In-Situ Characterization of Horse Racing Track Surfaces

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Motivation

A number of studies have been done in the past that have considered the economic cost of catastrophic injuries in race horses. Not only is the economic impact significant, but suffering of these wonderful animals must be a consideration. In horses, rarely does a single event cause an injury; instead the joint disease culminates with a number of factors on a particular day and time to result in catastrophic injuries. Excessive training of the young horse and the resulting increase in bone density can decrease the fracture toughness of the bones. Soft tissue injuries can be related to training as well as the conformation of the horse. However, specific training regimens and careful control of the race and training surface are primary factors which influence the likelihood of injury. The objective of this work is to begin to increase the amount of quantitative information which is available to the track superintendent for maintenance of a safe and fair racing surface. Ultimately, a system should be able to identify track problems before horse injuries begin to increase which will reduce animal suffering and economic loss.

Background

The demands on the track during the different phases of the gait are quite different and in some ways contradictory. During the impact phase of the gallop the loading of the foreleg is nearly vertical. The total load on the soil is small since it is primarily due to the mass of the hoof. However, the loading rate during the impact phase is high. As the animal moves into the stance phase, the loading rate is reduced since the hoof has already contacted the soil, and the weight of the horse is being transferred to the hoof. The deceleration of the hoof occurs during the impact with the top layer of soil, the cushion. As the body weight is transferred to the hoof, the stiffer lower soil layers become dominant. During the stance phase the vertical load increases to the peak of up to 2 ½ times body weight. During the stance phase a horizontal component is introduced which is associated with the transition from forward motion of the hoof during the swing into the propulsive phase of the gait. This horizontal component occurs because of the need to match the hoof speed to that of the ground during the propulsive phase. Initially, this horizontal component is in the direction opposite to that of the motion of the horse. During breakover, this horizontal load reverses direction in order to provide the propulsive force. This propulsive phase is then followed by unloading of the vertical component. 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.

Once the horse has moved fully into the stance phase, the shear strength of the soil becomes the dominant issue. A cuppy soil is a soil that does not sustain the force applied to it during the propulsive force of the gait. Thus minimum shear strength for the soil is a primary design criterion for a track surface. However, recent work has suggested that the horizontal deceleration of the hoof during initial contact with the soil may also be a critical issue [1]. Thus, a conservative design for a track surface may not exist, since an optimal soil may fail in shear during the initial stance phase and should not fail during the propulsive phase of the gait. Both shear strength and vertical stiffness are important and also are strain rate dependent. Thus the vertical and horizontal velocity for the hoof at the gallop must be replicated. This information does not exist in the exact form needed for the apparatus design [2], so for the initial system design the highest vertical velocity of a hoof, -5.0m/s, reported for a horse trotting at 10m/s is used [3].

While significant work has been done in the past to characterize track surfaces, much of it has not been able to adequately take into account the non-linear, elastic, plastic material characteristics. For example, systems have been developed for measuring the vertical properties (or hardness) of the soil [4], [5], [6].Clanton et. al. 1991, Oikawa et. al. 2000, Ratzlaff et. al. 1997. In some previous tests, loads as small as 10 kg dropped from heights of less than 1 meter were used [7]. This type of test only represents the impact phase of the gait and does not address issues with the shear strength of the soil. When smaller loads are used the importance of harrowing the fluff is overstated. Additionally, the shear strength was not considered in many of these investigations. Clanton et al [4] did some work on quantifying shear strength properties as well as other work by Pratt using a shear vane test. However, these tests only partially accounted for the complexity of soil, since
strain rates were not replicated.

Approach and Results

The device that has been developed is a high speed drop hammer which impacts the soil at an angle which replicates the impact of the hoof on the track and thus experiences the same horizontal deceleration that a hoof impacting the soil will experience. This horizontal deceleration serves as a test of the horizontal shear strength of the soil. The machine uses a synthetic hoof that impact at an angle to the soil which is adjusted based on biomechanical data. The speed of the hoof at impact replicates the velocity of impact of the hoof, with a secondary loading of the hoof through an adjustable gas spring. An adjustable gas spring replicates the compliance of the leg. A stiff mass is attached above the hoof which replicates the mass of the hoof which initially impacts the track. Attached to the mass is a three axis 100g accelerometer (Crossbow Technologies Inc, San Jose, CA). Load is transferred into the gas spring from the hoof mass using a dynamic load cell (PCB Piezotronics, Depew NY) with a DC to 36 kHz bandwidth. The position of the hoof on the drop rail is determined using a string potentiometer (Celesco Transducer Products, Chatsworth, CA). The redundant data from the acceleration and the velocity is used to estimate the penetration into the soil and to calculate the velocity of the hoof at impact. Unlike the actual hoof, the angle of the device is fixed during impact. The system replicates the strain rate, the loads and the hoof velocity of the horse. Comparison of data from a number of racing venues and types of track surfaces suggest that peak loads on the forelimb of a horse during the gallop vary dramatically. Much of this variation is not predicted by lower strain rate and lower load test methods.

