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Ground Penetrating Radar, Compaction Measurement Techniques and Methods

Submitted by:

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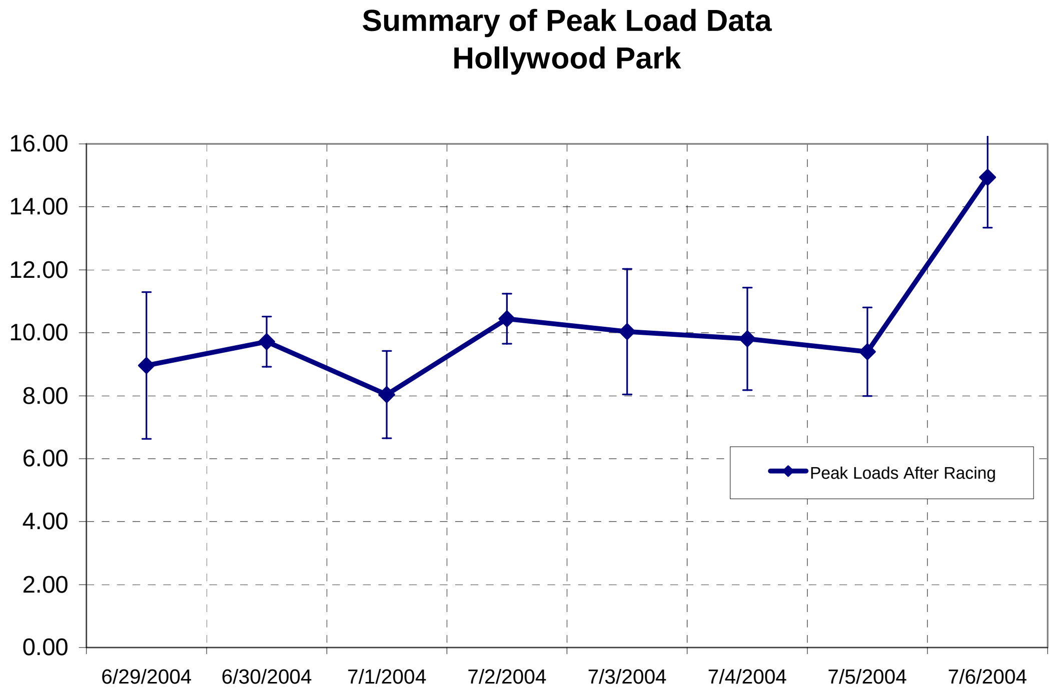
Motivation

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 a fair racing surface. Most notably, track compaction has recently been identified as a significant factor in the spatial and temporal variation in racetrack surfaces. Basic studies on racetrack materials need to be pursued that can verify the importance of track material compaction, and then these studies need to be linked to observed phenomena in track surfaces. Producing an even surface with reduced joint loading has the potential to significantly improve the health and longevity of horses.

Prior Work

Over the last two years a study has been undertaken to develop a tool that will allow 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 is being performed over the course of the summer of 2004, and has been 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 understanding of the track mechanics and characteristics of interest. The test system differs from previous studies in that the loads applied to the track are as high as those encountered from the impact of a hoof on the ground. This is important since previous work has been only able to characterize the performance of the cushion, or top layer of the track. At the 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 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, quantitative information that can be used to compare track surfaces. A summary of results for two of the tracks in the summer of 2004 are shown in figure 1.

Over the course of the initial testing significant changes in the understanding of the track mechanics have occurred. Anecdotally the most significant observation was the change in the track at Del Mar over the first week of the 2004 meet. From the data it is clear that over this time significant changes occurred to the track. Peak loads experienced on the track increased significantly. Most tellingly, these changes were accelerated when a harrow used on the inside of the track malfunctioned. This led to a statistically significant rise in the peak load as measured at the rail. This also led to a change in the view of the cushion. The cushion reduces the peak load experienced by on the foreleg of the horse by approximately 50%. However, the cushion also acts as a layer that protects the pad from compaction. Tellingly, 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 increase in scatter of the measures.



