered to create a more consistent surface and also loosen the surface particles, which reduces compaction of predominantly the top surface layer (Ratzlaff *et al.*, 1997). The results from Kai *et al.* (1999) also indicated that the magnitude of vertical forces exerted on the hoof change step by step, as a consequence of changes in the thickness and consistency of the surface layer.

Horses have also been shown to make proprioceptive gait modifications in response to different surface properties and preparations (Northrop *et al.* 2012, Walker *et al.*, 2012). Harrowing the top layer of a waxed sand and fibre surface was sufficient to increase the metacarpophalangeal joint extension of horses at mid-stance when data for walk, trot and canter was grouped in comparison to rolling, which was attributed to a change in dynamic posture (Northrop *et al.* 2012). The fore and hindlimb fetlock angle at mid-stance on a different waxed sand and fibre surface was also significantly greater post harrowing in comparison to non-harrowed (Walker *et al.*, 2012). The effects of harrowing on the mechanical properties of a surface have also been studied using a Biomechanical Hoof Tester (Peterson and Mcilwraith, 2008;

Tranquille *et al.*, 2012). A significant reduction in maximum load on a race track (Peterson and Mcilwraith, 2008) and on a waxed sand and fibre arena surface (Tranquille *et al.*, 2012) was measured after harrowing.

The significance of training on different surface types to allow appropriate musculoskeletal adaptation and proprioceptive development has been highlighted (Murray *et al.*, 2010b; Walker *et al.*, 2012). A sand-based surface has shown to create a risk factor for injury when a horse is initially ridden on this type of substrate, which reduces as the horse is ridden on the surface more often (Murray *et al.*, 2010b). The findings illustrate the process of adaptation where initial exposure to a new surface could result in tissues experiencing different loads (Murray *et al.*, 2010b). It was clear from the results of the questionnaire based study that riders prefer specific surface properties and may strive to work their horses on a particular preparation. Training and competition surfaces used by a rider often vary and therefore, riders should be encouraged to train on surfaces with varying properties to reduce the incidence of lameness (Murray *et al.*, 2010a).

The drainage type had a significant impact on the maximum load and created a clear divide between the test boxes and the interactions with the moisture contents and surface densities. The surfaces laid on gravel generated higher maximum load values than the surfaces laid on permavoid, which was a similar observation to the hardness readings. The surfaces on gravel appeared to have a greater range in readings for each treatment and would potentially provide an inconsistent footing for a horse to work on. The surfaces in this study were prepared in the same manner for every test day by the same person and variability for the same treatment was still evident, suggesting that the range in surface properties must be considered.

The permavoid units conversely, have reduced the degree of variability on all of the surfaces and therefore is a significant factor to consider during arena construction. The Equaflow™ system that consists of permavoid units was used as a sub-base for the Olympic equestrian events in 2012 and high speed video footage by Centaur Biomechanics demonstrates that the surface did not impede upon any of the technical movements (Centaur Biomechanics, 2012). There was no objective kinematic analysis performed however, which would be beneficial to include in future work to establish any sub-base effects on equine biomechanics.

The load rates appeared to be affected more by the surface type rather than drainage type. The loading rates have been shown to alter according to surface type in other studies using horses fitted with a dynamometric horseshoe (Robin *et al.*, 2009) and also accelerometers, which were used in conjunction with a force plate buried under different surfaces (Gustås *et al.*, 2006a). The stance duration of horses did not alter on a crushed sand track when compared to a waxed sand track however the higher magnitude of forces on impact with the harder crushed sand track increased the loading rate (Robin *et al.*, 2009). Higher loading rates have also been recorded on a harder sandpaper surface in comparison to a 1cm layer of sand (Gustås *et al.*, 2006a). The harder surfaces were associated with higher loading rates because they increase the shockwaves transmitting through the limb, resulting in a higher mechanical stress and risk for injury (Gustås *et al.*, 2006a). The sand and low fibre and low wax surface (surface four) in this study was the hardest and also associated with higher loading rates.

4.4 Horizontal and Vertical Acceleration

The maximum vertical and the horizontal accelerations are suggested to be major determinants of the mechanical stress the distal limb is subjected to at impact, making the variables an essential consideration (Gustås *et al.*, 2006b). The range of horizontal acceleration measured with the Biomechanical Hoof Tester was higher when the surfaces had a medium moisture content. The values were also lower when the surfaces had a low density. Deep beach sand has also created lower horizontal accelerations when the hoof impacted the ground when compared to more compact, firm beach sand (Chateau *et al.*, 2010). The horizontal and vertical acceleration on drop two and three were statistically non different however the drop two values were generally higher, which was also observed with the maximum vertical deceleration.

The maximum vertical deceleration values were higher when the surfaces had a low and medium moisture content and showed a relatively strong correlation to the Clegg Hammer readings. As surface hardness increased, the Clegg Hammer readings became a stronger indicator of the maximum vertical deceleration a horse would be expected to experience on impact due to the stronger positive correlation found between the two variables. Maximum peak deceleration, considered to be an indicator of impact shock has been recorded previously where harder surfaces such as asphalt and gravel created a larger impact shock in comparison to softer surfaces such as sawdust and sand (Barrey *et al.*, 1991). A rapid deceleration increases the risk of excessive strain application and therefore the potential injury to the leg (Parkin *et al.* 2004).

The importance of cushioning surfaces to reduce the risk of injury in horses was recognised over two decades ago by Drevemo and Hjertén (1991). The authors tested a harness race track with compacted woodchips under a surface layer and gravel. A drop hammer system revealed that deceleration on impact was lower and impact time was longer on a race track with a woodchip sub-base. The presence of woodchips was considered to improve the shock absorbing properties and reduce compaction of the surface layers. The use of woodchips as a sub-base would not be a viable long term option for equestrian arenas however, due to the organic matter degrading over time.

The maximum vertical deceleration reduced as the surface density reduced and the surfaces on permavoid generated lower decelerations on impact except at a high moisture content. The difference between the vertical deceleration on surfaces laid on permavoid and gravel was greater when the surfaces were harder, which could be due to the permavoid units absorbing some of the impact force. Accelerometer data has previously revealed that deep surfaces with lower moisture contents of 3% and 13.5% reduce the amplitude of shock on impact by 59% when compared to firm wet sand (19%) (Chateau *et al.*, 2010). The high vertical decelerations measured when the surfaces held a low moisture content during this study does not support the findings of Chateau *et al.* (2010). The deeper surfaces were less compact and could explain the lower decelerations recorded on impact and it is unfortunate that firm dry sand was not tested. There may have been more movement between the particles of the deep surfaces in comparison to the synthetic surfaces used for this study, which are manufactured in such a way to improve cohesive properties to support the load of the horse. The surface should allow some slide during the initial impact however, once loaded vertically by the weight of the horse, the surface should provide adequate carrying capacity and shear resistance to support the hoof without failure during the propulsive phase (Peterson *et al.*, 2008).

The shear modulus data was calculated using the range of horizontal acceleration and vertical deceleration. It is important to note that care must be taken when interpreting the shear modulus because the values are affected by the magnitude of both the vertical and horizontal acceleration data. A surface may be associated with similar accelerations in the horizontal and vertical plane where higher accelerations will be associated with a greater risk of injury however, the shear modulus will not always reflect this.

The medium moisture content in this study created the highest shear modulus and could be explained by a higher range of horizontal acceleration at the same level. A higher vertical deceleration was also recorded at the same moisture level. This however did not appear to be sufficient to reduce the shear modulus. It was evident that the low moisture level generated the lowest shear modulus values and appear to be in conjunction with higher vertical deceleration readings. The range of horizontal acceleration was relatively low at this moisture content, which also suggests why the shear modulus remained low. The horizontal acceleration is affected by the shear characteristics of the surface and could explain why the lowest traction values were also recorded at a low moisture content.

The shear strength is considered to reach a maximum at a particular water content with lower shear strength at both lower and higher moisture contents, which relates to the findings of this study (Bridge et al., 2010; Malmgren *et al.*, 1994; Peterson *et al.*, 2012). The shear modulus of the surfaces with a high moisture level in this study had begun to reduce and it would be of interest to establish if the parameter continues to reduce at higher moisture contents in future work. Moderate shear strength is ideal for disciplines such as dressage and show jumping because it allows the toe to penetrate the surface but offers a firm resistance to enable the horse to push off from the surface without strain. The riders who responded to the survey preferred a moderate amount of traction, which is also dependent upon the shear characteristics of a surface.

The percentage of moisture at which the maximum shear modulus occurs is highly dependent on surface type and age because as waxed synthetic surfaces wear with use and maintenance, it is likely that the sensitivity to moisture will increase as the hydrophobic coating is lost from the surface (Bridge et al., 2010; Peterson *et al.*, 2012). The moisture content is also dependent on the particle size distribution and surface composition (Barrey *et al.*, 1991; Bridge *et al.*, 2010). The moisture retaining ability must be assessed for each material and then monitored for change over time.

The different moisture contents in this study appeared to have a greater influence on the shear modulus in comparison with the surface densities. The effects of compaction were still significant however, where shear modulus values reduced with increasing bulk density. The shear angle measured on a waxed sand and fibre surface increased after harrowing and supports the findings of this study at a low degree of compaction (Tranquille *et al.*, 2012). The shear angle of a dirt race track appeared to be less sensitive to maintenance and therefore the degree of compaction in a study by Peterson and Mcilwraith (2008). The different surface types between studies and different climates under which testing took place may explain the varied findings.

4.5 Surface damping

The surface damping and energy lost on impact with the surfaces in this study was reflected by the hysteresis values measured with the Biomechanical Hoof Tester. The equine limb is subject to the same loading and displacement pattern during the hoof-surface interaction however, the damping characteristics of the surface will alter the magnitude of the respective variables. A similar pattern for these parameters potentially reduce the risk of injury because if the limb of a horse was loaded in a completely different manner on a different surface, soft tissue adaptation and gait modifications would be more difficult (Reiser *et al.*, 2000).

