To appear in Biosystems Engineering

System Development for In-Situ Characterization of Thoroughbred Horse Racing Track Surfaces

M. L. Peterson, Ph.D.
Mechanical Engineering, University of Maine, Orono, ME 04469, USA
C. Wayne McIlwraith, BVSc, Ph.D., FRCVS
Orthopaedic Research Center, Colorado State University, Fort Collins, CO 80523, USA
Raoul F. Reiser, II, Ph.D.,
Health & Exercise Science, Colorado State University, Fort Collins, CO 80523, USA

ABSTRACT: A significant challenge in the operation of a Thoroughbred horseracing venue is optimization of the racetrack for fairness, consistency and to reduce safety concerns. The trainers, jockeys, owners and betting public expect a properly maintained track for racing and training. Currently the track condition is evaluated in vague qualitative terms such as “fast and hard” or “wet.” Maintenance of the surface depends on the experience and judgment of the track superintendent. Improved methods to test the track by measuring functional parameters would benefit horses and jockeys while maintaining industry openness to innovative track designs.

The loading conditions of the track materials in horse racing are unique. More than 9 kN of force is applied during each stride to the solar surface of the hoof. The hoof is approximately 9500 mm^2 and moves downward at a speed of more than 5 m/s during each stride. This paper describes work on a system that approximates the initial impact and loading phase of the gait of a horse at a gallop. The system approximates the impact velocity and loads applied to the track while acquiring five data channels. Data from a load cell is monitored and the vertical and horizontal acceleration are obtained from the device measurement. Initial base line data from tracks around the country show a large coefficient of variation for the two simple measured parameters that are considered in this paper, the peak load and the ratio of the horizontal to the vertical acceleration. The ability to detect a change in the harrow depth due to a malfunctioning implement at one track is also demonstrated. The potential now exists for superintendents to develop track maintenance techniques which ensure that different tracks have the same performance characteristics in a manner similar to techniques used to compare soccer and other sports fields [FIFA, 2006]. This measurement technique will allow the effects of maintenance on the track performance to be evaluated.

Introduction

Horse racing is an important industry in the United States and in many countries around the world. A 2004 American Horse Council funded study performed by Deloitte Consulting puts the economic impact of horse racing on the United States economy at 26.1 billion dollars [American Horse Council Foundation, 2005]. This makes the horse racing industry as big as one of the 75 largest companies in the US. Within the context of this large industry the economic cost of catastrophic injuries to race horses is a significant factor. Catastrophic injuries include injuries that significantly alter the ability of the horse to continue to race or result in loss of the animal. A study in the 1980s by the American Association of Equine Practitioners estimated that annual loss of horses is on the order of $500 million which does not include secondary economic impacts of the sport such as lost attendance and wagering [AAEP, 1989; Carpenter, 2003]. Also significant is the suffering of the horses and the risk to jockeys and exercise riders. A reduction in injuries would thus have benefits both financial and humanitarian.

Racing and training Thoroughbreds often die or are euthanized because of catastrophic injuries, this wastage was first recognized in the literature 25 years ago (Jeffcott et al 1982, Rossdale et al 1985). Severe physical demands are placed on the musculoskeletal system of Thoroughbred race horses during the high speeds reached during racing and training (Evans GP et al 1992). Because of the importance of musculoskeletal injuries in the race horse there has been considerable interest in studying factors that predispose to such injuries (Estberg et al 1996, Peloso et al 1994, Mohammed et al 1996). Musculoskeletal injuries in Thoroughbred race horses have been associated with sex, age, age at first race, horseshoe characteristics, racing frequency, duration of racing career, number of starts per year, weather, season, pre-existing osseous lesions, experience of the trainer, class of race, physical interactions among horses during racing, racetrack, results of pre-race physical inspection and intensity of racing and training schedules. However, it is common to neglect or at least minimize these other factors in the absence of a consensus regarding the track surface. Often the assumption by owners, trainers and the racing fans is that the track surface is responsible for a catastrophic injury, when in fact this is a multi-factorial event for which the track is a single issue (Robinson *et al.* 1988). There has, however, been limited scientific study on the relationship between racetrack surface characteristics and equine musculoskeletal injury. The clearest associations that have been made are between the vertical impact characteristics of the dirt racetrack and injury in Minnesota (Clanton et al 1991, Robinson et al 1988).

Maintaining the track surface currently depends almost exclusively on the experience of the superintendent and track management. The aim is currently to maintain a uniform surface that will minimize the influence of the track on musculoskeletal injuries. Qualitative track performance terminology currently used by many in the industry include: cuppy track, fast track, soft track and hard track. These terms may reasonably be taken as descriptions of low and high shear strength and low and high vertical stiffness or modulus of the track respectively. The words currently used focus on the horse and jockey’s experience of the surface which also corresponds to the loading of the hoof on the surface. The primary quantitative measurements currently used are moisture content, particle size distribution and organic content. However there are no commonly accepted criteria for an acceptable range of the measured properties. The complex relationship which ties these quantitative values to the biomechanical performance characteristics is also not well understood. Thus it is necessary to develop a method of testing the surface that is based on the performance, rather than simply controlling the inputs. No criteria currently exist, which contrasts to other sports such as soccer where established criteria are used on fields for elite competition [FIFA, 2006].

Thus a tool is needed which allows the horse trainers, jockeys and owners to understand that a track does in fact have the required characteristics. The objective of this work is to create a system that provides relevant quantitative information for the superintendent to use for the management of track maintenance work. The testing provides important information useful in the assessment of surface consistency and can be used to assist decision making by horse owners and trainers. The performance characteristics of the track can also be considered within the context of a particular horse and in some cases the training regimen for the horse.