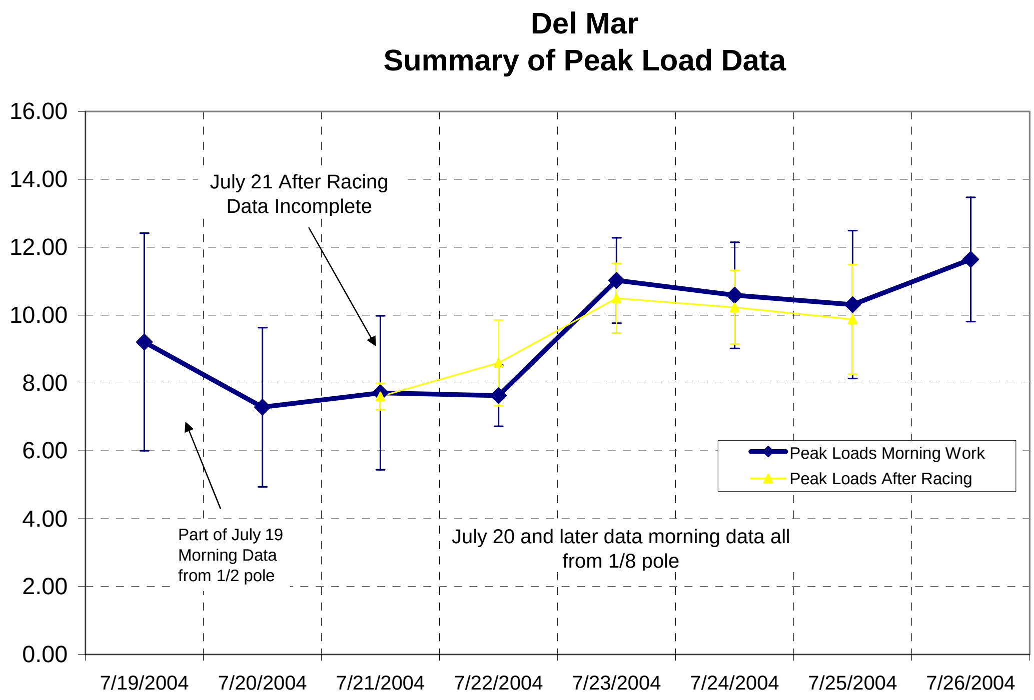


Figure 1: Peak load data from two tracks in summer 2004.

Del Mar is useful for observing these phenomena since the track is used for a number of different activities throughout the year including motor racing and a fair, in addition to the horse racing meet. This means that the track must be extensively modified each year to prepare it for horse racing. This preparation involves deep modification of the track. As a result the track may start the meet softer due to a lack of compaction of the cushion, and does not set up until later in the meet. The influence of the layers beneath the cushion is significant. Both the pad and the base sustain significant stress during the impact of the hoof. The depth of the stress created by the impact of a hoof on the dirt surface can be found analytically if certain simplifying assumptions are made. Figure 2, shows the stress in the soil at the center of the hoof as a function of depth for a horse at the gallop. What is evident from this figure is that the normal track maintenance to a depth of 10 to 15 cm (4 to 6 inches) is important, but may only account for half of the effective depth of the stress field from the hoof loading.