The hysteresis and therefore the energy lost on impact were higher when the surfaces had a low moisture content and high bulk density. The high surface densities for the other moisture contents also generated higher energy loss on impact than the other treatment combinations, which is comparable to the surface hardness and maximum vertical deceleration readings. The sub-base appeared to be key in affecting the hysteresis in comparison to surface type where a lower energy loss was recorded on permavoid than on gravel for all of the surfaces under all of the treatments. There were fewer differences between the treatment effects on hysteresis for the surfaces laid on permavoid, indicating a better surface consistency. The hysteresis fluctuated more on the surfaces laid on gravel according to the treatment and the range in values recorded for the same treatment was generally greater, especially when the energy loss on impact was higher.

The same amount of potential energy was inputted to the collision with all the surfaces on each drop of the Biomechanical Hoof Tester and it was the surface properties that affected the energy lost to the surface on impact. The higher energy loss was associated with a low deformation and a high load on impact, showing a higher load bearing capacity. A surface with a high load bearing capacity would be desirable however, more energy was lost on impact because the surfaces were supporting a higher load for the same energy input and suggests that the impact shock was also higher (Gustås *et al.*, 2006a).

The higher energy loss recorded for all of the surfaces with a low moisture content when compared to the other moisture levels were also associated with lower deformations and higher forces. The lower deformation supports why a higher surface hardness and maximum vertical deceleration were also recorded when the surfaces had a low moisture content. The higher energy loss at a mean low moisture content of 6.87% can also be supported by a different study investigating the effects of watering and harrowing a race track (Ratzlaff *et al.*, 1997). The highest energy loss was observed at a moisture content of approximately 7%, which progressively reduced as moisture content increased to 14% (Ratzlaff *et al.*, 1997). A different relationship was found between the energy loss and deceleration generated on impact however, where lower decelerations were associated with a greater energy loss (Ratzlaff *et al.*, 1997). The lower drop height of the track testing device of 12.7 cm will have greatly reduced the deceleration recorded on impact and may explain the different findings (Ratzlaff *et al.*, 1997).

The lower energy loss was created by a high deformation and lower load on impact, suggesting that a lower ground reaction force was created on the surfaces laid on permavoid and coincides with the lower maximum load values also recorded on permavoid. Horses galloping at speeds between 15.5 and 16.5 m/sec have also exhibited a decrease in force as energy lost to the surface reduced (Ratzlaff *et al.*, 1997). Lower energy loss and maximum loads were also recorded in this study when the surfaces had a low density. The findings of Ratzlaff *et al.* (1997) can support the relationship between forces and energy loss recorded on the different drainage type and for the different surface densities however, the relationship between energy loss and forces did not continue for the different moisture contents. The low moisture content regardless of surface density created the highest energy loss, which was similar to Ratzlaff *et al.* (1997) however, it was also associated with the lowest maximum load, which conflicts with Ratzlaff *et al.* (1997). The dirt race track tested by Ratzlaff *et al.* (1997) had a larger particle size, which has previously shown to affect surface properties (Baker and Firth, 2002; Barrey *et al.*, 1991). The surfaces used in this study also contained fibres, the presence of which has also affected the surface properties (Baker and Richards, 1995) and could explain the differences observed. Different surfaces have shown different surface damping properties in another study where a dirt surface was able to support a higher impact force under lower deformations and therefore improved the load bearing capacity in comparison to a synthetic surface (Setterbo *et al.*, 2011). Further investigations are clearly warranted to understand not only the relationship between the energy lost to the surface and maximum load on impact but also how the particle size and surface composition affects the respective variables.

The higher surface deformation associated with a lower energy loss demonstrates a form of damping on impact, which may be beneficial to the horse in terms of injury reduction as long as the surface does not continue to deform during the support phase of the stride (Ratzlaff *et al.*, 1997). After the support phase of the stride, the surfaces are unloaded, during which, the surfaces appeared to recover in a different manner according to the drainage type they were laid upon. The deformation generally did not alter during unloading of surfaces laid on gravel whereas the deformation of surfaces on permavoid continued to reduce. The reducing deformation suggests that there is some surface rebound after impact and may explain why a lower amount of energy was lost to the surface. The difference between deformation of the surface under load and when the load is removed represents rebound energy of the surface according to Ratzlaff *et al.* (1997).

The time between the end of the force peak created on impact and the start of the next smaller rebound peak provided information on the timing of energy rebounding from the surface. A longer time represented a larger energy rebound and therefore a lower amount of energy lost to the surface on impact. The surfaces on permavoid were associated with a lower amount of energy loss and a longer time between the termination of the impact peak and onset of the rebound peak, which generally varied from 0.09-0.14 seconds. A shorter time of 0.06-0.09 seconds was observed on the surfaces laid on gravel.

The timing of the rebound energy is critical and if it occurs immediately after the support phase, some of the energy may be returned to the hoof. The stance duration of the horse alters according to the speed and gait and creates another factor to consider when establishing the time elapsed for the rebounded energy to aid the propulsive stage of the stride (just before break over, Figure 1.1 D, p.4) (Gustås *et al.*, 2006b). A shorter stance duration is associated with faster speeds and therefore the time required after impact before the energy is rebounded to aid locomotion should be shorter. The energy returned to the track testing device used in a different study occurred within 0.06 seconds following the initial impact while the metacarpophalangeal joint was still maximally extended during the support phase of the stride (Figure1.1 C, p.4) (Ratzlaff *et al.*, 1997). Energy rebound occurring at this time would not assist in elevating the foot from the ground and may represent additional force that must be dissipated by the limbs and increase the risk of injury (Ratzlaff *et al.*, 1997). The shorter time elapsed before energy rebounded on the surfaces laid on gravel in this study could therefore be of detriment to the horse and surfaces laid on permavoid may be more desirable.

Research into human-surface interaction loading using the artificial athlete and other models simulating limb impact has demonstrated that the athlete adapts to the surface at, or soon after first contact on a change of surface properties by changing leg stiffness (Fleming, 2011; Mcmahon and Greene, 1979; Nigg and Yeadon, 1987).

Alterations in the gait and posture of the horse have also been identified in horses when working over different preparations and surfaces (Chateau *et al.*, 2009; Northrop *et al.*, 2012; Walker *et al.*, 2012). The findings suggest that it may be possible for a horse to adapt to a surface associated with a faster energy rebound time after impact. Future work should not only consider the energy lost to the surface on impact but also raise awareness of how the rebounded energy may affect equine kinematics.

4.6 Ideal treatment combinations

The traction hardness, loading rate, horizontal and vertical accelerations and therefore shear modulus are potential indicators of injury risk whereas the maximum load on impact and hysteresis values, which reflect the energy loss on impact with the surface are possible indicators of performance. All of the variables showed significant alterations to the different treatments and may be of significance to the horse and rider population. A surface with a moderate to high amount of traction that was preferred by the respondents of the survey is created by increasing the moisture content of the surface. Traction also altered according to surface type where the sand and low fibre and low wax surface (surface 4) generated the highest values and could be an alternative consideration to increasing the moisture content of the surface.

A firmer surface in terms of hardness and vertical deceleration that is preferred by the respondents of the survey is created by changing the moisture content to 6.83% and would allow the horse to work effectively over the surface rather than through it. The greater vertical decelerations are associated with a larger impact shock on impact however and may pose a risk for injury (Barrey *et al.*, 1991; Parkin *et al.*, 2004). The results from this study indicate lower maximum loads would be experienced at a low moisture content and may negatively affect performance because the horse is having to work harder and expend more energy to achieve the same movement. The loading rate at the same moisture level however, was lower and may not pose a significant risk.

The higher maximum loads and lower energy loss measured when the surfaces had a medium (17.45%) or high (21.19%) moisture content may be more favourable for the performance of the horse. The surface is able to support a higher load and is possibly performing better elastically due to the lower amount of energy being lost and therefore improves locomotion efficiency. The medium moisture content however, was also associated with a higher range of horizontal acceleration, which will increase the vibrational characteristics in the horizontal plane during the hoof-surface interaction. A high vibration frequency would increase the horizontal and vertical strains within the distal limb and increase the risk of injury (Barrey *et al.*, 1991). The range in horizontal acceleration significantly reduced again at the high moisture level and suggests that a surface with a higher moisture content would provide optimal performance properties yet reduce the risk of injury caused by a large magnitude of vibration on impact.

The rider must be educated that a firmer surface does not always provide the correct footing according to the results of this study. A firmer footing was achieved with a lower moisture content however the properties considered to be performance indicators were more desirable at higher moisture contents. All of the parameters generally increased with an increase in bulk density with the exception of the shear modulus being higher when the surfaces had a low density. Traction was also not affected by the different bulk densities. The surface density could be raised to provide a 'firm surface with a bit of give'. The highest degree of compaction would not be desirable with regards to performance or safety however, according to the results of this study. The higher vertical decelerations in conjunction with higher maximum loads and energy lost to the surface would create a large risk factor for injury. The particle size of the surface will affect the amount of compaction possible as shown in this study and previously and would need to be considered for other equestrian surface types in future studies (Barrey *et al.*, 1991). The findings from other studies suggest that surface density can be reduced in practice through harrowing and increased through working more horses over a surface (Kai *et al.*, 1999; Peterson and Mcilwraith, 2008; Ratzlaff *et al.*, 1997).

The drainage types also had a large impact on the surface properties. The maximum load was lower on the surfaces laid on permavoid suggesting a decrease in locomotion efficiency. The energy lost on impact with these surfaces however, was significantly lower than when the surfaces were laid on gravel and is potentially an important consideration for arena construction. The maximum vertical deceleration recorded on impact is an indicator of impact shock and was also lower on permavoid except when the surfaces had a high moisture content.

It is important to acknowledge that the bulk density of the surfaces on permavoid was lower indicating a lower amount of compaction and could explain the lower readings. The maximum force applied and how many strikes made with the 'tamper' was quantified rather than the degree of compaction because the researchers were trying to simulate the same conditions over all surfaces. It is proposed that if the surfaces laid on permavoid were exposed to a higher degree of force during compaction, the results may have been more comparable. The shock absorbing properties of the permavoid sub-base may prove to reduce the risk of injury. The surfaces would need to be tested again in future on permavoid and gravel with the same bulk density to confirm this suggestion. The longevity of the permavoid units is also yet to be established however and must be considered in the future due to the large financial costs involved with arena construction.

