Integrated Track Stability Assessment and Monitoring System (ITSAMS)

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16. Abstract

The overall objective of project is to continue the development of remote sensing technologies that can be integrated and deployed in a mobile inspection vehicle i.e. Integrated Track Stability Assessment and Monitoring System (ITSAMS).

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Acronym Glossary

Acronym	Description
API	Application Programming Interface
ASP	Active Service Provider
BIOS	Basic Input-Output System
CIFS	Common Internet File System based on SMB
CLR	Common Language Runtime
CORS	Continuously Operating Reference Station
CPU	Central Processing Unit
DGPS	Differential Global Positioning System
DHCP	Dynamic Host Configuration Protocol
DMZ	Demilitarized Zone
DNS	Domain Name System
EEI	Epoch Engineering
EM	Electromagnetic
EMPA	Swiss Federal Laboratories for Materials Testing and Research
FRA	Federal Railroad Administration
FTP	File Transfer Protocol
GIS	Geographic Information System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GSSI	Geographical Survey Systems, Inc.
HADGPS	High Accuracy Differential Global Positioning System
HBA	Host Bus Adaptor
HRS	High Resolution Seismic
HTTP	Hypertext Transfer Protocol
HTTPS	HTTP over SSL (Secure Sockets Layer)
IIS	Internet Information Services
ITSAMS	Integrated Track Stability Assessment and Monitoring System
KVM	Kernel based Virtual Machine
LI	Laser Inteferometry
LIDAR	Light Detection and Ranging
LSB	Linux Standards Base
LUN	Logical Unit Number
MU	Marshall University
NAS	Network-Attached Storage
NAT	Network Address Translation
NFS	Network File System used by Unix servers
OPUS	Online Positioning User Service
ORD	Office of Research and Development
OREIS	Operation Respond Emergency Information System
PAT	Post Address Translation
RAID	Redundant Array of Independent Drives
RDP	Remote Desktop Protocol
RLI	Robust Laser Interferometer
RM	Replacement Modernized

RTI	Rahall Transportation Institute
RTK	Real-Time Kinematic
SAN	Storage Area Network
SATA	Serial Advanced Technology Attachment
SCSI	Small Computer System Interface
SMB	Server Message Block;
SOW	Statement of Work
SPARC	Scalable Processor Architecture
SQL	Structured Query Language
SV	Space Vehicle or GPS satellite
UCS	University Computing Services
UDP	User Datagram Protocol
UNL	University of Nebraska-Lincoln
VLAN	Virtual Local Area Network
VLF	Very Low Frequency
VM	Virtual Machine
VPN	Virtual Private Network
VRS	Virtual Reference Station
WVSAMB	West Virginia State Addressing and Mapping Board

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Integrated Track Stability Assessment and Monitoring System (ITSAMS) Using Site-Specific Geotechnical/spatial Parameters and Remote Sensing Technologies

Executive Summary

The Federal Railroad Administration's (FRA) Office of Research and Development (ORD) sponsored a project to develop a mobile rail track surface and sub-surface surveying system capable of collecting data from a variety of remote sensing instrumentation and integrate this data with other site-specific data to assist in monitoring rail track behavior over time. The mobile surveying system was developed to be modular and adaptable to a variety of platforms and successfully integrated with High Accuracy Differential Global Positioning System (HADGPS) technology, resulting in the capability of measuring top of the track coordinates with centimeter precision at a variety of speeds. The mobile surveying systems were used to collect data from several geo-technically vulnerable sites located on active rail corridors in the State of West Virginia, and a statewide Web-based Geographical Information System (GIS) was developed to store and display the data collected from the field experimentation program, in addition to facilitating the integration of other geo-spatial information. It is complimented by a state-of-the-art information technology system constructed with multi-terabyte storage capacity in order to perform comparative studies over time of selected rail corridors in West Virginia (see Figure 1). The mobile surface surveying system has also been used in other states to evaluate its application for measuring track shift at curves, derailment analyses, and rail yard surveying.

The project's field work illustrated the usefulness of HADGPS in surveying and monitoring of railway track superstructure. Improvements in worker safety and general railroad operations can be realized through minimizing workers exposed to hazards around active rail lines required with the traditional surveying techniques. HADGPS precision can be adequate for certain construction specifications and does offer more precise measurements capability than the Light Detection and Ranging (LIDAR) technique for establishing baseline information for subsequent comparative purposes. Integration with non-invasive remote sensing technologies and other data sets in a GIS platform provides a very effective means for surface and subsurface data comparative and interpretive analyses.

Introduction

Marshall University of Huntington, WV (MU), in collaboration with the University of Nebraska Lincoln (UNL), submitted in November 1999 a technical proposal for a research grant "to develop an integrated track stability assessment and monitoring system using site specific geo technical/spatial parameters and remote sensing technologies".

Subsequent to the proposal, and as of result of meetings with FRA ORD staff members, a Statement of Work (SOW) consistent with the FRA strategic plan was approved from FY 00 funds. This grant was processed in a single award to MU with UNL as a sub-contractor. This

grant included non-FRA resources from other transportation entities and the individual universities. It focused on the evaluation and development of two separate technologies for track stability assessments and monitoring i.e. ground penetrating radar (GPR) for track structure and substructure and laser inteferometry (LI) for track vertical deflection.

As a result of discussions between MU, UNL and the FRA related to continued support, separate grant applications, one by each of the two universities, were submitted to the FRA for Phase II research (FY 01). However, the two institutions continued to coordinate their research work, including sharing of data and the preparation of an individual SOW to ensure that efforts were non-duplicative, complimentary and that each SOW contributed to, and were consistent with the project purpose as approved by the US Congress.

The Phase II grant for University of Nebraska focused on continuing the development of the GPR and LI technologies combined with an integrated track stability assessment modeling. The, while the Phase II grant for Marshall University continued the development of the GPR and LI technologies with expanded efforts that addressed other remote sensing technologies (geophysical, seismic, etc) in addition to the incorporation of state of the art Global Positioning Systems (GPS) technologies.

As mandated by the US Congress, FY 02 funding was approved to expand the scope of research efforts to include human factors which were addressed by the University of Nebraska in an approved SOW for Phase III. However, Phase III research for Marshall University focused on the previous efforts. The US Congress expanded the scope of research for FY 03 funding to address track and structures, human factors, equipment, train control, grade crossing and digital communications. However the Phase IV (FY 04) and Phase V (FY 05) efforts for Marshall University continued and built upon previous efforts in track stability inspection technologies and monitoring.

Background

Mobile Rail Track Inspection Using GPR

Recent work on a rail track inspection system was conducted by EMPA (Swiss Federal Laboratories for Materials Testing and Research) for the Swiss Federal Railways SBB. The GPR survey proved very useful to complement traditional inspection methods. Subsoil material penetrating into the ballast was identified very reliably. Such zones only remained undetected in a railway station where data quality was rather poor and in two cases where penetration was as little as 1.0 and 2.0 inches.

The GPR inspections are generally focused on the thickness of rail track ballast, subsoil material penetrating the ballast and the geotechnical properties of the sub-grade and subsoil materials. Typically, the inspection has been done by digging trenches at evenly spaced intervals and in locations of special interest. Data were acquired using a mobile system traveling at about 6 mph. Although quality information was obtained at the trench locations, only sparse

information between the trench sites and digging trenches is expensive and obstructed railway traffic. GPR has been successfully applied for the investigation of highway and bridge structures, and using a mobile acquisition system, data can be recorded economically causing minimal obstruction to traffic flow (Davis et al., 1994; Hugenschmidt et al., 1998). However, railway lines provide a new challenge due to presence of ties, tracks and numerous near- and subsurface installations. The focus of the GPR inspections was on ballast thickness and on the detection of zones where subsoil material had penetrated into the ballast. The total length of the inspected sections was about 9 miles. Forty-one trenches were available for GPR interpretation out of a total of 77 trenches. Of the 41 trench sites, subsoil material penetrating into the ballast at 19 sites. Twelve of the 19 zones of penetration were identified by the GPR survey, two more were defined as possible, and five remained undetected by the radar survey for two reasons. The GPR surveys revealed sub-grade and subsoil structures in only a few sections.

Data was acquired using a GSSI SIR-10A system and a 900-MHz antenna. The acquisition speed was 6 mph; horizontal sample rate: 5 scans per foot; samples per scan: 512, antenna height: 3 inches form top of tie to bottom of antenna casing; antenna orientation: at right angles to traveling direction; scan length: 25 ns. Raw data were copied to a PC for processing, the objectives being: establish the ballast surface as a common reference level; enhancement of signal/noise ratio; introduction of coordinate system used by SBB; reduction of effects caused by the ties.

Electromagnetic Data Interpretation: Neural Networks and Pattern Recognition

The literature indicates that efforts have been made to develop neural networks for classifying targets such as electromagnetic (EM) data. Artificial neural networks are a broad category of computer algorithms that solve several types of problems including: classification, parameter estimation and prediction, pattern recognition, filtering and optimization. A neural network relies upon a 'training set' consisting of electromagnetic data from which it can learn. Enhanced software has enabled real-time processing of electromagnetic data. Ideally, real-time processing of GPR data, and other EM data, would result in a very rapid evaluation of the track site.

Work conducted by Brown, M.P., et al was done to determine if neural networks could extract the same information from electromagnetic data as a trained geophysicist. One hundred and forty-five networks were trained and tested for purposes of target vs. background, conductivity classification and depth estimation. The results, although lacking a sensitivity analysis, indicated that including neural networks in decision-making is feasible and that these neural networks are capable of classifying targets included in electromagnetic data.

Neural networks and pattern recognition techniques are combined in the proposed system to automatically produce a high resolution image of the shallow subsurface in a highly reduced computation time, suitable for on-site GPR mapping of utilities and other objects such as

landmines. The neural network makes use of the spectral features of the data to identify areas in the radargram containing useful reflections. The Hough Transform is applied as a pattern recognition technique to locate and identify the hyperbolic anomalies associated with buried targets, generating high resolution images suitable for precise location and mapping of subsurface utilities and ordnance. GPR displays are usually either manually scaled and interpreted, or stored and subsequently processed off-line. Separating out clutter, and accounting for various system and subsurface effects require considerable operator skill, experience and time. The processing aides that have been developed to aid in data interpretation are generally computationally expensive systems inadequate for on-site application. As GPR is becoming more and more popular as a shallow subsurface mapping tool, the volume of raw data that must be analyzed and interpreted is presenting more of a challenge.

A system proposed by W. Al-Nuaimy, et al, 1999, employs a combination of neural network, signal and image processing techniques to provide a high-resolution image of the sub-surface in near real-time facilitating straightforward data interpretation and providing accurate depth and azimuth location information. The system comprises a neural network classifier, a pattern recognition stage, and additional pre-processing, feature-extraction and image processing stages. Automatic selection of the areas of the radargram containing useful information results in a reduced data set and hence a reduction in computation time. A backpropagation neural network is employed to identify portions of the radar image corresponding to target reflections by training it to recognize the Welch power spectral density estimate of signal segments reflected from various types of buried target. This results in a classification of the radargram into useful and redundant sections, and further processing is performed only on the former. The Hough Transform is then applied to the edges of these reflections, in order to accurately identify the depth and position of the buried targets. This allows a high resolution reconstruction of the subsurface with reduced computation time. The radar configuration used for this study was the GSSI SIR w -2 system with a 400 MHz center-frequency antenna pair.

Work has been conducted on the GPR technology to obtain predictive criteria for the rail track ballast and sub-grade. Preliminary research is being conducted on the potential application of ground penetrating radar (GPR), seismic and terrain conductivity instrument (EM31) and the fusion of data from each of these sensors for rapid real-time evaluation of the near surface and sub-surface of railway track. Non-invasive and non-destructive geophysical methods have numerous applications such as, measuring pavement thickness and voids, mapping underground utilities, landfills, characterizing groundwater contamination plumes, shallow bedrock profile and mapping soil stratigraphy. Effective target or anomaly detection requires strong contrasting physical properties and suitable size and shape (aspect ratio) of target. Man-made targets such as a large metal pipe in sandy-ground, buried metal drums, road pavement layers and tunnel linings are much easier to detect and identify than natural ground failure or voids in clay-rich ground. Initial readings using the LI technology to measure lateral and vertical rail deflection has been made at two sites in West Virginia.

Problem Statement

Track and structure defects are principal causes of reported railroad accidents and incidents in the United States. Based on FRA's statistics for the period 1988-1999, an average of 1,065 incidents was attributed specifically to track-related causes, which accounted for 34 percent of the total incidents. As reported by FRA for the year 2000, track defects were attributed for 36 percent of the total reported railroad incidents.

Recent newspaper stories citing FRA reports have reported that railroad accidents in West Virginia during 1996-1998 increased 56 percent when compared to the previous years (1993-95), and the leading culprit or cause was the track. This increase in track-related train accidents can be attributed to several sources. Site-specific factors include increased ton mileage, difficult terrain, and geologic conditions. Additionally, these sites are vulnerable to climatic events. This is particularly prevalent in locations in close proximity to drainage systems.

Parts of West Virginia experienced major floods in 2001 and 2002, which inflicted significant damages to the transportation systems. Geo-technical related potential safety hazards for the rail lines in West Virginia are now more prevalent as a result of these recent floods. To improve the safety of railroad operations in the United States, this project focused on: advancements in the detection of track and subsurface stability and analysis of the most appropriate remote sensing technologies for site-specific geo-technical/spatial data collection and monitoring.

Objectives

For the purposes of this project, and in particular this phase of the program, RTI research will focus on applying ITSAMS and technology/methods to the track sites under study with the aim of acquiring the necessary expertise to detect rail defects and deflection behavior. The initial issue here is to address is the ability to differentiate a “healthy” rail section from a rail with a defect, and to be able to discern which kind of defect it is (position within the rail, size, growth direction, importance).

The potential benefit of the application of technologies in tandem with the ITSAMS platform includes increased reliability and definition of subgrade imaging. Future work will be performed to enhance the mobility and integration of this system and to develop interpretive software to perform real time data evaluation and monitoring.

Technologies

Seven technologies and their usage and potential benefits within the Integrated Track Stability Assessment and Monitoring System (ITSAMS) are reviewed within this section. Among these are: global positioning systems (GPS), ground penetrating radar (GPR), terrain conductivity, DC resistivity, seismic profiling, very-low frequency electromagnetics, and laser interferometers.

Global positioning systems (GPS)

Of particular importance to the ITSAMS, is the ability to accurately and consistently mark and identify the location of recorded anomalies. System performance requires that vehicle position must be established to within 1 centimeter (cm) horizontally and 1 cm vertically along the track

on a real time basis. This includes the requirement that the vehicle must be able to indicate a return to the recorded site once it has left the area.

GPS technology is the only state-of-the-art technology that is able to meet this positioning requirement, but it does so only on a stationary (non-moving) platform. RTI researchers have had discussions with GPS system technicians and engineers regarding state-of-the-art GPS systems. RTI has also gained practical experience in the use and capabilities of a current high-end GPS system (Trimble 4800) at a workshop conducted with the Kentucky Transportation Center in Lexington, KY. Current state-of-the-art GPS systems, like the Trimble 5700 are capable of achieving the required level of accuracy; however, the system may require fixed receiver stations erected along the railroad right-of-way.

Literature review and discussions with GPS industry representatives have continued with the goal of matching performance requirements and component/system integration requirements into the ITSAMS. With the continued evolution of GPS technology, configuring a GPS with the ITSAMS to give precise spatial coordinates to data collected by the ITSAMS is feasible. Stated system requirements are for a vehicle traveling at 20–30 mph (32-48 km/h) to achieve data accuracy on the track to within 1 cm horizontally and vertically.

Figure 1: RTI personnel using a handheld GPS along the track

Current hand held GPS technology, like the Trimble GeoExplorer 3C as shown in Figure 1, is being utilized to delineate sections of track at current RTI test sites on CSX and NS property. Currently available GPS technology can provide real-time kinematics data horizontally to within 1 cm and vertically within 2 cm accuracy. Through an RTI course collaborated with the Kentucky Transportation Center, practical experience was gained in the use and capabilities of current technology GPS (i.e. Trimble 4800 series).

For optimal performance of a GPS providing real-time kinematic (RTK) data, technology may require permanent GPS stations along the rail corridor and inspection vehicles traveling at

lower speeds. Continued research and discussion with industry representatives will be conducted to develop an integrated product that will best fit the stated ITSAMS requirements.

Due to the fundamental basis of integrating GPS technology into ITSAMS and the rapid advancements being made in GPS technology, RTI researchers will continue to review advances in GPS technology.

To further the research in the GPS field and the state-of-the-art GPS technology, RTI is entering into a unique lease arrangement with Trimble to utilize the most advanced GPS unit, currently the Trimble 5800 series, with immediate upgrade to new advanced technology as it becomes available. RTI is also pursuing a project with the USDOT to extensively test the use of handheld GPS units to gain additional insight into the use, capabilities and potential application of GPS receivers. RTI will use this project experience and perspective and our continued access to current state of the art technology to integrate a GPS system into the ITSAMS. Final GPS system specifications will be developed after a final vehicle is designed.

Carrier phase GPS positioning technology

By counting the number of wavelengths of the GPS signal carrier wave, the distance between a GPS antenna and the space vehicle (SV, or GPS satellite) can be refined from C/A phase observations. Carrier-phase differential GPS (CPDGPS), also referred to as Real Time Kinematic GPS (RTK), uses two or more receivers capable of phase-shift measurements to provide positioning accuracies to 1 cm ± 1ppm horizontal and 2 cm ± 1ppm vertical. Using Trimble 5700 receivers, this technique requires that signals from at least five SVs be collected simultaneously throughout the measurement process. Dual frequency receivers, those capable of both L1 and L2 band reception (like the Trimble 5700, R8, NetRS and NetR5), are best suited for this work. Like Differential GPS (DGPS), one fixed position receiver is used for broadcasting corrections to the roving unit. An ad hoc base station broadcast typically employs a modulated VHF or UHF FM signal to broadcast corrections to a roving receiver. However with a connection to the Internet, continually operating reference stations (CORS) can supply corrections to a rover using cellular telephone network(s).

A single base station can provide coverage for an approximate 40 km radius from its position. Beyond 40 km, initialization times and the ppm error accumulates beyond acceptable levels. The ppm error indicates that, for every million parts distant from the base station, the error increases by one part. For example, a 10 km distance from the base adds an additional 1 cm position error. A 40 km baseline would then introduce and additional ± 4 cm error to the observation.

A network of base stations connected to a central server, can provide a virtual reference station (VRS) to the roving receiver. The server uses modeling software to create a VRS located a meter from the user's positions. As the error grows, the server is able to recalculate a VRS and automatically send the new VRS to the rover. This all but eliminates the error growth from the ppm error and reduces initialization times for the rover.

There are still difficulties to ubiquitous, reliable, RTK GPS usage. Particularly difficult conditions are under dense foliage or in an area with steep walls that limit line of sight to SVs. However, the GPS modernization program launched the first Block II-RM (Replacement Modernized) satellite in October 2005. The modernized signals (L2C) and higher power output address the problems of penetrating dense foliage.

Establishing a consistent rail measurement datum has been difficult. Development of a spring swing arm arrangement to engage the inside of a rail in order to mount a GPS antenna and pickup has been satisfactory on mailing track. Since the railroad gage measurement is specified as 4 feet, 8-1/2 inches from the inside of the rail, 5/8 inch down from the top, use of this location enables direct gage calculation from two GPS measurements. The spring swing arm performed well in main line track testing. This assembly was able to navigate all grade crossings and a set of switches and frogs without manual intervention. Measurements were collected at velocities of 1.3 to 6.7 m/s (3 to 15 mph). Due to slight damage to the GPS takeoff arm from the survey point slipping between bolted rails, a wider contact area on the GPS takeoff arm is under consideration.

Survey Procedures

Procedures for obtaining survey quality (3D position less than 2 cm RMS) have been developed and recorded. Setup procedures are provided in the appendix. The steps involved are:

1. Select a location that provides for:
    a. Safety of workers
    b. Optimal view of SVs (space vehicles)
    c. Clear southern sky
    d. Freedom from obstructions; lack of trees, overhanging branches, buildings
    e. Publicly access or privately owned with permission
2. Marking location with wooden survey hub, spike, or pin.
3. Setting up base station on point.
4. Starting GPS receiver
5. Collecting GPS observables, minimum 2 hours
6. Post-process observables with NGS OPUS

Transmission of a differential correction via radio requires an FCC license. The licensing procedure was initiated using an FCC authorized frequency coordinator (LR_WV_00RR_00042_02) in August 2002. The FCC license authorized the Appalachian Transportation Institute to operate throughout the state of West Virginia on 14 January 2003 with a station call sign of WPWS414. The station license limits operation to 25 watts and only digital emissions designated 16KOF1D. The use of fourteen frequencies is authorized (matching the Trimble Trimark 3 transmitters capability). Any antenna structures are restricted to a height of 60.96 meters (200 feet).

Figure 2: GPS pickup location

Survey Grade GPS

Field testing of the high accuracy differential GPS configurations were performed in various locations over a variety of terrain and in various weather conditions.

- CSXT mainline, single rail, RTI's 'electronic corridor' between Huntington and Point Pleasant, WV
- NS mainline, two rail, between South Point and Ironton, OH
- NS classification yard, Irondale, AL
- BNSF mainline, single rail near Folsom, NM
- IHB classification yard, Blue Island, IL
- BNSF classification yard, North Kansas City, KS

The equipment used for rail yard surveys:

Trimble Base Station

- Trimble 5700 receiver
- Trimble Zephyr Geodetic GPS Antenna
- Trimble Trimmark III UHF data radio
- Trimble UHF antenna, 8db gain

Trimble Roving Receiver

- Trimble 5700 receiver
- Alternate: Trimble R8 receiver/antenna
- Trimble Geodetic GPS antenna
- Trimble TSCe survey controller
- Trimble UHF antenna

Ground penetrating radar (GPR)

Ground penetrating radar, GPR, also known as ground-probing radar, provides a graphical, picture-like representation of the subsurface. It is based on the idea that objects of different materials have different electrical and physical properties. It has the highest resolution of any geophysical method and, if the proper antennas are used, it can be possible to use GPR for determining the stratigraphy of a region. GPR uses a reflection technique that utilizes high-frequency magnetic waves to penetrate the ground and obtain the required results. It is useful for locating objects with electrical properties different than their surroundings, such as water plumes, buried tanks, pipes, or other metal objects. Its efficiency; however, depend on the predominant lithology and soil type. It has been successfully used to study karst (Collins et al., 1993) because of the different physical properties of the limestone and air-filled cavities, and floodplain deposits (Leclerc and Hickin, 1997).

The GPR signal is process in the frequency domain of the GPR electronic magnetic signal. A custom program converts the sampled GPR scan signal from time domain to frequency domain, and then determines the frequencies that contain the greatest component of returned energy. Since the dominant frequency changes when the track bed conditions change, rail track changes such as moisture content can be identified and mapped.