Loading of Track Material in the Equine Gait

It would be rational to just accept test methods that have been developed for other sports and apply those to horse racing. However, the size and speed of the animals and the limited time available during the complex operation of a thoroughbred race course makes it necessary to carefully assess the needs of the track monitoring and to develop methods specifically for horse racing. In this context, the loading and dynamics of the track-hoof interface during the different phases of the gait are quite different because of the biomechanics of the gait. The front leg of the animal is considered in this work, since fore limb injuries are the most common on tracks in the United States [Gardner, 2004]. Starting with the impact phase of the gallop (top image in Fig. 1), the loading on the foreleg is primarily vertical since the hoof has not come fully in contact with the hard underlying track material and so the lateral strength of the material is limited. The forces during the start of impact are primarily due to the deceleration of the mass of the hoof moving downward toward the surface. However, the loading rate during this initial part of the impact phase is high. Currently no complete data set which includes the vertical and horizontal velocity data for the hoof at the gallop exists [Reiser et. al., 2000]. The highest reported vertical velocity of a hoof, 5.0m/s, is for a horse trotting at 10m/s [Johnston, 1991]. Extrapolated to a gallop speed this would give a hoof speed of more than 8 m/s. While clearly better data is needed, the speed of the hoof would be expected to be over 5 m/s. As the animal moves into the stance phase (second image in Fig. 1), the loading rate is reduced since the hoof has already come into contact with the loose top layer of the soil. During the stance phase the vertical load increases to the peak of up to 2 ½ times body weight due to the dynamic weight transfer to the limb [Witte et. al., 2006]. This force of 10 kN for a typical thoroughbred is distributed over the small area of the hoof. The load rate is initially high, with a decreasing rate during the period of loading. The hoof also stops moving forward during the stance phase and matches its speed to the ground. This horizontal deceleration is quite abrupt when a horse is moving at a gallop because the contact time with the ground is short. Once the horse has moved into the stance phase the magnitude of the horizontal deceleration is approximately one hundred times the acceleration due to gravity depending on the shoe and the track surface [Dallap, 2005; Nunamaker, 2003]. The leg then moves from the deceleration phase in the stance to breakover (the third picture in Fig. 1) where the muscles apply the horizontal force to the hoof needed to propel the horse forward. Primary propulsion is from the hind limb, but the fore limb also contributes some propulsive force as the horizontal load reverses direction. Finally the hoof is unloaded for the swing phase (the bottom picture in Fig. 1) when the hoof lifts off the ground and quickly moves forward to maintain position with regard to the nearly constant forward motion of the center of mass of the horse.

The horizontal and vertical decelerations of the hoof require a track surface that provides the appropriate response. During the impact phase the hoof is moving at high speed downward and so the track must decelerate the downward traveling hoof. The top loose layer of the track, the cushion, is compressed by the hoof and gradually decreases the speed of the hoof in the vertical direction. As the body weight is transferred to the hoof in the stance phase, the stiffer pad layer under the cushion begins to carry load. During the stance phase the horizontal load component associated with the deceleration of the hoof must also be resisted by the track surface. The hoof is simultaneously decelerating in the vertical direction and has penetrated the top loose layer of the track material. The horizontal loads associated with the transition from forward motion during the swing phase must occur after contact with the soil has begun. The initial horizontal component is in the direction opposite to that of the motion of the horse. The horizontal deceleration is on the order of 100 g's or more [Dallap, 2005]. This deceleration is, however, reduced if there is a partial shear failure of the soil during this time. The importance of the initial grab of the soil on the hoof is emphasized by concerns regarding shoe design [Kane et. al., 1996]. The toe grab shoe reduces the ability of the hoof to slide after initial impact with the soil, thus increasing the magnitude of the deceleration. During breakover, the load on the soil is fully reversed in direction to provide the propulsive force. An impact on the performance of the horse may be associated with shear failure of the track during the propulsive force of the gait [Biewener, 2003; Wong, 2001; Thomason and Peterson, 2008]. Thus it is likely that optimal shear strength for the soil will reduce the magnitude of the abrupt deceleration of the hoof while ensuring the surface does not fail in shear during the propulsive phase while the load in the vertical direction continues to be applied to the surface [Biewener, 2003, Clayton, 2004, Reiser et. al., 2000]. As the propulsive phase ends, the soil is unloaded and the swing phase occurs with the associated acceleration of the hoof to catch up with the forward motion of the center of mass of the horse.

A combined horizontal and vertical response from the soil is required during the gait. The assessment of human athletic surfaces has been previously separated into "cushioning properties" and "frictional properties" [Nigg, 1990]. These two directions of loading correspond to the vertical and horizontal fore-aft loading described in the literature for gait of animals [Biewener, 2003]. Qualitative track performance terminology which is in use by many of the horsemen in the industry refers back to these two primary directions of soil loading. Low shear strength is referred to as a cuppy track since the hoof shears out the surface of the track during the propulsive phase. A fast track has high shear strength. Both hard and soft refer to the vertical stiffness of the surface, although often it is assumed that the shear strength and the vertical modulus are correlated. This assumed correlation is not, in general, true regardless of the composition of the track.

Previous tests of the track performance may have not met with widespread success because of observed differences in measured and observed characteristics. This difference is likely due to differences in the rate of loading. Most soil measurements are made with instruments that are essentially static since they are meant for civil engineering applications. In contrast dynamic measurements which mimic the effect of a human athlete use relatively small loads in comparison to horse racing. The initial loading rate is determined by the impact of the hoof with the soil.

Recent work with instrumented horse shoes however has provided important information regarding the expected accelerations of the hoof [Dallap, 2005; Nunamaker, 2003]. The insight into the biomechanics of gait provided by this research can also inform the design of racing surfaces and can be used to improve the measurements used to characterize racing surfaces.

Previous Equine and Human Research

The vertical and horizontal response properties of the soil have been known to be important parameters related to racetrack performance. In the past a number of researchers have approached the testing of track surfaces although most have addressed only a portion of the issues associated with loading of the material. For example, complex systems have been developed for measuring the vertical properties (or hardness) of the soil using various drop test apparatus [Clanton et. al., 1991; Oikawa et. al., 2000; Ratzlaff et. al., 1997]. However, the shear strength was predominantly ignored. Only Clanton et al [1991] quantified any of the shear strength properties. In one measure a load cell was placed in the hitch of a harrowing device and in another loaded cadaver hooves were dragged across the track while measuring the force with a load cell. These tests only partially accounted for the complexity of the shear strength of soil, since strain rates similar to those encountered by the hoof at a gallop were not replicated. In the drop tests the load applied was much smaller than what was required to test the soil to the correct depth. In some previous tests, loads as small as 10 kg dropped from heights of less than 1 m were used [Pratt, 1985]. In most cases the data compared in the vertical direction was the peak measured vertical acceleration. This type of test represents the impact phase of the gait and does not address issues with the shear strength of the soil. In other tests, shear vane tests were performed, however because of the small loads on the device they were most appropriate to the early phases of the shear loading of the soil during the impact phase of the gait. The key element of the gait is not discussed in the papers which focus on the vertical loading of the soil. An exception is the one more complete model of injury to the foreleg which includes both the initial impact and slide of the hoof [Pratt, 1997]. The shear strength of the soil during stance or breakover was not addressed in this work however.