When considering the optimum conditions for arenas, a high surface density should be avoided potentially through regular maintenance. The surfaces with a medium (17.45%) to high (21.19%) moisture content when laid on permavoid had the most favourable results when taking into account all of the measured parameters. The low moisture content (6.83%) was associated with a higher energy loss and a greater impact shock on impact with the surface especially when the surfaces had a high bulk density, thereby increasing the risk of injury. The lower maximum loads measured at this moisture content would also have a negative effect on performance. It would be of interest to establish in future work whether the indicators of injury risk and performance continue to rise or decline when greater ranges in moisture contents are used.

The higher values recorded were generally associated with a greater range and surface properties with a larger variation may not provide a consistent footing. The permavoid sub-base was not only implicated with more favourable properties but generally reduced the variation of the surface properties and should support the use of the sub-base when constructing new arenas. The surface types also created different properties due to the variation in composition. The sand and low fibre and low wax surface (surface four on gravel) laid on gravel generated the highest readings for all the properties and treatments throughout the study. The higher values have been attributed to the low fibre rate enabling more compaction and the low percentage of wax, which provided sufficient cohesive properties to reduce the air space within the surface. A horse working over such a combination would be at great risk of injury due to the low damping characteristics in conjunction with higher maximum loads and loading rates, which would increase the force that must be dissipated by the limbs. The sand and high fibre and non-wax surface (surface 2) generally showed the lowest readings for all the variables. The surface is not necessarily safer due to low maximum loads and loading rates because the horse may have to work harder to achieve the same movements on such a composition. The findings may be expected because the largest range in surface composition was evident between surface two and four. The sand and medium fibre (9.6%) and wax (3.08%) (surface 1) and sand and high fibre (12.36%) and wax (3.8%) surface (surface 3) generally appeared in the mid- range for all the surface properties. Discrete differences in composition, especially in the wax content did not appear to have a significant impact on the two surfaces.

The study has demonstrated that surface properties can be accurately measured using the Torque Wrench, Clegg Hammer and Biomechanical Hoof Tester and should support the use of the mechanical equipment in future investigations. The results were similar to other studies testing arena surfaces and demonstrate that the test boxes used were a reliable simulation of an actual arena (Tranquille *et al.*, 2012; Walker *et al.*, 2012). A new arena surface takes a period of time to settle once laid and it would be of interest to establish the effects of the treatments on a settled, established surface in the future.

The potential exists to produce a surface that can enhance performance as well as safety according to the results from this study, which has been done for humans previously (McMahon and Greene 1979). Horses fitted with devices to quantify the hoof-surface interaction have shown in other studies that individual (Chateau *et al.*, 2009; Ratzlaff *et al.*, 1997; Robin *et al.*, 2009) and inter-breed differences (Thomason and Peterson, 2008) exist in the responses shown to a particular surface type. The locomotion pattern will also be influenced by the conformation and shoeing technique used for each horse, affecting the angles and loads experienced on impact (Chateau *et al.*, 2010; Johnston and Back 2006). A lot of variation between factors is created when using horses and it is important to develop baseline data using mechanical devices to establish and understand true treatment effects initially. Kinematic analysis using a large sample of horses would be beneficial to consider in the future and has the potential to further verify data recorded using mechanical testing equipment (Peterson *et al.*, 2008).

4.7 Conclusion

A complex combination of factors must be considered when preparing an arena to enhance performance and reduce the risk of injury. Management for one arena will differ to another due to different locations, climate and possible surface composition if materials have been sourced from different manufacturers. The study has considered combinations of not only moisture and bulk densities that potentially enhance performance and reduce the risk of injury but also drainage type and surface composition. The permavoid units have created favourable surface properties and demonstrate that sub-base is a large factor to consider during arena construction. It must be acknowledged that rider preferences should not be the sole concern and should only inform the preparation of a surface that is deemed suitable for equestrian use. Awareness must be raised on how factors such as moisture and the degree of compaction affect the hoof-surface interaction so the industry can strive for a surface that combines performance and consistency with safety. Research performed in the future should include investigating the surface properties under a larger range of moisture contents and of other surface types in common use.

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6.0 Appendices

Appendix I

University of Central Lancashire

UNIVERSITY OF CENTRAL LANCASHIRE
Ethics Committee Application Form

PLEASE NOTE THAT ONLY ELECTRONIC SUBMISSION IS ACCEPTED

This application form is to be used to seek approval from one of the four University Research Ethics Committees (BAHSS; BuSH; PSYSOC & STEM). Where this document refers to 'Ethics Committee' this denotes BAHSS (ADP; ESS; IsLands; JOMEC; Languages; Law; LBS; Archaeology[Forensic]); BuSH (Built[BNE]; STTO & Health) PSYSOC (Psychology & Social Work) & STEM (CEPS; Dentistry & Medicine; Environment[BNE]; Forensic[except Archaeology]; Pharmacy).

If you are unsure whether your activity requires ethical approval please complete an UCLan Ethics Checklist. If the proposed activity involves animals, you should not use this form. Please contact the Graduate Research Office – roffice@uclan.ac.uk – for further details.

Please read the Guidance Notes before completing the form. Please provide all information requested and justify where appropriate. Use as much space as you need – the sections expand as you type. Click on box or circle to select relevant option (e.g. type or Yes/No) and click on 'grey oblong shape' to start typing for the free text entry questions. Each question on this form has instructions on how to answer that particular question. In addition links to relevant documents (e.g. templates, examples, etc.) and further guidelines are available in the Guidance Notes which can also be access from the question by clicking on appropriate question number.

Your application needs to be filled in electronically and emailed to roffice@uclan.ac.uk. Please insert in the subject line of your email the acronym of the committee that needs to deal with your application. Committee acronyms are BAHSS, BuSH, PSYSOC or STEM – see Appendix 1, at the back of this form, for list of Schools associated with each ethics committee.

If this application relates to an activity which has previously been approved by one of the UCLan Ethics Committees, please supply the corresponding reference number(s) from your decision letter(s).

Section 1
DETAILS OF PROJECT

All applicants must complete Section 1

1.1 **Project Type:**

☐ Staff Research ☐ Commercial Project	☑ Master by Research ☐ MPhil Research ☐ PhD Research ☐ Professional Doctorate	☐ Taught MSc/MA Research ☐ Undergrad Research

1.2 **Principal Investigator:**

Name	School	Email
Sarah Jane Hobbs	Sport, Tourism & the Outdoors	SJHobbs1@uclan.ac.uk

1.3 **Other Researchers / Student:**

Name	School	Email
Charlotte Brigden	Sport, Tourism & The Outdoors	CBrigden@myerscough.ac.uk
Jamie Martin	Sport, Tourism & The Outdoors	JMartin@myerscough.ac.uk
Danielle Holt	Sport, Tourism & The Outdoors	DHolt@myerscough.ac.uk

1.4 **Project Title:**

Analysis of Equestrian Arena Construction Materials: The development of Industry Guidelines.

1.5 **Anticipated Start Date:**

03/01/2012

1.6 **Anticipated End Date:**

31/12/2012

1.7 **Is this project in receipt of any external funding** (including donations of samples, equipment etc.)?

⬤ Yes ⬤ No
If Yes, *please provide details of sources of the funding and what part it plays in the current proposal.*
1.8 **Brief Project Description** (in lay's terms) including the aim(s) and justification of the project (max 300 words)
Give a brief summary of the background, purpose and the possible benefits of the investigation. This should include a statement on the academic rationale and justification for conducting the project.
Synthetic Arena surfaces are being used more frequently within the equine industry for training and competition (Murray *et al.*, 2010). The type of surface a horse is ridden on is considered to be a risk factor to injury amongst other factors according to Peterson *et al*. (2011). Research on equine surfaces has consequently been performed but has predominantly focused on thoroughbred and standardbred racing where the incident of injury is high (Williams *et al*., 2001). There is currently little research however investigating the hoof-surface interaction in other disciplines such as Dressage and Show Jumping. The use of synthetic surfaces for non-racing disciplines must be supported by scientific evidence in order to determine an optimal surface that combines performance and consistency with safety (Peterson *et al*., 2011). There have been major innovations throughout the last decade in the development of surfaces designed for human sports. Surface testing equipment has been used to create guidelines and standards on optimal values for different properties such as acceptable hardness values and moisture content. Research has shown that injury risks can be reduced and performance enhanced if training and competition is performed on a suitable surface according to Swan *et al*. (2009). The surface testing equipment used in human sport has been adapted for use on equine surfaces. There is however, still a lack of industry guidelines to regulate the construction of arenas and to specify the optimal surface properties for certain disciplines. There are two main aims of the study: 1) To measure the effect of moisture, compaction and drainage on different equine arena surfaces and contribute to the development of industry guidelines on equine arena construction and 2) To establish the preferences of riders regarding surface type and preparation with the use of an arena survey. The alternative hypothesis for the study states there will be a significant change in surface properties under different testing conditions and a significant difference between the preferences of riders from different disciplines.
1.9 **Methodology** Please be specific
Provide an outline of the proposed method, include details of sample numbers, source of samples, type of data collected, equipment required and any modifications thereof, etc
Synthetic arena surfaces that have been provided by Andrews Bowen will be used for the study. High quality sub-angular silica sand that is suitable for equestrian use will be the main component of all the surfaces and additives including polypropylene fibres and a binding polymer will be used. The control test box will contain silica sand without any additives and undergo the same tests as the other prepared surfaces in order to determine the true effect of the additives on the measured variables. In order to test numerous surfaces under the same controlled conditions, eight test boxes

(L100cm x W100cm x D20cm) will be made and situated next to the test track at Myerscough College. The Equaflow™ drainage system will be situated in four of the boxes to determine the effects of hydraulic conductivity on the measured surface properties and a traditional drainage system will be placed in the remaining four boxes. The effects of different levels of compaction and moisture contents will also be established. A similar experimental protocol will be followed to Setterbo *et al*. (2011) where a test box was also used and a track testing device measured different surface properties. The dimensions of the test boxes have been selected according to the boussinesq theory as stated by Setterbo *et al*. (2011) in order to reduce the boundary effect on the measured parameters. The surface depth of 15 cm was also selected according to the findings of Setterbo *et al*. (2011) where there would be little or no change in the measured parameters if more surface was to be added.

Pilot work

To ensure the test box is set up correctly, pilot work will be carried out during the weeks preceding the data collection. The measurements taken from the test boxes must be equivalent to data obtained from the same surface laid in an arena when prepared in the same manner. The surface on the test track located at Myerscough College will be prepared and tested and the same surface will also be placed in a test box and tested under the same conditions in order to make comparisons. The data will be analysed to ensure that there are no significant ($p>0.05$) differences between the results obtained. A small sample ($n=10$) of arena surveys will also be handed out and there will be an opportunity for the respondent to provide feedback at the end on the quality of the questions and whether they were easy to understand.