RTI employees conducted several GPR surveys in this first research phase. The surveys are detailed in this section. A brief background about GPR is also provided in this section with the aim of helping to provide a better understanding of the results. The particular GPR instruments that RTI personnel have gained practical and beneficial experience with are the Geophysical Survey Systems, Inc. (GSSI) 100 MHz antenna model and SIR-2000 hardware (Figure 3 left), and the unit utilized by GECOH Exploration, the Noggin 250 MHz antenna model (Figure 3 right).

Figure 3: 100 MHz GPR (left) and noggin unit (right)

Antenna Results

Experiments conducted with the 400Mhz GSSI antenna have been encouraging. Preliminary testing on yard and mainline rail, using an air-launched mount, indicates that characteristics such as moisture content of the ballast correlate well with readings taken from electromagnetic induction measurements of soil conductivity. Further testing with a directly coupled antenna (antenna in direct contact with the earth) is necessary to better define the ballast substructure.

Figure 4: Lexington Survey

Figure 5: Route 2 in Guyandotte Survey

Ballast Survey

To further define the ballast/sub grade interface, a GPR survey on Feb. 25, 2003 of wet and dry ballast placed in a hole was conducted by RTI staff. The purpose was to collect GPR data on the differences between wet and dry ballast and clay. Analysis helps provide a basis for determining the differences between ballast and clay sub-ballast signatures in both wet and dry conditions as well as changes in the water table influence signature.

Figure 6: Clay Soil

Figure 7: Wet Ballast

Figure 8: Dry Ballast

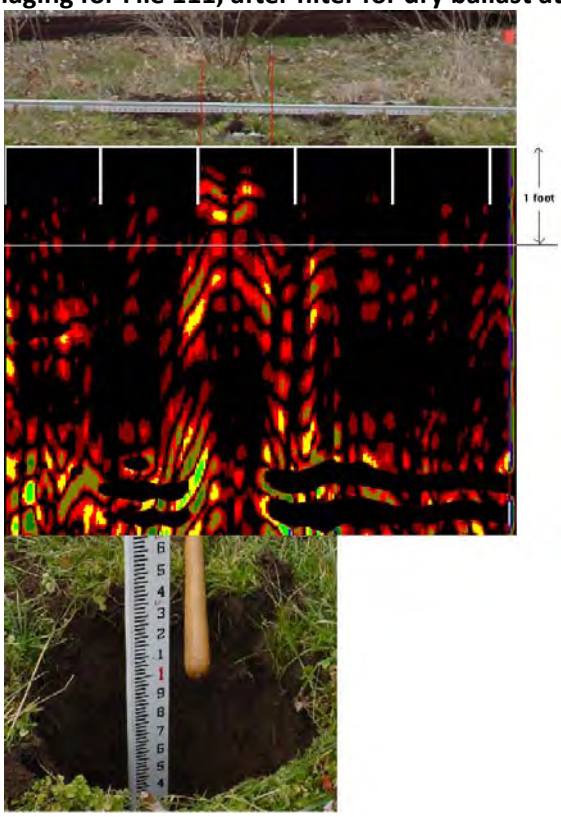
Table 1: Ballast survey collection record

File Name	Range (ns)	Scan/m	m/mark	Location
103	100	100	0.5	River side of track
104	60	100	0.5	River side of track
105	60	100	0.5	Track centerline
106	100	100	0.5	Track centerline
107	100	100	0.5	Wet ballast
108	60	100	0.5	Wet ballast
109	60	100	0.5	Dry ballast
110	100	100	0.5	Dry ballast
111	20	100	0.5	Dry ballast
112	40	100	0.5	Dry ballast
113	10	100	0.5	Dry ballast

Figure 9 shows the GPR reflection from dry ballast placed in the hole. The ballast is observed to be the highest reflection for that depth. The depth is directly observed. Filters applied to files 104a and 105a provided images that were not clearly observable at 60ns. Images using a 100ns range are more distinguishable, enhancing the ability to determine differences between track and ground between track and river.

Future efforts will use a 100ns range to collect ballast data.

Figure 9: Imaging for File 111, after filter for dry ballast at range 20ns



Vision information data collection

Photographic data collection recorded an image at 2 second intervals. Spatial information from the GPS was recorded simultaneously. A custom program was developed to simultaneously collect and store image and spatial information.

Integrate GPR and vision information into GIS system

GPR data is collected and processed based on linear reference system which uses a position along the rail, usually measured as some distance from a reference mark, such as a mile marker. However, to display the GPR data in a Geographic Information System, a program was developed to convert the railroad linear reference to a geographic coordinate system. The conversion program finds the reference point on the rail and converts the linear position to latitude and longitude of each GPR scan and associates the GPR process values to this point. The program's output provides a GIS formatted file (.shp) that includes the GPR scan data.

Terrain conductivity

Terrain Conductivity or Electromagnetic (EM) surveying is a non-invasive geophysical surveying technology. The particular EM instrument that RTI personnel have gained practical and beneficial experience with is the Geonics EM-31.

Figure 10: The EM-31 terrain conductivity meter

The Geonics EM-31 is used to detect subsurface anomalies at depths of up to 20 feet. These subsurface anomalies can either be man-made (pipes, conduits, culverts, etc.) or a result of some geologic phenomena (faults, voids, karst topography, joints, etc.). The EM-31 indicates anomalies as either high or low conductivity readings, depending on the situation. Some of the advantages of the EM-31 are that it is easy to operate, it can operate at high speeds, it only requires one operator to use, it can be used for a multitude of applications, and the output data is relatively simple to interpret.

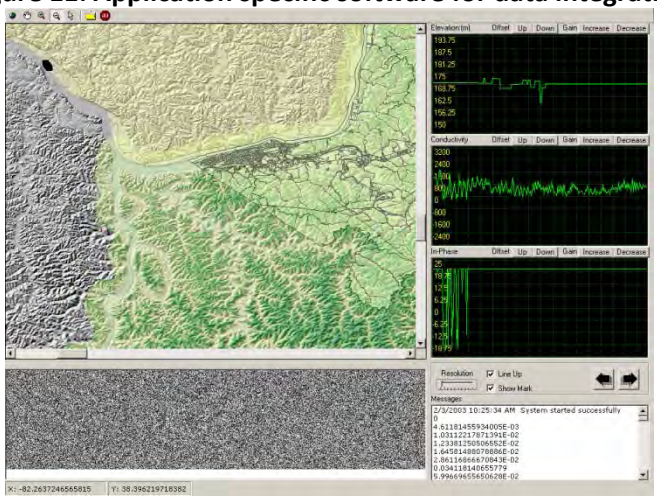
The EM-31 has been used extensively on the different rail sites throughout the summer, fall, and winter of 2001 and has proven to be an instrument that will complement the GPR and other ITSAMS equipment. Discussion of the results of the work done with EM-31 may be viewed in Section

The Geonics EM-31 is mounted on a modified Nolan RD-1 rail dolly. The stake points on the track dolly have been relocated and a steel table added to mount the instrument. Aluminum drawbars attach the stake points on the rail dolly to the instrument platform. The drawbars are not pined or otherwise secured at the stake points. This arrangement allows the EMI rail dolly to track over grade crossings, through curves, switches and frogs. The EMI dolly has been successfully towed at speeds up to 6.7 meters/second (15 miles/hour). Railroad personnel have warned that the dolly may not be heavy enough to trip 'spring frogs', yet no observations of such issues were encountered during testing

The application-specific software collects and displays the following EM31 data:

- Conductivity (graphic, numeric)
- In-Phase (graphic, numeric)
- GPS
- Horizontal (mapped)
- Elevation (graph)
- Lat/Long/#of SV/quality (numeric)

Figure 11: Application specific software for data integration



Data collection occurs simultaneously through two serial interface connections to a laptop computer. The software has been expanded and refined from the description in the Phase I report. The team tested the EMI system on the ITSAMS cart over a section of Norfolk Southern yard track in Ironton, Ohio. Conditions during this study were rainy. The data generated had good quality. However, the instrument readings varied greatly across switch points and frogs. This was expected due to the iron in the rail.

Additionally, the EMI was tested over a section of CSXT track Route 2, near Barboursville, WV (see Figure 15). To date, this data has not been analyzed. The ballast over this section of track was much thicker than the Ironton track. It is notable that this data was also collected during a rainy period.

DC resistivity

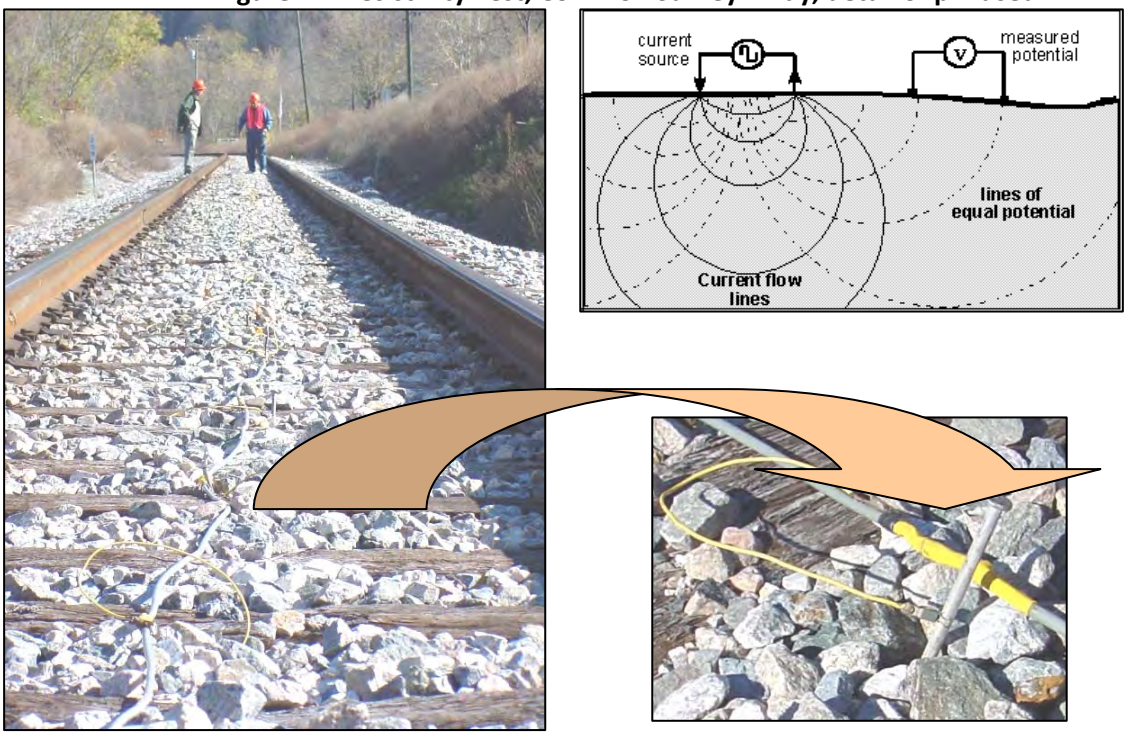
DC resistivity is a geophysical exploration technique that allows the operator to determine the resistivity of the terrain by observing the electric field induced in the ground by the surveyor. The use of DC resistivity for track assessment has been explored by RTI with the final goal of being able to detect track sections presenting abnormal resistivity values. Abnormal resistivity values could be correlated with track anomalies. For instance, an unusual low resistivity section could indicate high moisture content in water that can be correlated with slippage areas of mud saturation.

The DC resistivity method requires the establishment of physical contact with the terrain under study by means of an array of transducers that must be half-buried in the track. This makes it a time-consuming technique. The results obtained by DC resistivity exploration match quite well the data gathered with the EM-31.

This detection method operates by creating an electric field in the soil by passing DC electric current through the ground. In the fall-of-potential method using three pins, one of the three pins partially buried in the ballast supplies the DC current. A known amount of current is passed

through the inner pin and the voltage drop between the outer two pins is measured. Using Ohm's law, the drop in potential can be easily converted to resistivity (or conductivity). Soil resistivity varies depending on the soil type, temperature and moisture. Once the conductivity at that particular arrangement is recorded, the test is repeated for the next group of three pins; the inner pin becomes now an outer pin, and acts as a receiver instead that as a transmitter. The test must be repeated for the following groups of pins, advancing until the total length of study is covered.

Figure 12: Resistivity Test, Common Survey Array, detail of pin used



Left: Two RTI engineers conducting a resistivity test. CSX line, Guyandotte.
Right above: Common survey array. Below: Detail of one of the pins used in the test

Seismic profiling

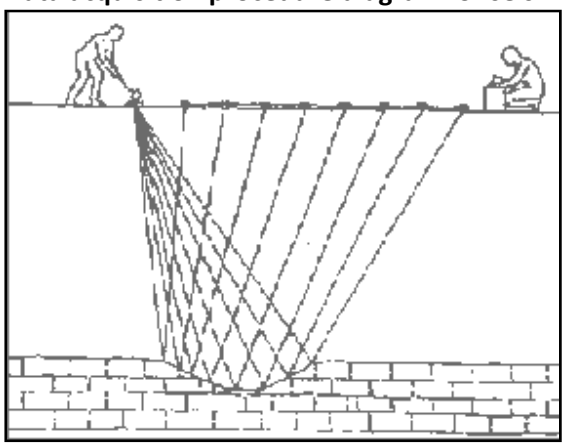
High-resolution seismic profiling (HRS) is another of several geophysical techniques that RTI is using for track integrity assessment. The primary application for this technology as related to this project is for determination of geologic layers, and thereby identification of potential slip planes.

The potential benefit of application of this technology in the ITSAMS is increased reliability and definition of subgrade imaging. Discussion of the results of the work done with HRS may be viewed in section 6. Future work will be performed to enhance the mobility and integration of this system and to develop interpretive software to perform real time data evaluation and monitoring.

"Seismic reflection profiling involves the measurement of the two-way travel time of seismic waves transmitted from the surface and reflected back to the surface at the interfaces between

contrasting geological layers. Reflection of the transmitted energy will only occur when there is a contrast in the acoustic impedance (product of the seismic velocity and density) between these layers. The strength of the contrast in the acoustic impedance of the two layers determines the amplitude of the reflected signal. The reflected signal is detected on the surface using an array of high frequency geophones. The seismic energy is provided by a 'shot' on surface."[1] For this particular application, a hammer was used to provide the needed shot on surface. Please see Figure 13 for a graphical representation of the technique.

Figure 13: Data acquisition procedure diagram for seismic profiling



Very-low frequency electromagnetics

VLF surveys measure various components of the VLF EM fields in the frequency range of 15 to 25 kHz generated by military communications stations scattered around the world. Long linear conductors give rise to localized anomalies in these VLF fields, therefore the VLF method is an effective tool for mapping conductive fault and fracture zones, especially water-bearing fracture zones in hard rock environments to a depth of some dozens meters.

VLF distortions occur because of local changes in electrical conductivity, usually found within steeply dipping geologic features. The primary application for this technology, as related to this project, is for determination of geologic depth to bedrock and depth to clay, thereby enabling the identification of potential slip planes.

Among the advantages of the VLF method is the speed of execution, since it is only necessary to carry out a survey, with no need to extend a complex array. Also, since it is not necessary to produce a signal generator, only one field operation is necessary. All this implies that the investigations carried out by this method are quick and less expensive than many alternative methods.

As above, the potential benefit of application of this technology in the ITSAMS is increased reliability and definition of subgrade imaging. Future work will be performed to enhance the mobility and integration of this system and to develop interpretive software to perform real

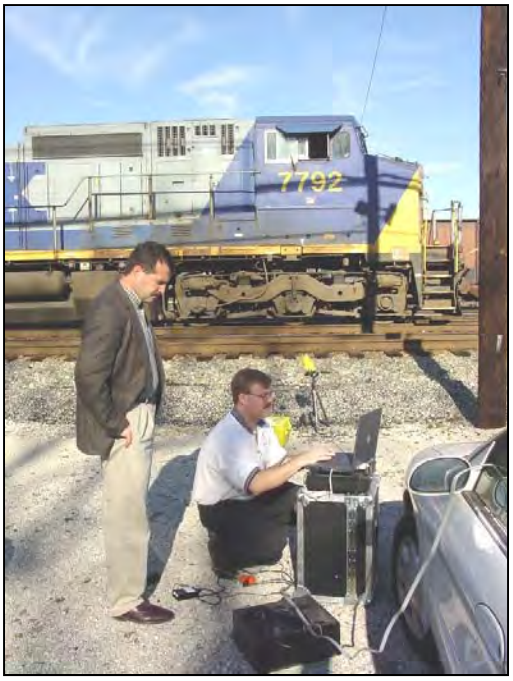
[1] http://www.geophysics.co.uk/mets3.html

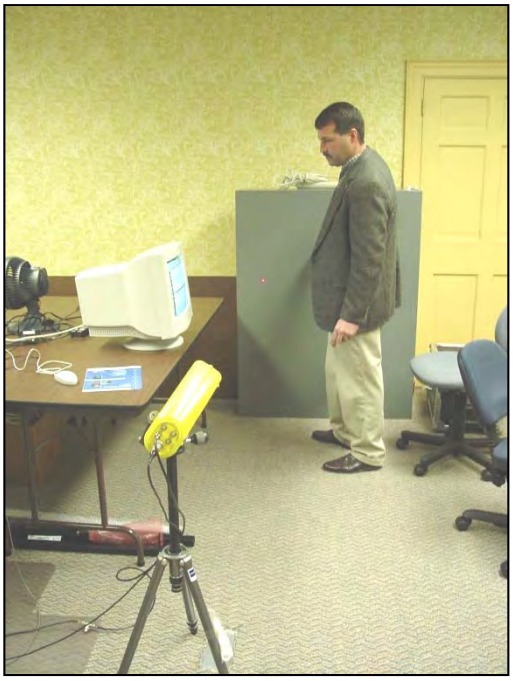
time data evaluation and monitoring. Discussion of the work done with VLF may be viewed in the results section.

Laser interferometer equipment

The Laser Interferometer technology of ITSAMS is the component designated for rail track assessment. The LI system will assess rail track via an integrated non-contact track deflection (vertical and horizontal), acoustic emission, and vibration measurement and diagnostic program. By "signature" interrogation and diagnostics, the LI would thus be capable of detecting many rail defects, even those undetectable by current technology. Past RTI evaluation of the LI system has indicated that it is a promising technology.

Figure 14: RTI personnel testing LI equipment





Left: on-track testing. Right: At RTI headquarters.

Between 24 April 2001 through 30 August 2001, an Epoch Engineering, Inc. (EEI) developed Robust Laser Interferometer (RLI) measurement system was employed, under a service agreement with the Rahall Transportation Institute (RTI), to make measurements of railroad tracks under a variety of conditions. From these tests, RTI has succeeded in taking both lateral and vertical deflection measurements. On 20 September 2001, RTI hosted a workshop to review the measurements taken and to analyze the opportunities for interpreting the information presented in these measurements.

The potential for the LI system to develop into a high-speed rail track defect detection system is promising. The LI system would have the ability to be used either as a stand-alone rail track defect detection system or as an integrated component of the ITSAMS. Future work will be performed to enhance the understanding of the data recorded by the LI and integrate this data

into a neural network database. Data surveys will be conducted over areas of known rail track defects. Discussion of the work done with LI may be viewed in the results section.

A laser vibrometer (a type of laser interferometer) measures vibration velocity based upon the Doppler effect. The data is then processed by special software in real time, displaying results similar to those that of a regular accelerometer. Thus, the LI performs as a vibration transducer, but requires no physical contact for measuring. Moreover, the LI's impressive frequency measuring range (for instance, the RLI tested is able to register vibration frequencies ranging from < 1Hz to 500 kHz) makes this technology extremely versatile, being able to replace accelerometers and microphones in most cases.

The technology represented by the RLI is provided by the ability to measure, via non-contact laser, small displacement (<10 to <10-11 meters) in the presence of large displacements (>10 to <10-1 meters), [demonstrated dynamic range of 180 dB (demonstrated in both displacement and acceleration)] over a measurement bandwidth from 0 Hz to over 500 kHz. Measurements taken of the rail exhibit characteristics that enable the extraction of information from the measurement data.

In addition to the tests performed with EEI (using their human resources expertise and proprietary system), on two occasions Brüel & Kjaer representatives demonstrated to RTI engineers the use and capabilities of the most powerful commercial LI system, both on the track and at RTI headquarters.

A presentation of data from the various tests performed on the rail track is presented in Appendix G. The short annotation of each figure is not designed to present the full range of information available from the RLI.

Ongoing LI research is oriented towards rail defect detection and rail deflection behavior exploration. The capabilities acquired by RTI in this first phase make this technology suitable for further research not only regarding rail assessment, but also to track evaluation. Sound imaging and acoustic holography are candidate techniques for future investigations.

In the short-run, RTI research will focus on applying LI technology to the track sites under study with the aim of acquiring the necessary expertise to detect rail defects and deflection behavior. The initial issue to address is the ability to differentiate the emission pattern obtained from that of a "healthy" rail section from a rail with a defect, and to be able to discern which kind of defect it is (position within the rail, size, growth direction, importance). Another issue to study is rail deflection behavior. LI has been demonstrated to be a useful tool for measuring rail deflection in static applications. The next step considered by RTI is deflection measurement from a moving platform. By measuring the deflection for a given load, (ITSAMS load initially) track stiffness (modulus) can be easily computed for each section and compared to a reference pattern.

In a second stage, RTI plans to develop a LI integrated system capable of comparing data in real time (both, rail deflection and internal rail defect detection) from a LI mounted on the ITSAMS with patterns corresponding to “healthy” track.

Field Investigations

Active Rail Corridors

West Virginia

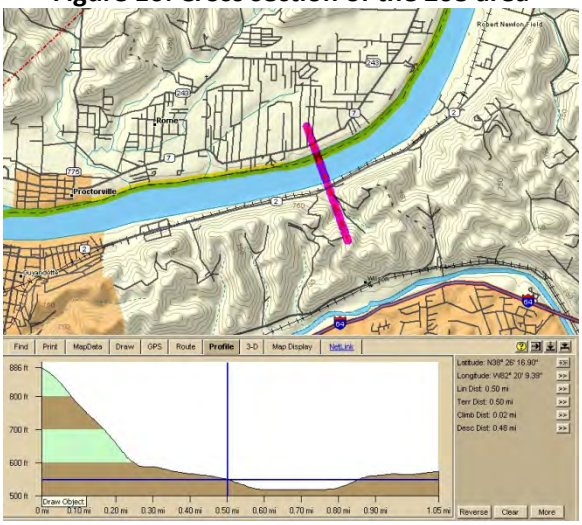
Due to the close proximity of CSXT’s mainline rail paralleling U.S. Route 2 to the Marshall University Huntington campus, the sections of track referred to by CSXT mile marker numbers 208 and 201 have been the primary test sites for ITSAMS platform testing. The 3D topographic representation in Figure 16 shows the close proximity of track to the Ohio River. This view is from the northwest, with Rome Township, OH on the left and Huntington, WV to the right. The marker points to the 208 study area.

Figure 15: Study area 208 topography

Other areas of study included abandoned rail yards in Huntington, West Virginia (CSXT) and Ironton, Ohio (Norfolk Southern). The yard sites provide immediate access for testing. Sections of the yard have been locked out by the rail supervisor to allow immediate inspection vehicle setup and testing. Experiments in the yard areas allow checks of mechanical function, instrument operation, and data collection all without removing blocks of working mainline rail to perform mechanical tests.