The closest human biomechanics application of measurements to the testing of a racetrack is the ergonomics of slip trip and fall injuries and the literature related to assessment of sports surfaces for human athletes. Ergonomics researchers have developed techniques that relate the velocity, contact area and normal force used in testing to experimental work on the biomechanics of gait [Grönqvist, 1995]. In particular it is clear that the dynamics of the gait are important factors when evaluating a wet or sliding interface between the shoe and surface [Marpet, 1996]. Based on this literature, the approach that has been taken to the characterization of track surfaces is to replicate the critical portion of the gait of the horse. Until the mechanisms of interaction between the hoof and the track are better understood it is necessary to assume that a test of the surface performance must replicate both the accelerations and the loads from the horse. It may also be the case that measurements which replicate the motion of the animal are required. In the human ergonomics literature this has been the case because of the complex interaction of the variables [Powers, 2007]. In tractive measurements of tires on soil four parameters are usually considered to be required [Ageikin, 1987] although empirical methods based on standard static tests have also been used [Wong, 2001]. In horse racing simple measures are unlikely to be accurate since the materials are both non-linear and strain rate dependent [Horn and Baumgartl, 2000]. Thus the loads and loading rate represent the best equine biomechanics data currently available and in general make use of the human ergonomic literature when appropriate.

System for Track Testing

The system that has been developed makes it possible to load the track at the rate and loads that are applied by a horse at a gallop. This system mimics the point at which the forelimb contacts the track and the weight of the horse is transferred to the hoof. This is the period of the gait during which both the highest vertical loads and the highest shear loads are applied to the soil [Biewener, 2003]. In order to make the system usable it must be mounted on a mobile platform that allows the system to be positioned on the track for sampling of the surface. Due to the wide geographical distribution of horse racing venues it also must be possible to ship the system cross-country. These design constraints have led to a research system which can be shipped cross-country, assembled on-site and mounted to the receiver hitch of a vehicle at the track. To provide a consistent platform for testing a large sport utility vehicle (Expedition, Ford Motor Company, Dearborn MI) has been used as a standard base for mounting the track test system. A three point category zero [ASAE Standards, 2001] electro-hydraulic tractor hitch has been adapted for use in a standard receiver hitch. This hitch allows the system to be positioned flat on the track surface.

Motion of the Test System

The device that has been developed is a two axis drop tower type of apparatus which impacts a synthetic hoof at an angle to the soil (Fig. 2). Two non-orthogonal axes of motion allow acceleration due to the sliding of the hoof in contact to be measured as well as vertical loads and vertical acceleration. From the figure, (Fig. 2) the two axes can be seen as a long set of rails and a shorter linear bearing apparatus which is attached to the hoof. With gravity acting on the first axis, the long rails on which the hoof and instrumentation slides, the force is generated by accelerating this mass down the rails. The total mass of the portion of the system that drops on the long rails is 30 kg which provides an energy at impact of approximately 540 Joules. This impact energy accounts for the energy of the hoof impacting the surface as well as the partial weight of the animal and associated musculature. A second set of shorter linear rails moves down as a part of the mass attached to the slide. This second axis is preloaded by a gas spring (EFA 20-50-FC, Efdyn, Tulsa OK) and only moves once the hoof is in contact with the soil. The difference in the angle between the first and second axes, 5 degrees from the long rail angle, forces the hoof to slide forward toward the toe as it impacts the soil and the second preloaded axis is compressed. The angle at which the hoof impacts the soil is adjusted to match the published biomechanical data for initial impact of the hoof [Ratzlaff et. al, 1993].

Unlike the hoof during the actual gait of a horse, the angle of the hoof relative to the soil is rigid during impact. During testing the consistency of the velocity at impact is verified by taking a numerical derivative of the data from the position sensor attached to the sliding carriage. The velocity is calculated to ensure that the energy at a time immediately prior to impact is consistent. Comparison of the data to high speed video and acceleration data obtained from instrumented horse shoes has the potential to be used to further verify the impact loading of the hoof on the surface.

The sequence of motions of the apparatus is shown in Fig. 3, with the system shown configured for mounting to a test vehicle. The testing of shear strength and vertical stiffness is usually considered in orthogonal directions. However, in this case, the loading rate is difficult to replicate unless non-orthogonal directions were used. This condition does make it possible to match the contact of the hoof with the track. Because the loading rate is dependent on both the modulus of the specimen and the impactor, the surface of the machine that impacts the track is a hoof cast from a two part casting rubber (Duo-Matrix Neo, Smooth-On, Easton PA). The hoof casting material has an impact resistance of 30 $kN \cdot m / m^2$, which allows repeated impacts with the soil while matching the surface area of the hoof. A standard racing plate with a low toe grab is attached to the hoof (see for example the American Front Plate, Victory Racing Plate, Baltimore MD). The adjustable gas spring in the second axis is intended to replicate the compliance of the leg. Adjustability of the compliance of the apparatus is included in the design to accommodate the potential for future biomechanical research which may alter the understanding of the role of compliance in the gait of the horse.

Instrumentation

A total of five data channels are used in the testing. Attached to a stiff mass above the hoof is a three axis 100g accelerometer (Model CXL100HF3-Al, Crossbow Technologies Inc, San Jose, CA). Load is transferred into the gas spring from the hoof mass using a dynamic load cell (Model 208C05, PCB Piezotronics, Depew NY) with a 0 Hz. (DC) to 36 kHz bandwidth. The position of the hoof on the 1.6 m long drop rail is determined using a string potentiometer (PT5A-100-N34-DN-10K-M6, Celesco Transducer Products Inc., Chatsworth, CA). Redundant data from the acceleration and the position measurement is used to estimate the penetration into the soil and to verify the velocity of the hoof at impact. The angle of the hoof with respect to the soil is adjusted to 7 degrees from the vertical to match treadmill data from horses at a gallop [Reiser et. al., 2005].