Moisture content

The surfaces will be tested with very little moisture (approximately 3% moisture) (Chateau *et al*., 2010), moderate moisture (approximately 8% and 20%) (Chateau *et al*., 2010; Ratzlaff *et al*., 1997) and when fully saturated. The values have been selected according to current literature in order to make comparisons between results more feasible. To establish the exact moisture content, a sample of 150 grams (g) will be taken from the impact location after each experiment and weighed again after being dried in an oven at 65 ˚C for 24 hours (Setterbo *et al*., 2011). The temperature was chosen according to the research published by Setterbo *et al*. (2011) to ensure that the surface was dried out but also to prevent destroying the synthetic surface components. The moisture content will be calculated using the following equation:

$$\text{Moisture Content} = \frac{\text{Total mass before being placed in the oven} - \text{Dry mass}}{\text{Dry mass}} \times 100$$

Compaction

There will be three different levels of compaction to replicate a low, moderate and high amount of traffic on the surface. An elephant foot tamper will be used to simulate the different compaction levels.

The surface testing equipment to be used will include the specialised dual-axis synthetic hoof drop hammer (Peterson et al., 2008) which calculates the force and deceleration of the synthetic hoof on impact with the surface and provides information on the energy loss of the surface; a clegg hammer which provides information on the surface hardness by calculating the deceleration (in gravities) on impact with the surface; and a torque wrench which measures the traction of the surface.

Dual-axis Synthetic Hoof drop Hammer

The surface testing device (Figure1 and Plate 1) was first created by Mick Peterson (University of Maine, Orono) for the progression of racing surfaces research and to improve understanding on the hoof interaction with different racing surfaces. The testing device was replicated by Glen Crook (University of Central Lancashire) in 2011 in order to continue with equine surface testing and research within the United Kingdom (UK). The testing device makes it possible to load the surface in a manner that simulates the hoof of the horse impacting the surface. At this stage during locomotion, the horse will experience the highest vertical and shear loads which make it necessary to investigate this part of the stance phase further because it creates a risk factor for injury (Peterson *et al*., 2008, 2011).

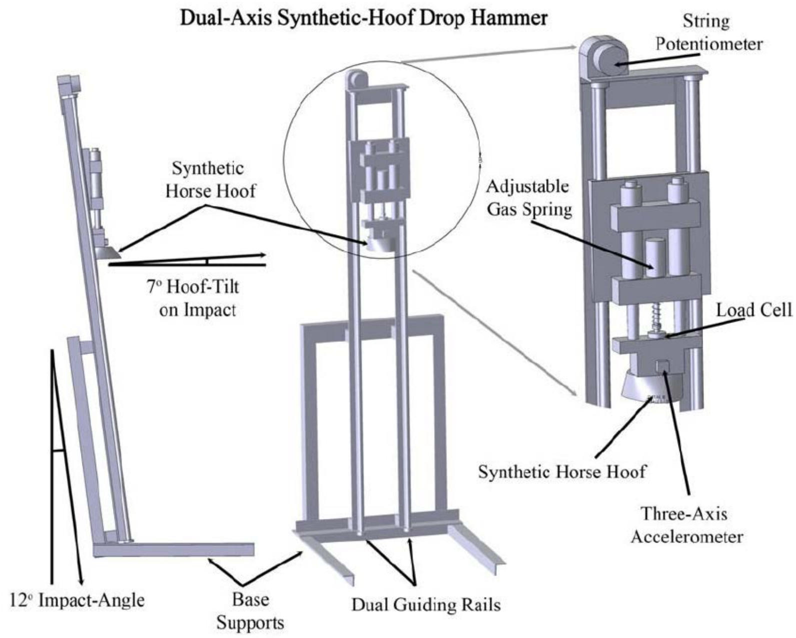

Figure 1: A surface testing device which shows two axes of motion and the configuration of the instrumentation on the test machine. Extracted from Peterson et al. (2008).

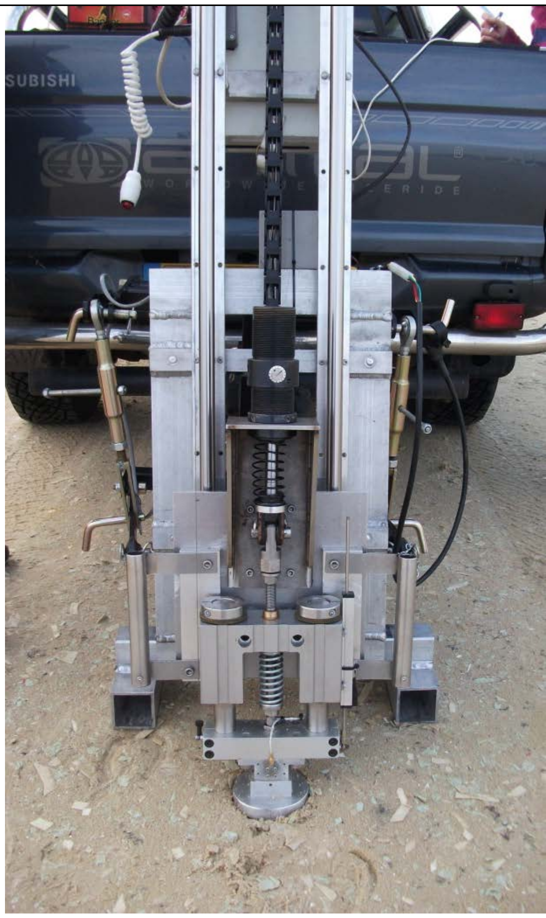

Plate 1: The dual axis synthetic hoof drop hammer has been constructed so that it is possible to mount it to a vehicle.

The surface testing device shown in Figure 1 and Plate 1 is a two axis drop tower type of apparatus which impacts a synthetic hoof into the surface at an angle of 7˚ in order to match biomechanical data recorded by Reiser *et al*. (2005). Two non-orthogonal axes of motion allow acceleration and impact force in the vertial and horizontal planes to be calculated when the synthetic hoof impacts the surface (Peterson *et al*., 2008). The impact energy accounts for the energy of the hoof impacting the surface including the partial weight of the horse. The adjustable gas spring in the second axis is intended to replicate the compliance of the leg.

Clegg Hammer

A Clegg hammer suitable for use on equestrian surfaces will be used to indicate the hardness and compaction of the surface (Clegg, 1976). Drop test results depend on contact area, mass and drop height therefore a consistent weight of 2.25kg will be dropped from the same height of 45cm. The clegg hammer will be dropped four times in the same location and once in four different locations within the test box and this will be repeated for all the different types and preparations of surfaces. Higher gravitational values will demonstrate a higher deceleration and therefore hardness of the tested surface.

Torque Wrench

A torque wrench will be used to measure the traction of the surface. The torque wrench will be used once in three different locations within the test box and this will be repeated for all the different types and preparations of surfaces.

There are published performance requirements for winter games pitches where acceptable and preferred ranges of variables such as hardness and traction are stated (Baker *et al*., 2007;

Chivers and Aldous, 2003). It is important to meet the preferred ranges where possible by testing the surface because the parameters are strong indicators of playing surface quality (Baker *et al*., 2007; Chivers and Aldous, 2003). The data obtained with the surface testing equipment during this project will enable acceptable and preferred ranges for impact forces, hardness, moisture, compaction and traction to be stated for the equine surfaces used. The data collected during the developmental work will also help contribute in calculating acceptable ranges.

Arena Survey

A pilot test will be run with the Arena Survey where some of the equine staff at Myerscough College will be asked to complete the survey and provide a small amount of feedback. The survey will be accessible to complete online via a link that will be posted on relevant equine forum pages to obtain information regarding the preferences of riders on surface type and preparation (see end of ethics form). The questions used will be strongly linked to the way the surfaces are prepared in the test boxes. It will be of interest to establish the preferred surface characteristics of riders and compare them to the preferred and acceptable ranges of hardness, moisture contents and compactions. It may also be possible to determine whether a safe surface or a surface that provides an optimal performance is a priority of the rider.

Internship work

An additional question has been added to the arena survey (see questionnaire). Once the questionnaire data has been analysed the venue of the most preferred competition surface will be contacted to ask if the suite of mechanical/physical tests (moisture, drop hammer, clegg hammer and torque wrench tests) could be carried out at that venue. These data will provide an insight into rider preference and their perception of surface performance v actual surface performance.

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Swan, P., Otago, L., Finch, C. and Payne, W. (2009) The policies and practises of sports governing bodies in relation to assessing the safety of sports grounds. *Journal of Science and Medicine in Sport*, **12**, 171-176.

Williams, R. B., Harkins, L. S., Hammond, C. J. and Wood, J. L. N. (2001) Racehorse injuries, clinical problems and fatalities recorded on British racecourses from flat racing and national hunt racing during 1996, 1997, 1998. *Equine Veterinary Journal,* **33** (5) 478-486.

1.10 **Has the quality of the activity been assessed**? (select all that apply)

- ☐ Independent external review
- ☑ Internal review (e.g. involving colleagues, academic supervisor, School Board
- ☑ Through Research Degrees Sub-Committee (BAHSS, STEM or SWESH
- ☐ None
- ☐ Other

If other please give details

1.11 **Please provide details as to the storage and protection for your data for the next 5 years**

The guidelines created by university of central Lancashire will be adhered to: All primary data as the basis for publications will be securely stored for at least 5 years unless otherwise required by contractual terms or the guidance of relevant professional bodies in a paper and /or electronic form, as appropriate, after the completion of a research project. Proper documentation and storage procedures will minimise cases of allegations of research misconduct where original data cannot be found or allegedly been lost. Researchers will utilise means of data storage appropriate to the task. http://www.uclan.ac.uk/schools/adp/Research_Policies.php

1.12 **How is it intended the results of the study will be reported and disseminated**? (select all that apply)

- ☑ Peer reviewed journal

- [ ] Internal report
- [x] Conference presentation
- [ ] Other publication
- [ ] Written feedback to research participants
- [ ] Presentation to participants or releveant community groups
- [x] Dissertation/Thesis
- [x] Other

If other, please give details Reporting to Andrews Bowen

1.13 **Will the activity involve any external organisation for which separate and specific ethics clearance is required** (e.g. NHS; school; any criminal justice agencies including the Police, Crown Prosecution Service, Prison Service, Probation Service or successor organisation)?