Problems arise during yard testing that have not occurred on continuously welded mainline rail. Continuously welded rail offers smooth transitions between track segments, while typical yard track is bolted, with significant gaps between rail sections. These gaps catch the survey point used to survey the inside rail (please see Figure 16).

Figure 16: Cross section of the 208 area



Discussions of track history with a CSX Roadmaster concerning the 208 study area gained several insights about the rail bed. The curved section of 208 has been moved away from the river to its present location. The magnitude of the displacement is on the order of 10 to 20 feet. The track was relocated away from the river to prevent the river bank under the track washing away. Some sections of the rail between Huntington and Point Pleasant had bridge structures that were filled in. These areas may be located with the aid of old track charts. The field team will attempt to obtain copies of the old charts.

Numerous field surveys have been performed using the GSSI 100 MHz antenna at off-track and on-track locations in Huntington, WV. Two surveys have been made using the GECOH supplied 250 MHz antenna at the track locations in Huntington, WV. Field surveys were conducted on active CSXT rail sidings in Huntington, WV and on a CSXT main line track at our test site located near MP 208 and MP 201 on the Ohio River Subdivision in Huntington, WV.
Numerous field surveys have been performed using the Geonics EM-31 conductivity meter (see Figure 5) at off-track and on-track locations in Huntington, WV. The field surveys were conducted on an active CSXT rail siding in Huntington and on a CSXT main line track at our test site located near MP 208 on the Ohio River Subdivision in Huntington, WV.
Another EM-31 survey was conducted on a CSXT rail line between MP 208 and MP 208.6, just Northeast of Huntington, WV. The railway here is located between the Ohio River and WV Route 2. The close proximity to the river has made this site problematic for CSX in the past. In fact, much remediation has already been done here. Multiple surveys were performed here at varying times during the year, with each of them showing a distinct anomalous region of high conductivity. This high conductivity region occurs between two culverts marked as E and F on the data log.

Via a service agreement with GECOH Exploration, Inc., DC Resistivity methodology was tested at MP 208 in Huntington, WV. Via a service agreement with GECOH Exploration, Inc., Very-Low Frequency Electromagnetics (VLF) methodology was tested at the track siding at MP 208 in Huntington, WV.

A field survey has been performed using high-resolution seismic methods at a CSX main line track at our test site located near MP 208 on the Ohio River Subdivision in Huntington, WV. In addition to the seismic profile included in section 6, a survey of the MP 208 site, near Huntington, WV was conducted. The seismic profile of the site is presented in Appendix D. The survey was performed using instrumentation supplied by GECOH Exploration.

Outside West Virginia

Kentucky

Numerous field surveys have been performed using the GSSI 100 MHz antenna at off-track and on-track locations in Lexington, KY. The field surveys were conducted on active CSX rail sidings in Lexington, KY. Of particular interest was one test performed in Lexington, KY where the EM-31 was used to survey a section of track that had previously been assessed by other geophysical survey instruments in a RTI test performed using instrumentation supplied by GECOH Exploration.

Via a service agreement with GECOH Exploration, Inc., DC Resistivity and Very-Low Frequency Electromagnetics (VLF) methodology were tested at the track siding in Lexington, KY. A field survey has been performed using high-resolution seismic methods at on-track locations in Lexington, KY. The field surveys were conducted on an active CSX rail siding in Lexington, KY. Using multiple geophysical instruments (Seismic and VLF), GECOH and RTI performed an initial geophysical survey of the Lexington, KY track siding.

Illinois

As a result of a previously published research report, Transystems Company approached the RTI with a proposal for surveying the Indiana Harbor Belt Railroad (IHB) Blue Island, IL a 44 track classification yard. The purpose of this survey was to provide top-of-rail elevations to aid in resurfacing the yard. This paper details the survey data, collection, and processing steps.

Traditional methods for this work involve a survey crew walking each rail and measuring elevations at 100 foot stations. Additionally, traditional methods require a clear line of site using yard locomotives to clear wide sight lines, dedicated track safety workers to lockout switches and act as watchmen lookouts. For this job, a typical working crew would require a three person survey party, two yard safety persons, an engineer and conductor, and an locomotive. The estimated survey time is 4 to 6 weeks of field work, with several additional weeks of office work.

The technique developed at the Rahall Transportation Institute allows the survey to be conducted by no more than two surveyors, a locomotive, engineer, and conductor. The estimated completion time for this job was three days, with minimal disruption to yard traffic, and minimally exposing workers to yard hazards.

Data Collection, Processing and Storage

Field Data Collection and Processing

Hardware and Software

Platforms were designed and constructed in order to provide a base for mounting GPS, GPR, EM31 and Laser Interferometry instruments (please see Figure 17). Two platforms were constructed and field tested. The first platform tested (Type I) was constructed using a Nolan model TD-3 track dolly (three wheel) as the base instrument stage. The Nolan TD-3 has 3, 5 inch cast aluminum wheels with sealed bearings. The weight is 49 kg.

Figure 17: Nolan model TD-3 track dolly

The Type I platform was:

- Small, light, easy to transport
- Tracked well when towed at speeds to 13 MPH
- Wheel bearing temperature acceptable over continuous 13 km segment

Tests with this platform concluded the Nolan TD-3:

- Exhibited unacceptably low ground clearance
  - One to two centimeter clearances were not enough to prevent grade crossing contact
  - Dolly bottomed and lifted at crossings
- Dual flanged wheels did not negotiate switches and frogs without manual assistance
- High vibration due to the lack of wheel cushioning or suspension resulted in loosened fasteners on some equipment

Due to the ground and switch clearance difficulties, plans to fully instrument the Type I platform were suspended. Construction of the Type II platform uses a Nolan model TS-1 track cart for a base. Unit has four, five inch aluminum wheels in a two piece interlocking design that eases handling. The section fit easily in the back of a pickup truck or Chevy Suburban. The total weight is 79 kg.

Testing with the Nolan TD-3 dolly concluded that:

- Provides acceptable ground clearance through grade crossings
- Allows full speed operation across crossings, switches and frogs
- Requires a larger vehicle than the Type I for transportation to site
- Is easily propelled by hand
- Is constructed heavier than required for instruments

Several pieces of tubing were removed from the factory supplied structure to enable instrument placement and reduce weight. Both platforms sway laterally. Dual and single flanged wheels meander between rails, exhibiting a side-to-side movement of approximately 3 to 8 cm.

Figure 18: Nolan model TS-1 track cart

Hy-rail and Hy-rail GPS

The main survey vehicle was a Chevrolet Suburban equipped with a Fontaine hy-rail. The Hy-rail GPS module consist on the installation of the 5700 GPS receiver on one of our two specialized track surveying trucks. The GPS devices were powered by the hy-rail's 12 volt electrical system. A GPS antenna was mounted to a rack on the top of the hy-rail and aligned over the gage side of the rail. A UHF radio antenna was also mounted to the rack. When local surveys were within range of a cellular connection and within the operational area of a CORS, a cellular phone was used corrections via the Internet.
Fabricated magnetic mount for rover antennas was mounted to locomotive roof.
Theodolite/Total station was used to align antenna to the centerline of locomotive roof.

Vehicle Antenna mount

Experiments were conducted employing several antenna mounting configurations. Several antenna mounts were discussed in previous reports. The mounting configurations examined were:

- The antenna is mounted so the survey point is in contact with the gauge side of the rail.
- The cart and tow arrangement was cumbersome for the research team to handle, transmitted a great deal of vibration to the instruments, frequently sustained

damage when encountering bolted joints, and was difficult to navigate through switches and frogs.

- The elevation difference between the top of the rail and the bottom of the GPS antenna mount was determined by:
  - First measurement with the subject antenna on a standard 2 meter survey pole. Survey controller set with range pole height of 2 meters. Measurement point was on top of rail.
  - Second measurement with antenna fixed in mount. Survey controller set with range pole height of zero.
  - Height of antenna mount is the difference in elevation between the two measurements. Accurate to within 2 cm.

Figure 19: Survey cart trailed behind a hy-rail

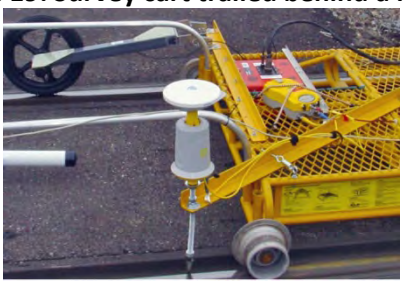


Figure 20: Hyrail mount, modified tracking

The rigid, hyrail mount illustrated in Figure 20 used a round cross-section Yakima utility rack as a base of support in anchoring a clamp to which was bolted a 6 inch range pole stub fixing a survey grade Trimble GPS antenna.

The center of the antenna was aligned over the inside flange of the hyrail's rear wheel. The method in which this was accomplished is illustrated (in gps surveyed to rail) photo. The elevation difference between the top of the rail and the bottom of the GPS antenna mount was determined by:

- First measurement with the subject antenna on a standard 2 meter survey pole. Survey controller set with range pole height of 2 meters. Measurement point was on top of rail.
- Second measurement with antenna fixed in mount. Survey controller set with range pole height of zero.

- Height of antenna mount is the difference in elevation between the two measurements. Accurate to within 2 cm.
- The hyrail wheel alignment was slightly modified in order to drive the starboard side of the hyrail against the rail. The modification had the effect of eliminating the hyrail 'hunting' between rails. Tests from unrestrained vehicles indicated that the accuracy of the rail position was improved by several centimeters.
- Sustained use of the modified hyrail showed increased wear to the inside flange. The modified hyrail was run approximately 200 miles. The hyrail's rail gear was then rotated with the opposite side.

"Portec" mount

The Portec mount uses an existing product from Portec, a supplier of Maintenance-of-Way equipment. The photograph (Portec arm) indicates that the standard arm was modified in order to use a clamp with a stub survey pole to mount the roving GPS antenna. A theodolite was set over the gage side edge of the rail to be surveyed, a laser plummet on the theodolite helped to establish the gage side edge. The hy-rail vehicle was moved 300 meters away from the theodolite. The center of the antenna mount was observed with the theodolite, the mount moved over the gage side of the rail by sliding the antenna clamped mount across a mounting tube welded across the Portec arm.

Figure 21: Portec mount

The elevation difference between the top of the rail and the bottom of the GPS antenna mount was determined by:

- First measurement with the subject antenna on a standard 2 meter survey pole. Survey controller set with range pole height of 2 meters. Measurement point was on top of rail.
- Second measurement with antenna fixed in mount. Survey controller set with range pole height of zero.
- Height of antenna mount is difference in elevation between the two measurements. Accurate to within 2 cm.

Magnetic mount

Fabricated magnetic mount with a 6" range pole stub, 5/8" x 11 tpi to engage the antenna mounting thread. Range pole stub fitted with UHF antenna mount (see Figure 22). The range pole stub was aligned to the centerline of the track testing a straight (tangent) section of track, approximately 300 meters line identified.

Figure 22: Magnetic mount

Theodolite

The elevation difference between the top of the rail and the bottom of the GPS antenna mount was determined by:

- First and second measurement with the subject antenna on a standard 2 meter survey pole. Survey controller set with range pole height of 2 meters. Measurement point was on top of both rails. Centerline elevation was determined by averaging the top of rail elevations.
- Third measurement with antenna fixed in mount. Survey controller set with range pole height of zero.
- Height of antenna mount is the difference in elevation between the antenna mount and the centerline elevation. Accurate to within 2 cm.

<u>Static GPS Survey Point Collection</u>

A Trimble Geodetic antenna and 5700 receiver was mounted on a range pole in conjunction with a TSCe survey controller. GPS corrections broadcast from an ad hoc base station were received with and attached UHF “rubber duck” style radio antenna. In later instances, a Trimble model R8 High Accuracy GPS receiver was mounted to a heavy duty 2 meter range pole. Wireless communications between the R8 receiver and survey controller used a Bluetooth connection. This requires a Bluetooth cap attached to the TSCe. When receiving corrections from an ad hoc base station a rubber duck antenna was attached to the R8. For long baseline surveys with range of a CORS, a Bluetooth enables cellular phone was used as a modem to receive connections from the CORS via the Internet. A bipod attached to the range pole adds stability when longer point setups were required, as in establishing bench marks.

Locomotive GPS

The Locomotive GPS module utilizes the locomotive as a survey platform when collecting GPS data. The GPS antenna is positioned on the roof of the locomotive by with a broad, four magnet mount. A six inch stub is fitted with a bracket that holds a Trimble cylindrical UHF antenna, with a Trimble Zephyr Geodetic high accuracy antenna mounted to the top of the stub. This fixture is aligned with the centerline of the locomotive roof using a Total Station instrument. The TSCe survey controller and Trimble 5700 High Accuracy GPS receiver are inside of the cab. Power for the instrument and controller is provided by a small 12 volt sealed rechargeable battery. This power arrangement was proven to be more reliable for ten to twelve hour yard surveys than using the individual receiver and survey controller rechargeable batteries.

Base Stations

Three base station configurations were used in sending differential corrections to a roving receiver.

Ad-Hoc Base Station

The base station components are a Trimble 5700 receiver with a compact flash card installed for storing satellite observations during the survey, a Trimmark 3 radio modem, a Trimble Zephyr Geodetic antenna with ground plane, a UHF gain antenna and standard survey tripod used to mount the UHF antenna.

The UHF transmitter antenna was positioned to the north of the GPS antenna to insure a clear line of sight to the satellites. The radio transmitter and 5700 receiver are housed inside a weather proof case. The cable connections are routed through a come through the side of this. Power is received from a 12 volt deep cycle battery. Usually the base station is installed and positioned on a place of higher altitude that where the survey shall be conducted, in order to receive a full and clear signal.

GPS Base Station Installation

The Zephyr Geodetic GPS antenna was positioned using a tripod in a known point in order to base our initialization on this previously surveyed location. If no known point was to be found, then, the receiver was programmed to collect and store its geographical position for later processing and calculate a precise reference point. The radio antenna is positioned to the north and a few meters away of the GPS antenna in order to minimize errors and multipath. The antennas are later connected to the GPS and radio, the 12 volt battery is then connected to the panel energizing the radio and GPS. To initialize the survey, the controller is then connected and set up of the survey base station is realized.

Weather conditions like strong winds sometimes knocked the GPS antenna down, so a set of counterweights positioned at the feet of the tripod where sometimes used.

Figure 23: Ad-hoc base station

Continuously Operating Reference Station (CORS)

A continuously operating reference station consists of:

- A Trimble NetRS receiver/web server
- Trimble Zephyr Geodetic antenna
- Antenna mount, lighting suppressor, low loss coaxial cable
- Uninterruptible power supply
- Internet connection

Three CORS were established; Huntington, South Charleston, Ravenswood, WV. Two CORS (Huntington and Ravenswood) through a cooperative agreement with the Ohio Department of Transportation, were incorporated into ODOT's Reference Network. A reference network, with appropriate software, creates a 'Virtual Reference Station' on automatically on demand from the survey controller when the accumulated ppm errors grow beyond a defined limit. A discussion of CORS and VRS's is in the attached appendix. Long baseline rail surveys (> 1 mile in length) were conducted on separate occasions using both a single CORS and ODOT's VRS.

The advantages of using a CORS over an ad hoc base station are:

- Simplified setup and use of GPS rover
- Simplified logistics and security of base station
- Longer base line surveys. Our longest baseline was the Huntington to Point Pleasant WV survey of approximately 50 miles.

During surveys outside of the coverage area of a CORS, a portable base station receiver and UHF data radio provided real time corrections to the roving receiver. Typical base lines in

Appalachian terrain were on the order of 5 kilometers. In the Rocky mountain foothills we were able to obtain a maximum 15 kilometer base line.

Figure 24: Base station

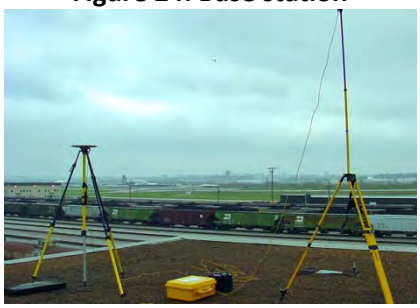
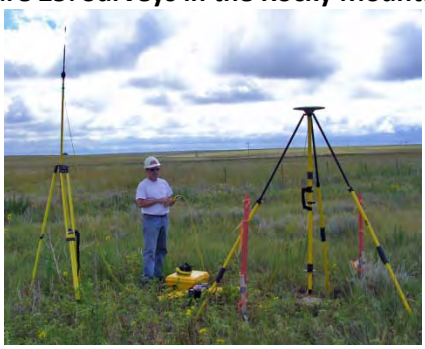


Figure 25: Surveys in the Rocky Mountains



Two out of three yard surveys demonstrated that the greatest yard coverage was obtained when the reference station was located on the roof of the yard control tower. During the Irondale yard survey, the base station was located at ground level close to the hump-end control tower. The roving GPS receiver on the locomotive frequently lost carrier phase lock at the far end of the yard.

The base station survey monument must be referenced to a coordinate system. The coordinate system most commonly chosen was Universal Transfers Mercator (UTM) projection, with the NAD83 as the elevation datum. Project units were generally collected in meters. Communications with railroad entities generally maintained the UTM projection, in US customary units. In the event existing spatial data referenced a State Plane projection, then that system was adopted during the project.

Due to the ease in establishing high quality reference marks with differential GPS survey equipment, the National Geodetic Survey (NGS) no longer establishes new survey marks, and is reducing maintenance of established monuments. Typical main line and yard surveys are devoid of established ground control monuments. Our procedure in establishing accurate ground control in locations too remote from a CORS is to first locate the ad hoc base station in a position that would provide the best coverage for transmitting corrections to the rover utilizing the UHF transmitter. Secondary considerations examine the stability of the position. This means that lighting or radio antenna towers, as well as certain manned yard towers were deemed unsuitable due to the instability inherent in structure. Masonry buildings were preferred for yard survey work due to their inherent stability.

During the course a typical yard survey, the ad hoc base station observations were collected at fifteen second intervals and recorded to a flash RAM in the base receiver. A two hour minimum observation interval is required by the NGS Online Positioning User Service (OPUS) program. As RTK surveys determine the vector between the base station and the roving receiver, base

station position modifications post-survey will be propagated to the surveyed points. The procedure used an autonomous position for the initial location of the base station, (accurate to within eight to thirty feet) and then post-processed the base station observations by uploading them to the NGS OPUS site[2]. OPUS uses the nearest three CORS locations to determine the base station position. The result is emailed to the user. OPUS positions obtained are generally accurate to under a centimeter. The OPUS calculated position is then entered as the near base station position using Trimble Geomatics Office software, and the entire data set is recalculated based on the new base position.

Base stations are almost always setup in locations where continuous electrical power is unavailable. By far, the greatest power consumption is the UHF radio transmitter. The Trimble Trimark III transmitter draws approximately 5 amp at 12 VDC with a duty cycle of 30%. Sufficient power to operate 12 hours a day in sub-zero temperatures was available from a single, low amp-hour deep cycle battery. The deep-cycle battery's ability to withstand repeated deep discharges (to less than 10 VDC) proved to be a trouble-free source of power, even during extended surveys.

Virtual Reference Station (VRS) Net

A virtual reference station network consists of:

- Four or more Trimble NetRS, NetR5, or 5700 GPS receivers
- Trimble Zephyr Geodetic or choke ring antennas
- Monuments, cables, interconnect wiring
- Internet connection
- Servers for collecting, processing, storage, and ionispheric modeling

The roving GPS receivers used when performing rail surveys consisted of Trimble 5700 and Geodetic antenna or Trimble R8 receiver with integrated antenna.

Trimble Survey Controller (TSC)

The Trimble Survey Controller software simplifies surveying by configuring and controlling receivers for GPS surveys, also allows to communication with conventional instruments. The software allows to store points, performs calculations and calibrations, configure the necessary parameters and monitor the status of the receiver and the radio. A filename is created every time a new survey is performed. The following parameters must be configured:

- File Name
- Coordinate system
- Measurement Units
- Linked and background files
- Feature code Library

[2] http://www.ngs.noaa.gov/OPUS/

A survey style (a definition of the equipment attached to the survey controller) is selected by choosing the desired configuration. Within the survey, different ways of collecting points are available. The survey controller also produces a log of all operations. Individual data can be reviewed at any time during the survey.

Feature codes are assigned to survey points in order to identify the points when post-processing or to generate line art from downstream software. Two survey controllers were used in setting up the ad hoc base and roving receivers.

- Trimble TSCe, early model, black and white display
- Trimble TSCe, later model, color display
- Trimble Bluetooth interface, for communicating with cellular phone configured as a modem, or Trimble R8 - Bluetooth enabled receiver

Data Collection

The Trimble Survey Controller (TSCe) was used for data collection. It uses the Windows CE operating system and is capable controlling and obtaining data from the GPS receivers. The controller acts to store survey points, perform surveying calculations and transfer data to a laptop computer for further processing. The controller is configurable to modify the GPS receiver's parameters (survey style, coordinate system, data radio receiver channel) as well as monitoring the status of the data collected.
The TSCe controller is capable of several different types of survey methods:

- RTK, real time Kinematic
- WAAS,
- RTK using the CORS station

In the field two different methods of data collection were employed:

1) Continuous Topographic Survey

The continuous topographic survey style is most commonly used in data measurements over long distances: long baseline surveys (anything over a mile in length) need an automatic collection method to provide a measurement over a fixed time or distance interval. The most effective way of conducting data was using a fixed distance.

During the Irondale Yards survey, a fixed distance of 3.3 feet (1 meter) was used. This resulted in collecting some 27,000 shots over a period of three days. NS engineers found that this volume of data was unacceptably high due to restrictions on computing power.

The Blue Island Yard survey (approximately two thirds the size of the Irondale yard) collected shots at ten foot stations. The collection rate resulted in a manageable 9,000 elevation shots.

2) Static Point Acquisition

Static points are used for features that require setting the GPS antenna over a particular spot for at least 5 seconds. The times spend collecting observation data can be varied depending on the degree of accuracy desired.

Certain points of interest were better suited to collection as a static point feature. Static point surveys are used to identify point of frog, point of switch, retarder position, rail joints, mile markers, grade crossings, marks stamped on the rail foot or other particular points. Monitoring track shifts was performed by comparing readings of a static point stamped on the foot of a rail at a designated section of a curve. Changes in the geographical position of the point indicate movement of the rail.

Trimble Geomatics Office

Trimble Geomatics Office (TGO) software is a field tool for downloading and viewing the data set. The TSCe is connected to the computer via a USB cable. The files stored on the TSCe are transferred using the Microsoft Activesync tool, decompressed, converted on the fly, and ready for processing in TGO.

