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Ground Penetrating Radar to

Assess Slope and Irregularities in the Base of Racetracks

Report on Results of Testing

Submitted by:

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Motivation

While recent decades have seen a great expansion of sensor and measurement technology, relatively few of these new tools have developed into techniques that can assist racetrack personnel in developing a safe and fair racing surface. Most notably, the variation of racetracks has been identified as an important issue. Variation of racetracks takes the form of changes between locations on a single track, changes over time to a track and differences between tracks. A horse that ships between several different tracks would be subjected to both these spatial and temporal variations in racetrack surfaces and would be more likely to have injuries.

Several studies have been undertaken to better understand these variations in track surfaces. Previous work documented variation at a number of California racetracks using a test system that replicates the loads and load rates of a horse at a gallop. A summary of these results are included in Appendix A. It became clear from the observed variation that an improved understanding of composition and base profile on tracks is needed. This understanding will help to address the variation and to provide a safe and fair racing surface. The current work evaluates the feasibility of using ground penetrating radar and has developed techniques for applying this technology to characterize the base and materials of racetracks.

Ground Penetrating Radar Results

Pilot data indicated that ground penetrating radar showed promise as a way to characterize the condition of the base on a racetrack. The pilot data, included as appendix B, was used to determine the frequencies that would be likely to work on the tracks and also helped to determine what type of device would need to be designed to carry the antenna across the track.

Three tasks were included in the current study to determine if ground penetrating radar could be used to help in racetrack management and as a research tool for development of new racetrack surface materials. First a calibration task was needed to determine the depth of features that are detected using the radar system. Second the effect of compaction was to be investigated with the ground penetrating radar. Finally a track was to be tested using the radar to see if the base of a track could be investigated under normal conditions of moisture and maintenance.

The effort described below represents work initiated using funding from the Southern California Equine Foundation and the Oak Tree Foundation. This work not only includes the completed testing of the racetrack surface as proposed but was also expanded to consider synthetic tracks. The extra effort that was made to include the synthetic tracks was considered a priority because of the great interest in the use of these new track surfaces in several locations in California.

Task 1: Radar Calibration

Development of calibration techniques for soil samples is needed in order to determine the depth of features that are detected using the radar system. The radar system provides the time required for the electro-magnetic wave to travel to a particular feature.

But the time is dependent on both the soil composition and moisture content to convert the measured times to depth. The signal must be calibrated using the velocity of propagation for a particular soil sample in order to convert the time delay into a depth value. The approach which was initially proposed was to make use of a cone penetrometer to measure the base depth and to map the surface of the base. However, due to device limitations an alternative methods was developed for the calibration process.

It was initially understood that the cone penetrometer is not well suited for accurate characterization of layered soils. However, for calibration purposes only a single layer needed to be defined which could then be identified in the radar image. For this purpose a digital cone penetrometer was acquired (Field Scout SC-900 Soil Compaction Meter, Spectrum Technologies, Inc., Plainfield, Illinois). This system is supposed to be able to acquire data from a global positioning system to create a map of the compaction and base layer depth for a track surface.

However two problems emerged, one of which is well known in the area of racetrack surfaces. The top surface of a properly prepared track is too loose for the cone penetrometer to make a proper reading even if a larger than standard cone is used. In addition to problems with the loose cushion on the track, the Spectrum unit, like most other penetrometers, did not have sufficient dynamic range to test racetracks. In order to provide a reading from the top surface or the fluff, a very large diameter cone must be used. Even using the largest standard cone the reading is often too low for the instrument to measure. In addition at the base and sometimes in the pad, depending on moisture content, the loads are too high for the instrument to measure even when the standard smaller cone is used. This situation is unlike other soil applications where the goal is either a hard surface for traffic or else a very loose layer is desirable for planting various crops. A non-critical but further difficulty with the cone penetrometer unit used for the calibration was that the GPS connection on the system unit was not reliable. The combination of the major problems and the secondary communication problem with the GPS greatly reduced the attractiveness of this unit for base mapping of the racetrack. In particular quantitative data could not be obtained in this application.