● Yes ● No

If Yes, please provided details of the external organisation / ethics committee and attached letter of approval
NB – external ethical approval **must** be obtained before submitting to UCLan ethics.

1.14 **The nature of this project is most appropriately described as research involving:-** (more than one may apply)

- [ ] Behavioural observation
- [x] Self-report questionnaire(s)
- [ ] Interview(s)
- [ ] Qualitative methodologies (e.g. focus groups)
- [ ] Psychological experiments
- [ ] Epidemiological studies
- [ ] Data linkage studies
- [ ] Psychiatric or clinical psychology studies
- [ ] Human physiological investigation(s)
- [x] Biomechanical devices(s)
- [ ] Human tissue
- [ ] Human genetic analysis
- [ ] A clinical trial of drug(s) or device(s)
- [x] Lab-based experiment
- [x] Archaeological excavation/fieldwork
- [ ] Re-analysis of archaeological finds/ancient artefacts

☐ Human remains analysis

☐ Other (please specific in the box below)

If 'Other' please provide details

Please read all the following questions carefully and if you respond 'Yes' then you should provide all relevant details and documentation (including risk assessments), and justify where appropriate.

Section 2
HUMAN PARTICIPANTS, DATA OR MATERIAL

2.1 Are you using human participants (including use of their data), tissues or remains?

(please select the appropriate box)

☑ Participants [proceed to question 2.2]	
☐ Data [proceed to question 2.20]	Click here for Q2.20
☐ Tissues / Fluids / DNA Samples [proceed to question 2.20]	
☐ Remains [proceed to question 2.24]	Click here for Q2.24
☐ No [proceed to Section 3]	Click here for Section 3

2.2 Will the participants be from any of the following groups:
(tick as many as applicable)

☑ Students or staff of this University

☐ Children/legal minors (anyone under the age of 16 years)

☐ Patients or clients of professionals

☐ Those with learning disability

☐ Those who are unconscious, severely ill, or have a terminal illness

☐ Those in emergency situations

☐ Those with mental ilness (particularly if detained under Mental Health Legislation)

☐ People with dementia

☐ Prisoners

☐ Young Offenders

☐ Adults who are unable to consent for themselves

☐ Any other person whose capacity to consent may be comrpomised

☐ A member of an organisation where another individual may also need to give consent

☐ Those who could be considered to have a particularly dependent relationship with the investigator, e.g. those in care homes, medical students

☐ Other vulnerable groups (please list)

Justify their inclusion

*Ethical approval covers **all participants** but particular attention must be given to vulnerable participants. Therefore you need to fully justify their inclusion and give details of extra steps taken to assure their protection. Where the 'Other vulnerable groups' box has been selected, please also describe/list.*

The arena survey will be piloted and a few members of the equine staff at Myerscough College will be asked to complete the survey and provide feedback on the types of questions used. The feedback will ensure that the questions are relevant and are legible to the intended reader. The participant will not have to disclose any personal information, they will complete the survey online prior to the feedback session and so they will remain anonymous and are free to withdraw from the survey and/or the feedback session.

2.3 **Please indicate exactly how participants in the study will be (i) identified, (ii) approached and (iii) recruited**?

i) For the main study it is envisaged that a link to the survey will be included on consenting equine organizations websites (BD, BHS, The Pony Club, BS, Horse and Hound). Participants would be identified as horse riders.
Ii & iii) Consenting organizations will be approached to ask if a link to the survey may be included on their website. Participants would then be given the opportunity to complete the questionnaire voluntarily from promotion on the consenting organizations websites.

2.4 **How exactly will consent be given**?

It is not compulsory for the participant to complete the arena survey and it will be made clear at the start of the survey that by completing the questions, the participant is providing consent for the answers to be used for research purposes.

2.5 **What information will be provided at recruitment and briefing to ensure that consent is informed**?

Please see the arena survey attached.

2.6 **How long will the participants have to decide whether to take part in the research**?

The survey will be available to complete online for approximately 6 weeks and it is up to the reader if they decide to participate in the survey or not.

2.7 **What arrangements have been made for participants who might not adequately understand verbal explanations or written information given in English, or who have special communication needs**?

It is brought to the attention of the reader that if they have any problems with the survey, they are to contact myself. The questions have been written in layman's terms where possible.

2.8 **Payment or incentives: Do you propose to pay or reward participants**?
● Yes ● No
If Yes, please provided details
2.9 **Does the activity involve conducting a survey, interviews, questionnaire, observational study, experiment, focus group or other research protocol**?
● Yes ● No
If Yes, please provide details and attach copy of what you will be using *Give details of the specific procedures/activities being used and indicate where documentation (i.e. questionnaire or agendas) will be developed as part of the project. Also include what is the experience of those administering the procedures*
Please see Arena Survey attached. A letter will be sent out to equine organisations including British Dressage, British Show Jumping, The British Horse Society, Horse and Hound and Pony Club as soon as the project has received ethical approval. A link will then be posted on their relevant web pages once approval has been granted. The survey itself will not be password protected because it will reduce the response rate however the responses of the participants will only be accessible with a username and password through the Survey Monkey website. The researcher has a small amount of experience in administration however, the director of studies and supervisors are available for full support to ensure the correct procedures are strictly adhered to. All completed questionnaires will be anonymous.
2.10 **Will deception of the participant be necessary during the activity**?
● Yes ● No
If Yes, please provide justification *Gives details of the deception and explain why the deception is necessary.*
2.11 **Does the activity (e.g. Art) aim to shock or offend**?
● Yes ● No
If yes, please explain *Give details, justify and what measures are in place to mitigate.*
2.12 **Does your activity involve the potential imbalance of power/authority/status, particularly those which might compromise a participant giving informed consent**?
● Yes ● No
If Yes, please detail including how this will mitigated *Describe the relationship and the steps to be taken by the investigator to ensure that the participant's participation is purely voluntary and not influenced by the relationship in any way.*
2.13 **Does the procedure involve <u>any</u> possible distress, discomfort or harm (or offense) to participants or researchers** (including physical, social, emotional, psychological)?

● Yes ● No
If Yes, please explain *Describe the potential for distress, discomfort, harm or offense for research participants as a result of their participation in your study and what measures are in place to protect the participants or researcher(s). Please consider all possible causes of distress carefully, including likely reaction to the subject matter, debriefing or participants.*
2.14 **Does the activity involve any information pertaining to illegal activities or materials or the disclosure thereof**?
● Yes ● No
If Yes, please detail *Describe involvement and explain what risk management procedures will be put in place.*
2.15 **What mechanism is there for participants to withdraw from the investigation and how is this communicated to the participants**?
The participant may end the survey at any time and this will be made clear to them at the start of the questions.
2.16 **What is the potential for benefit for participants**?
Briefly describe the main benefits and contribution of the study. Include any immediate benefits to participants as well as the overall contribution to knowledge or practice.
The participants would be ultimately contributing to the research project and would improve knowledge on rider preferences regarding equine surface type.
2.17 **What arrangements are in place to ensure participants receive any information that becomes available during the course of the activity that may be relevant to their continued participation**?
Describe how participants will be made aware of relevant information that was not available when they started.
If the participant is interested in the results obtained they will be made aware that it is possible to contact myself.
2.18 **Debriefing, Support and/or Feedback to participants**
Describe any debriefing, support or feedback that participants will received following the study and when.
The participants will be made aware that their contribution is very much appreciated.
2.19 **Adverse / Unexpected Outcomes**
Please describe what measures you have in place in the event of any unexpected outcomes or adverse effects to participants arising from their involvement in the project
The data will be presented in the Masters project. The participant will have the right to

withdraw at any time. Contact details will be clearly presented at the start of the survey if the participant experiences any problems.
2.20 **Will the activity involve access to confidential information about people without their permission**?
● Yes ● No
If yes, please explain and justify *State what information will be sought, from which organisations and the requirement for this information.*
2.21 **Does the activity involve medical research, human tissue samples or body fluids**?
● Yes ● No
If yes, please detail *Clearly state the source of the material and anonymisation protocols*

2.22 **Confidentiality/Anonymity** - Will the activity involve:

	Yes	No
a. complete anonymity of participants (i.e. researchers will not know the identity to return responses with no form of personal identification) is not possible?	●	●
b. anonymised samples or data (i.e. an irreversible process whereby identifiers are removed from samples/data and replaced by a code, with no record retained of how the code relates to the identifiers. It is then impossible to identify the individual to whom the sample or information relates)?	●	●
c. de-identified samples or data (i.e. a reversible process in which the identifiers are removed and replaced by a code. Those handling the data subsequently do so using the code. If necessary, it is possible to link the code to the original identifiers and identify the individual to whom the sample or information relates)?	●	●
d. participants having the option of being identified in any publication arising from the research?	●	●
e. participants being referred to by pseudonym in any publication arising from the research?	●	●
f. the use of personal data?	●	●

*If **yes to any** proceed to question below*
*If **no to all**, please skip to question 2.24*

2.23 **Which of the following methods of assuring confidentiality of data will be implemented**? (Please select all relevant options)
N.B. Attach DP Compliance checklist and DP security questionnaire
☐ data and codes and all identifying information to be kept in separate locked filling cabinets ☐ access to computer files to be available by password only ☐ other
If other, please describe method.

2.24 **Does the activity involve excavation and study of human remains**?

● Yes ● No

If yes, please give details
Discuss the provisions for examination of the remains and the management of any community/public concerns, legal requirement etc.

Section 3
BIOLOGICAL ORGANISMS/ENVIRONMENT

3.1 **Does the activity involve micro-organisms, genetic modification or collection of rare plants**?

● Yes ● No

If yes please provide further details below State the type and source of the samples to be used in the project and include compliance with relevant legislation.
If no please continue section 4

Section 4
HAZARDOUS SUBSTANCES

4.1 **Does the activity involve any hazardous substances**?

● Yes ● No

If yes please continue
If no please continue to section 5

4.2 **Does the activity involve igniting, exploding, heating or freezing substances**?