A common first task uses TGO to correct the absolute position of an ad hoc base station coordinates. The TGO software performs an adjustment to all data points gathered during the survey that were dependant on the base station. This procedure insures data precision to a centimeter level of accuracy. The work flow for this process follows this procedure:

- Raw satellite observations are recorded at 15 second intervals to a Flash memory card in the base station. A minimum of two hours of observations are required by the NGS for processing.
- The Flash card is connected to a computer running TGO or the Trimble Data Transfer Utility[3]. The file to be transferred is right-clicked, presenting "convert to DAT" menu choice. This option converts the proprietary, highly compressed, observation file to a larger DAT formatted file.
- A DAT to Rinex conversion utility converts the observation file to a text file formatted in a standard data interchange format.
- The Rinex file is uploaded to the NGS Online Position User Service[4]. The resultant position calculation is delivered from NGS via email.
- The coordinates calculated by NGS OPUS are used as the base station location one the survey data has been imported to TGO.
- The data is organized by point type. The data can be separated into layers, grouped by name, renamed, or the feature codes can be processed to generate line work, such as centerlines.
-

After the initial data organization, TGO is capable of reformatting the data file so that it can be exported to a number of software packages in for display or analysis.

[3] http://www.trimble.com/datatransfer.shtml
[4] http://www.ngs.noaa.gov/OPUS/

ArcGIS

ArcGis is a set of software packages that enable the user to create a complete Geographical Information System (GIS). This software is used to create, import, edit, query, map, analyze, and publish geographic information. Within this package we have the following software applications.

ArcCatalog

When we want to make a deeper analysis of a particular area of the survey, we have to select, cut and zoom into that surveyed data. In some occasions this means that we will loose our coordinate system at the time of exporting as a shapefile. ArcCatalog is a tool that can assign all this information back to the shapefiles. Also it organizes Geographical data such as such as maps, globes, data sets, models, metadata, and services. This allows us to browse and find geographic information, record, view, and manage metadata, define, export, and import geodatabase schemas and designs.

ArcMap

ArcMap is the central application of ArcGIS? for all map-based tasks. Once the exported data has its corresponding coordinated system, additional information can be displayed by using ArcMap. ArcMap is capable of reading the data embedded within every surveyed point such as altitude, geographical position, accuracy, etc. This facilitates a graphical display of all this attributes.

When the data from a classification yard survey has been collected cleaned and analyzed we process it by assigning a color code to the different altitudes that each surveyed point has. This way there is graphical representation of the problem spots. Same thing can be done with track displacement, color coding the shifting distance and this way identify the critical parts.

Analytical Procedures

The GPS radio base station is the first thing that had to be planned, set up, configured, and started. An optimal location maximizes height above average terrain (HAAT) and minimizes obstructions to GPS satellites. Maximizing HAAT provides for continuous reception of differential GPS corrections over the entire yard. In the case of the IHB yard, optimal placement was found on top of the yard control tower. Wind conditions were severe, with gusts through the day to 30 mph. To counter the effects of the wind on tripod stability, tie plates were attach to tripod antennas legs to insure firm ground to prevent the wind from knocking over the base antenna.

The base station is started by plugging the TSCe to one of the 5700 ports and set the survey style to base station. The data radio output power is 25 watts in the 460 MHz band. Corrections broadcasted are to a Compact Flash card at a 15 second interval. The base station observations are converted to a *.dat file format using Trimble File Transfer software. Trimble Geomatics Office software is then used to convert the Trimble compressed *.dat format to a Receiver INdependant EXchange format.

RINEX data is emailed to the National Geodetic survey OPUS . The RINEX file compared will observations surrounding the survey location, and an accurate position report for the base station is email back to the user. This position is entered in the Trimble Geomatic Office project file as the corrected base station location, and the observed points from the survey are recomputed. The radio broadcast is checked by using a handheld radio tuned to the same frequency of the base station. The mobile GPS unit was set on top of the locomotive. A Zephyr Geodetic antenna is attached to the magnetic mount and then attached to the steel of the locomotive by means of the magnets. The Zephyr Geodetic antenna was selected due to the integral ground plane. The ground plane is thought to improve multipath reflections of the GPS signal.

The antenna had to be aligned to the center line of the rail in order to have a real representation of the condition of the track. Setting the locomotive on a long stretch and the use of a theodolite allowed for a centerline position.

The antenna height was determined by taking a measurement on the top of both rails with a 2 meter range pole. The elevation of the top of both rails was averaged to calculate a centerline elevation. The antenna was placed in the magnetic mount on top of the locomotive and recorded with no offset. The elevation difference between the top of rail and magnetic mount gives the height of antenna. This value is entered as the elevation offset in the survey controller. Subsequent elevation readings subtract this height to provide top of rail elevations.

The yardmaster authorizes the track sequence through the yard. The survey style selected was Real Time Kinematic (RTK) the measurement units where feet, and US State Plane as the coordinate system. Location and elevation was measured every ten feet. The survey started at the hump, with the locomotive progressing through the main retarder, to the group retarder. The engine was moved through the group retarder but stopped before the track switch. The line number was entered as the point name per the convention described below. The survey of the line began through the switch, with the survey controller automatically incrementing a point number to the point name.

Pullout end retarders were measured from the locomotive, with the engine stopping at the entrance and exit points of the retarder. With continuous topo mode active on the survey controller, the static point could be accessed simultaneously to measure the retarder position. The survey for the line was stopped at the end of the line. The locomotive was switched to the next line, and the survey continued in reverse of the previous description.

It was periodically necessary to use the locomotive to push or pull cars in the route of travel. This activity had no discernible effect on the quality of the survey.

The IHB survey was a result of 41 rail lines surveyed for elevation points creating a survey point every 3 meters (10 feet) with a total of some 9000 elevation shots recorded. Each point was given a feature code and a point name using the convention described below.

Point name, coded by type and yard reference (lead number, track number)

- Centerline Top-of-rail with feature code 'Centerline'
- Lead (eg: name prefix 1Lxxx, 2Lxxx, ..., 6Lxxx)
- Track (eg: prefix with 1/xxx, 2/xxx, ... 44/xxx)
- Point of switch feature code (POS)
- Point name POSxx
- Point of frog (POF)
- Point name POFxx
- Retarder
- Main and Group retarders, feature code (RET)
- Area of retarder outlined by surveying static corners
- Point name (eg: name, M = main, G = group + number
- Point = a thru d for corner
- Pullout end retarders, feature code (RET)
- length by two points
- Point name = track# + R + point 1 or 2
- Rectangular grid coordinates in Northing and Easting referencing the US State Plane coordinate system, Illinois East
- Elevations referenced to 1983 North American Datum.

Static points were measured on the ground for the point of frog, point of switch, main and group retarders with a Trimble R8 receiver, 2 meter range pole and survey controller.

A search for National Geodetic Survey (NGS) marks was conducted on the last day of the surveying job to reference our survey with a known point to use a known surveyed mark as reference for our data. Two survey marks were identified that were close to the site, however the marks were not recovered.

Data Storage and Dissemination

Architecture

This section provides a description of the system architecture for TEDIS including both the software and hardware for use in the storage and dissemination of ITSAMS data and results.

There were four primary goals for this system. First, design a flexible environment for delivering information to industry, public agencies, researchers, engineers, and administrators as appropriate. Second, once projects are put in production, defend against obsolescence and disruptions of service without incurring massive costs. Next, create an extensible system that can economically accommodate short term research projects, small single-purpose projects, but also longer term service oriented projects with a larger user base. Last, provide a development environment for testing and debugging applications on identical hardware and software configurations as used in the production environment.

Hardware

The Marshall University Computer Center at Drinko Library hosts the TEDIS network including all communications equipment, servers, on-line storage, and offline tape libraries. This gives TEDIS the advantages of a modern, environmentally controlled and secure data center at a fraction of the cost of constructing such a facility. It also lets TEDIS share staff with University Computing Services (UCS) which provides better system administration and maintenance coverage than RTI staff could achieve alone.

Software

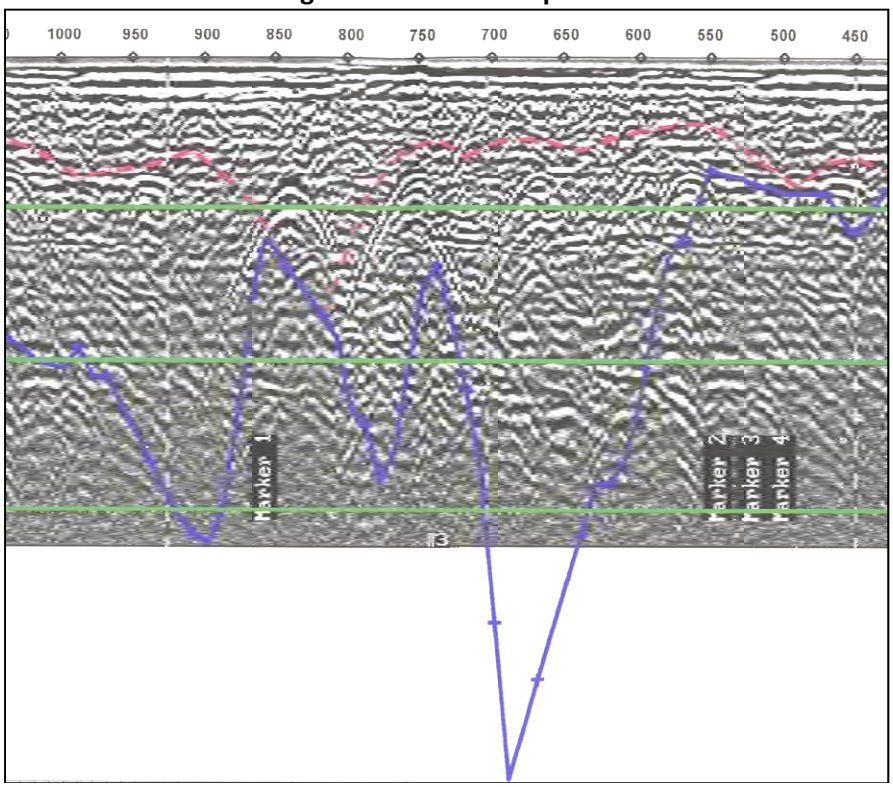
The primary focus of the software stack in this system is to provide the infrastructure to house GIS data and to deliver that data via a web based user interface. While there are other applications that will run within the system, those will likely use some or all of the GIS based software stack.

Results

GPR

The physical environment of performing a GPR survey over rail track (cross ties and steel rail) proved a challenge. On all GPR models, certain environmental conditions must be factored to ensure that minimal extraneous data is displayed. This would minimize misinterpretation, either by an operator or by pattern recognition software. On two occasions, unusual color bands and patterns appeared which could not be correlated with anything known to be under or near the track.

Figure 26: Results snapshot



Further evaluation by Geophysical Survey Systems, Inc., suggest that the bands were noise bands that had not been removed by the applied filters. The route was later surveyed by GECOH Inc. using a 250-megahertz antenna, and some anomalies fitting the known locations of pipes were found.

Figure 26 shows the results for the same section of the track (stations 450 to 1000 at MP 208 Huntington WV), overlaying the GPR results (grayscale) with the data obtained used seismic profiling (red and blue line).

Numerous trials and comparison of GPR data has been made with both the 100 MHz and 250 MHz antenna, and in the case of UNL, the 400 MHz antenna. These test have been made over both a test bed with known ballast, subballast, and subgrade characteristics (UNL) and over active rail track, in field conditions (MU and UNL). Early evaluation performed using the 100 MHz antenna by MU did not result in any visually discernable subsurface features, including known drainage culverts (location and depth), reaction block ties-backs, and an apparent slide failure plane.

Failure of the 100 MHz antenna to record significant results in this situation may be attributed to the inability of the 100 MHz antenna to delineate small (<24”) objects and the large amount of clay in the sub-soil, which makes penetration by radar difficult. Based upon this scenario, a 250 MHz antenna was evaluated. The results of these trials did result in discernable shallow subgrade anomalies. The significance and correlation of these anomalies with subgrade anomalies identified by other subgrade assessment technologies is apparent in some areas. Additional data analysis and correlation with other assessment technologies is still being performed. The most appropriate GPR system to achieve the objective of evaluating a number of differing subsurface strata along the rail track may be a system utilizing a range of antenna frequencies (100 MHz to 400 MHz).

Practical experience and application scenarios have resulted from RTI experience with GPR on the rail track environment. The precedent has been set where GPR has been used successfully to map sediment structures in rivers with GPR (Naegeli et al, 1996). GPR is also being used to monitor blacktop road conditions in some states (Naegeli et al, 1996).

The ground penetrating radar is most useful when it is properly setup for the task and for the physical operating environment. To date, few specific features or definitive observations have been realized. This revelation leads to the observation that a multi or variable range antenna system GPR is necessary for application on the track environment. This system would benefit from integration with other subsurface assessing technologies that would lead an operator or pattern recognition software to look for anomalies from a particular range of GPR data.

Development of the GPR technology with the integration of other geophysical survey technology and pattern recognition software will continue. Future work will be performed to

enhance the mobility and multi-frequency antenna capability of this system and to develop interpretive software to perform real time data evaluation and monitoring.

Terrain Conductivity

Using multiple geophysical instruments (Seismic and VLF), GECOH and RTI performed an initial geophysical survey of the Lexington, KY track siding. Two fracture zones were initially located in the bedrock. They are indicated on the seismic profile by the green dashed lines at stations 40 and 70 (Figure 27). The VLF data registered these two readings as anomalously low. From the resistivity profile (Figure 28) these fractures also register as low readings at stations 40 and 70, indicated by the blue coloration. This low resistivity also indicates that the fractures are most likely water bearing.

Figure 27: Seismic Reflection (blue and red lines) and VLF data (green lines)

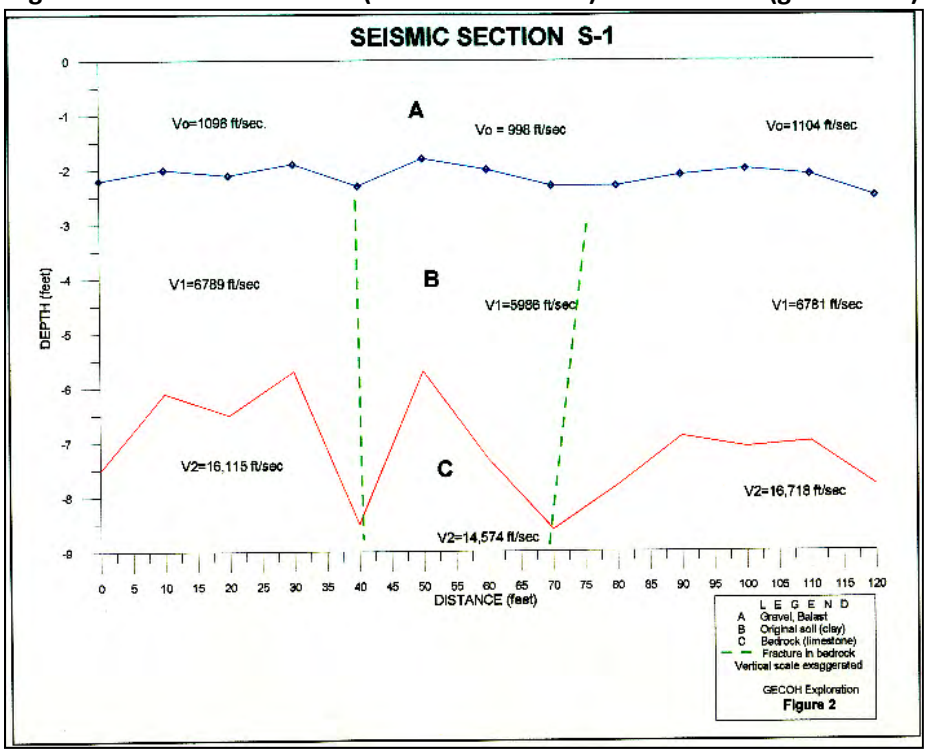
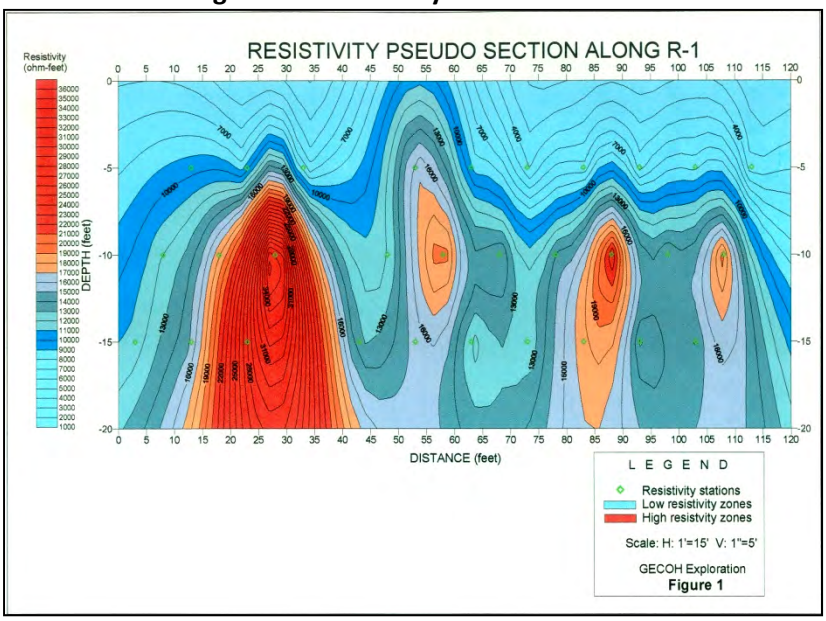


Figure 28: Resistivity Pseudo section



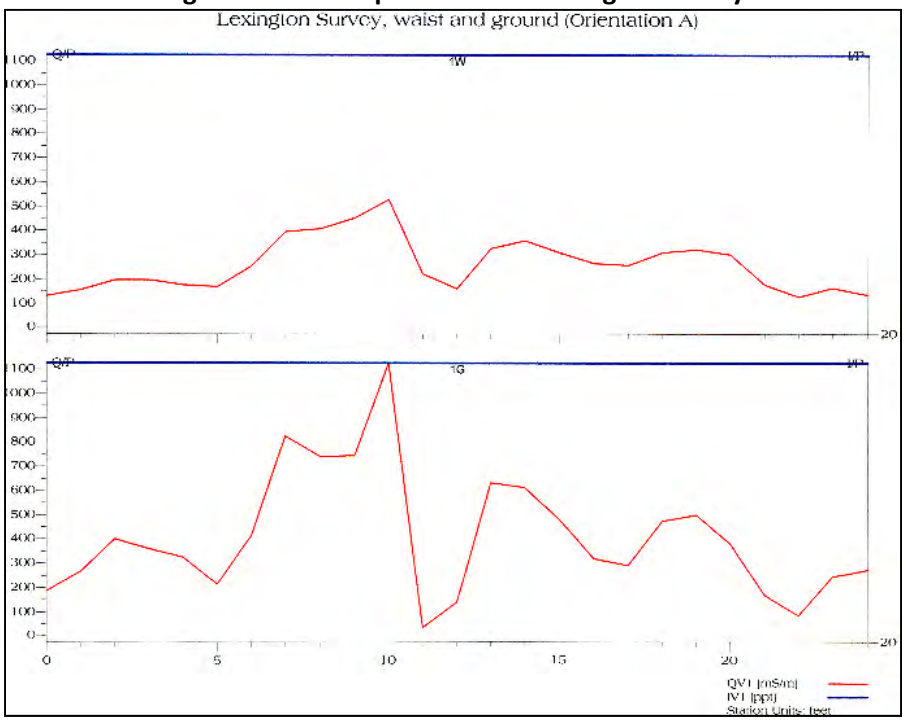
RTI tested the EM-31 to see if this instrument would be able to detect the anomalies already found by GECOH Exploration with the other geophysical methods. The data log, (Figure 48) shows measurements taken at both the ground and waist instrument heights.

The ground and waist surveys were near mirror images, but the conductivity values obtained from ground height were nearly double those of the waist height. The average conductivity for the ground height was 409.4 mS/m; at waist height it was 258.6 mS/m. Despite the differences in intensity, the spikes and drops in the readings occurred at identical stations. GECOH's data showed anomalies at 40 feet and 70 feet along the line, which would correspond to stations 8 and 14 on the data log (See Figure 29).

Since conductivity is the reciprocal of resistivity, areas of low resistivity should show high conductivity values (Keary and Brooks, 1984). From the data log there are two areas of extremely high conductivity. The first occurs over an area between stations 7 and 10, with station 10 having the highest conductivity value (1123.0 mS/m). The next region of high conductivity occurs at stations 13 and 14, with 13 being the higher of the two (631.0 mS/m). Thus, the EM-31 results concur with what was already found by GECOH exploration.

Although some difficulties were encountered due to the particular morphology of the railroad track, the EM-31 electromagnetic ground conductivity instrument has proven to be a valuable piece of equipment for the assessment of track stability. Its mobility allows the surveyor to collect data at high speed and on a continuous basis. The EM-31 data is being used as a reference for comparing the results obtained with other geophysical techniques.

Figure 29: EM-31 profiles from Lexington survey



EM-31 surveys are being conducted on a regular basis. These records have shown consistency with the data gathered using other instruments. Other than continuing to gain experience with the EM-31, future research will focus on investigating how the instrument can be implemented on the ITSAMS and how to control the sampling rate by a GPS generated signal.

DC Resistivity

By increasing the distance between the nails the survey depth can be varied. Wider electrode separation provides information about deeper layers. In figure 49 the results obtained for three different depths can be observed. An irregular increase of the apparent resistivity is detected within the 700-1100 ft. region.

The same results can be also represented using a plot format called pseudosection, that is obtained by assigning to each point a resistivity value and contouring the section, as shown in the figures 11 and 12. The 45º angle used to determine the points to represent is arbitrary. A pseudosection is not a true geological section, and some experience is needed for proper interpretation.