An alternative approach to the calibration has been developed using simple materials. After trying several different approaches a soil sample was placed in a standard container that could be used to calibrate soil type and moisture content for the depth of the material used on the racetrack. While the compaction and moisture content is not perfectly represented, a general calibration of depth from the time delay can be done in this way. Specifically a five gallon bucket is filled with a material sample from each of the tracks. The radar is used to determine the time delay to a metal grid placed underneath the bucket. It is important that to the extent possible the bucket itself be kept consistent because of the effect of the bucket material on the tested time delay. Because of the availability in most locations, the standard bucket used is an Homer Bucket (Model RG5555, Home Depot, Atlanta GA) and lid (Model RG5503, Home Depot, Atlanta GA). As shown in Figure 1, the testing configuration is simple. However the calibration signal cannot be acquired with the radar unit so the calibration factors need to be manually entered into the analysis software. It is also useful to retain the samples for verification of the results and to retest the sample if questions arise regarding the effect of compaction on the time delay. Using this calibration method it has been possible to identify the depth of features that were detected using the ground penetrating radar. While the use of the cone penetrometer would have had lower uncertainty on the depth measurement, this technique should be repeatable and suitable for identifying locations of problems.

Task 2: Develop Technique for Spatial Compaction Survey

The analysis of the 2004 track comparison study showed a wide range of peak load and shear strength measurements at different, sometimes adjacent, locations on a track. The only possible explanation for this variability was that the hoof prints continued to be evident in the track surface even after the track had been harrowed or even cut. This variation was identified as perhaps the single most significant factor in the track surface design. For example in appendix A when looking at the data taken on a track with the biomechanical hoof, the spatial variation from on the track is represented by the length of the vertical line crossing the top of the bar (the error bar) for the data on a particular day. It is clear that this spatial variability is of a significant amplitude relative to the temporal variation which is the represented by the height of the bars on the chart associated with each of the days. Both hardness and shear strength showed this variation which suggests that compaction is the cause. This is only one likely explanation however since other factors such as problems with the base layer may also play a role depending on the age and design of the track.

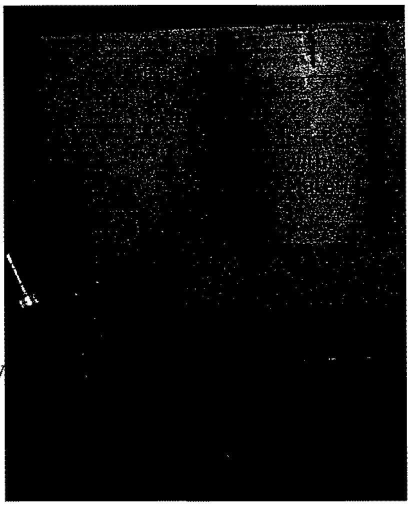


Figure 1: Test configuration for track material.

This task was intended to explore the use of ground penetrating radar to evaluate the compactability of soils. A tool that could compare this compaction process in different soils would then make it possible to create soil mixtures that were more resistant to compaction. Reduced compaction would reduce the variability in the track surface which would in turn make a safer track.

However, even if the ground penetrating radar is the appropriate tool for this effort, a research initiative is needed that will focus on the appropriate track materials to reduce compaction due to traffic from horses and equipment while maintaining low peak loads and an appropriate shear strength to the track. That work will need to be done once tools are available that will allow tests to be done to measure compaction. The ground penetrating radar could be used as a part of an experimental design for a study of compaction in traditional and synthetic racetrack surfaces. The future study will be of quite a large scale since it is not possible to directly confirm the compaction hypothesis on a track without being able to completely control the track maintenance for the period of the study. Specifically, the track would need to be cut, set, and then harrowed, prior to testing compaction. A single horse and/or the biomechanical hoof tested would then be used on to compact the track surface. The track would then need to be harrowed again prior to being tested using the ground penetrating radar. The compaction test using this protocol would then make it possible to evaluate the relative performance of track surfaces for resistance to compaction. Such a study would also need to compare different track construction materials. In order to understand if the ground penetrating radar would be suitable for this comparison of track surfaces task 3 was also expanded beyond the scope of the original proposal to include testing of several different track materials.