Data Obtained

The raw data obtained from the instrument consists of three accelerations, the position of the drop mass, and the load cell output. An example of the unprocessed data are shown in Fig. 4. Initial analysis of the data has used two measures, peak load and dynamic shear angle. The peak load is measured in the vertical loading direction. The peak loads measured in the vertical axis will overstate the loads somewhat since the suspensory structures in the limb will reduce the peak loads that the joints would experience [Swanstrom et. al., 2005]. The dynamic shear angle is analogous to the shear angle measurement that is used in soil mechanics. In this case the angle is the inverse tangent of the peak acceleration in the horizontal direction divided by the peak acceleration in the vertical direction. The shear angle is reported in radians measured from the horizontal, with a larger angle corresponding to lower shear strength, and thus higher relative vertical accelerations. The choice of this format for presenting the data is somewhat arbitrary; however it has the advantage of including a lower level of processing than the impact injury score [Dallap, 2005], rebound rate [Ratzlaff et. al, 2005] or other measures which may prove to be important. The correct choice of comparison metrics depends on the mechanisms for bone remodeling which include both static loading effects [Cowin 1986] as well as strain rate effects [Luo 1995]. Given the rapid and complex developments in the understanding of mechanics in bone, a simple measure is used in this work which must eventually be tested against results from epidemiological research. The general measurement technique is not, however, constrained to simple metrics and should be adapted to include a better understanding of bone remodeling.

Because of the combined shear and vertical loading that are applied by the apparatus, it is currently only possible to look at the repeatability of the system since calibration specimens are not available that provide a controlled vertical modulus at the same time that the shear strength is known. The most repeatable material found for the vertical component is quartz sand, which is sifted prior to impact and laid to a set depth on a thick concrete slab base. This test is done in addition to the verification of the impact speed and the load cell operation done using the rubber pad described below. This configuration makes it possible to verify the functionality of the instrument at each test site.

A representative example test for repeatability using quartz sand from one of the tracks in a sand storage bunker was done with material with a mean particle size of 300 microns and less than 2% above 600 microns or below 75 microns with a measured moisture content of the sand less than 1%. Nine tests were performed on the same material area with sifting and remixing of the sand between each strike of the test apparatus. The sand was kept at a depth of 3 inches over the concrete base. The average peak load for the tests was 5.16 kN with a standard deviation of .40 kN. The dynamic shear angle measured for the same conditions was 0.59 radians with a standard deviation of 0.07 radians. The coefficient of variation for the two measures is 0.08 and 0.12 which is typical of the most repeatable measurements. Compaction is critical even with dry sand and a narrow particle size distribution. Without sifting and resetting of the sand surface using the same materials and base, the average peak load for nine tests is 11.49 kN with a standard deviation of 2.26 kN and a shear angle of 0.36 radians and a standard deviation of 0.18 radians. The higher coefficient of variation (0.20 and 0.49) with repeated impacts is associated with increased shear angles and peak loads. This effect shows that with the high loads that are applied compaction is important even with this material. The compacted sand has a higher shear strength and increased vertical modulus as expected.

Test Protocol

Tests using the apparatus described were performed at five racetracks over a period of six months. The tracks were of similar construction with generally a sand construction with typical composition of 12% silt and clay, 85% sand with the balance organic material and a small amount of gravel. Additives in the form of fibers or waxes were added at two of the tracks to reduce moisture sensitivity and increase the shear strength. These tracks represent some of most well established maintenance and materials practices on the west and east coast of the United States.

For the first test location the dynamic shear angle was found to be unreliable due to accelerometer problems, so the shear properties are not reported for the first track. The peak load was measured using the same procedure on all of the tracks and was verified using a 15 cm. square 80A durometer nitrile machinery vibration damping pad as a reference specimen. While the nitrile pad is effective as a reference material for the vertical axis, at this point the only reference specimen available is the loose sand which is not mobile for use in calibration at each testing sites.

Data was taken for all of the tracks after training in the morning (which is the last access to the track prior to racing) and after racing in the afternoon at those tracks when a race meet was underway during the study period. When a race meet was not underway data was taken prior to opening of the track for training in the morning and after training was finished for the day. In all cases the moisture content for the organic tracks tested were within a range of 11 to 15% (based on a thermo-gravimetric tests of four samples consistent with ASTM 2216 [ASTM, 1998]). The objective was to measure the track at times that were most relevant to the benefit of the horses and riders. Three data points or individual impacts were obtained at each 1/8th pole. The measurements were clustered in a 1 meter square area. The data was taken at a location where no hoof prints were visible and with a new data point taken if the impact overlapped any exiting hoof prints. The impact points were approximately 12 feet off of the inside rail with adjustments made to avoid portions of the track where tractor traffic might lead to compaction. This provides an equivalent condition to that which a horse would experience traveling over a newly harrowed surface. Thus for analysis of the data 24 points were obtained for a one-mile long track with more or fewer points depending on the length of the track. When a more complete statistical analysis is performed between tracks and the tracks differ in length, the final portion of the track is used for comparison. It is assumed that when horses breeze they are run on the portion of the track just before the finish. Thus the last portion of the track is most important since it is used for every race and for rigorous training

Pilot Test Results

Data is shown for a comparison of the peak vertical force measured at five tracks in Fig. 5. This data shows the range of values that is obtained from a test with the proper load and impact rate on the track. Of particular interest is the variation in the track for these five racing venues. The coefficient of variation in the response from the tracks studied is shown as an error bar on top of the bar chart. The data in each bar represents a minimum of three days of testing with two tests per day and with a minimum of 15 measurements for each test. The variation represented on the bar chart includes both the spatial variability or the differences between tests at particular locations on the track and the temporal variation or the differences between tests on different days on the same track. The variation of the data ranges from 0.15 to 0.27. This compares to a variation of 0.08 in the reference sand material.

A slightly smaller data set is shown for the shear properties of the track because of a malfunction of the accelerometers early in the testing. The data shown is comparable to the peak load data and includes the estimate of the standard deviation as a vertical error bar and represents the same data size for the tracks shown (Fig 6). The coefficient of variation in the shear angle ranges from 0.42 to 0.15. In the reference material the coefficient of variation in the shear measurement is 0.12.

In Fig. 7 the temporal variation over a period of four days at one track is shown. The data was taken both after the morning work and after racing was completed for the day. This example of temporal variation in the average peak load is shown as an example of a temporal variation which can be used to diagnose problems in track maintenance. Each data point represents 24 measurements with only the average value shown on the graph.