● Yes ● No
There will be a short period of time spent in the laboratory heating the surface samples in order to determine moisture contents. The risk assessment has been attached.
4.3 **Does the activity involve substances injurious to human or animal health or to the environment**?
● Yes ● No
4.4 **Are you using hazardous chemicals**?
● Yes ● No
*If **Yes to any** please attach all relevant COSHH and/or risk assessment forms* N.B. Please address issues of quantity involved, disposal and potential interactions as well as a thorough evaluation of minimisation of risk

Section 5

OTHER HAZARDS

5.1 **Does the activity relate to military equipment, weapons or the defence industry**?
● Yes ● No
If yes please provide details and attach relevant permissions and risk assessments. Describe the hazard, clearly explaining the risks associated and specify how you will minimise these *If no please continue*
5.2 **Does the activity relate to the excavation of modern battlefields, military installations etc**?
● Yes ● No
If yes please provide details and attach relevant permissions and risk assessments. Discuss the provisions for examination and the management of any community/public concerns, legal requirement, associated risks, etc. *If no please continue*

Section 6
FIELDWORK/TRAVEL

6.1 **Does the activity involve field work, lone working or travel to unfamiliar places**?
● Yes ● No
If yes, answer the following questions *If no, go to Section 7*
6.2 **Where will the activity be undertaken**?
N.B. If your work involves field work or travel to unfamiliar places (e.g. outside the UK) please attach a risk assessment specific to that place *Give location(s) details (e.g. UCLan campus only)*
Myerscough College, Preston campus – on the test track. At the most popular equestrian venue (as decided by the survey). Additional risk assessments will be provided for this activity including transportation and risks associated with the venue.
6.3 **Does the activity involve lone working**?
● Yes ● No
If yes please provide further details below and attach a completed risk assessment form *Describe the lone working element, clearly explaining the risks associated and specify how you will minimise these*
There may be periods where the researcher has to work in the laboratory alone when carrying out developmental work and whilst calculating the moisture contents of the surface samples. Please find attached a risk assessment for lone working.
6.4 **Does the activity involve children visiting from schools**?
● Yes ● No
If yes please provide further details below and attach a completed risk assessment form *Describe the nature of the visit, clearly explaining the risks associated and specify how you will minimise these*

Section 7
ETHICAL AND POLITICAL CONCERNS

7.1 **Are you aware of any potential ethical and/or Political concerns that may arise from either the conduct or dissemination of this activity** (e.g. results of research being used for political gain by others; potential for liability to the University from your research)?
Yes No
If yes please provide details below *If no please continue*
7.2 **Are you aware of any ethical concerns about collaborator company / organisation** (e.g. its product has a harmful effect on humans, animals or the environment; it has a record of supporting repressive regimes; does it have ethical practices for its workers and for the safe disposal of products)?
Yes No
If yes please provide details below *If no please continue*
7.3 **Are there any other ethical issues which may arise with the proposed study and what steps will be taken to address these**?
Yes No
If yes please provide details below *If no please continue*

Section 8
DECLARATION

This section needs to be signed by the Principal Investigator (PI), and the student where the study relates to a student project (for research student projects PI is Director of Studies and for Taught or Undergrad project the PI is the Supervisor). Electronic submission of the form is required to roffice@uclan.ac.uk. Where available insert electronic signature, if not a signed version of the submitted application form should be retained by the Principal Investigator.

Declaration of the:
● Principal Investigator
OR
● Director of Studies/Supervisor and Student Investigators
(please check as appropriate)
• The information in this form is accurate to the best of my knowledge and belief, and I take full responsibility for it.
• I have read and understand the University Ethical Principles for Teaching, Research, Knowledge Transfer, Consultancy and Related Activities.
• I undertake to abide by the ethical principles underlying the Declaration of Helsinki and the University Code of Conduct for Research, together with the codes of practice laid down by any relevant professional or learned society.
• If the activity is approved, I undertake to adhere to the study plan, the terms of the full application of which the Ethics Committee* has given a favourable opinion and any conditions of the Ethics Committee in giving its favourable opinion.
• I undertake to seek an ethical opinion from the Ethics Committee before implementing substantial amendments to the study plan or to the terms of the full application of which the Ethics Committee has given a favourable opinion.
• I understand that I am responsible for monitoring the research at all times.
• If there are any serious adverse events, I understand that I am responsible for immediately stopping the research and alerting the Ethics Committee within 24 hours of the occurrence, via roffice@uclan.ac.uk.
• I am aware of my responsibility to be up to date and comply with the requirements of the law and relevant guidelines relating to security and confidentiality of personal data.
• I understand that research records/data may be subject to inspection for audit purposes if required in future.
• I understand that personal data about me as a researcher in this application will be held by the University and that this will be managed according to the principles established in the Data Protection Act.

* Ethics Committee refers to either BAHSS, PSYSOC, STEM or SWESH

• I understand that the information contained in this application, any supporting documentation and all correspondence with the Research Ethics Committee relating to the application, will be subject to the provisions of the Freedom of Information Acts. The information may be disclosed in response to requests made under the Acts except where statutory exemptions apply.
• I understand that all conditions apply to any co-applicants and researchers involved in the study, and that it is my responsibility to ensure that they abide by them.
• **For Supervisors/Director of Studies:** I understand my responsibilities as Supervisor/Director of Studies, and will ensure, to the best of my abilities, that the student investigator abides by the University's Policy on Research Ethics at all times.
• **For the Student Investigator**: I understand my responsibilities to work within a set of safety, ethical and other guidelines as agreed in advance with my Supervisor/Director of Studies and understand that I must comply with the University's regulations and any other applicable code of ethics at all times.

● Signature of Principal Investigator: **or** **● Supervisor or Director of Studies:**	
Print Name:	**Dr Sarah Jane Hobbs**
Date:	**02/05/2012**
Signature of Student Investigator:	
Print Name:	**D.S.Holt**
Date:	**23/02/2012**

Section 9
ACCOMPANYING DOCUMENTATION

Please indicate here what documentation you have included with your application:
☐ Proposal / protocol ☑ RDSC2 form – Application to Register for Research ☐ External ethics approval letter ☐ Letter of permission ☐ Participant consent form(s) ☐ Participant information sheet(s) ☐ Interview or observation schedule ☑ Questionnaire(s) ☐ Advert ☐ DP Compliance checklist ☐ DP Security Questionnaire ☑ Risk Assessment ☐ COSHH ☐ Other

Appendix II

Myerscough College
Providing opportunities for all

MYERSCOUGH COLLEGE

RISK ASSESSMENT TITLE	PROGRAMME AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
Pilot work and data collection	**Equine Research Group**	**Signed:** Danielle Holt **Date:** March 2012	**Date:** March 2013

STEP ONE	STEP TWO	STEP THREE
List significant hazards here:	*List groups of people who are at risk from the significant hazards you have identified.*	*List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:*
Repetitive Strain Injury or general injury sustained from using the surface testing equipment or moving surfaces and test boxes.	The researcher and co-workers	All study researchers and participants will have had manual handling training and wear sufficient personal protective equipment. If the item in question is considered too heavy it must be moved between two people to avoid injury. All researchers and co-workers will be aware of this. A qualified first aider and first aid kit will be on site during set up and testing. It will also be ensured that there is a mobile phone available in case the need to call the emergency services arises. A first aid box and the first aider will be located before the testing begins
The study includes risks of the researcher and co-workers, bumping	The researcher and co-workers	The testing area will be kept as tidy as possible and not crowded with testing equipment or too many co-workers. Equipment that is not in use will be put

into or sliding on equipment used.	The researcher and co-workers	away.
Electrical equipment could become faulty and cause injury.	The researcher and co-workers	All equipment will have been PAT tested and checked prior to use for loose wires or possible problems. Equipment which needs to be connected to a main power supply will have a circuit breaker attached.
The testing procedures includes the risk of slipping when inside or exiting the arena due to the surface material underfoot.		Be aware at all times of the surface being stepped on and take time to clean any excess build up of surface material of shoes whilst in and outside the arena.
The dust from the arena surfaces may cause irritation to the eyes, nose and mouth	The researcher and co-workers	The researcher and co-workers will be warned about the possible affects the dust may have and will be asked to report any discomfort to these areas to the first aider immediately.
Risk of electrocution due to rain	The researcher and co-workers The researcher and co-workers	The testing will not be performed in the outdoor arena if it is raining however there is always a potential risk. The weather forecast will be continuously checked throughout the day.
Unauthorised personnel	The researcher and co-workers	No unauthorised persons shall be allowed into or around the testing area or near the equipment. The testing area will be cornered off.
Being sunburnt	The researcher and co-workers	Precautions will be taken to ensure that sun cream is worn or skin is covered from UV rays. It will be a priority to ensure the researcher and co-workers stay hydrated throughout the pilot work and data collection.
Zoonotic disease		Hands washed and good hygiene will be expected by all personnel involved.

RISK ASSESSMENT TITLE	LEARNING AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
Orono Biomechanical Hoof Tester (OBHT).	Equine	**Signed:** Danielle Holt **Date:** March 2012	**Date:** March 2013