Figure 30: Resistivity data for the MP 208 site – three depths plot

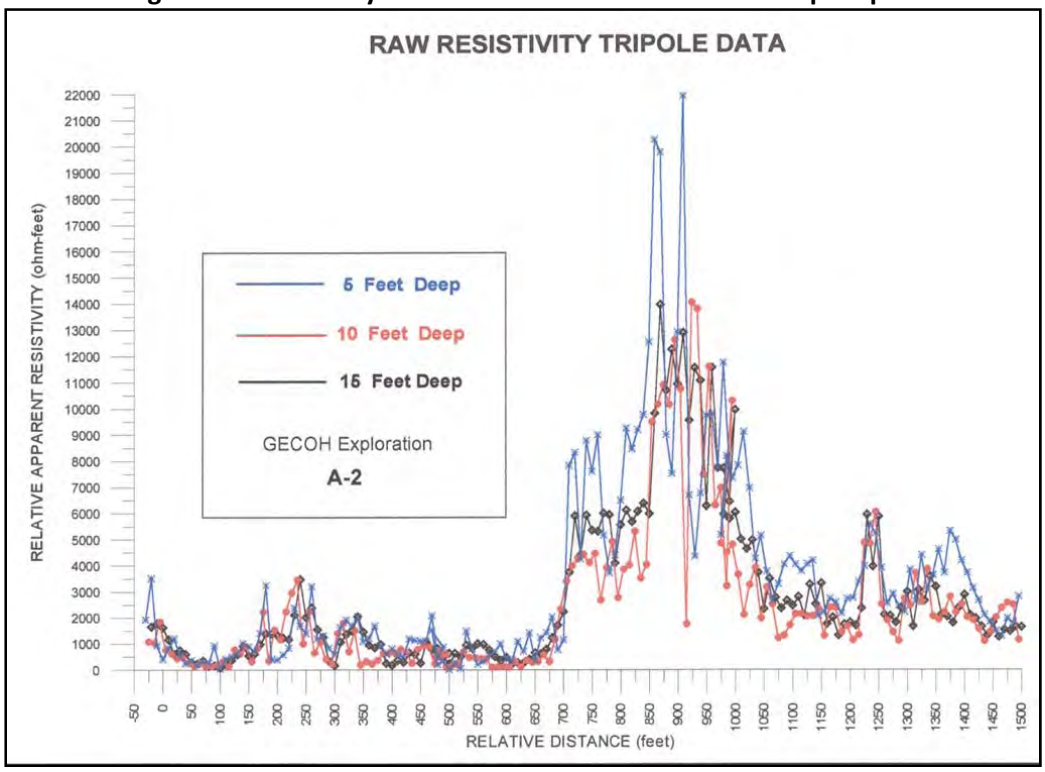
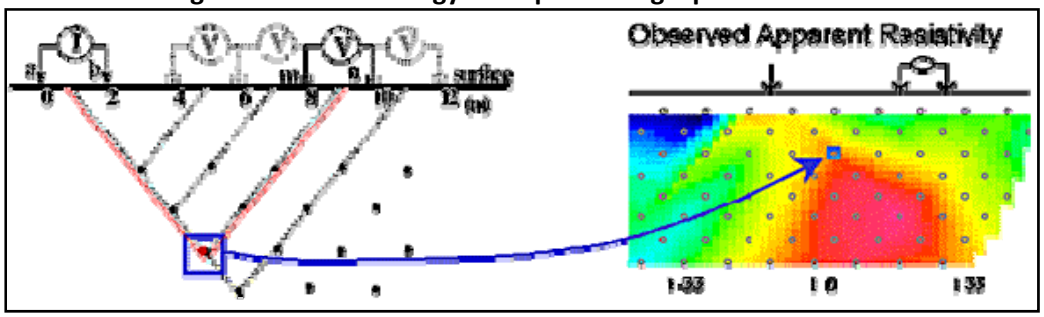


Figure 31: Methodology for representing a pseudo section

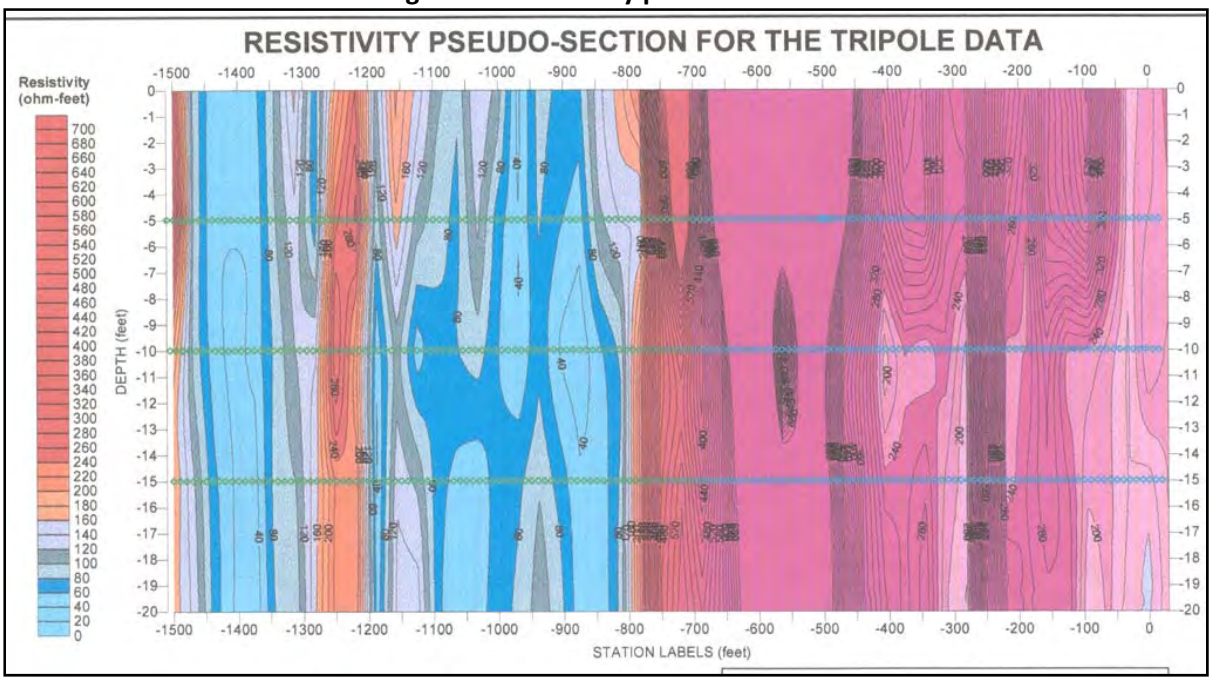


DC resistivity has proved to be effective in locating track sections with abnormal resistivity values. Future track surveys will be conducted in order to get a deeper understanding of the capabilities of this method applied to track assessment.

The possibility of using an innovative arrangement of transducers to conduct both seismic profiling and DC resistivity exploration using the same stations is being studied. Future work will focus on exploring different designs for integrating DC resistivity on ITSAMS.

From the raw resistivity data can be obtained the pseudo section exposed in Figure 32.

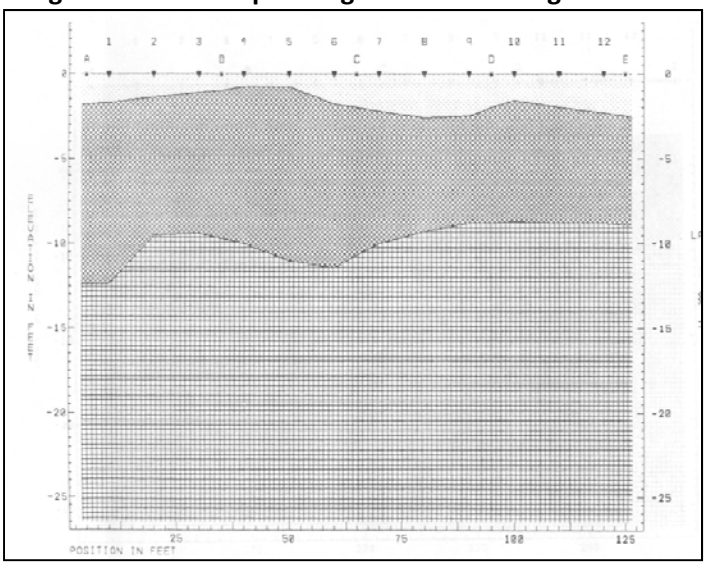
Figure 32: Resistivity pseudo section



Seismic Survey

Figure 33 is a representation of seismic recording data obtained from the seismic testing performed near MP 208.

Figure 33: Seismic profiling results for a single section



The first delineated boundary layer represents the change from ballast fill to the earthen subballast. This data may indicate an intrusion into the ballast near stations 50 and 1460. Likewise, a dip in the boundary layer between sections 800 and 850 may indicate an excessive ballast load at this section.

The second delineated boundary layer represents the general change from constructed earthen fill (subballast) to the underlying silty clay subgrade. Again, any excessive dip in this second boundary layer may indicate a chronic or potential area of failure. The seismic compressional velocities indicate change in soil density, corresponding to ballast, subballast, and the intrinsic sub-soil.

The profile obtained between stations 1 and 25 is shown in figure 52 above and can be observed in detail in Appendix F. The position of the twelve geophones used for data acquisition can be observed. The three layers can be clearly differentiated. As explained above, the change in the density and wave velocity between the ballast and the suballast, and between the suballast and the subgrade create two clear acoustic impedance changes. The attached legend displays the velocity of the wave through each material.
The results obtained using seismic surveying technologies in the first phase of the research are promising. Future work will be performed to evaluate the mobility requirements of this system and to develop interpretive software to perform real time data evaluation and monitoring.

Mobility is an important issue to be addressed. The seismic profiling surveying procedure utilized involves discrete measuring. A certain length of the area under study (equivalent to a set of 12 geophones, ~100ft.) is surveyed at a time. After obtaining the data from this particular section, the equipment must be moved to the next section of the area under study, which implies the relocation of the geophones and the rest of the equipment (personal computer, cords, hammer). This is a time-consuming practice, and a design for automating the data collection process will be addressed in the next research stage, with the final aim of implementing the system in ITSAMS.

Another subject to investigate is the importance of the position of the geophones in the track. The data collection process would be accelerated if the geophones were installed in the shoulder of the ballast, which would avoid synchronizing problems for placing the transducers in-between the ties.

VLF

The results obtained with VLF are consistent with the terrain conductivity values gathered with the EM-31 for the MP 208 survey in Huntington, WV. Both techniques detected areas presenting high conductivity close to the starting point of the survey area (stations from 250 to 500 ft), near a reported slippage area.

Further VLF research will focus in the short-run on surveying the rest of the track sites and comparing the results with those obtained using other geophysical techniques.

VLF has demonstrated to be an efficient and fast surveying technique when applied to track assessment. Future work will be performed to evaluate the mobility requirements of this system and to develop interpretive software to perform real time data evaluation and monitoring.

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Appendix A: Hardware Inventory

Part Number	Description	Quantity
Gigabit Switches		
WS-C3750G-24TS-S	Cisco Catalyst 3750 24 port Gigabit Switch	2
PC5224	Dell 5224 24 port Gigabit Switch	2
Fast Ethernet Switches		
	Dell 12 port Fast Ethernet Switch (unmanaged)	1
Content Switches		
CSS11501-2PK	Cisco CSS11501 Content Switch	2
S11K-500EN-7.3	WEBNS 7.3X Enhanced Feature Set Software	
S11K-SEC2-K9 CSS5-HDUFD S11K-LCC-7	WEBNS Secure Management License Hard Disk to Flash Disk Upgrade WEBNS License Claim Certificate	
Firewalls		
PIX-525-UR-GE-BUN	Cisco PIX 525 Firewall Chassis	1
	Unrestricted Software	
	2 x Gigabit Ethernet Ports 2 x Fast Ethernet Ports	
PIX-VPN-3DES	PIX 3DES Software License	
SF-PIX-6.3	PIX Version 6.3 Software	
PIX-VAC-PLUS	VPN Accelerator Card Plus	
PIX-VPN-CLNT-K9	VPN Client Software	
PIX-525-FO-GE-BUN	Cisco PIX 525 Firewall Chassis	1
	Fail-over Software	
	2 x Gigabit Ethernet Ports 2 x Fast Ethernet Ports	
SF-PIX-6.3	PIX Version 6.3 Software	
PIX-VAC-PLUS	VPN Accelerator Card Plus	
PIX-VPN-DES	PIX 506 License 56Bit DES IPSEC	
PIX-VPN-CLNT-K9	VPN Client Software	
Servers		
PE650	Dell PE650 Server	1
	3.06GHz CPU	
	1GB RAM	
	40GB HDD, CD drive	
PE1750	Dell PE 1750 Server	2
	Dual 3.06GHz	
	12GB RAM	
	2x73GB HSS, ROMB RAID 1 CD drive	
Part Number	**Description**	**Quantity**

PE2650	Dell PE 2650 Server	6
	Dual 3.2GHz/533FSB/1GB Cache 12GB RAM	
	2x36GB 15K HDD, RAID1, PERC4/DC CD-RW/DVD drive Intel Dual Port 1000T NIC	
PE2650	Dell PE 2650 Server	2
	Dual 3.2GHz/533FSB/1GB Cache 6GB RAM	
	2x36GB 15K HDD, RAID1, PERC4/DC CD-RW/DVD drive Intel Dual Port 1000T NIC	
	Dell Firewire controllers	2
	(used for data loading from external drives)	
Storage Area Networks		
CX-700	Dell / EMC CX-700 SAN	1
	Storage Processor	
	Standby Power supply	
	SATA Drive Cabinet	1
	250 GB, 10K RPM SATA Drives	15
	Fiber Channel Drive Cabinet	4
	146 GB, 15K RPM FC Drives	60
	Navisphere Software	
	Snapview Software	
	16 port Fiber Channel Switch	2
	with 16 Optical GBICs	
CX-200	Dell / EMC CX-200 SAN Storage Processor Standby Power supply	1
	Fiber Channel Drive Cabinet	1
	146 GB, 15K RPM FC Drives	10
	8 port Fiber Channel Switch	1
	with 8 Optical GBICs	
PV136T	Dell PV136T LTO-2 Tape Library	1
	2 x LTO-2 Tape Drives	
	72 Tape Slots	
Miscellaneous Equipment		
4210	Dell 4210 Rack	3
	APC-3000 UPS	2
	Dell Digital KVM, 16 port	1
	with cabling	
	Dell LCD Console	1

Appendix B: Software Inventory

Part Number	Description	Quantity
Operating Systems		
	VMWare GSX Server (Windows Host)	1
	VMWare Virtual Infrastructure Node	8
	VMWare ESX Server	
	VMWare VMotion	
	Microsoft Windows 2000 Server	1
	Microsoft Windows 2003 Server, Standard Edition	20
	Microsoft Windows 2003 Server, Enterprise Edition	2
	Fedora Core Linux	-
Relational Database		
	Microsoft SQL Server 2000	2
	Oracle 10g	2
	PostgreSQL 8.1	-
GIS Application Server		
	ArcSDE for SQL Server	1
	ArcGIS Server	
	ArcEditor	
Backup and Recovery		
	CommVault Galaxy Backup	1
	Tape drive option	
	Direct to disk option LAN attached Windows Servers	
	LAN attached Linux Servers	
	SAN nodes	
	Application agents (SQL Server) Application agents (Oracle)	
Other Software		
	VMWare Virtual Center	2
	(virtual infrastructure management software)	
	Microsoft Internet Information Server	-
	Microsoft Exchange Server	1
	Apache Web Server	-
	Drupal Content Management System	-

Appendix C: Application of Geophysical Methods to Evaluate Rail-Track Subsurface

Tony B. Szwilski, College of Information Technology and Engineering, Marshall University
Richard Begley, Nick J. Rahall Transportation Institute
John Ball, Nick J. Rahall Transportation Institute
Peter Dailey, Nick J. Rahall Transportation Institute

Abstract
Geophysical tests are being conducted on sections of active main line rail-track adjacent to major rivers, in areas of considerable ground movement. Various methods used include ground penetrating radar (GPR), very low frequency (VLF), resistivity (TRP), seismic, terrain conductivity (TC) and gravity. This work is part of a project to develop a mobile rail track sensing and monitoring system (1). The goal is to provide real-time assessment of track sub-surface, and surface conditions significant in maintaining a stable, safe and productive track (2)

Introduction
Initial geophysical assessments were conducted on several sections of main line track, each 1,200 feet in length, on the banks of the Ohio River and Kanawha River in West Virginia, results of two sections will be discussed in this paper. The rail track sites experience significant slope/ground movement toward the rivers which has resulted in considerable track maintenance and ballast replacement over the years. These sites, and others, are part of long-term study areas to understand the geological anomalies and ground movement mechanisms and their influence on railway stability. A baseline 'geophysical footprint' for each test sections was established using seismic, resistivity, very low frequency and gravity methods. Later, data from GPR and terrain conductivity was taken and compared to this baseline data. Notably, GPR technology has been used by numerous investigators to evaluate railway subsurface conditions (3, 4, 5, 6)

The degree of vertical deflection of a loaded rail is a good indicator of track stability, life and quality. Rail deflection depends on the track stiffness or modulus which is dictated by key track structural components: rail, fastenings, ties, ballast, sub-ballast and sub-grade. Track modulus is defined as the force to depress the rail one inch for each inch of track length along which the load is applied. Modulus values typically range from 2,000 lb/in to 8,000 lb/in. Ideally track substructure should permit drainage, anchor the track superstructure, distribute and transfer loads to the underlying roadbed, and facilitate track alignment. The track ballast and sub-grade interface is also a key stability and design factor. Excessive track deflection leads to ballast deterioration due to inter-particle abrasion, formation of water and ballast pockets, muddy-pumping track, and permanent deformation or settlement. Ballast deterioration and settlement is directly related to haul tonnage rate (tons per year), average train velocity, axle load, rail track structure and type of sub-grade. Stable track requires clean, compacted and well-graded ballast, firm and well-drained sub-grade, as well as good ties. Replacing the millions of tons of degraded ballast every year to maintain the rail track safe and productive is a

high maintenance cost. Numerous techniques have been tried to reduce maintenance costs such as applying recycled ballast with a composite layer to extend the track life.

Track Sites Investigated

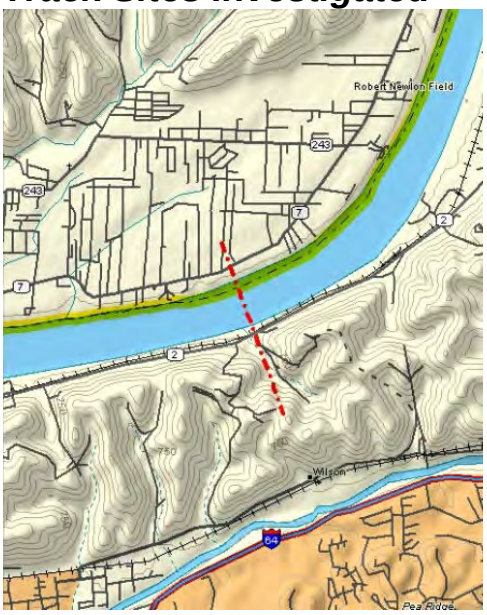

Figure 1: Main line track at site 208

Six rail track sites evaluated are located adjacent to two major rivers in West Virginia: four at the Kanawha River and two sites at the Ohio River, the results of the latter are presented. Each site has a history of considerable track structure, sub-surface and ground movement. The initial phase of the project is to assess the track structure and sub-surface at each site, define and delineate the track sub-structure to the bedrock: ballast, sub-ballast, sub-grade and natural sub-soil. Figure 1 shows the rail track at Site 208 alongside the Ohio River and cross-section across the river, near Huntington in West Virginia.

The sites are located in western West Virginia. The Appalachian Plateau covers the western two-thirds of the state and is mostly Pennsylvanian with some Permian rocks. The whole region is overlain by Quaternary Alluvium.

The Appalachian Plateau is a high plain about 1,100 to 1,200 feet above sea level. Erosion has predominated, leading to sharp v-shaped stream valleys. The Jackson-Mason-Putnam area is located in the Appalachian basin. All sites are on colluvium overlying bedrock of alternating sandstone and shale. Ground truth-values have been taken from borehole data at the six sites, provided by the rail road companies. Most of the cores were drilled, over ten years ago, at the sides and a few at the centerline of the rail track. The borehole data for sites 201 and 208 indicate that the thickness of the ballast/sub-ballast varied from about 5 to 18 feet; depth to bedrock from 30 to 50 feet.

Rail Track Maintenance History

Figure 2: Topography of site 208

The rail track structure sections under investigation consist of steel rails and wood ties supported by mostly limestone ballast. Over a few decades records indicate that considerable general slope and rail track movement has occurred alongside the rivers, resulting in occasional train derailments. Therefore, extensive track maintenance and repair has been carried out involving rebuilding the ballast to previous track levels, often adding considerable fly ash to the river bank and track. At Site 208, tie-backs (bolts), concrete retaining walls and driven steel (rail) piling were used to reinforce the ground beneath the rail track.

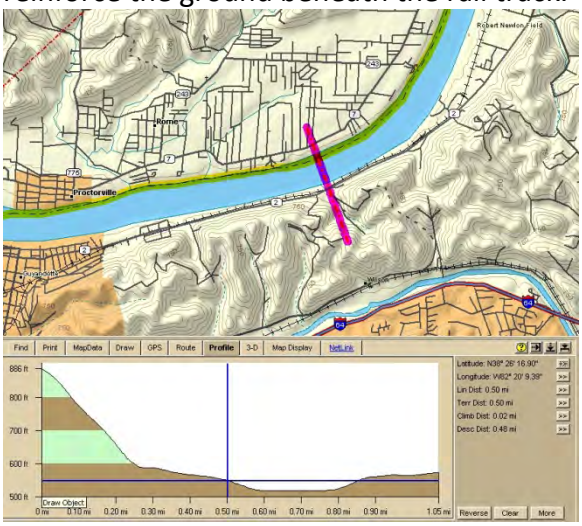

Figure 3: Topographical features of site 208

Therefore, each site evaluated has specific conditions of ballast thickness, sub-surface constituents and depth to bedrock and varied along the test section length of site 208. The zone of the greatest ground movement has occurred from the 450 feet to 960 feet mark (Figure 6) on the site 208.

Results from Rail Track Sites

A baseline "geophysical foot print" was established for each site using gravity, seismic and resistivity methods. Gravity data was obtained to evaluate the proximity of the bedrock and investigate the change of ground mass density due to ground failure and movement. The geophysical tests will be repeated at each site every few months to determine the nature of ground movement and impact on track structure and sub-structure. Figure 3 shows a cross-section the Site 208 and valley.

Seismic Evaluation

For the seismic investigation, twelve geophones were used, each spaced ten feet apart.

Location	Ohio River		**Kanawha River**			
Site	**201**	**208**	**Poca**	**Leo**	**Red**	**Arb**
Layer 1 (Ballast)	2,000	2,300	1,800	1,800	1,800	1,800
Layer 2 (Sub –Ball)	9,600	11,400	10,300	8,900	10,000	8,500
Layer 3 (Sub-grade)	12,800	13,700	14,100	12,500	13,200	12,300

Table 1: Average Values of Seismic Velocity (ft/sec)

Five seismic sources were activated for every set-up. To cover the 1,200 feet track section nine layouts were used resulting in data collected from 540 (12x5x9) seismic traces. Each of the traces was analyzed manually to identify the first signal arrivals. The seismic model was

developed using proprietary contractor software and the resultant inverted model output graphed using Grapher software.

The results of the seismic tests for Sites 201 and 208 are shown in Figure 4, 5 and 6. In Figure 4(a) three seismic layers have been delineated and correlated with borehole (ground truth) data for Site 201. Although the rail track sub-surface layers have been categorized as ballast, sub-ballast and sub-grade and implicitly homogeneous, the layers (stratum) have often mixed constituents of limestone fragments (old ballast), fly-ash/cinders and natural soil/clay and are very difficult to distinguish. The three layers 1, 2, 3 at the two sites defined as follows: Layer 1 consists of loose railway ballast, mostly limestone; Layer 2 comprises the transition from ballast to mixture of ballast, ash fill and some clay; and Layer 3 is comprised of stiffer ash/clay transitioning to natural clay.

GPR Evaluation and Terrain Conductivity (Geonics EM-31)

The GPR data collected is shown in Figures 5 and 6 with a 250 MHz (Noggin) receiver. The WIN-EKKO-Pro software that accompanies the Noggin GPR was used to produce the GPR image section using the autogain and 'dewow' time filter processes, then corrected for normal move out, migrated and stacked. A band pass was used to eliminate spurious data. An algorithm and software is in development that identifies the appropriate filters to enhance the image and highlight target features. By inspection specific radar image features were highlighted and a low-pass running average filter plotted the green line, shown in Figure 5: This line approximately delineates the partition between the ballast and fill/natural clay. Earlier trials conducted using a 100 MHz antenna did not yield useful data in the clay dominated sub-grade/sub-soil and the resolution is too low to define the smaller features of the ballast/sub-ballast interface.