The absence of a well controlled reference specimen makes it difficult to characterize the error of the apparatus developed in this work. However, the apparatus is effective if differences between locations can be evaluated as well as any changes in the track due to maintenance or weather. The four day data set shown in Fig. 7 is a case in point. It appears that a transition occurs between day 2 and day 3. The data is grouped into days 1 and 2 and days 3 and 4. Given the variation in the testing the statistical test was whether this was in fact a change in the observed peak load in the track. Using an ANOVA two-factor with replication, if the two groups of days are compared a P-value of 2.6×10^{-6} is obtained. However, after observing this change on the third day a problem was tracked down to a lead harrow which had clogged with clay soil. Because of other factors on the track and to avoid abrupt transitions, the track was gradually loosened up over a period of time. Thus the observed change in the peak loads made it possible to track down a problem in the harrowing of the track and avoid a further increase in the peak load which could lead to broken bones.

Conclusions

A system has been described that makes it possible to measure the key mechanical performance parameters for a Thoroughbred horse racing track, the vertical stiffness and the horizontal shear strength. The ability to detect a change in the track which was determined to be caused by malfunctioning equipment suggests that this is a useful tool for monitoring the maintenance of horse racing tracks. Future work will include determining the differences in surfaces which are intended to reduce maintenance of the track, while providing a safer racing surface. Prior to extensive use of the system a method of calibrating the system at each of the tracks will be required to ensure that data is repeatable and that the system is functioning properly.

ACKNOWLEDGMENTS

Support for this work has been provided by the American Quarter Horse Association, the California Association of Racing Fairs, Santa Anita Racetrack, Hollywood Park Racetrack, Del Mar Thoroughbred Club, Fairplex Park, California Thoroughbred Trainers and the Thoroughbred Owners of California. Track superintendents Steve Wood and Dennis Moore provided technical assistance and helped to identify and gain access to a number of the facilities tested.

CAPTIONS

Fig. 1. Drawings associated with video frames showing the phases of the gait with load direction on the soil shown with arrows.

Fig. 2. A schematic of the machine for testing track surfaces which shows two axes of motion and the configuration of the instrumentation on the test machine.

Fig. 3. Photos of the apparatus mounted to the test vehicle (top left) with the offset angle between the two slides (top right), gravity propulsion and the strike and slide which allows both shear and vertical properties to be measured in a single test.

Fig. 4. Raw data traces which show the load and position (top trace) and three channels of acceleration data.

Fig. 5. Peak load test results for tests performed at five racetracks with an error bar shown which represents the estimated standard deviation.

Fig. 6. The results for shear strength measurements were taken at four racetracks shown as a bar chart with the standard deviation as an error bar.

Fig. 7. The average peak load measured at one track during a four day period. Lines show tests taken after morning work (dashed) and after racing (solid).

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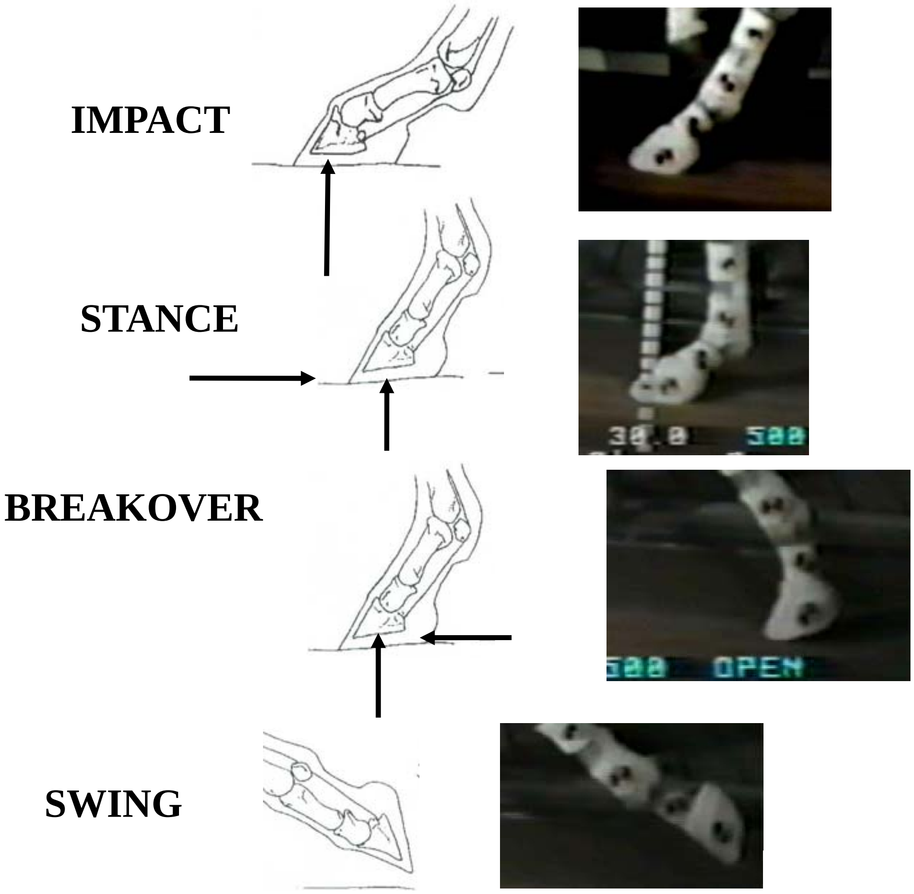
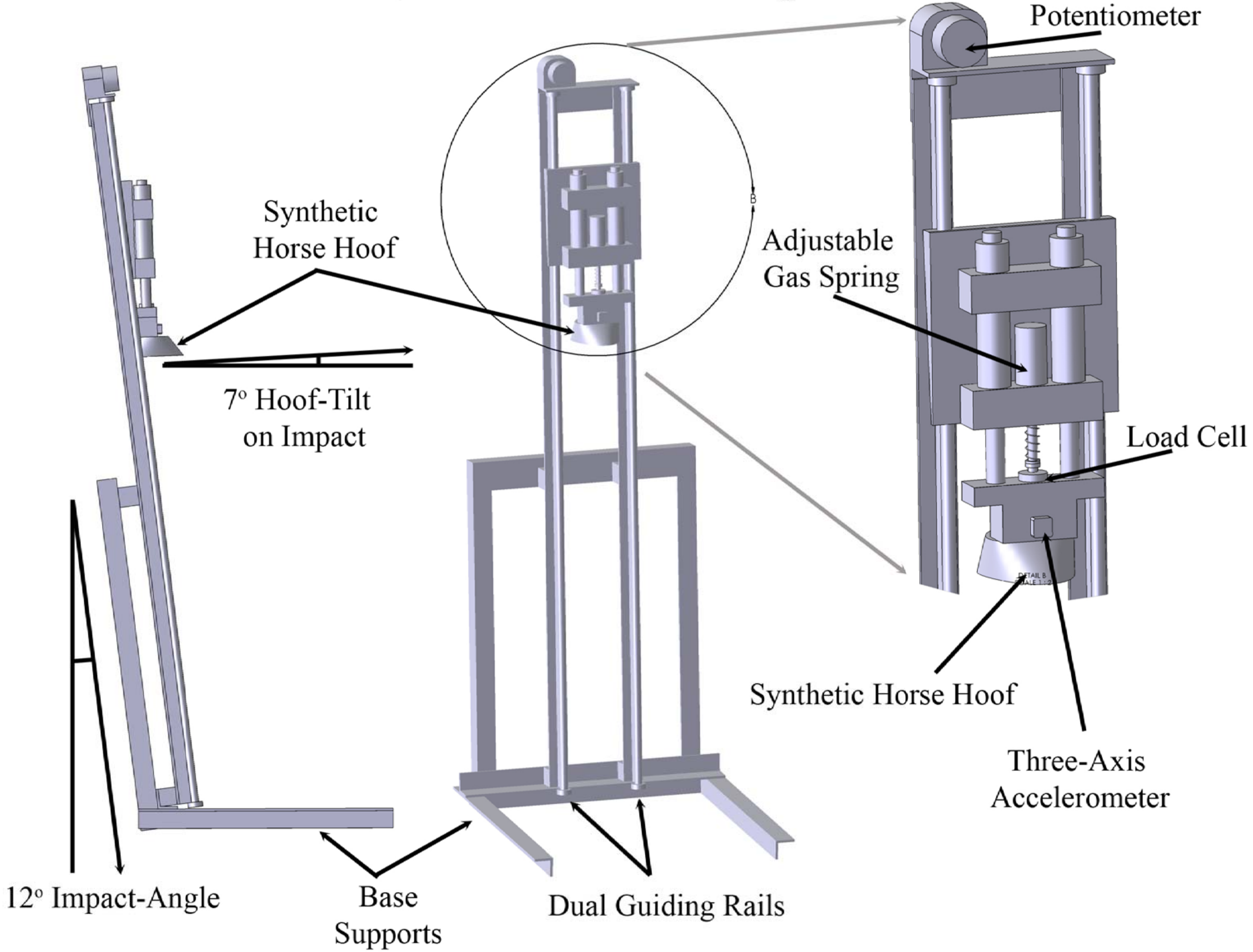
FIGURES