Given the complexity of working on a operational racetrack, it was not possible to use hoof prints to test the radar because of the large number of prints that almost immediately cover a track after the morning renovation. It was hoped that the ground penetrating radar would be able to identify hoof prints on the track. However initial ground penetrating radar results made it clear that the compaction pattern from multiple passes of so many horses was too complex for isolating hoof prints. An alternative, more controllable method was used to create an understandable compaction pattern. A completely prepared track exists in many locations when racing is not being conducted. The track is fully prepared for the next day of training at the end of the work session. In the morning before training the track is watered and harrowed prior to exercising horses. It is not advisable to use the biomechanical hoof at this time since it can cause a hard place in the track because of the high loads applied. Multiple hits from the biomechanical hoof should be followed by cutting of the track because of deep compaction. Otherwise a hard spot on the track exists which is not removed with the normal roller harrow but requires use of the cutting harrow. The lower loads associated with tire tracks from vehicles are however regularly placed on the racing line close to the rail. Thus it is possible to see if this lower level of compaction produced by tire tracks is evident in the ground penetrating radar image. Figure 2 shows two of the places where the test truck drove across a fully prepared surface at Fairplex Park. The left image is taken closer to the rail where the two tire compaction areas are close to each other due to the truck turning. In the right image which is further from the rail it is possible to see the separate tire impressions in the soil.

It is clearly evident that it is possible to detect compaction in track surfaces even when it is caused by the lower pressure of a light truck passing across the track. Compaction from either a water truck (the highest compaction from any equipment that is used on the track) or galloping horse (either a biological or robotic hoof print) would thus be expected to be very evident. Future work would be to use this new tool to compare track materials, maintenance methods as well as some of the new synthetic track surfaces to develop methods and materials that will reduce sensitivity to compaction and thus reduce spatial variability of track hardness and shear strength.

Task 3: Evaluate Example Track

The original proposal was to perform a two week study during active racing at a California style track. The proposed work was expanded to include a second California track to provide some range of compositions and moisture content. In addition a third track was added because of the potential need to evaluate the use of ground penetrating radar on synthetic tracks. Because of the expansion of interest in synthetic track materials, in particular Polytrack, it is important that the ground penetrating radar technology be developed in a way that allows it to be used with these new materials as well on existing tracks. The tracks that were tested as a part of this study were Fairplex in