The EM-31 Soil Conductivity sensor has proven to be very useful for the project. Initially there were concerns regarding using the EM-31 instrument over the steel rail tracks and potential interference of the rail on the readings. To prove its viability several trials were conducted with the EM-31 to measure terrain conductivity for various rail track conditions: rails and wood ties; wood ties without the rail and the same ground with both the rails and wood ties removed. Using the instrument antennas in the center and parallel to the track, in the vertical dipole mode, consistent and accurate readings of terrain conductivity can be obtained. The conductivity values are an average of the ground 20 ft below the level of the instrument. As soil moisture influences the electrical properties of the track subsurface terrain conductivity (EM-31) were made with each series of tests. Figure 4(b) shows raw data from the EM-31 low-pass filtered and plotted for Site 201; and Figure 6(b) for Site 208. The peak conductivity values appear to coincide with the thicker ballast/ash fill upper layer. The figures also show the relationship between conductivity and resistivity, and VLF.

Gravity Measurements

The gravity measurements taken for each of the six sites were not corrected for elevation change as the sections were level. Generally, the data collected was filtered using a low-pass filter to eliminate part of the noise that is contributed by the very shallow layer (between the surface and two feet deep). The filtered data was then used to obtain a best fit

simple model. Low gravity reading could be interpreted as topographic lows, fault zones with low density contrast (mass deficiency). The gravity profile has been superimposed on the GPR cross-section in Figure 5, together with the seismic layer profiles. The higher values of gravity likely coincide with the closeness of the bedrock and least thickness of ballast. Gravity profile changes will be monitored and related to observable sub-surface ground movement.

VLF Measurements

An ABEM WADI VLF instrument was used to take measurements over the six sites. The instrument used a low frequency radio station centered at 23.7 kHz, and read one point every 10 feet, from 0 to 1,200 feet for each section. The instrument directly records the ratio of the vertical and horizontal electro-magnetic (EM) field, both real and imaginary components, in percentage terms. A Hjelt filter was used to process both the real and imaginary components, and then plotted. The VLF data is very sensitive to fractures and underground water. Seismic and VLF data show some correlation in active zones (ground movement). Large amplitudes of both the Hjelt filtered real and imaginary components often correspond to ground fractures or displacements with high moisture content, and may indicate a potential hazardous active zone. The ground fractures and displacements may also be represented by topographic lows in the site cross-sections.

Resistivity Measurements

The Tripole (TRP) survey was performed using electrode separation of 10 feet, which is consistent with the other geophysical methods in the project. The TRP is a resistivity method that samples simultaneously three target depths (5, 10 and 15 feet). The method involves a four electrode basic configuration in which the current and potential electrodes interchanged by an external control switch. The raw data was passed through a low-pass filter to eliminate the high wave component of the resistivity signal.

Discussion of Results

Track and roads located adjacent to rivers often experience significant ground movement primarily due to the change level of the rivers inducing corresponding changes in the water table in the river banks and the clayey soils. All six sites studied have a history of ground movement resulting in settlement of the track corresponding to sub-surface vertical and lateral displacement toward the river. As the bore data was produced over ten years ago numerous episodes of maintenance work has been conducted on the track. However, when the borehole data is taken into account together with the seismic, gravity, VLF and resistivity data a good representation of the track subsurface components and properties can be made.

Over the years the mainline track has been well maintained by depositing new ballast to achieve the desired elevation and reinforcing the track subsurface when necessary. The resulting sub-surface migration of the ballast can be observed depicted in the GPR images taken at sites 201 and 208. In the images shown, the processed 250 MHz GPR data has mapped the approximate surface of the predominantly clay sub-grade. The most significant ground movement at Site 208 has occurred between the relative distances 480 to 920 feet, shown in

Figure 6(a). Further research will being conducted with other GPR antennas to identify track surface and sub-surface features or signatures associated with track integrity and instability. Pattern recognition algorithms and software are being developed to process GPR, and other sensor data, and identify these features in real-time. Later these programs will be tested for various track conditions.

Conclusions

A better understanding of the nature and behavior of the considerable track subsurface ground movement adjacent to major rivers has been achieved from geophysical data: GPR, seismic, gravity, resistivity, VLF and terrain conductivity. There is significant value in sensing and monitoring track to evaluate and understand the nature and role of ballast and other key structural components. Integrating the results from various geophysical methods has proven to be an effective means of track subsurface sensing and monitoring. Research will continue at track sites experiencing considerable ground movement. Patterns or 'signatures' will be established both for sub-surface anomalies and rail flaws to be identified by pattern recognition software.

Acknowledgements

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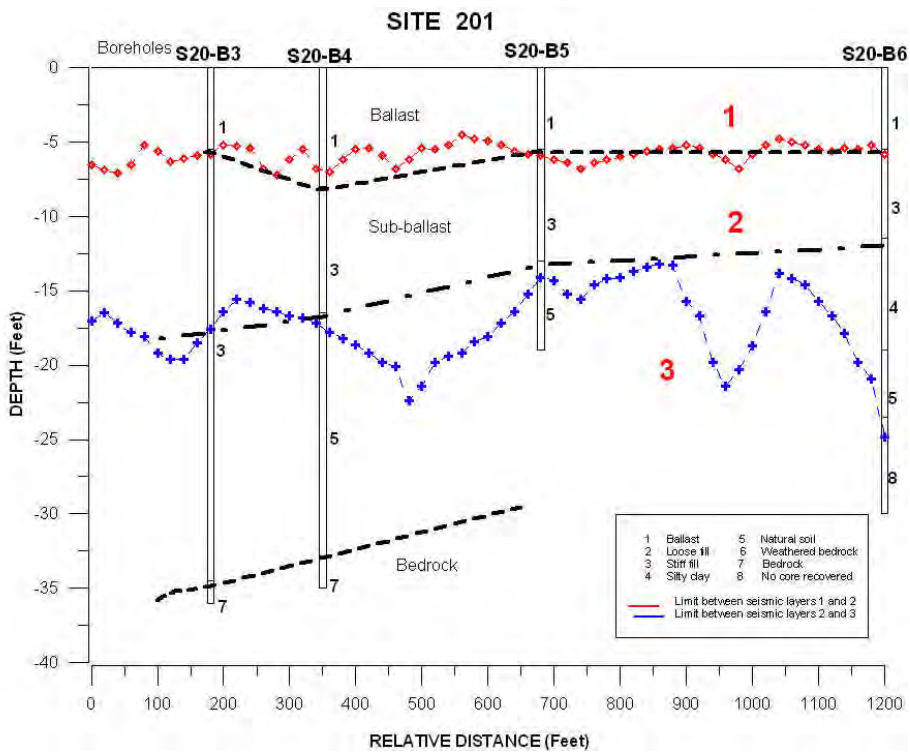


Figure 4 (a): Seismic results and borehole data delineating the ballast, sub-ballast, sub-sub-grade and bedrock at Site 201

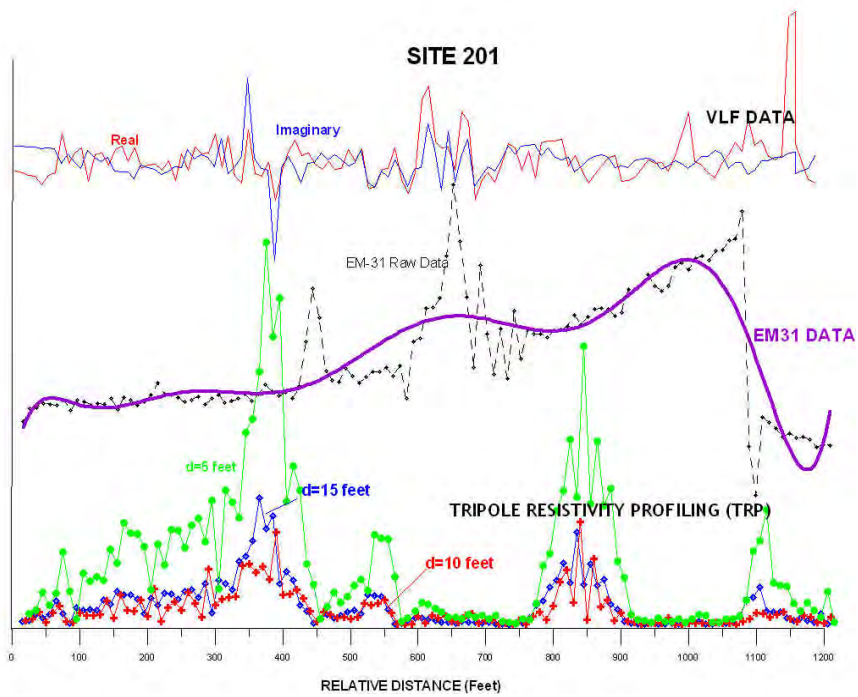
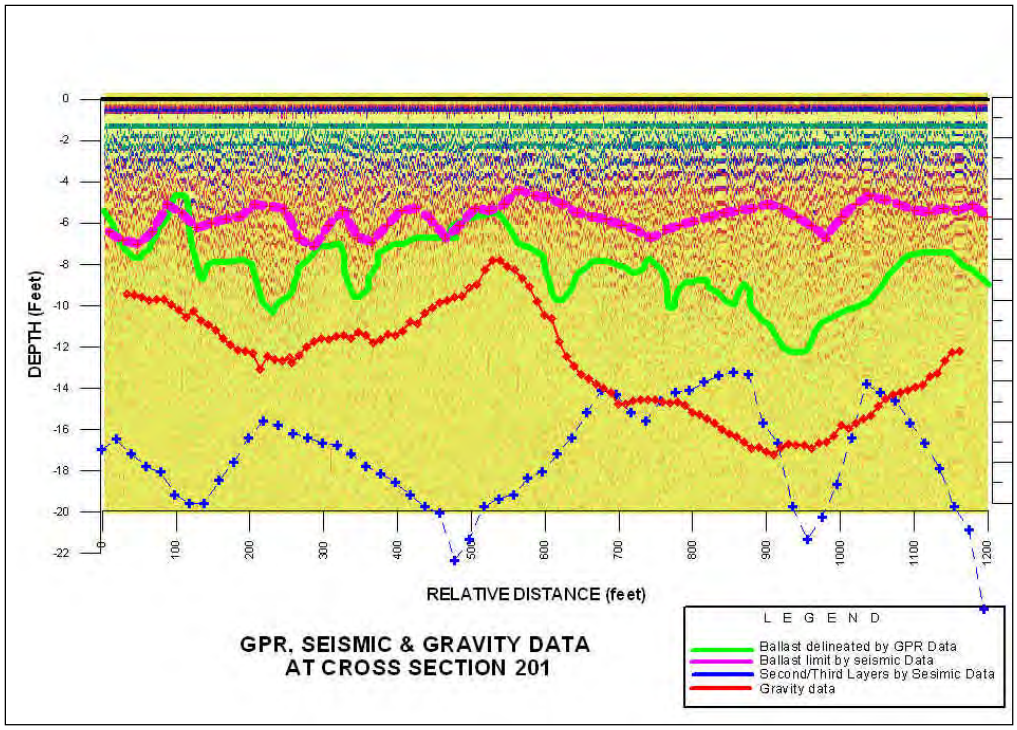


Figure 4(b): VLF, Terrain Conductivity and Resistivity (TRB) data for Site 201.



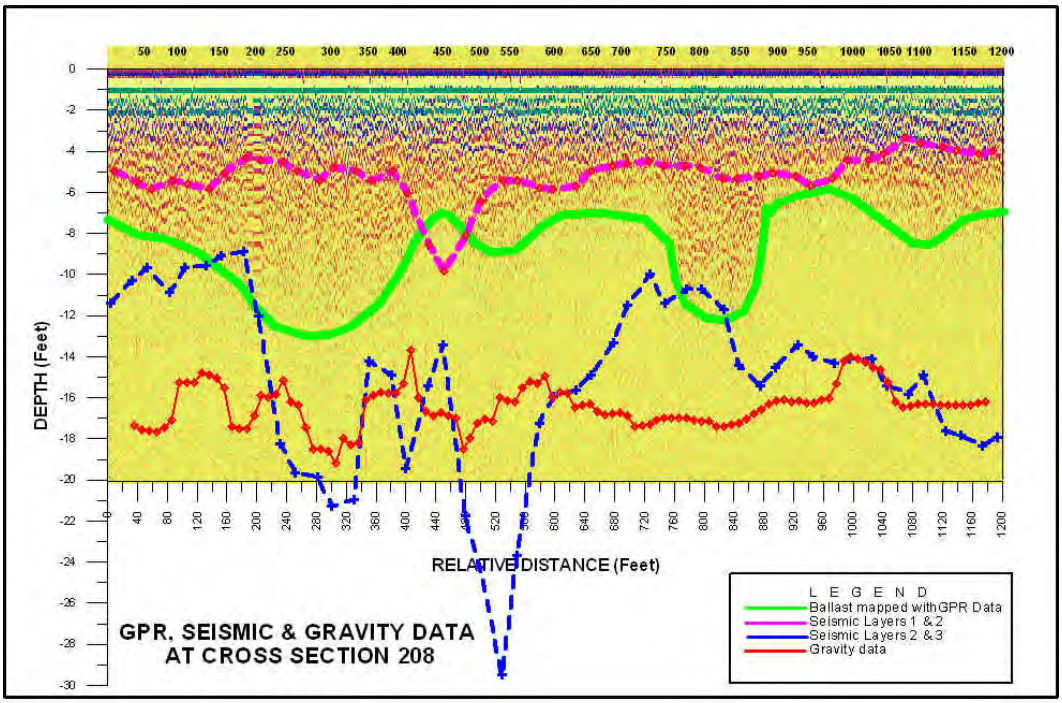


Figure 5: GPR (250 MHz) results for Sites 201 and 208 on the Ohio River, with Seismic and Gravity data superimposed. The green line delineates approximately track ballast and the clayey subgrade.

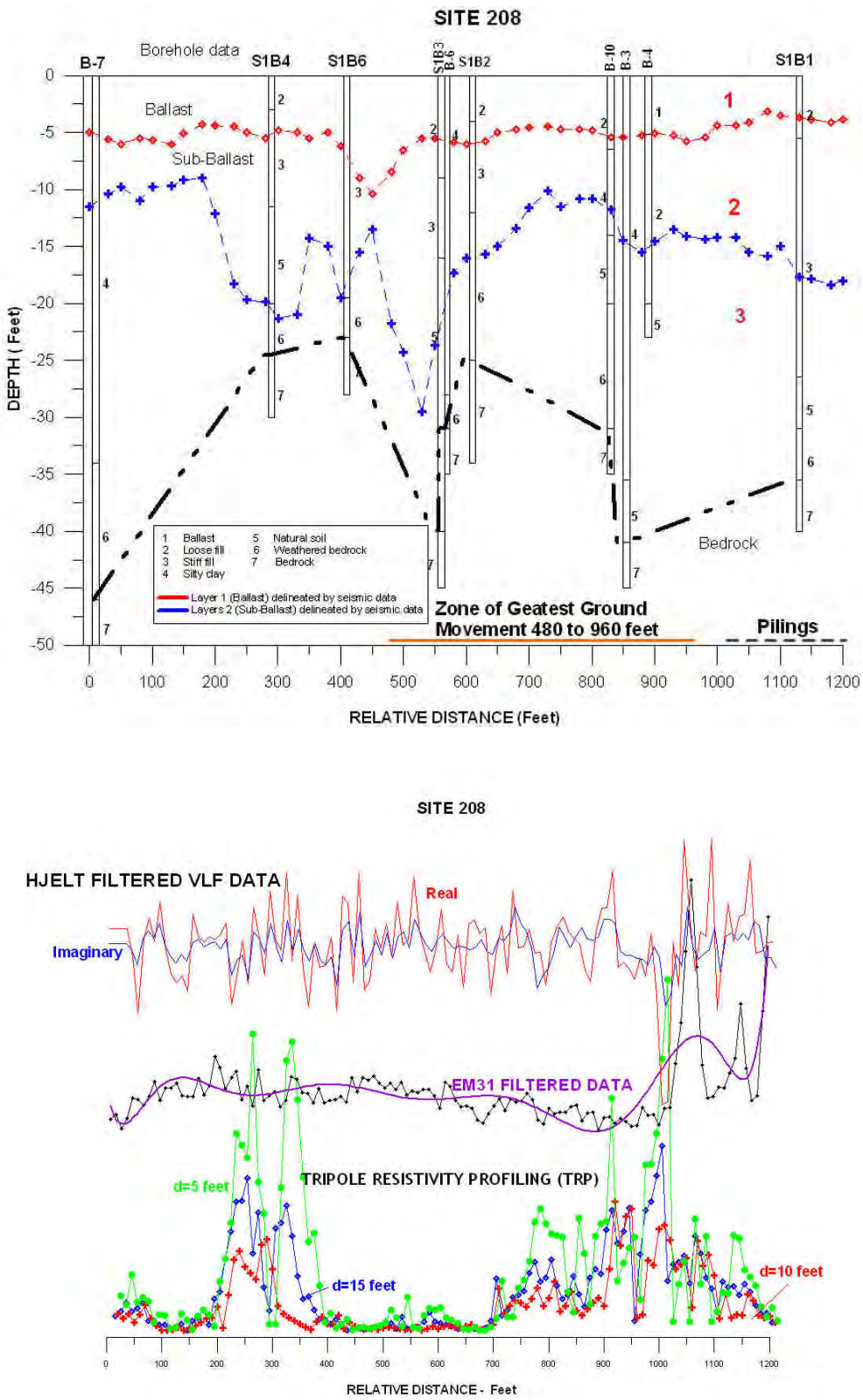


Figure 6: (a) Borehole and Seismic data and (b) GPR (250 MHz), Seismic and Gravity data for site 208 (Ohio River).

Appendix D: Multi-Sensor Mobile System to Monitor Track Superstructure and Substructure: Initial Studies with Non-Invasive Technologies

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ABSTRACT

A project to configure multiple sensors on a mobile platform to monitor track superstructure and substructure anomalies in real-time has been undertaken. Ground Penetrating Radar (GPR) and terrain conductivity sensors provide subsurface images and moisture content values. Data from seismic, gravity and resistivity geophysical surveys are compared to GPR and terrain conductivity data for six rail sites, on embankments of two major rivers. High Accuracy Global positioning system (HADGPS) provides data to determine track position for maintenance realignment and displacement vectors. This is part of a long-term study of ground and track movement using non-invasive technologies.

INTRODUCTION

The application of non-invasive technologies to monitor track sub-surface conditions have been reported by numerous investigators (1-3). For this initial project phase, data from GPR, and terrain conductivity sensors are compared with seismic, gravity and resistivity data from surveys of six rail sites on the embankments of two major rivers. The sites have a history of ground and track movement. The objective of the project is to configure multi-sensors on a mobile platform to monitor track and produce meaningful track quality data in real-time. Figure 1(a) shows the concept of the multi-sensor mobile system. Figure 1(b) gives an example of how GPR, terrain conductivity and geographic can be presented in real-time while monitoring track. The HADGPS is configured with other sensors to provide track position data for maintenance realignment and calculating track displacement vectors (4). The track geometry data collected, using HADGPS, has focused on horizontal and vertical position data (5). Track location and displacement trajectory data will be stored in a GIS database (Figure 1(a)).

The inability of technology or sensors to monitor and accurately map track superstructure and substructure has resulted in a lack of knowledge of track structure behavior and problems. Thus there is a growing need for a mobile multi-sensor platform that can survey track and collect accurate geometry, surface and subsurface condition data (6, 7). Providing decision-makers with timely, rich information increases the likelihood that the appropriate track geometry maintenance such as lifting, tamping and lining will be conducted, avoiding costly corrective maintenance (8). Good track maintenance management and optimal utilization of railroad resources is required to achieve the desired performance level (9). The track substructure should permit drainage, anchor the track superstructure, distribute and transfer loads to the underlying roadbed, and facilitate track alignment. Excessive track deflection can lead to ballast deterioration due to inter-particle

abrasion, formation of water and ballast pockets, mud-pumping and permanent deformation or settlement. Therefore, stable track requires clean, compacted and well-graded ballast, firm and well-drained sub-grade, as well as good ties. As millions of tons of degraded ballast is replaced every year at a substantial cost, good (timely) information regarding the state of the track would help minimize costs.

SITES INVESTIGATED

Six rail sites on the embankments of two rivers in West Virginia: four beside the Kanawha River and two sites on the Ohio River were selected for study. Each site was 1,200 feet in length with a history of significant track and ground movement. The Appalachian Plateau is a high plain about 1100 to1200 feet above sea level and covers the western two-thirds of the state and is mostly Pennsylvanian with some Permian rocks. The region is overlain by Quaternary Alluvium and the six sites are on colluviums overlying bedrock of alternating sandstone and shale.

Borehole data at the six sites, provided by the rail road companies providing some ground-truth values. Most of the cores were drilled at the sides of the track and a few at the center of the rail track. The borehole data for sites 1 and 2 (Figure 2) indicate that the thickness of the ballast/sub-ballast varied from about 5 to 18 feet; depth to bedrock from 30 to 50 feet. Track subsidence over the years has resulted in a build-up of ballast in the substructure. The use of steel furnace slag from the nearby steel mills was very common in the 1940s and 1950s. The influence of the iron content in the slag, if any, on electromagnetic instruments, such as the GPR and EM-31, has yet to be determined.

GEOPHYSICAL SURVEY OF SITES

As the first step in a long-term study, a baseline “geophysical foot print” was established for each site using gravity, seismic and resistivity methods (5). Gravity data was obtained to determine the depth of the bedrock and monitor ground mass density change due to ground failure and movement. As the seismic method is very similar in principle to GPR the sub-surface features identified by each method can be compared. The seismic, gravity and resistivity surveys were conducted by a contractor (Gecoh Inc).

For the seismic survey twelve geophones were spaced ten feet apart. Five seismic sources were activated for every set-up. To cover each 1,200 feet track section nine layouts were used collecting from 540 (12x5x9) seismic traces. Each trace was analyzed manually to identify the first signal arrivals. The seismic model was developed using proprietary contractor software and the resultant inverted model graphed using Grapher software.

A gravimeter (Graviton-EG) was used to record the gravity field and measure density variations in the sub-surface. A low-pass filter was applied to eliminate part of the noise emanating from the shallow layer. A low gravity reading can be interpreted as topographic lows, fault zones with low density contrast (mass deficiency). Higher gravity may indicate the shallowness of the bedrock. The gravity measurements were not corrected for elevation change as the sections were assumed to be level.

The Tripole Resisitivity Profiling (TRP) survey involved inserting four electrodes in the ballast spaced 10 feet apart and taking measurements simultaneously at three target depths of 5, 10 and 15 feet. Four electrodes were configured so that the current and potential electrodes interchanged by an external control switch. The raw data were passed through a low-pass filter.