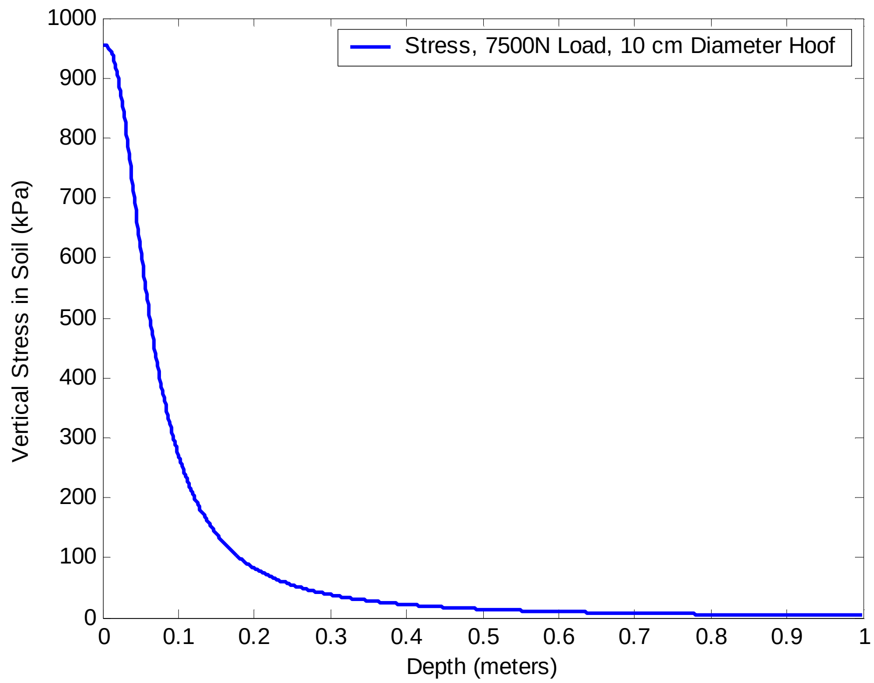


Figure 2: Strain as a function of depth at the center of hoof, homogeneous elastic model.

It is evident from the standard deviation and the changes over time in the track at Del Mar that some understanding of deep compaction on California style tracks is needed. The California tracks will significantly reduce the peak joint loading seen in the horses that run on the surfaces even with low water content for the soil. However, if unevenness in the track (the large standard deviation in the figures) is caused by compaction, then an effort should be undertaken to understand track material compaction and the resulting unevenness of the track surface.

Ground Penetrating Radar for Track Characterization

Pilot data has been obtained that has shown the ability of ground penetrating radar to be used to characterize racetrack surface materials. Such a system has the potential to provide important information regarding subsurface compaction and spatial variation in moisture content on dirt race tracks and training surfaces. Currently, the track slope and moisture content are evaluated based on feel and visual evaluation. Laser measurement devices are also used periodically to evaluate the slope of the top surface of the track. A method is needed which would make it possible to look below the top surface of the racetrack to determine if the track provides the consistent surface required for safe racing. An imaging technique could also be used to judge the degree of work needed on a track to maintain a safe and smooth surface for training and racing. In some cases, significant renovations to the track may be needed to address problems with the base and the composition of the track.

GPR PILOT TESTING APPROACH

In order to determine if ground penetrating radar was appropriate for evaluation of track surfaces, a test plot was consturcted. The primary issue to be addressed in the test protocol was whether the ground penetrating radar could be used at frequencies which would be practical. The frequency chosen must have sufficiently low attenuation in track materials to be useful. This test required that samples of track material be used in the testing. The test equipment used was from Geophysical Survey Systems, Inc. and included multiple contact antennas as well as a test of a horn type antenna that could be used with an air coupling. Extensive consideration was made to removing of the moisture from precipitation in the test plot because of the need to simulate California race track conditions in New England, an area of much higher annual rainfall. Photos of the test plot are shown in figure 2. Figure 2 shows the perforated PVC pipe which was laid on each side of the test plot. The pipe terminates in a deeper gravel filled pit (top of figure 2) which is used as a water catch basin. The deeper pit used a vertical stand pipe and a dewatering pump to ensure that it would not be saturated. The objective of this system is to provide a way to test California track surfaces in New England where the equipment from Geophysical Survey Systems is located. Key to providing an appropriate test configuration is to ensure that the drainage and moisture content is similar to the California tracks even when the material is located in New England.

In addition to replicating the conditions of the California tracks, the approach taken was to provide targets that could be used to set up the system (the PVC pipes). This test determined if the system could penetrate the material and image discontinuities in the base. For set up of the radar, targets made from three ½ inch and two 1 inch PVC pipes were grouped and placed in the track soil samples. These targets were equipped so that they could be alternately filled with water or air to change the target strength. Two sections of the test pit were also excavated to an additional 4 inch depth. This allowed the penetration of the radar to the full 6 to 8 inch material track depth to be tested. The sides of the deeper section were tapered both for practical reasons and to provide the opportunity to evaluate the spatial discrimination of the system. The resolution of the system in the direction of scanning is a convolution of the antenna profile and the target.