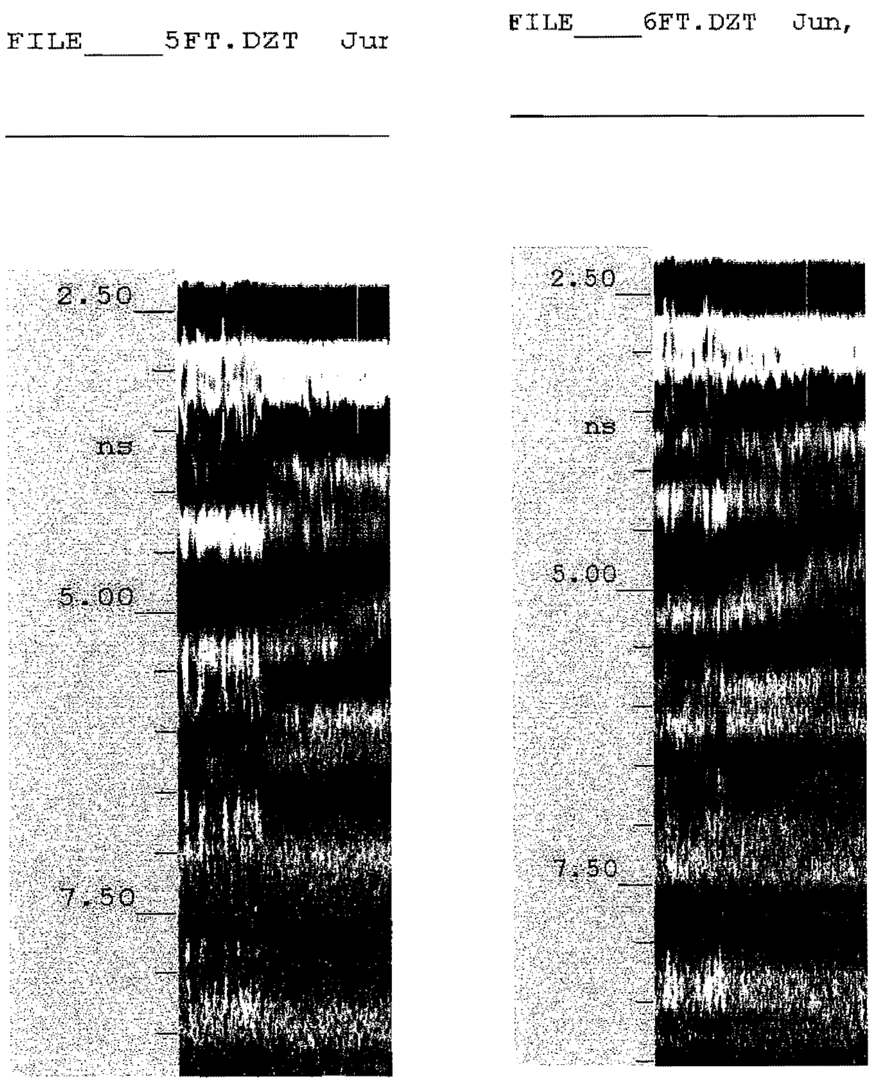


Figure 2: Images of compaction of soil. Compaction in these images is caused by tire tracks of Ford Expedition rolling cross the track to take data from rail.

Pomona, CA; Del Mar Racetrack in Del Mar, CA and the Keeneland Training Track in Lexington, KY. While only one track was included in the initial proposal, the testing of a synthetic surface such as the Keeneland training track was considered to be a priority.

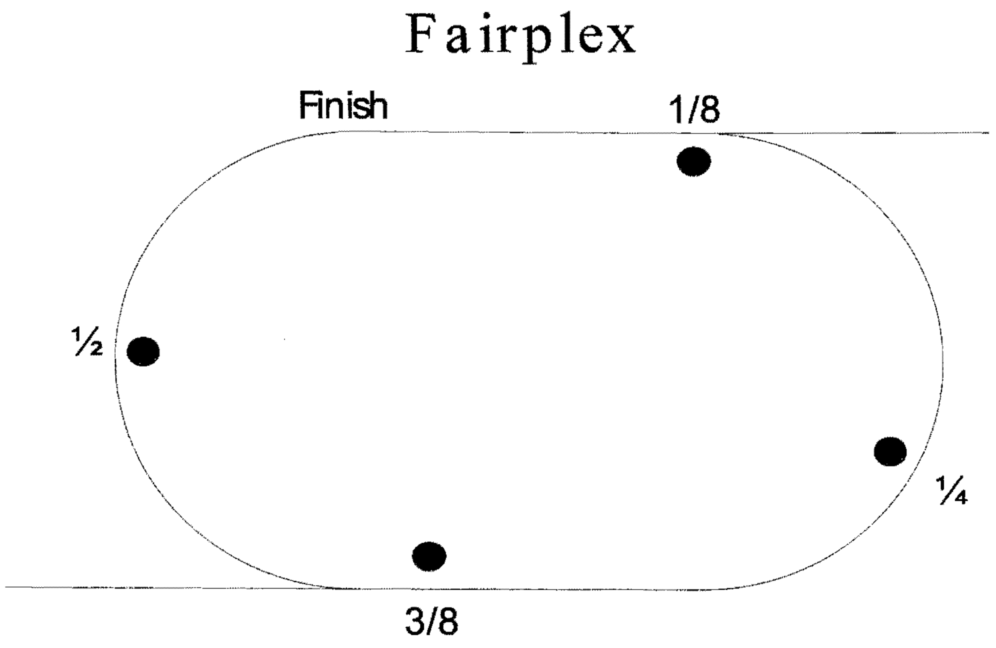
The primary concern of the testing was to determine if the base layer could be imaged in-situ. This requires that the radar be capable of penetrating as deep as one foot into the material depending on track construction. This test was used to begin the process of understanding how hoof impact effects the soil compaction on California tracks. We now have a greater understanding of the source of the spatial variation in track stiffness.