GROUND PENETRATING RADAR

Ground Penetrating Radar has been widely used to monitor track (10-12). Sussmann used GPR to investigate track performance related to embankment problems (13). A few investigators have reported success in utilizing GPR to monitor the track substructure in real-time on routine track inspection (14). However, three decades after the initial use for underground mine detection and tunnels (15) the speed of data interpretation, GPR hardware and software reliability is still limited.

Initial trials using the GPR 100 MHz antenna did not yield useful data as the clay dominated sub-grade/sub-soil attenuated the electro-magnetic (EM) energy quite readily and the resolution is too low to define the smaller features of the ballast/sub-ballast interface. A 250 MHz (Noggin) GPR receiver was used to collect data over the six sites. The transform-EKKO software that accompanies the Noggin 250 Plus Smart card was used for the initial post-processing of the GPR data. The solid green line shown in Figures 2-4 represents the partition between the ballast and fill/natural clay. Below the green line, the natural clay horizon has attenuated the EM wave, limiting data collected from greater depths.

GROUND PENETRATING RADAR VS SEISMIC AND GRAVITY DATA

Figures 2, 3 and 4 show the data collected from GPR, Seismic and Gravity for the six sites. The movement and natural features of the track substructure and structure of the underlying sub-soil and bedrock can be observed. The apparent sinking of the ballast layer can be observed particularly by the GPR data in Figure 1: Sites 1 and 2 are located on the embankments of the Ohio River, the other four sites on the Kanawha River. Very Low Frequency data (not presented) and terrain conductivity (Figures 4 and 5) were also collected for the six sites. Figures 2-4 also indicates the seismic velocity values at various points in the track substructure: the less dense the ballast material (medium) has a lower value of seismic velocity than the layers below for site 1. Generally, the bulk density of the sub-surface layers increases with depth.

MONITORING SUBSTRUCTURE MOISTURE CONTENT

Moisture content level in the substructure may be influenced such features as fouled ballast, culvert location, ballast degradation and poor drainage efficiency. Archie (16) established an empirical relationship between the bulk rock resistivity and pore fluid resistivity, the ratio of which he termed the formation factor, which is a function of the volume fraction, porosity. Thus electrical conductivity and resistivity (inverse of conductivity) are sensitive to moisture content in soils and frequently used as a proxy for moisture content. GPR and EMS-31 have been used to map moisture variations in soil (17, 18). Conducting a resistivity survey involves inserting a series of electrodes into the ground and passing a electrical current through them into the ground, and is therefore labor intensive and time consuming. Whereas the EM-31 (Geonics) was used to collect ground conductivity data carried hip-high at normal walking pace.

Although ground or substructure resistivity (Ohm-feet) and conductivity (milliSiemens per metre or mS/M) are closely related each instrumentation measure different values.
The values of conductivity or resistivity measured from an induced magnetic field are a function of the applied current frequency. When a DC current applied into ground is switched off the voltage across the electrodes decays slowly. These effects are more pronounced in ground containing clay and metallic minerals. The resistivity survey measures the approximate ground

resistivity at various depths: Resistivity tomography graphics of the track substructure in two or three dimensions can be produced.

A resistivity survey was conducted for each of the six sites; EM-31 ground conductivity measurements were also taken. The raw data was low-pass filtered and plotted. To test the validity of using the EM-31 over track preliminary trials were conducted various rail track conditions: rails and wood ties; wood ties without the rail and the same ground with both the rails and wood ties removed. It was found that using the EM-31 with the instrument antennas parallel to the rail track, in the vertical dipole mode, produced consistent readings. EM-31 terrain conductivity measurements were taken each time a GPR survey was conducted. The dielectric constant of soil materials is influenced by moisture content which influences reflectance values prominent in a GPR image.

MOISTURE CONTENT DATA: TERRAIN CONDUCTIVITY VS RESISTIVITY

Figures 4 and 5 show data collected from the terrain conductivity (EM-31) and resistivity (TRP) surveys. The graphs were developed using a five-point running average filter. The validity of the EM-31 as mobile sensor was tested by comparing the data to corresponding TRP data. For sites A and R the EM-31 and TRP data show general (inverse) agreement, but the data from the other sites are not consistent.

DISCUSSION

The data presented in Figures 2-4 show the depth (thickness) variation of the ballast layer, which in this case is effectively the partition between the predominantly ballast material and the natural sub-soil dominated by clay. As damp clay attenuates the electromagnetic waves readily the ballast/clay interface seems to be more easily distinguished. The rail track substructure layers of ballast, sub-ballast and sub-grade are not easily distinguished. The layers in this case have mixed constituents of granite and limestone fragments (old ballast), fly-ash/cinders and natural soil/clay. For the three layers 1, 2, 3 defined in Figures 2-4): Layer 1 consists of loose railway ballast, mostly granite; Layer 2 comprises the transition from ballast to mixture of ballast, ash fill and some clay; and Layer 3 is comprised of stiffer ash/clay transitioning to natural clay.

The TRP data shows the variation of resistivity values between the track substructure layers at different depths (Figures 5, 6). The highest resistivity values were generated for the upper layer which consists mostly clean ballast. This data highlights the distinctive granite ballast of high porosity and complex nature of clay dominated soils, and mixed with old ballast and perhaps cinders and slag. The EM-31 which effectively measures the average conductivity of the ground 20 ft below the instrument data shows a general (inverse) relationship with the resistivity for sites A, L, P and R, but not for sites 1 and 2. Therefore the EM-31 may not selectively indicate ballast and sub-ballast moisture. Further resistivity and conductivity surveys will be conducted with other sensors, under better controlled conditions, to determine the most suitable proxy for track moisture content, with focus on the upper ballast layer.

The depression or migration of the ballast layer, depicted by the green line in the GPR graphs (Figures 2-4) is probably the result of periodic replenishing of clean ballast to maintain level track, following track settlement. The track has also been moved laterally during maintenance

operations. This characteristic was also reported by Sussman and Selig (11) and noted the role of the ballast and underlying mixture of ballast, slag and cinders. Track and roads located adjacent to rivers often experience significant ground movement primarily due to the change level of the rivers inducing corresponding changes in the water table in the river banks and the clayey soils

The seismic and gravity surveys will be conducted periodically as part of a long-term study of the nature and behavior of track substructure and ground associated with significant ground movement. Material density change is a factor in both substructure movement and ground mass failure, which influences seismic velocities and gravity readings. As previously noted, the GPR, Seismic and Gravity data presented have many common features, and together with the terrain conductivity and Very Low Frequency (VLF) data provide a comprehensive assessment of the track substructure and ground features. At site 2, tie-backs (bolts), concrete retaining walls and vertically placed steel rails where used to reinforce the ground beneath the rail track. The zone of the greatest ground movement has occurred from the 450 feet to 960 feet mark.

CONCLUSIONS

Data from multiple sensors are providing good insight into the nature and behavior of the track and supporting ground. The fusion of data collected in real-time from multiple-sensors such as GPR, terrain conductivity and HADGPS on a mobile platform will be a valuable tool for track maintenance management. Considerable research work lies ahead to improve the application of these and other sensors to provide valuable just-in-time information to engineers. Greater attention will be given to presenting timely track quality data in a meaningful format. Efficient software and computing capability is being developed to collect, fuse, store and interpret the multi-sensor data in real-time.

ACKNOWLEDGEMENTS

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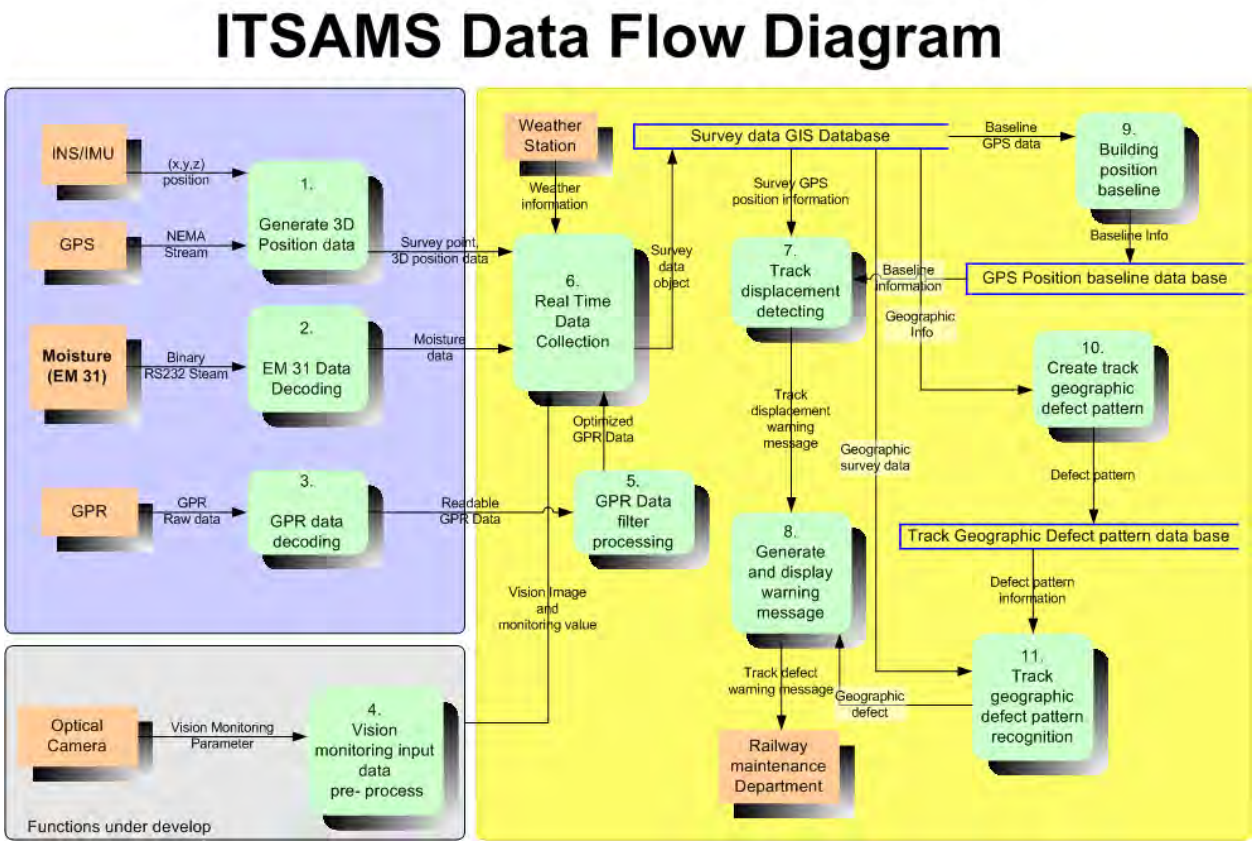
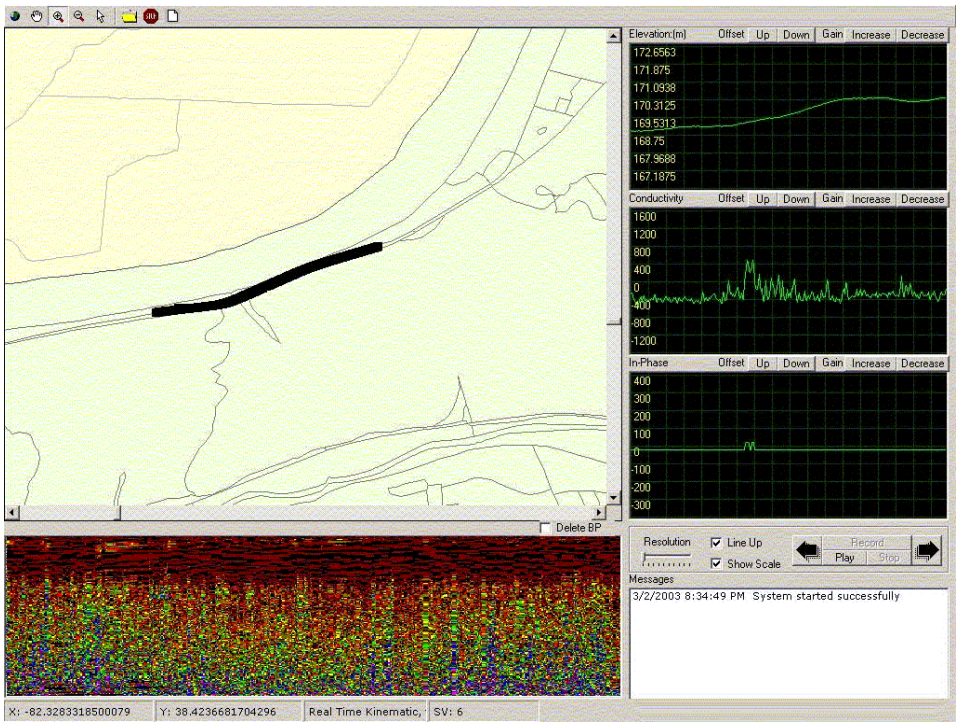


(a) Multi-Sensor Mobile System



(b) Presentation of geographic GPS, elevation, EM 31, and GPR data for a site.

Figure 1

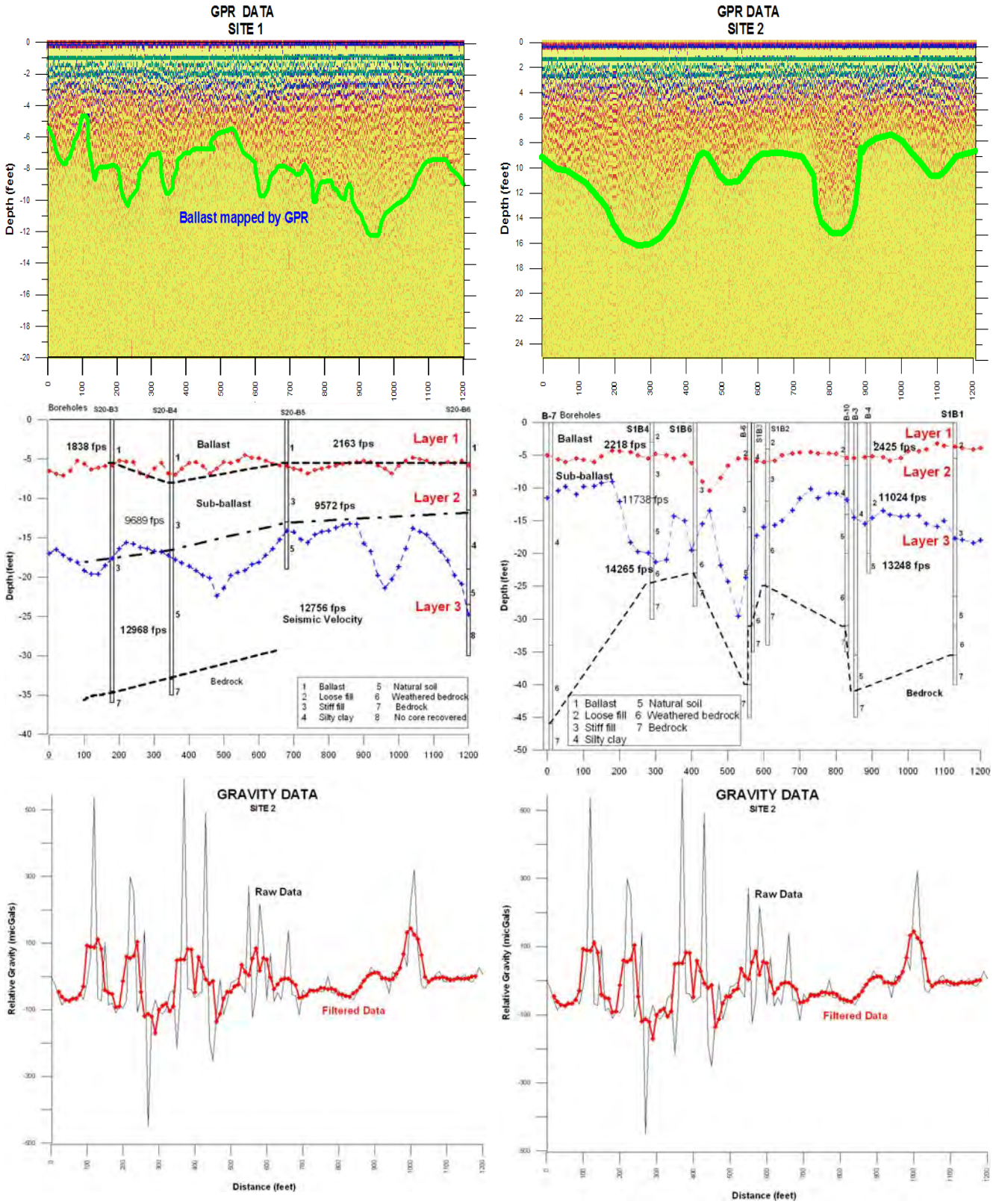


Figure 2: Data from GPR, Seismic and Gravity Surveys for sites 1 and 2

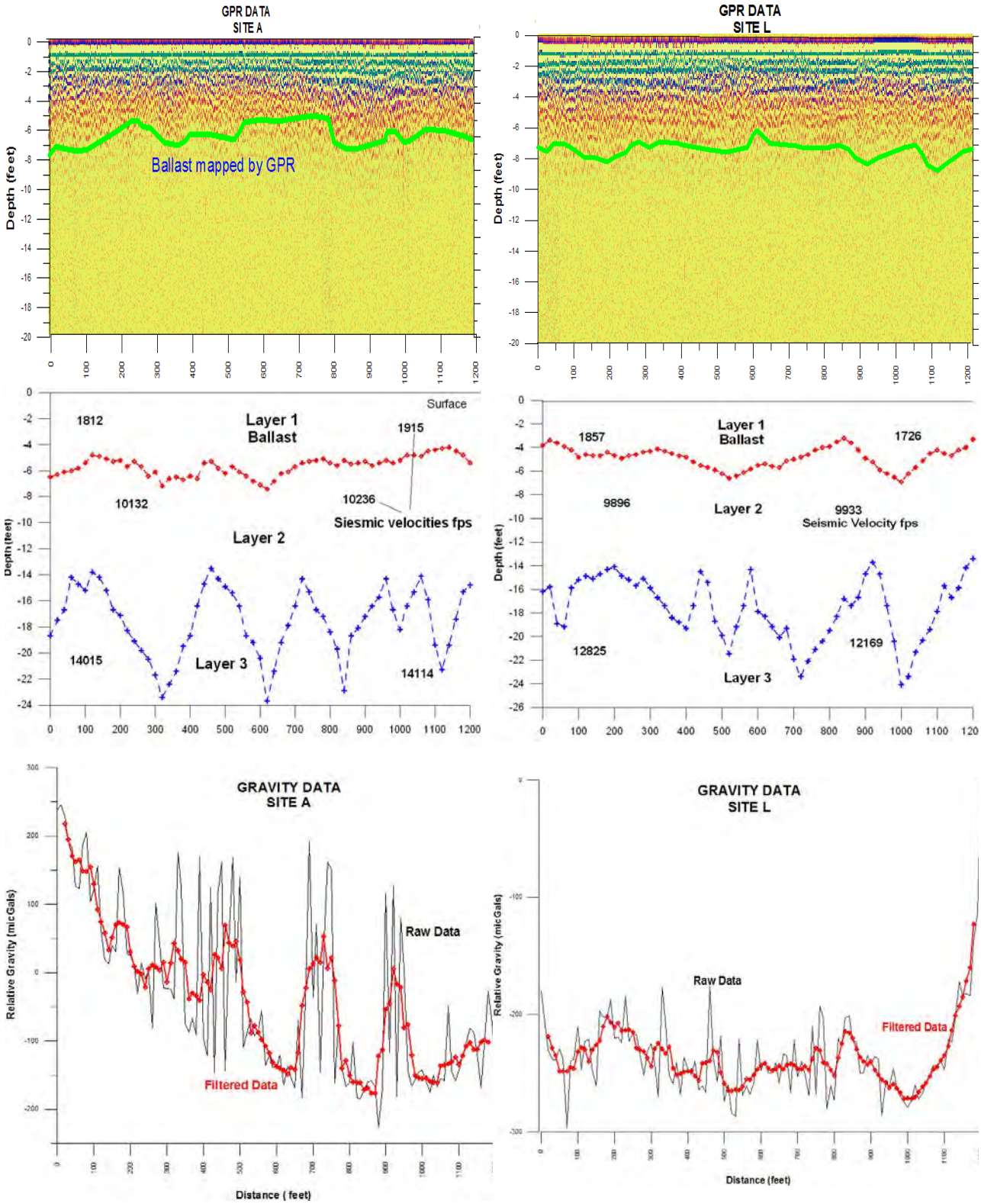

GPR DATA
SITE A
Ballast mapped by GPR
Depth (feet)
GPR DATA
SITE L
Depth (feet)
Surface
1812
Layer 1
Ballast
1915
10132
10236
Siesmic velocities fps
Layer 2
14015
Layer 3
14114
Depth (feet)
1857
Layer 1
Ballast
1726
9896
Layer 2
9933
Seismic Velocity fps
12825
12169
Layer 3
Depth (feet)
GRAVITY DATA
SITE A
Raw Data
Filtered Data
Relative Gravity (micGals)
Distance (feet)
GRAVITY DATA
SITE L
Raw Data
Filtered Data
Relative Gravity (micGals)
Distance (feet)