Fig 1 Drawings associated with video frames showing the phases of the gait with load direction on the soil shown with arrows

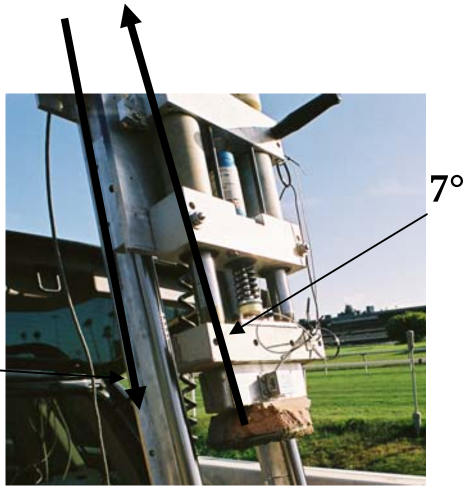


Dual-Axis Synthetic-Hoof Drop Hammer



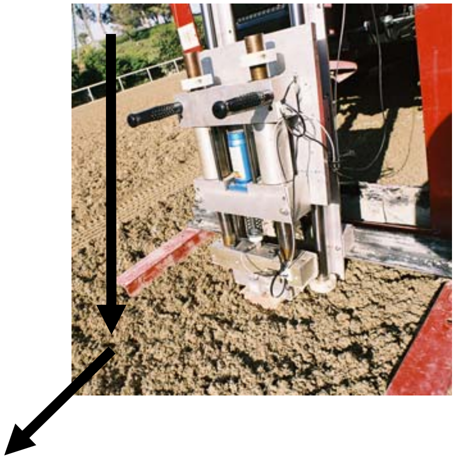
**1…
Mounts
to
Receiver**

**2…
7 degree
offset for
two slides**



**3….
Carriage
moves
down –
gravity**

**4…
Hoof hits
and
slides**



Photos of the apparatus mounted to the test vehicle (top left) with the offset for the two slides (top right), gravity propulsion and the strike and slide which allows two both shear and vertical properties to be measured in a single test.