Example Track, Case Study

Rather than simply focusing on the specific results from the engineering perspective, it is more important to the long term goals of this work that the outcome relative to protecting the horses and helping to manage the track surface be considered. For this reason this report will highlight the observations from the summer of 2004 and 2005 regarding one track in California, Fairplex in Pomona. This is generally considered to be a small but very forgiving and well maintained track from discussions with horsemen. The maintenance team is small and very dedicated and includes very conscientious people led by Angela Aguire and Steve Wood. At Fairplex one of the maintenance personnel is also an occasional exercise rider who then brings back his impressions of the track to guide maintenance efforts. The track was tested in 2004 using the biomechanical hoof tester over approximately a one week period during the second week in August.

From the data and observations made in 2004 (as described in Appendix A) it was found that a distinct issue was associated with the track at the end of the back stretch and into the turn to the measurement point at the ¼ pole. At the 5/16th pole a distinct decrease in the hardness of the track was observed. While it is somewhat evident in the lower value of the average peak load on the hoof over the time period tested, the data was even more compelling when considered for a single day. Table 1 shows the summary data from the testing and Table 2 show the data taken on August 11, 2004. The average value for the ¼ pole was 7.1 kN for the test period with a standard deviation of 3.0 kN, which is a slightly lower average than the rest of the track and a larger standard deviation. However if the specific data for a day is considered, table 2, then the peak loads are seen to be as low as 3.2 kN, which compares to a hard fast track that would have values as high as 12 to 14 kN. The issue appears to be localized in the area at the end of the backstretch and moving into the second turn. The low levels were not seen in all areas and the track was not found to have a low shear strength in these same areas. This combination suggests that the low readings are either from local variability in the composition of the track material or damaged or missing base in that region of the track. Without any ability to look inside the racetrack it is necessary to remove the pad and cushion in a large area of the track to see if a difference in the track base exists and to remix material in that area of the track.

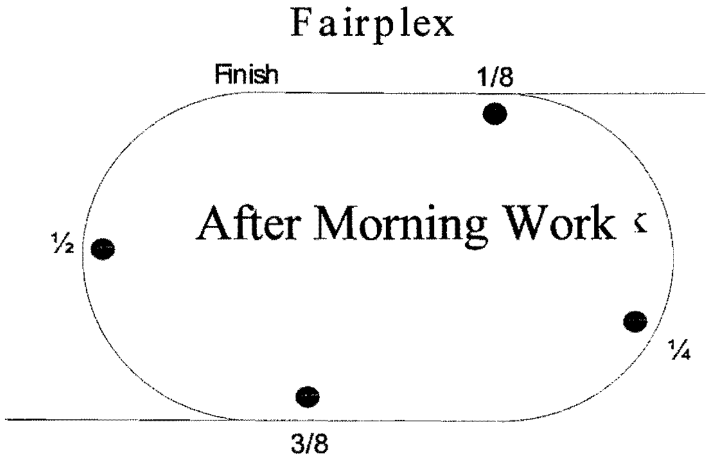
The use of the ground penetrating radar in this application can be used to evaluate the base of the track is in the areas where lower peak loads are seen using the biomechanical hoof. If the composition of the soil is different in this region that could be evaluated using standard soil testing. Although large differences in soil composition may be used to identify issues in this area, in some cases the composition change may also be evident in the ground penetrating radar data. In general traditional soil testing such as particle size distribution along with more advanced techniques such as X-ray diffraction are best for analysis of the conditions of the track in this case.