Thus a sharp transition will be smoothed by the antenna radiation pattern. In the lateral direction the result is an average response (a convolution in the spatial domain) of the antenna profile and the target. The test pit was limited to variation along the length and depth axes, and to the degree possible is smooth in the lateral direction. Exceptions include naturally occurring tree roots, some more of which were removed after the photo was taken.

The configuration shown in the figure was then used with the two test sections filled with dirt from Hollywood Park and Santa Anita Park.

Figure. 3 A photo of the complete test pit with PVC pipe for reference targets and large diameter pipe at far end connected to the drainage system and pump.

The two materials tested provide a range of soil composition which would be expected at the California tracks. The Hollywood Park track uses polymeric fiber reinforcement. Polymer fibers can be used to reduce the required clay content while still obtaining the required shear strength for the track. The Santa Anita track uses a more traditional mixture of sand clay and silt to obtain the required track shear strength properties. From the perspective of the ground penetrating radar this difference is significant because the depth of penetration is quite sensitive to the presence of clay. Clay is hydrophilic and so the bound water in the clay particles that will attenuate the electromagnetic waves. This attenuation occurs in addition to the attenuation from the free water which will be clearly visible in the radar images. The moisture content of the soil was adjusted prior to placing the material in the test wells. The target moisture content was 14% using a thermo-gravimetric technique for measurements.

RESULTS AND CONCLUSIONS

Testing of the two track materials was performed in Orono Maine on July 15, 2004. The tests evaluated the ability of the radar to penetrate track material and to show the use of ground penetrating radar to find soil interfaces such as the boundary between the pad and the cushion and the base. Data are shown for two frequencies tested. If the frequency of the electromagnetic wave is increased, the spatial and depth resolution is increased. However, at higher frequencies the attenuation of the wave as it propagates through the soil increases. Thus a maximum frequency exists that can be used to penetrate to a depth of interest. Using a lower frequency wave results in lower spatial and depth resolution, but is more likely to be able to detect an interface at the depth of interest, or even to evaluate problems in the base materials.

The first data shown (figure 4) is using a 1.5 GHz antenna, the higher frequency considered in this evaluation. It is apparent that the Model 5100 ground penetrating radar system with a 1.5 GHz antenna is able to find several features of interest in the test pit. In all of the radar plots shown, the PVC pipes are removed to simplify the interpretation of the results. In the lower portion of figure 4 it is clear that even using automated tracking software (the red line) the contour of the bottom of the test pit can be seen. It is also notable at the higher frequency that the differences in density between the layers of soil can be discriminated as well as several features of interest below the layer of excavation. The base material in this case is a dried clay material which would be difficult to penetrate at high frequencies and was selected both because of availability and because of the clear discrimination that would be expected.

The data from the higher frequency antenna and system is compared to the contours of the test pit in figure 5. The clear distinction of known features with the smoothing caused by the response of the antennas is evident. Figure 6 shows the lower frequency, 900 MHz, data. Reduced resolution is evident and the tracking function is clearly able to detect the bottom layer of the test pit for evaluation purposes.

Most importantly, from figures 4 through 6 it is clear that the ground penetrating radar is easily able to penetrate track material at either 1.5 GHz or 900 MHz. Reduced resolution is evident at lower frequencies, but even at the higher frequencies evidence of features below the clay base interface is evident. The free moisture content would change the reflected power from any of the interfaces. The frequencies that would be used in this application fall in the transition region between the low and high frequency attenuation of radar with respect to the moisture. Outside of the transition region, the fit of attenuation to moisture content is linear, with an inflection point around 1 GHz. [1]. This means that the moisture content in the volumetric moisture range of interest would be represented as the brightness of the reflection from the bottom interface. This would allow a system such as the one shown to be used both to image the base material if the track was dried, as well as to perform an area survey of the consistency of moisture content of the track to determine if areas of greater or reduced drainage exist.

[1] J.O. Curtis, C.A. Weiss Jr, and J. B. Everett "Effects of Soil Composition on Complex Dielectric Properties" U.S. Army Corp. of Engineers, Technical Report EL-95-34, 1995.p. 48.