The resulting data from one track is shown in figure 1. The ratio of the horizontal to the vertical acceleration is plotted on the vertical axis, and the peak load of the load cell is plotted on the horizontal axis. The data in this case was taken every 1/8th of a mile on the track with three data points obtained at each location on the track. In all cases the data was taken after harrowing of the track and in a location without any visible evidence of hoof prints. The oval is at a point that passes through the one standard deviation for each of the axes. Thus this visually tells not only the condition of the track, but by the size of the oval the variability of the track condition.

![Figure 1. Example of data obtained from a track which shows the mean and standard deviation of the track condition plotted as an oval](image-url)
The Effect of Harrowing on Track Surface Response

Two types of dirt racetrack designs are used in the United States. This discussion focuses on the type of track used primarily in the western US which will be referred to as a California Style track. In a California Style race track three layers of track material are maintained, the top layer which is called a cushion, a semi-compacted region below the cushion called a pad, and a hard flat base layer. The top layer of the track, the cushion, is harrowed between each race and at breaks in training. The cushion is harrowed between races using a larger and heavier harrow than would be familiar to people who know the East Coast horse racing tracks. The harrow for the California track is typically set to cut about 2 5/8” inches deep. This heavier design probably developed on the west coast because of the heavier clay soil and differences in the tine spacing and the number of tines on the harrows used.

In addition to this top layer a second or middle layer exists over the base of the California Style track. To create this additional layer two other pieces of equipment are used on the track. Both a cutting harrow and a grader with a ripper attachment are used to set and manage this intermediate layer between the cushion and the base. The primary piece of equipment is a cutting harrow with forward angled tines. The cutting harrow is used on the track prior to racing to set the pad. The depth of the cut with the cutting harrow is 2 3/8” below the top of the compacted cushion. This would correspond to approximately 1 ½ inches below the cushion assuming that the cushion is compacted 70%. Or in other words, the volume of the soil that is loosened by the cutting harrow and the amount of soil loosened by the roller harrow is approximately the same. While the volume of soil disturbed by the cutting harrow and the roller harrow is approximately the same, the compaction of the material in the two layers is different when the track is ready for racing. As the tines of the roller harrow pass above the soil in the pad a stress field is generated in the pad that then serves to compact the soil in the pad and stiffens this layer of the track. Therefore the pad must be loosened and then reset on a regular schedule in order to retain its compliance.

Figure 2. Style of harrow used between races at most California racetracks
Finally a grader with a pavement ripper or road rake attachment is used to make a deeper into the track to a typical depth of 6". This ripping of the track is also done on a weekly or more frequent schedule depending on local soil conditions. This cut is followed by compaction by either a roller compactor or a water truck. The function of this ripping of the track is to set the lower part of the pad and then to form a layer of more highly compacted soil above the base. The pad is thus a combination of the soil disturbed by the cutting harrow and by ripping process. When the track is fully set the pad is approximately twice as stiff as the top layer and has a much higher shear strength. The loosening of the soil in the pad resets the effect of the travel of the roller harrow over the surfaces which gradually compacts the soil in the pad.

The effects of this ripping and tilling operation should be immediately evident from the hoof testing equipment. Figure 4. shows the effect of ripping and using a cutting harrow to reset the pad on
a California style track. The increase in the variation in the vertical direction is accompanied by a decrease in the variability in the horizontal direction. This is not intuitive until it is recalled that the track is “set” in the horizontal direction by passing rolling equipment over the surface, prior to setting the top layer or cushion. Also note that since the horse hits the ground with 2 ½ times body weight distributed over tiny thoroughbred hooves, the compaction of the soil by the passage of horses over the surface is greater than any other effect on the surface, except possibly water trucks which are not permitted near the rail on a thoroughbred racing track.

Conclusions

This work has made use of a technique which has been developed for characterizing thoroughbred racing tracks. The results of the testing are shown for resetting the pad on a thoroughbred race track. It is clear from these results that not only does the technique present interesting opportunities for the racing industry, but that it also has the potential to provide important insight into maintenance techniques that have developed based on experience and extensive observational data.

References

1. Nunamaker, D, 2003, e-mail communication, November 3, 2003