Date of Testing: August 2004
Start Testing: 11
Finish Time: 13

	Vertical Load Newtons		Dynamic Angle Radians	
	Average	Sdev	Average	Sdev
1/2	9.3	2.6	0.53	0.13
3/8	9.9	2.0	0.49	0.19
1/4	7.1	3.0	0.53	0.22
1/8	11.2	1.6	0.48	0.13
Finish	10.4	1.9	0.51	0.10
Average	9.6		0.51	
Std. Dev	1.5		0.02	
C.O.V.	16%		4%	

Table 1: Summary of data taken in August 2004 from Fairplex racetrack in Pomona California.



Date of Testing: **August 11, 2004**
Start Testing: **10:20 am**
Finish Time: **10:37 am**

	Vertical Load Newtons			**Dynamic Angle Radians**			**Moisture Content % Weight**
	Data set 1	Data set 2	Data set 3	Data set 1	Data set 2	Data set 3	
1/2	8.7	9.6	7.1	0.54	0.60	0.59	15%
3/8	7.7	9.5	9.1	0.63	0.66	0.64	14%
1/4	3.2	5.7	7.6	0.59	0.69	0.69	14%
1/8	11.4	10.3	10.8	0.75	0.50	0.61	13%
Finish	10.0	12.0	10.5	0.56	0.53	0.51	12%
	Average	8.9		**Average**	0.6		14%
	Std. Dev	2.3		**Std. Dev**	0.1		1%
	C.O.V.	26%		**C.O.V.**	12%		8%

Table 2: Data taken August 11, 2004 at Fairplex racetrack in Pomona California. Detail data for the day shows large variation in peak loads at the ¼ pole.

The first ground penetrating radar data taken on a thoroughbred racetrack was at Fairplex. The main focus of the effort was to determine if the base or the composition was different on the end of the back stretch and into the turn. In this work as in all use of the ground penetrating radar it is important to section the data in a way that makes the quantity of information more manageable. One of the most difficult aspects of the use of the ground penetrating radar is the low aspect ratio of the images produced. For example, when the data is presented to scale for a typical racetrack the data set is one mile long and 1 foot deep. This makes for a huge amount of data to evaluate and suggests that an approach that would look at key features may need to be developed. It is not yet clear how to work with this issue, but additional software could be evaluated to allow images to be reformatted in a reasonable amount of time to fit on a single screen. The difficulties with 3 dimensional display of data were also evident from the initial testing this summer and will also need to be resolved. The data shown then is all just for a single slice through a section of the track of limited length.

Some smaller images are presented to highlight the area of concern in Figure 3. Because the calibration procedure was not developed at the time this data was taken all depths are approximate in the image. Three images are shown which are strips taken from the 7/16 to the 5/16 pole at 5 feet, 6 feet and 10 feet from the rail. Each of these image strips shows the track to at least one foot below the surface. On the left side of the image a section of compaction due to tire tracks is evident. The first dark strip below the top of the image is the base of the track. The consistency of the base is clearly defined by a dark line at a fixed distance from the top surface of the track up until about 200 feet past the 3/8 pole. At that point the base drops off precipitously and clearly indicates an area in which the track would be expected to be soft. The lack of a firm base would not be evident if the testing was done with a small load (such as the playing field test which uses a 1 kg mass) or if the just standard material testing was performed. The only way to find this area would be to use the biomechanical hoof and then to diagnose the problem with the radar. As a result of this study the area of the track of concern has been renovated and the base has been repaired with a high clay content material.

Summary of Study Results

Significant opportunities continue to exist both to advance the state of knowledge regarding the condition of tracks used for horse racing as well as to help support the safe and fair operation of racing venues. This study has shown that the ground penetrating radar as currently configured is able to be used for these studies and that proper design can make it possible for significant knowledge to be developed.

The objectives of the proposed research have been met. The outcomes include a calibration procedure that makes it possible to obtain depth of observed features with reasonable accuracy. A second outcome is the design of a study that can be used to investigate the relative sensitivity to compaction of different track surfaces. A third and important outcome is that the ground penetrating radar was shown to be suitable for inspection of base conditions for racetracks and has already been used to eliminate a potentially dangerous condition on a racetrack.