STEP ONE	STEP TWO	STEP THREE
List significant hazards here:	**List groups of people who are at risk from the significant hazards you have identified.**	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:**
General handling, lifting and moving of equipment includes risk of back injury as well as arm, hand, leg and foot injury if equipment is dropped.	Researcher and co-workers	Ensure correct manual handling techniques are known and used at all times when moving equipment. If the item in question is considered too heavy it must be moved between two people to avoid injury. All researchers and co-workers will be aware of this.
The testing procedures includes the risk of slipping when inside or exiting the arena due to the surface material underfoot.	Researcher and co-workers	Be aware at all times of the surface being stepped on and take time to clean any excess build up of surface material of shoes whilst in and outside the arena. The correct Personal Protective Equipment must be used including sturdy boots with sufficient grip.
Electrical equipment could become faulty and cause injury.	Researcher and co-workers	All equipment connected to the mains power supply will have been PAT tested and checked prior to use for loose wires or possible problems. Equipment which needs to be connected to a main power supply will also have a circuit breaker attached. The rig will be checked fully for loose

		connections and care will be taken at all times to make sure that it is positioned on a safe suitable area before testing commences.
Using equipment outdoors in wet conditions.	Researcher and co-workers	When not in use, equipment should be secured to prevent contact with water. Use of suitable trip switches or circuit breakers to be used. Researchers must wear suitable PPE: suitable gloves, face / eye protection and steel toe capped boots.
The study includes risks of the researcher and co-workers, bumping into or sliding on equipment used.	Researcher and co-workers	All electrical equipment attached to a mains power supply shall be placed as near as possible to the side of the arena so that wires are not running across the researchers or the vehicles path. All wires that do cross the floor shall be safely placed under matting and covered with the arena surface. Wires running out of the arena shall be securely taped to the floor to avoid trips. The site will have been risk assessed before hand to make sure that the arena surface is level and in good condition and that researchers are aware of entrances and exits, fire assembly points and first aid stations. No unauthorised persons shall be allowed into or around the testing area or near the equipment.
The study involves the risk of driving a vehicle with attached machinery in a possibly confined space. The driver may crash and become injured or strike a researcher or member of the public	Researcher, co-workers and members of the public	All operators must hold the correct license for operating particular vehicles. e.g. car or tractor. Drivers must be taught the correct techniques for handling the machines at speeds, with implements, braking, and parking before commencement of testing. All other researchers must be aware of their position in relation to the vehicle at all times and exit the area when the vehicle is being driven from one location to the next. The driver must ensure the area is clear and safe before attempting to move the vehicle. Members of the public must be kept away from the testing area and informed by researchers of areas which are unsuitable to enter.
The study involves the risk of researchers hands, feet becoming trapped or injured by the machinery	Researcher and co-workers	All researchers must be clear of the rig before it is activated. Researchers must be aware of other researchers' whereabouts at all time to avoid accidental activation of any parts of the rig. All researchers must wear suitable PPE including gloves and hard foot wear when using the rig or

and rig whilst in use.		machinery.
Zoonotic disease through working near animals.	Researcher and co-workers	Hands washing and good hygiene will be expected by all personnel involved.

RISK ASSESSMENT TITLE	PROGRAMME AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
All Laboratory Practicals	Laboratories	**Signed:** Danielle Holt **Date:** March 2012	**Date:** March 2013

STEP ONE	STEP TWO	STEP THREE
List significant hazards here: • Chemicals • Equipment • Gas and all equipment powered by gas. • Broken glass and other sharp objects such as blades and knives. • Contaminated surfaces/equipment • Slipping on wet surfaces. • Incorrect handling of heavy equipment • Injury sustained whilst using equipment • Heat/fire generating equipment. • Zoonotic diseases	**List groups of people who are at risk from the significant hazards you have identified.** • Staff/Researcher • Students • Cleaners • Visitors	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:** ***ALL PERSONS INVOLVED IN PRACTICAL WORK SHOULD BE AWARE THAT:*** • COSHH/Chemical safety data sheets will be available in the labs. • Risk assessments for equipment and glassware will be found on the staff intranet of all computers. • The researcher will have undergone the correct manual handling training. • Copies of chemical safety data sheets and risk assessments will be available from the Laboratory Office if you are unable to obtain them any other way. • Staff/students should have a basic understanding of health and safety, COSHH and laboratory rules before undertaking any practical work. Important issues such as where the nearest First Aider and First Aid boxes are, where emergency exits are, what

		to do in an emergency, chemical spillage or fire need to be discussed. Any accidents or near misses must be reported in the accident book. Medical advice should be sought when an injury is sustained. • Gas and equipment that is known to be dangerous should: *Have a warning sign on it. *Not be used unsupervised by a competent member of staff. *Have safety measures in place to stop students accessing it or altering settings. • Before each practical commences, full instructions will be given as to how to carry out the practical correctly and any dangers or precautions to be taken should be highlighted. Such precautions may include: 1. Laboratory coats to be worn at all times to prevent contamination of clothes and skin. If this happens, the coat can be removed and disposed of by autoclaving, incinerating or washing as appropriate. 2. Heat proof gloves to be worn when necessary i.e. when lifting things out of ovens. 3. Protective goggles to be worn when necessary. 4. Facemasks should be worn when necessary, sometimes in conjunction with fume cupboards. 5. Long hair to be tied/clipped back to prevent contamination from items used in practical work. 6. Safe disposal of chemicals - COSHH procedures should be followed for chemical disposal. If items such as tissues have come into contact with or been used to mop up chemicals, they should be rinsed in the sink until the chemical is diluted to

		a safe level before disposing of. This will prevent injury to persons responsible for emptying bins in the laboratory. 7. Broken glass - broken glass should be swept up and put in the Broken Glass box within the laboratory. 8. The importance of cleaning workbenches and any equipment that maybe contaminated by bacteria or chemicals must be stressed. Correct procedures must be followed if a spillage occurs. This involves following COSHH procedures if necessary to clear away the spillage and using yellow signs to notify others of the potential hazard, thus preventing a fall. 9. Hands washed and good hygiene will be expected by all personnel involved

RISK ASSESSMENT TITLE	**LEARNING AREA**	**ASSESSMENT UNDERTAKEN**	**ASSESSMENT REVIEW**
Working Alone In Labs and on the test track at Myerscough College	Labs	**Signed:** Danielle Holt **Date:** March 2012	**Date:** March 2013

STEP ONE	**STEP TWO**	**STEP THREE**
List significant hazards here:	**List groups of people who are at risk from the significant hazards you have identified.**	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:**
Working alone and unforeseen circumstances.	Researcher	When possible work in pairs Must have mobile phone and leave number with reception Must inform a lab technician when working in the lab or a colleague when going to the test track Follow appropriate lab risk assessments for the drying oven The appropriate member of staff should be informed if there is a spillage or equipment gets broken Must have completed Manual Handling Training.

RISK ASSESSMENT TITLE	PROGRAMME AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
Drying Ovens	Laboratories	**Signed:** Danielle Holt **Date:** March 2012	**Date:** March 2013

STEP ONE	STEP TWO	STEP THREE
List significant hazards here: • Burns due to lifting out hot objects or touching shelving. • Contamination of discharged volatile material within the oven, which may release toxic fumes into the laboratory. • Danger of explosion if flammable material is placed in the oven. • Danger of explosion if glassware has been rinsed in solvents. • Electrical faults i.e. the plug.	**List groups of people who are at risk from the significant hazards you have identified.** • **Researcher** • **Other Staff and Students** • **Cleaners** • **Visitors.**	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:** • Protective gloves must be worn when handling objects that have been in an oven. • Always check that the material is safe to go in an oven and not temperature sensitive. • Be sure that anything put in the oven has not come into contact with any flammable substances. • Have the oven serviced regularly to ensure it is running safely. • Report any damage or faults to the oven.

Appendix III

Arena Survey

Rider Details

Dear Sir/madam,
Please could you spare a few minutes of your time to answer all of the questions in the survey below. The survey will remain anonymous at all times and will contribute to a Masters Degree project investigating Equine Arena Surfaces. You can also be entered into a free prize draw for a chance to WIN £50 Derby House Vouchers. By submitting the survey, you are providing consent for the answers to be used for research purposes only and you have the right to withdraw at any time. Should you have any further queries or require any assistance in completing the questionnaire then please contact Dani Holt on 01995642333(Ext: 2020) or dholt@myerscough.ac.uk

*1. Are you regularly riding or competing?

- Yes
- Have done in the past

Arena Survey

Rider Details

***2. What discipline (s) are you currently competing in or training towards?**

- Dressage
- Show Jumping
- Eventing
- Other

***3. What region(s) do you ride in?**

- North
- North West
- North East
- Wales
- West Midlands
- East Midlands
- South West
- South East
- East Anglia
- Scotland
- Other

Arena Survey

*4. Please state the names of three equestrian centres within the United Kingdom that have arena surfaces that you most prefer to compete or train on in order of preference. If a centre has more than one arena, please identify which arena is your preferred (for example, the indoor arena, or small outdoor).

1st Choice

2nd Choice

3rd Choice

*5. Please describe in detail what it is about each surface that you prefer.

Arena Survey

Horse Details

If you ride several horses, please consider the horse you ride the most.

*6. What level is your horse currently working at?

Competition

Training

Arena Survey

Training and Competition Surfaces

When answering the questions, please consider the surface that you use most frequently unless specified otherwise.

***7. What type of surface do you train and compete on (please select all the surfaces that you use)?**

	Training	Competition
Just sand		
Sand and fibre based non-wax		
Sand and fibre based with wax		
Sand and pvc granules non-wax		
Sand and pvc granules with wax		
Rubber based (mixed in)		
Rubber based (rubber on top)		
Woodchip		
Carpet fibre		
Grass		
Other		

***8. Do you mainly train indoors or outdoors?**

- Indoor
- Outdoor

***9. In which conditions does your training surface provide you with the best performance of your horse?**

- All the time regardless of weather
- During a period of dry weather
- During a period of slightly wet and dry spells
- During a period of wet weather
- When you have thoroughly watered the arena
- Other

Arena Survey

Surface Preferences

The following questions are about your preferences in surface type.

*10. What type of surface do you prefer to ride on (You may select more than one type)?

- Just sand
- Sand and fibre based non-wax
- Sand and fibre based with wax
- Sand and pvc granules non-wax
- Sand and pvc granules with wax
- Rubber based (mixed in)
- Rubber based (rubber on top)
- Woodchip
- Carpet fibre
- Grass
- No preference
- Other

*11. How would you describe the type of 'going' you prefer to ride on?

- Hard with no give
- Firm with a bit of give (leaves a slight hoof mark)
- A softer surface with a bit more give (leaves a distinct hoof mark)
- Deep (the surface has cupped away)
- No preference
- Other

Arena Survey

*** 12. How would you like the surface you ride on to be prepared/maintained?**

- Rolled
- Harrowed (levelled with 'fluffy' top layer)
- Graded (levelled)
- No preference
- Other

*** 13. How much grip or traction would you like the surface to have with the horse?**

- A large amount (almost no slip)
- Moderate (small amount of slip)
- A small amount (a larger amount of slip)
- No preference

Arena Survey

Thank you for completing the Arena Survey

If you wish to be entered in a free prize draw for a chance to win £50 worth of Derby House Vouchers, then please send a blank email to dholt@myerscough.ac.uk.

Appendix IV

Composition Determination of a Sand/Fibre/Rubber/Wax Test Track

It is expected that the intern will take some of the lead for this aspect of the work, in determining the optimum weight of surface required for analysis and the number of samples required across the test track. This should be determined through literature searching, discussion with supervisors and some pilot work.