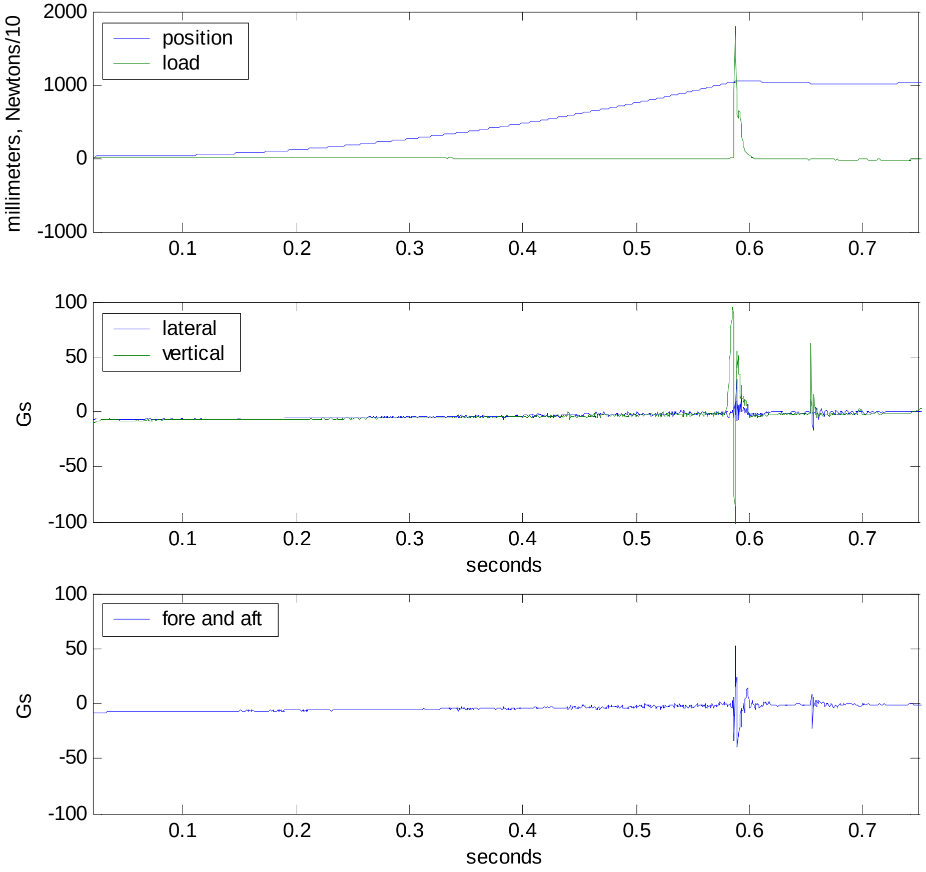


Fig 4 Raw data traces which show the load and position (top trace) and three channels of acceleration data.

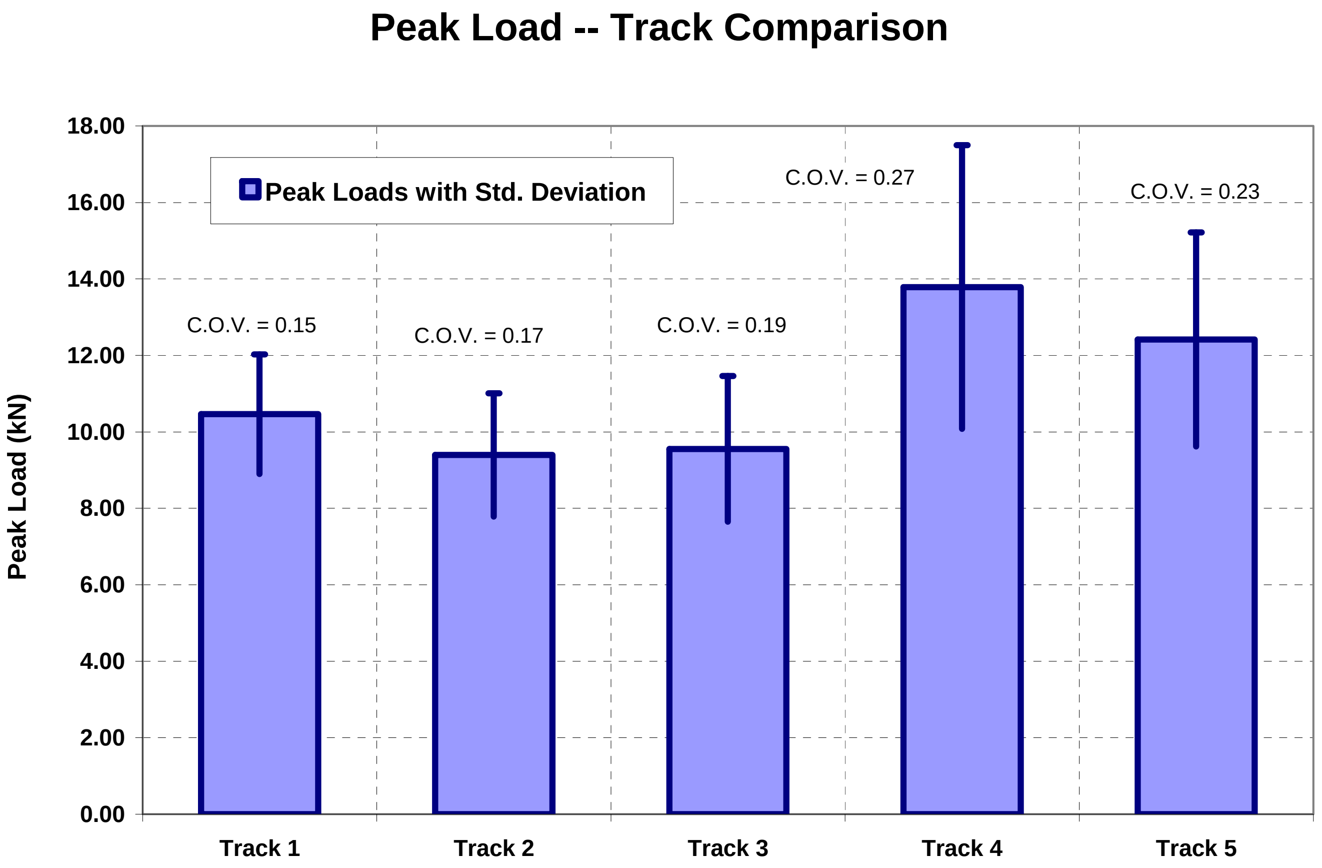


Fig. 5. Peak load test results for tests performed at five racetracks with an error bar shown which represents the estimated standard deviation.