Future Work

A high priority given the interest in different track surfaces should be to develop a facility where synthetic surfaces can be tested for compaction relative to traditional track designs. Based on preliminary results using the biomechanical hoof tester these track surfaces are superior to existing track materials. However the condition of these new track surfaces over time must be monitored and the depth to which the track needs to be maintained must be better understood.

Secondly, better methods of analyzing and displaying the data obtained on base maps of tracks need to be developed. These may either take the form of existing software which may be used, macros for analyzing the data in existing software, or even the development of custom software for analysis of ground penetrating radar data for racetrack applications. In any case, the data needs to be processed in a way that the time is reduced and the likelihood of error is minimized.

The continuation of this work has the potential to make a more consistent and fairer surface on all tracks. This is as true of the new synthetic track surfaces which show tremendous promise as a way to tune the track for particular performance. They also seem to be less affected by compaction from horse traffic. It remains to be seen what the long term issues will be with these new tracks and whether there may be maintenance approaches that would continue to make the organic tracks a viable economic alternative to these new tracks. The promise shown by the combination of the biomechanical hoof and the ground penetrating radar was shown in the case of Fairplex to be capable of finding potentially important problems prior to observing an increased injury rate at the track.

Appendix A: Biomechanical Hoof Work Prior to Current Study

Over the last two years a study was undertaken to develop a tool that will produce the track surface impact characteristics at the same loads and loading rates produced by a horse at a gallop. The first phase was the development of the machine along with pilot data which was funded by AQHA Racing. The second phase was a comparison test of a number of tracks in California. The second phase was performed over the course of the summer of 2004, and supported by the Thoroughbred Owners of California, California Thoroughbred Trainers, the California Association of Racing Fairs and a number of racetracks including Santa Anita, Hollywood Park and Del Mar. This second phase has significantly altered the understanding of track mechanics and characteristics of interest. The test system differs from previous studies in that the loads applied to the track and the rate at which they are applied are the same as those encountered during the impact of a hoof on the ground. This is important since previous work has typically only characterized the performance of the cushion, or top layer of the track, at a rate that was much slower than the hoof ground impact. At most California tracks a second layer, or pad, is used to reduce the peak loads and ensure that a consistent tractive surface is available for the horse. The consistency of the base, which is always critical, becomes even more important if a pad is not used on the track. The system developed measures the dynamic performance of both the pad and the cushion. Strength and stiffness of the cushion and the pad have been measured, providing quantitative information that can be used to compare track surfaces. A summary of results from tracks tested in the summer of 2004 are shown in Figures 5 and 6.

Over the course of the initial testing significant changes in the understanding of the track mechanics have occurred. Anecdotally one of the most significant observations was the change in the track at Del Mar over the first week of the 2004 meet as shown in Figure 7. From the data it is clear that over this time significant changes occurred to the track. Peak loads experienced on the track increased significantly. A statistically significant rise in the peak load was measured at the rail. Investigation of the cause uncovered the fact that the harrow that was being used on the rail had malfunctioned. This also led to a change in the view of the cushion. The cushion reduces the peak load experienced by the foreleg of the horse by approximately 50%. However, the cushion also acts as a layer that protects the pad from compaction. The locations where the tractors turn also appeared to precede the rest of the track in the compaction related changes. It is not apparent though that these changes are statistically significant because of the scatter of the data. The scatter of the data is in itself important. The scatter is most likely caused by compaction of the track material. This suggests that landing on a hoof print may in fact be a larger factor than maintenance variability and changes over time to the track. More work is needed to determine what can be done to create a track that is both forgiving and resistant to compaction. Further investigation of track variation over time may require that a very large number of data points be obtained to separate those effects from the spatial variation that is most likely a result of compaction.