The low frequency behavior of the radar (below 1 GHz) tends to be significantly impacted by ionic presence in the soil. This is an important consideration at tracks such as Hollywood Park or Del Mar where recovered water is used for track watering. High frequency loss is dominated by free water molecules and would be more clearly related to the volumetric moisture content[2]. A simple model of the performance of the material with various soil types and water content could be developed as a way to ensure that the radar would find the features of interest in track surfaces. It would however be preferable in this case to use a single channel system in conjunction with existing efforts to evaluate soil. It is clear however that the clay content of the soil is not sufficiently high to preclude the use of radar.

[2] Ibid. p. 54

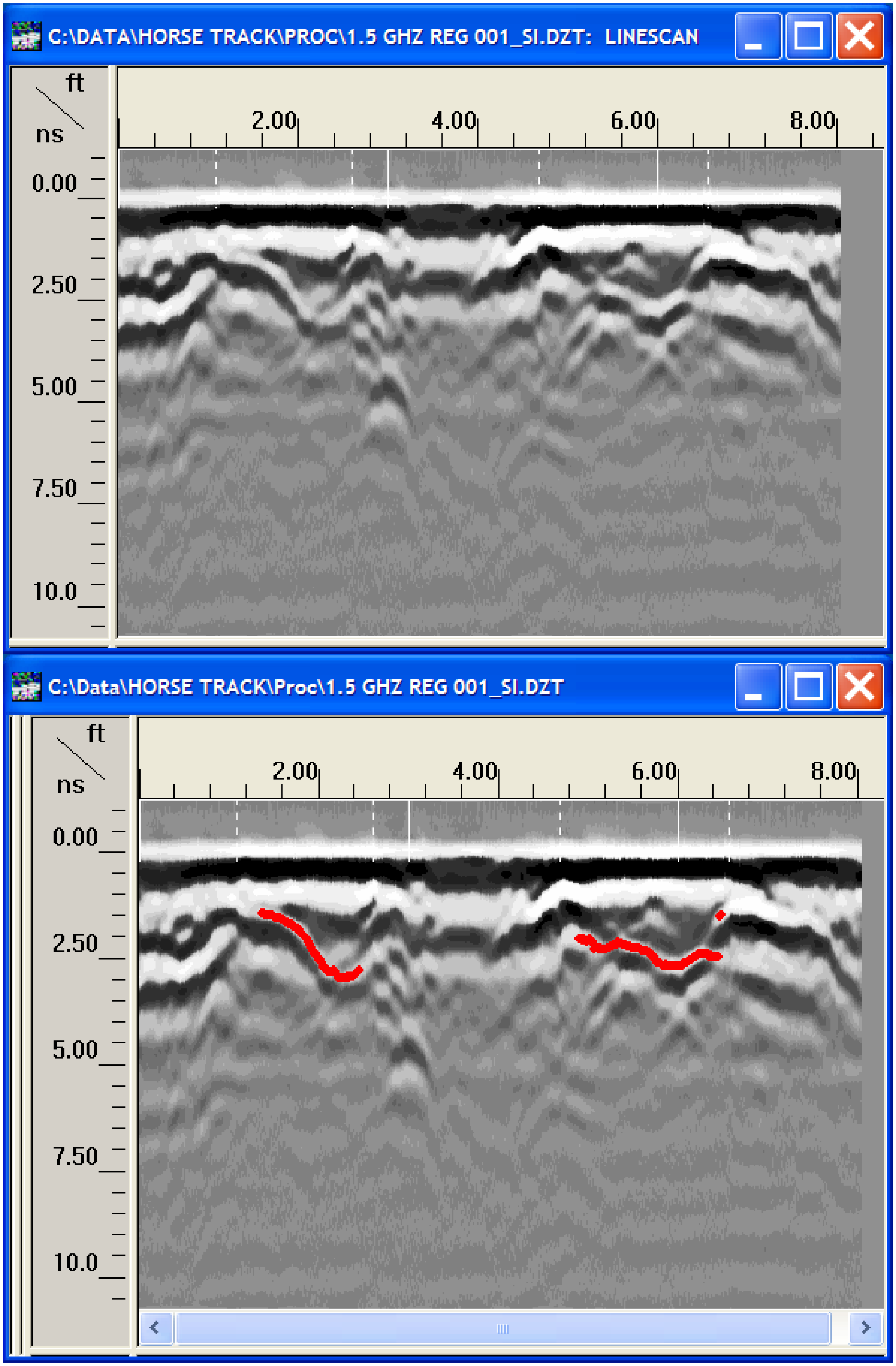


Figure 4: 1.5 GHz. Images with layer bottom reflections tracked using interactive interpretation software from Model 5100 in lower figure.