Protocol

1. Collect X number of samples of surface weight Y grams from across the test track

2. Place a single sample into a beaker and add Iso-Octane (volume to be determined during pilot work)

3. Stir solvent into the surface material to ensure full contact between solvent and surface

4. Place the beaker into a water bath set at 45°C for one hour, followed by 100°C for one hour

5. Ensure that the solvent / sand mix is regularly agitated to ensure full exposure

6. Remove the beakers and allow them to stand for one hour to allow the surface material to settle

7. Pour the solvent into a separate beaker, pre-weighed; ensuring that no organic components are lost (this may be done through a sieve).

8. Allow the remaining components, and the beaker containing the Iso-Octane to stand for 24 hours at room temperature in order for the solvent to evaporate

9. Wet sieve the surface components using a fine jet of cold water through a 1mm sieve placed over a bucket.

10. Separate and retain the fibre and rubber in a pre-weighed metal drying tray

11. Pour the sand / water mix through a pre-weighed, pre-dried 63µm sieve

12. Place the metal drying trays and the sieve in an oven set to 102°C for 24 hours

13. Allow to cool and re-weigh

14. Re-weigh the original beaker containing the dissolved wax (at this stage this will only be an approximation of wax content until appropriate equipment for extraction can be sourced).

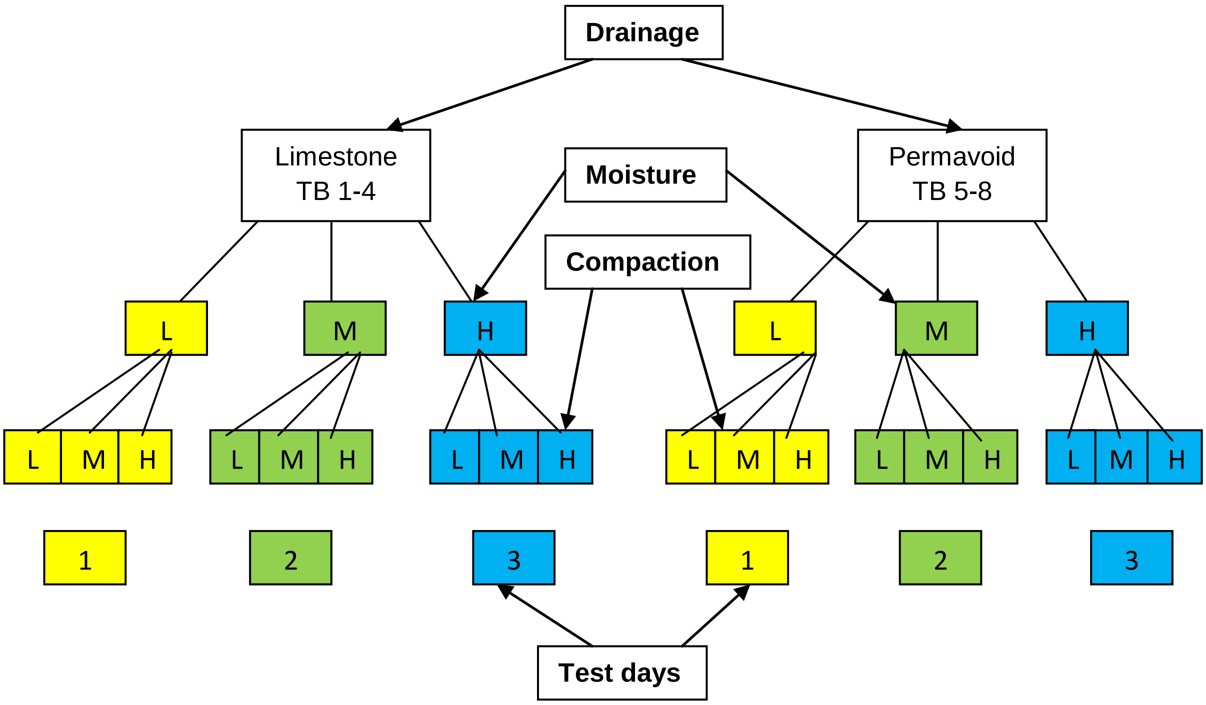
Appendix V

Timetable for data collection

Drainage: Equaflow and Limestone

Moisture: low (0 litres), medium (10litres) and high (20litres)

Compaction: low (top couple of cm are level but not compacted), medium (compact top level) and high (compact top level as much as possible)



Suite of mechanical tests (in order) =

Rig 3 drops x4

Clegg Hammer 4drops x4

Torque Wrench x4

Moisture samples x 1

Levelling and compacting

Testing will be done on TB1-4 for all compaction levels and then on TB5-8 for all compaction levels to avoid losing too much moisture throughout test days.

Timetable:

Before 9.30am: Collect all equipment and make sure surfaces are under light compaction with low/moderate or high moisture depending on day.

9.30: everyone arrive and set up.

10.30am: mechanical tests on TB 1-4 (60 mins)

Dani to re level and put surface (TB1 – 4) under medium compaction as tests go on

11.30 am: Mechanical tests on TB 1-4 (50 mins) and also add moisture to TB 5-8 if needed (for moderate and high moisture level test days)

Dani to re level and put surface (TB1 – 4) under heavy compaction as tests go on

12.20: break/lunch

1 pm: Mechanical tests (50 mins) on TB 1-4

Dani to add moisture to TB5-8 if needed as tests go on

1.50pm: mechanical tests on TB 5-8 (50 mins)

Dani to re level and put surface (TB 5 –8) under medium compaction as tests go on

2.40pm: Break

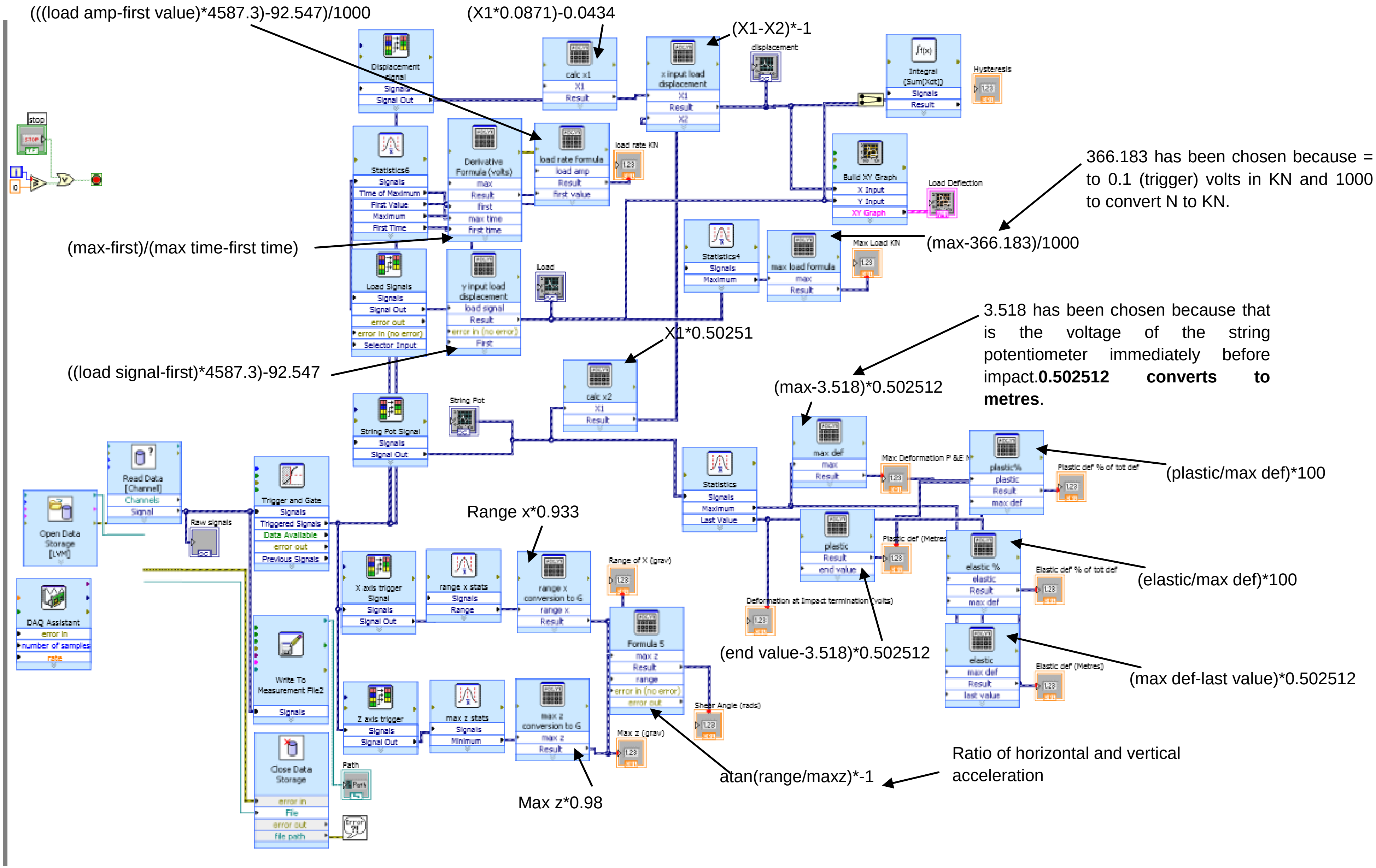
3.00pm: Mechanical tests on TB 5-8 (50 mins)

Dani to re level and put surface (TB5 – 8) under heavy compaction as tests go on

3.50pm: Mechanical tests on TB 5-8 (50 mins)

4.40: FINISH

Appendix VI


(((load amp-first value)*4587.3)-92.547)/1000
(X1*0.0871)-0.0434
(X1-X2)*-1
366.183 has been chosen because = to 0.1 (trigger) volts in KN and 1000 to convert N to KN.
(max-first)/(max time-first time)
(max-366.183)/1000
3.518 has been chosen because that is the voltage of the string potentiometer immediately before impact.0.502512 converts to metres.
X1*0.50251
((load signal-first)*4587.3)-92.547
(max-3.518)*0.502512
(plastic/max def)*100
Range x*0.933
(elastic/max def)*100
(end value-3.518)*0.502512
(max def-last value)*0.502512
Ratio of horizontal and vertical acceleration
atan(range/maxz)*-1
Max z*0.98