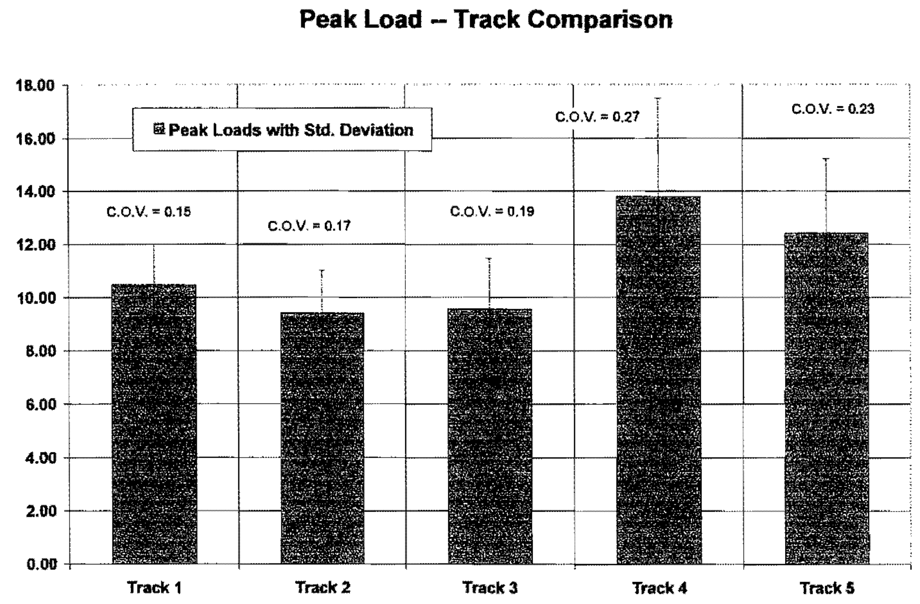


Figure 5: Comparison of peak loads measured at five different tracks along with variability.

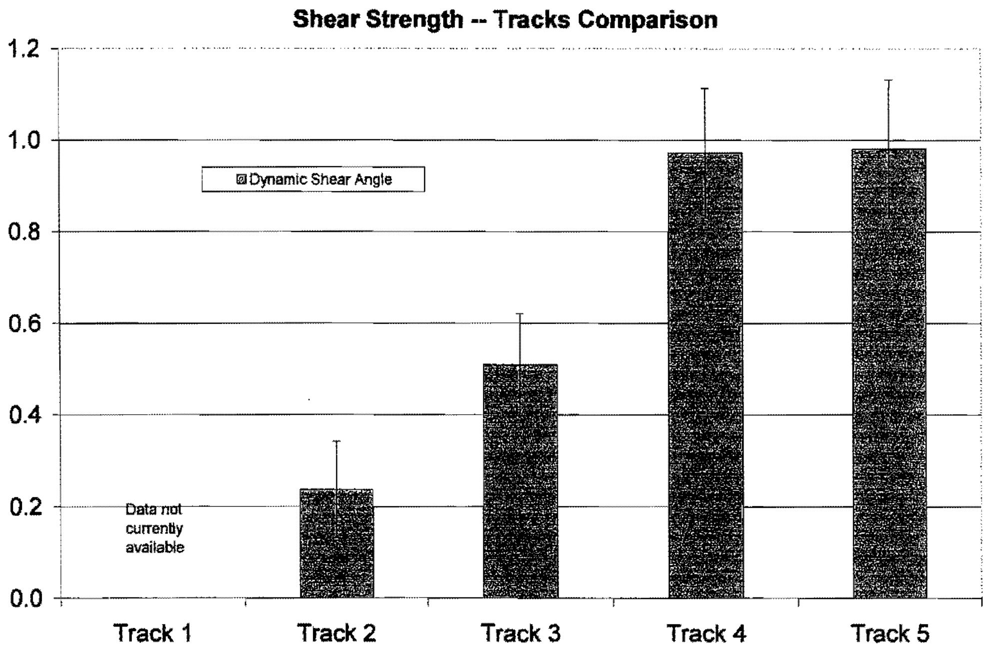


Figure 6: Comparison of dynamic acceleration ratio measured on four of the same tracks shown in Figure 4 for peak load.