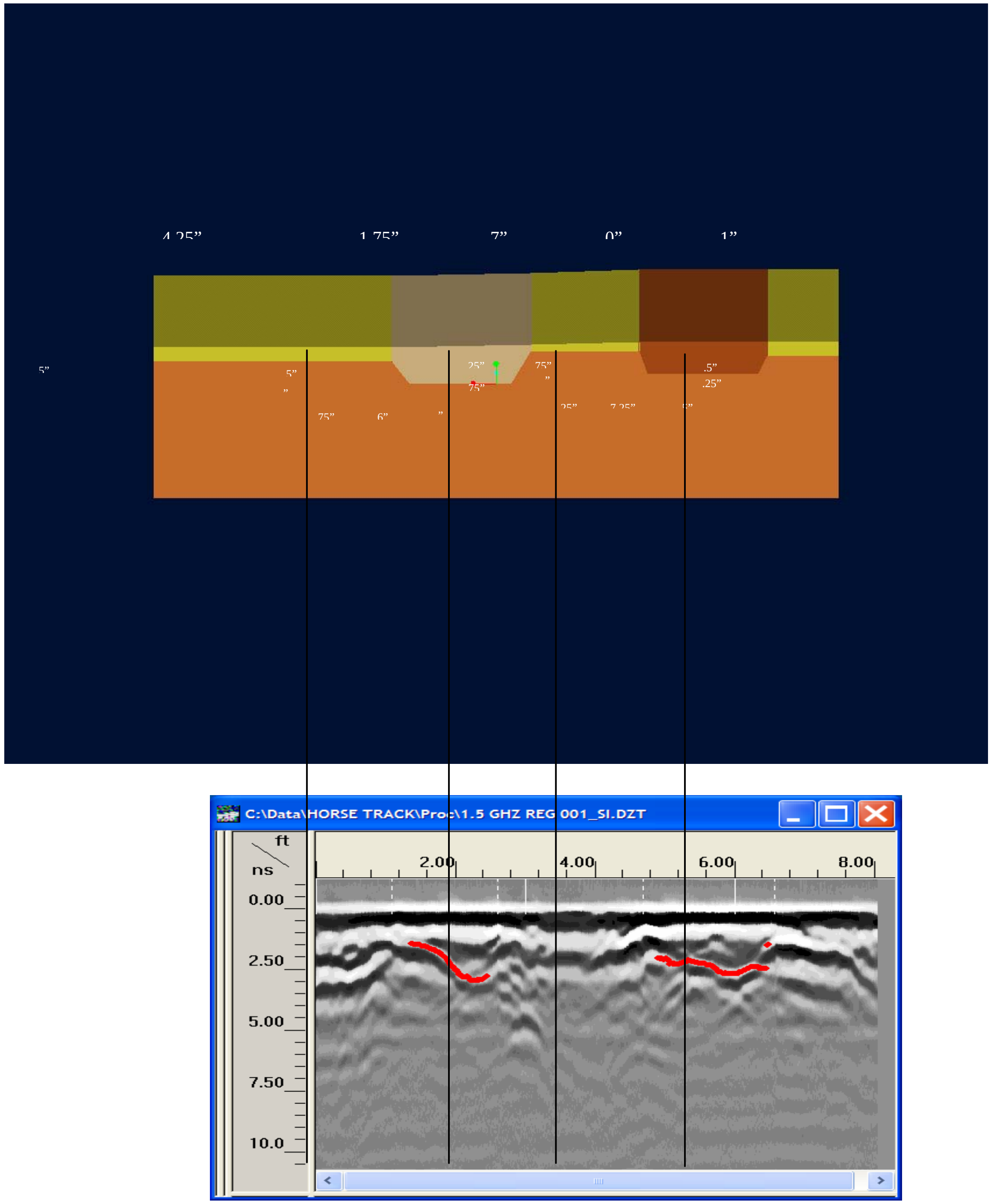


Figure 5: Alignment of ground penetrating radar image with a model of the test pit, showing ground contour images in both views.