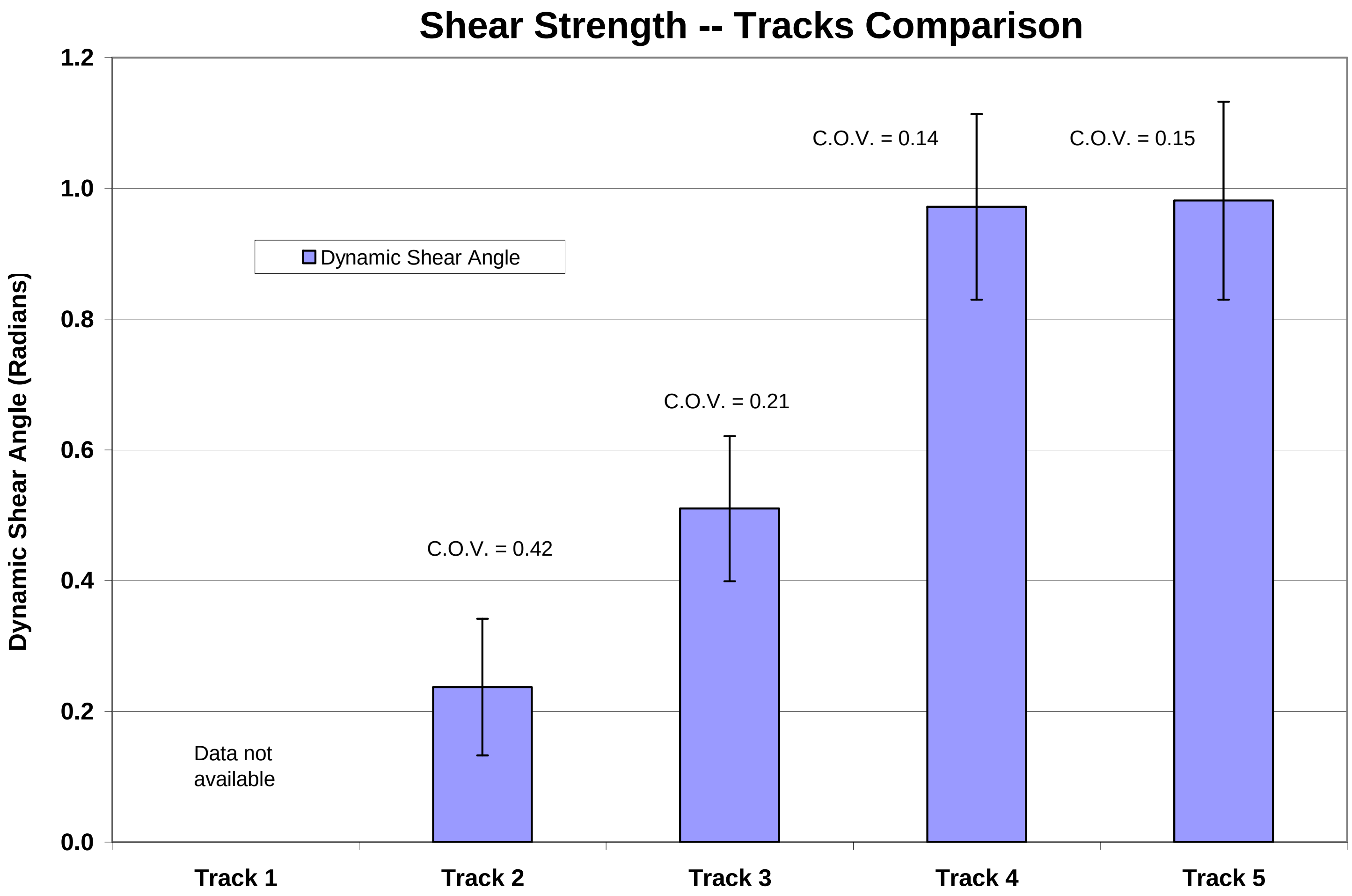


Fig. 6. The results for shear strength measurements were taken at four racetracks shown as a bar chart with the standard deviation as an error bar.

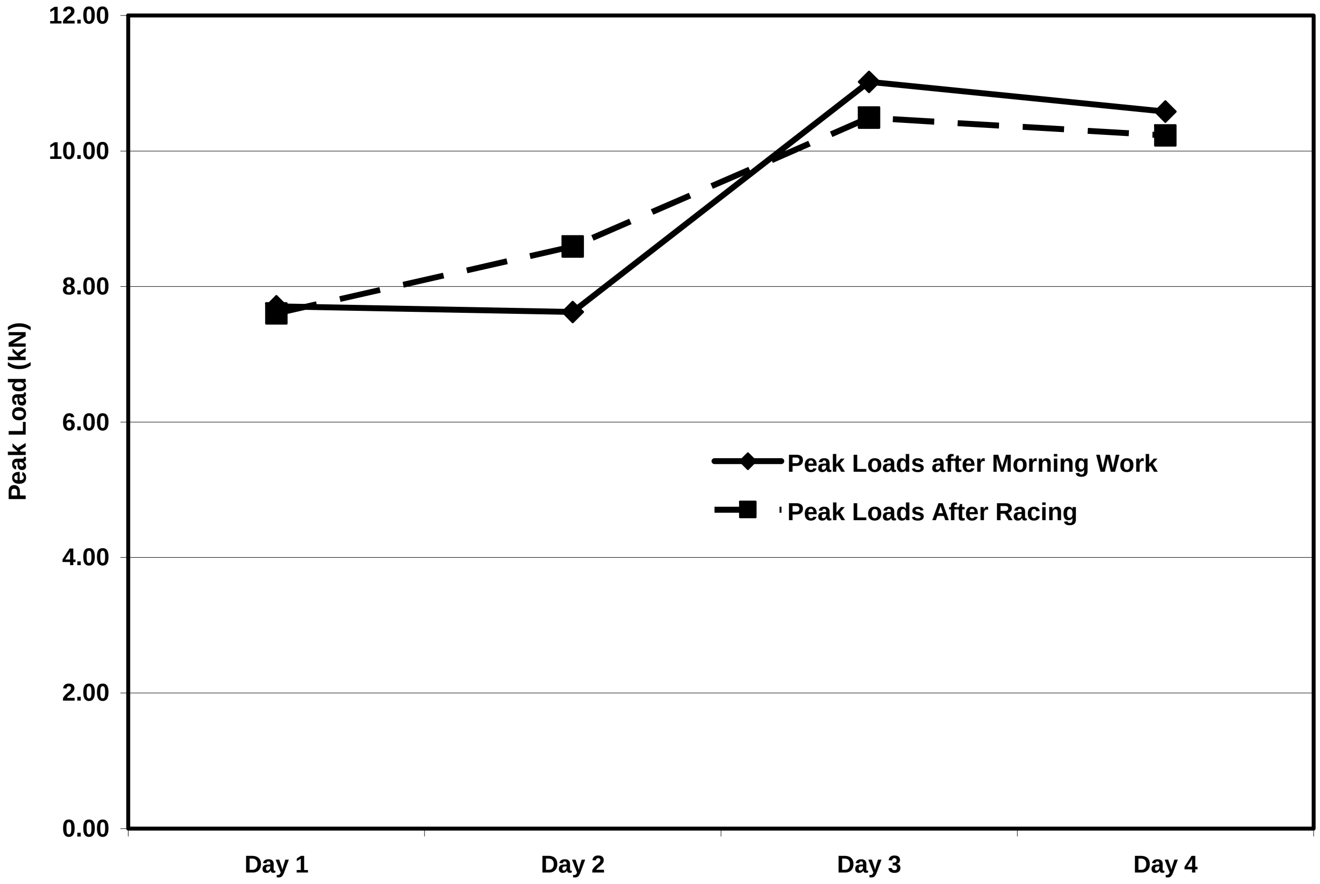


Fig. 7. The average peak load measured at one track during a four day period. Lines show tests taken after morning work (dashed) and after racing (solid).