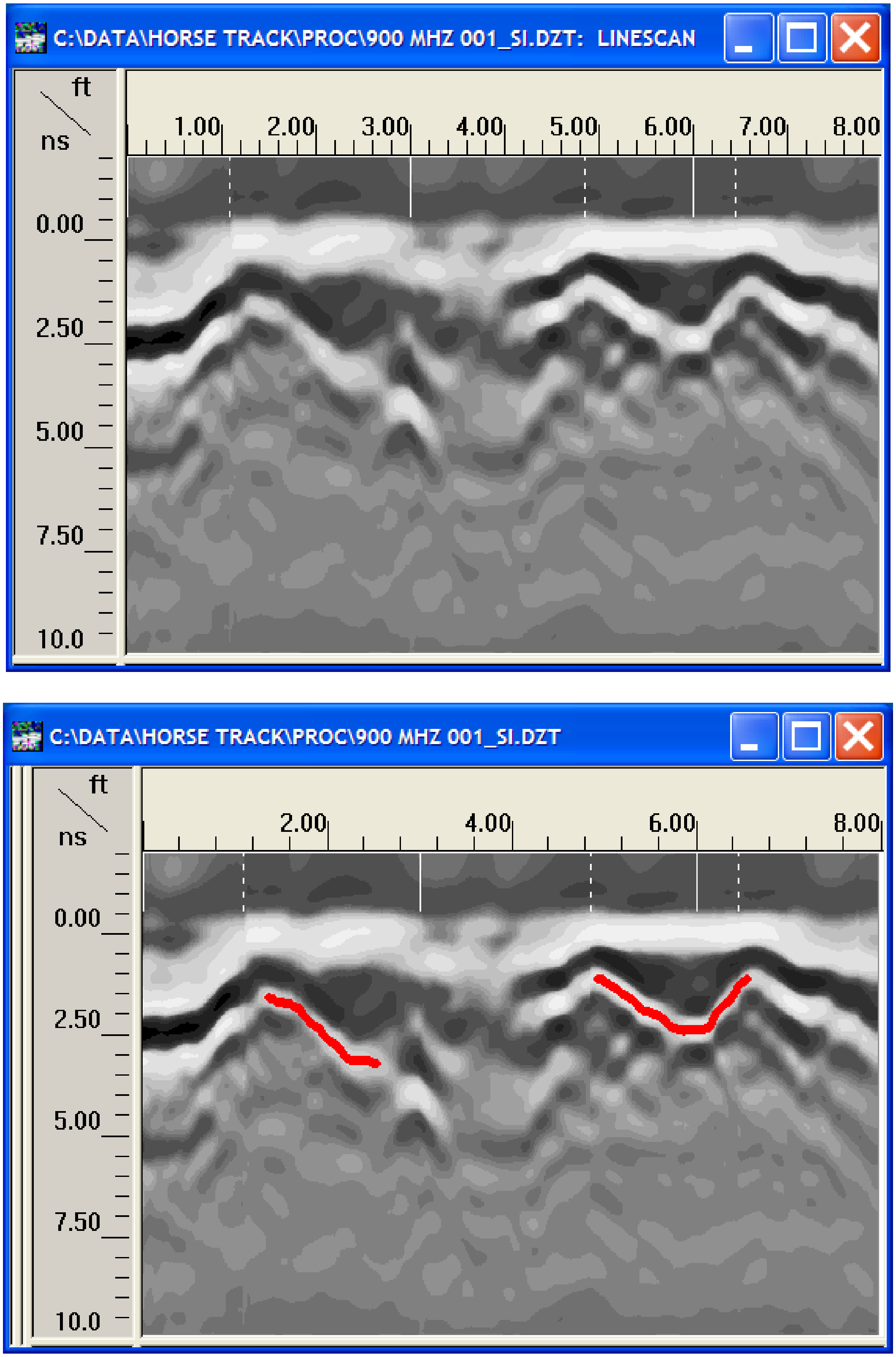


Figure 6: 900 MHz antenna on data over test pit images with layer bottom reflections tracked using interactive interpretation software from Model 3101D in lower figures.

Plan of Work

Task 1: Calibrate Radar for Compaction of Track Materials

The first task is to develop comparative techniques for the ground penetrating radar for compaction testing. Cone penetrometers are used for a point test of compaction of soil. While not well suited for accurate characterization of layered soils, the radar can be compared to cone penetrometers if the soil is built up each layer is tested. This task will focus on calibration the radar to compaction of material which is representative of those soils found at the racetrack that will be used for initial testing.

Task 2: Develop Technique for Spatial Compaction Survey

Based on the initial analysis of the 2004 track comparison study, spatial variation of compaction is a significant factor in the evolution of the track surface and significantly impacts the track hardness. In order to verify these observations and understand how they affect the racing surface, the spatial variation of the radar with compaction must be tested. The hoof print tested that was developed using the support from AQHA racing will then be used to create a pattern of compacted soil that can then be tested using the ground penetrating radar. Soil density measurements will be used based on sampling tests, and then the cone penetrometer will be used for testing of the soil in compacted regions.

Task 3: Evaluate Track Example Track

A two week study will then be undertaken during active racing at a California style track to supplement the final stages of the track testing study with ground penetrating radar surveys. This test will then be used to begin the process of understanding how hoof impact effects the soil compaction on California tracks. This will also allow a greater understanding of the source of the spatial variation in track stiffness to be gained.

Future Work

Once data on loading variation has been obtained, it is important to link these observations to the health of the animal. Extensive work on the effect of loading on joint disease and bone density has been done previously. Using this work combined with the measurements from the summer of 2004, it is possible to provide a range of loading that would be observed in the animals racing on the surfaces. From these models it would be possible to estimate the effects of the loading changes seen in the track on peak joint loads and to compare those results to existing research on exercise induced arthrosis. While it is expected that the large variation observed will be significant, the modeling will provide an opportunity to set targets for range of acceptable stiffness based on the health of the animal.

Once targets have been set for load variation in the track, materials must be identified that can meet these targets, as well as maintenance procedures that will allow the track to be held to these standards. Materials and maintenance procedures must be evaluated to determine the performance as well as the durability of the materials. Previous experience has shown that evaluation of issues such as climate and maintenance procedures must be a part of the development of track procedures. In particular, if synthetic materials are used, climate is a significant factoring use of these materials, and not only the theoretical compaction but also the compaction in use must be evaluated. Tests for this portion of the work can be done in areas of candidate tracks where normal maintenance procedures are used, but where likelihood of injury to the horse is low, or else in tractor turning areas or in areas of the track where mechanical compaction equipment may be used. This portion of the work will also include the continuing development of the track strength and stiffness machine to begin to transfer this technology for use in track maintenance.

The research from this effort will only be of academic interest unless it is shown to be applicable to design of improved racetrack surfaces. The ideal venue for this demonstration would be a track that attracts high profile racing participation but that has a limited season. It is anticipated that if the development of track materials is successful, the test track could be set up as soon as fall of 2005, or preparation for summer of 2006. This would allow at a minimum the summer of 2005 for the test plot to be evaluated.

Budget

This effort will result in a broader understanding of the issues associated with track compaction and determine if the variation seen in the initial testing is in fact related to track compaction. Success in these phases will allow a future effort to be undertaken that can help to help select appropriate materials or to support maintenance procedures for tracks to reduce the compaction observed in the initial work.

Compaction Survey using Ground Penetrating Radar

Labor			
	Salary -- Graduate Student Statistical Work	$5,000	
	Salary -- Engineering Graduate Student	$7,500	
Hardware			
	Ground Penetrating Radar	$31,500	
	Consumables	$2,250	
	Wiring Modifications	$1,800	
	Receiver Hitch	$500	
Operating Expenses			
	Shipping	$1,500	
	Insurance	$2,000	
	Support Vehicle	$700	
	Travel	$1,000	
	Shipping	$1,200	
	Room	$2,520	
	Per Diem	$840	
		Total	$58,310