Figure 3

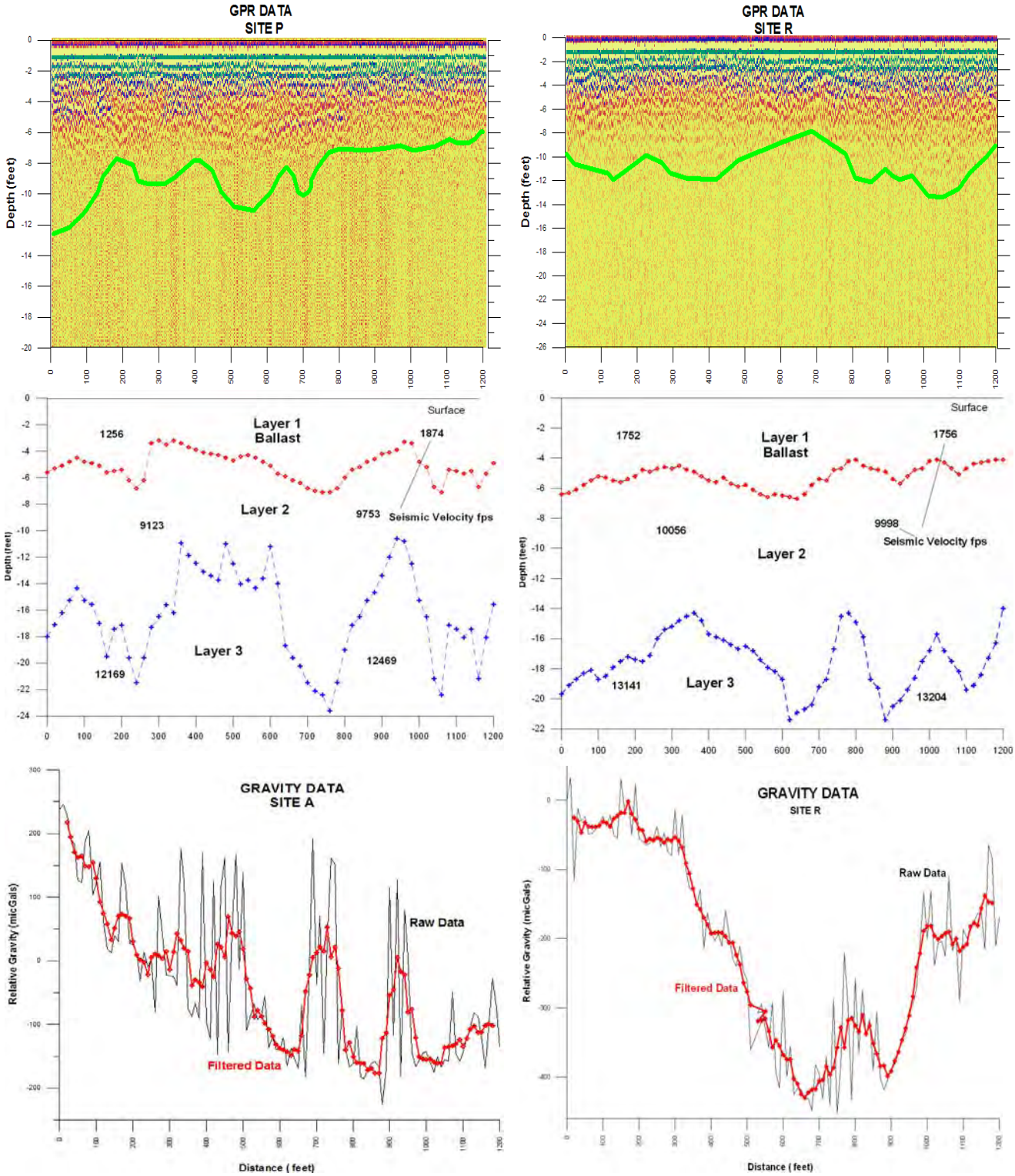

GPR DATA
SITE P
Depth (feet)
GPR DATA
SITE R
Depth (feet)
Surface
Layer 1
Ballast
1256
1874
Layer 2
9123
9753
Seismic Velocity fps
Layer 3
12169
12469
Depth (feet)
Surface
Layer 1
Ballast
1752
1756
Layer 2
10056
9998
Seismic Velocity fps
Layer 3
13141
13204
Depth (feet)
GRAVITY DATA
SITE A
Raw Data
Filtered Data
Relative Gravity (micGals)
Distance (feet)
GRAVITY DATA
SITE R
Raw Data
Filtered Data
Relative Gravity (micGals)
Distance (feet)

Figure 4

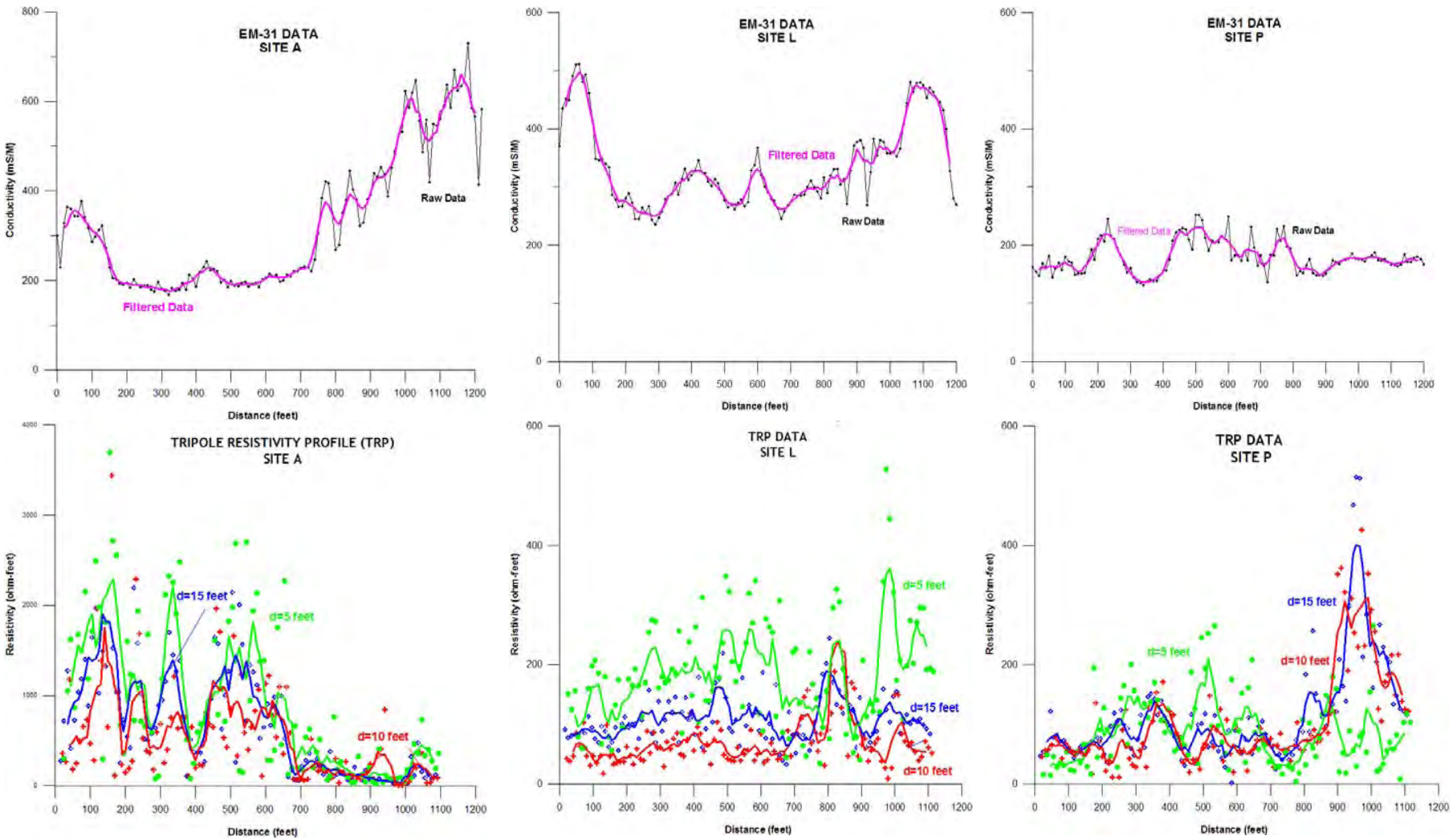


Figure 5: Track conductivity and resistivity data for each site

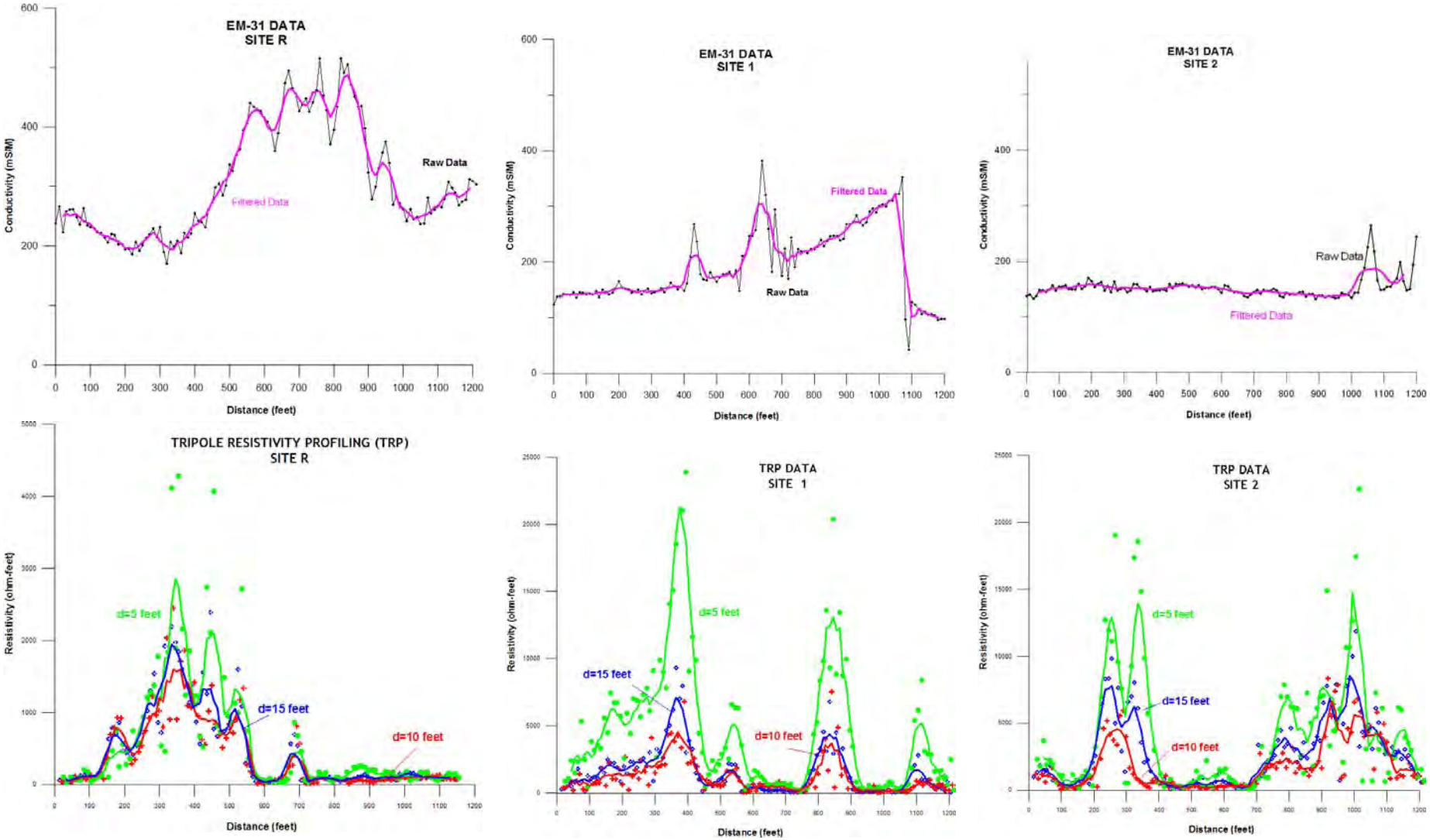

EM-31 DATA
SITE R
Conductivity (mS/M)
Raw Data
Filtered Data
Distance (feet)
EM-31 DATA
SITE 1
Conductivity (mS/M)
Filtered Data
Raw Data
Distance (feet)
EM-31 DATA
SITE 2
Conductivity (mS/M)
Raw Data
Filtered Data
Distance (feet)
TRIPOLE RESISTIVITY PROFILING (TRP)
SITE R
Resistivity (ohm-feet)
d=5 feet
d=15 feet
d=10 feet
Distance (feet)
TRP DATA
SITE 1
Resistivity (ohm-feet)
d=5 feet
d=15 feet
d=10 feet
Distance (feet)
TRP DATA
SITE 2
Resistivity (ohm-feet)
d=5 feet
d=15 feet
d=10 feet
Distance (feet)

Figure 6

Appendix E: Determining Rail Track Movement Trajectories and Alignment Using HADGPS

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ABSTRACT

High Accuracy Differential Global Positioning System (HADGPS) was employed to conduct repeated track position surveys, at different speeds, over a 1,400 ft section of track. A parametric curve fitting best-fit Splines (B-Splines) algorithm was used to smooth the real-time kinematic (RTK) GPS data and optimize track position accuracy. The data generated from surveys employing HADGPS positioned atop a hy-rail vehicle yielded a baseline average horizontal and vertical accuracies of 1.2 cm (0.47 ins) and 2.2 cm (0.87 ins) respectively. Accurate position data is provided for track alignment and track displacement trajectory determination. The coordinates also provide location data for track superstructure and substructure anomalies identified during track monitoring.

INTRODUCTION

The project objective is to determine the accuracy of the HADGPS for routine surveying of track in a simplified set-up (platform), collect accurate track position data at different surveying speeds. Track surveying data is stored in a GIS database and will be used for track alignment and track movement monitoring, especially in areas of considerable ground movement. The data can also be processed applying a statistical model to calculate horizontal and vertical displacement, and including the time factor, the rate of displacement which may be indicative of a substructure or geological anomaly.

Significant technological advances have been made in Mobile Multi-Sensor Systems (MMS) that accurately inventory geometric data along transportation routes such as roads, rivers and railways *(1).* Global positioning systems (GPS) is becoming more of a precise and inexpensive surveying tool that is readily integrated with other sensors to provide three position and three orientation parameters to describe the position of the track and vehicle trajectory. The HADGPS is a key component of a multi-sensor platform that is being developed to measure rail track movement and monitor subsurface maintenance and stability features in real-time. Initial trials were conducted with the HADGPS rover both located on a lightweight sensor platform towed behind a hy-rail, and attached to the hy-rail roof. Besides the high-tech hardware being configured, fusing data from multi-sensors in real-time requires efficient software to collect, store and interpret the data.

Accurate coordinates from the HADGPS provide location data to correct track misalignment and monitor movement, in real-time kinetic (RTK) mode. As the sampling rate of the GPS is constant, surveying at a higher speed will result in a lower density of data collected.

For example, the HADGPS (Trimble 5700) samples every second and sampling at 30 mph collects a data point every 44 feet, at 10 mph about every 15 feet. Traditional surveying practices are labor intensive and have produced mixed results especially when used in areas on significant ground movement, which often results in the continuous movement of the surveying monuments.

The HADGPS requires base-stations be setup at strategic intervals to achieve signal continuity and sufficient number of satellites within the appropriate geometric limits. Presently there are no other technologies that can compete in provide such location accuracies economically. However, in areas where the satellite signal is interrupted the GPS has to be integrated with other sensors such as Inertial Navigation Systems (INS) or vision-based systems (digital cameras) *(2).* The GPS-derived positions can act as an excellent external up-date for the INS and the INS can provide precision position data for the GPS during signal acquisition interruptions. This redundancy improves the reliability of the system. Similar to other hi-tech products, the unit price of GPS has dropped dramatically this past decade, for the 300 feet to the 0.4 ins accuracy range.

Wildi (*3)* developed a modular platform for kinematic track surveying (GPS-RTK) at speed up to 3 mph. An 11 mile section of railway line was surveyed with back and forth runs of the GPS platform. In sections without signal interruptions an accuracy of 0.6 ins horizontal and 1.0 ins vertical was reported. Using GPS to measure or survey the three dimensional coordinates of track geometry kinematically, with high accuracy, has been a significant recent trend. From 1993 to 1995, the Technical University Graz and the Research and Testing Department of Plasser Theurer studied the use of GPS for track surveying (*4).* The study showed that GPS yielded surveying accuracies of +/- 0.24 ins horizontal and +/- 0.4 ins vertical, traveling at a speeds of 1 to 2 mph. Zywiel (*5)* describes a GPS-supported electronic track surveying device (EM-SAT) used to complement an automatic leveling, alignment and tamping machine that can smooth existing track errors. Using a computer-assisted laser (chord measuring) technology, level accuracies of 1 mm (0.04 ins can be achieved. For this high precision it is necessary to have fixed GPS base-stations 6 to 12 miles apart. Ebersohn *(6)* used a profile geometry roughness factor (R^2) as an indicator of track service ability, based on 62.3 ft (19 m) chord geometry measurements. Munsen *(7)* has been developing GPS algorithms to precisely monitor rail position, then combine track survey and rail temperature data to infer contained rail stress to permit a prediction of some types of rail buckling.

HADGPS SYSTEM PERFORMANCE AND APPLICATIONS

High accuracy, RTK GPS surveying requires three modes of space vehicle (SV) signal reception and correction. Basic GPS location requires reception of the Course Acquisition Code (C/A phase). This provides a single point accuracy of less than 15 meters (47 ft). Using a second base station to calculate differential corrections and transmit them to a rover provides sub-meter accuracy in real-time. Operation of a real time differential station transmitter requires FCC licensing. One centimeter (0.4 ins) accuracy uses the SV carrier signal emissions. Carrier phase techniques count the number of wavelengths in the L1 and L2 band SV transmission to refine the position to within one centimeter horizontal and 2.0 cm (0.08 ins) vertical accuracy.

RTK surveying performance is influenced by several site-related factors. Most significant is a blocked horizon. The GPS antenna must have a clear line-of-site to the SVs. Hills, track

below roadway grade, foliage, and structures all present difficulties for RTK surveying. Significantly, in the Appalachia region the dense foliage surrounding the track quite easily blocks the low power SV carrier signals, resulting in a loss of initialization and data dropout.

GPS TRACK SURVEYS

To initiate HADGPS data collection the base station is established, see Figure 1. The antenna is placed on the hy-rail rack and aligned with the inside edge of the rail using a theodolite. The GPS RTK data is collected while the hy-rail is traveling at a specific speed. Firstly, a baseline was established, then data was collected traveling at speeds of 5, 10 and 15 mph and statistically compared to the base line to determine measurement accuracy. An accurate baseline for the track, or more specifically rail, is established by collecting high density of data from the HADGPS traveling less than 3 mph and stored in a GIS database. Conducting additional surveys periodically will generate new data sets.

Mobile Platforms Designs

The initial platforms initially considered to support the HADPS and other sensors are inexpensive and robust. Two towed GPS platforms were constructed and tested. The first platform, designated Type I, was constructed using a Nolan model TD-3 track dolly (three wheel) as the base instrument stage, weighing 108 lbs. The Nolan TD-3 proved to have unacceptably low ground clearance. The dolly bottomed and lifted at crossings. Further, the dual flanged wheels did not negotiate switches and frogs without being manual lifted. Vibration due to the lack of wheel cushioning or suspension loosened fasteners on some instruments. However, the TD-3 dolly is small, light and easy to transport in the back of a small station wagon. The Type I base was replaced by a Type II platform employing a Nolan model TS-1 track cart a base of weight 175 lbs. Both platforms meandered between gauge-side rails exhibiting a side-to-side movement of approximately 1 to 3 ins. A spring loaded swing arm arrangement engages the gage side of the rail, the GPS antenna and pick-up to which are directly mounted. The assembly was able to navigate all grade crossings and pass through switches and frogs without manual intervention. Measurements were collected at velocities of 3 to 15 mph. However, due to damage to the GPS takeoff arm on bolted rails; reduced sky visible to the GPS antenna; and site assembly/disassembly requirements, mounting the GPS antenna directly to a hy-rail vehicle was explored.

Hy-Rail Platform

The GPS receiving antenna and UHF differential receiving antenna were mounted to a rack attached to the roof of the hy-rail equipped vehicle. This orientation maximizes the sky visible to the GPS antenna and reducing data dropouts. Alignment of the GPS antenna location on the rack is accomplished with the use of a theodolite, set up on the gage side of the rail. The center of the GPS mount is aligned with the inside flange of the hy-rail vehicle. A standard differential level circuit is used to determine the elevation offset from the top-of-railway to the bottom of the antenna mount. Entering the elevation offset into the survey controller corrects elevation for data collected during a survey.

Several error sources in this method are apparent. Using a fixed antenna mount, the out-of-plumb error due to grade and cross-level are shown in Figure 2. More subtle errors stem

from the vehicle 'wandering' between the gauge side of the rail. Vehicle speed has an influence on wandering. Testing confirms that at low speed the vehicle 'falls' to the inside of a super-elevated curve. These errors can be accounted for and a correction to the data made in real time.

TRACK MODELING ALGORITHMS

As previously indicated, sets of data was collected with the HADGPS atop a hy-rail traveling at speeds of 5, 10, 15 mph. Initially baseline was established with GPS data form a survey speed of less than 3 mph. The HADGPS rover was then moved along the hy-rail rack, perpendicular to the line of the track, to a fixed a distance of 139.33 cm (54.9 ins), an arbitrary number. The above process was repeated with GPS RTK data sets collected at speeds of 5, 10 and 15 mph. If the fixed sample rate of the GPS is one data point per second then at 5, 10 and 15 mph data points will be collected every 7.3 ft, 14.7 ft and 22 ft respectively. A parametric curve fitting B-Splines algorithm was used to fit the baseline data, generated at a survey speed of less than 3 mph. Then two methods were used to determine the accuracy of the collected data sets compared with the fixed distance the rover was moved on the hy-rail rack.

1. The shortest distances of each point in the monitoring data sets (5, 10, 15 mph) (normal) to the baseline (B-Spline) curve is calculated, each set representing the position of the rail. Subtracting the fixed distance between the rovers 139.33 cm (54.9 ins) from the distance of the points of the monitoring data set to be baseline curve and plotted an error (Gaussian noise) distribution is generated, see Figure 3.
2. The curve fitting algorithm is applied the each monitoring data set and the shortest distance between the two curves (baseline and new curve) can be determined.

Track monitoring surveys conducted periodically will generate GPS data sets to be compared to baseline data, utilizing a GIS database. Tables 1 and 2 present position data repeatability or accuracy, which is mean of the horizontal and vertical differences, respectively, of each 5, 10 and 15 mph speed data sets, to the baseline, surveyed with the rover in the same position. The other values shown in Table 1 are the mean of the horizontal distance between the points generated by the rover moved a distance of 139.33 cm (54.9 ins) and the baseline created by rover in initial position; and the last column, the mean distance between the B-Splines created from the data set generated by the rover in the second position, and the baseline.

DISCUSSION

From Tables 1 and 2 present the horizontal and vertical components of GPS data from repeated runs over a 1,400 ft section of track with the simple hy-rail set-up. The data generated yielded average accuracies of 1.2 cm (0.47 ins) horizontal and 2.2 cm (0.87 ins) vertical for speeds of 5, 10 and 15 mph. As expected, the vertical component accuracy of the GPS data is less than the corresponding horizontal component. Figure 4 presents a graph of the elevation data for the track position data surveys along the 1,400 ft track, for speeds 5, 10, 15 mph. The vertical axis is marked in 10 cm (3.9 ins) intervals to demonstrate the narrow range of data collected using the HADGPS. Although the density of data collect decreases with

increase in speed, the vertical and horizontal component accuracies are similar, for the GPS system (one data set) and using the data set differences using the B-Splines algorithm. From the two GPS surveys with the rover positions at a fixed distance apart yielded: average accuracies from the two methods to calculate the rover separation using the B-Splines algorithm of effectively 0.2 cm (0.08 ins) and 0.4 cm (0.16 ins) respectively. However, the usefulness of HADGPS for track alignment and displacement monitoring will depend on the application system errors: DGPS station accuracy, environmental (weather, obstructions) and platform/sensor set-up. Thus system errors would probably increase significantly when the HADGPS is applied for larger scale track surveys. Locating rover on the hy-rail is very practical but not the most precise for definitive rail or track position data. An inexpensive inclinometer or gyroscope could quite easily be configured to compensate the data for change in track super-elevation. System errors could be reduced by locating the rover closer and directly over the rail: A double flange wheel to reduce lateral movement relative to the rail.
The GPS/INS configurations can provide continuous accurate data, but is expensive. There are other lower-cost systems, and less accurate, such as employing a Kalman Filter algorithm to integrate GPS and Dead-Reckoning (DR) data, using a odometer (measuring wheel) and digital compass, for example. There has been a continuous improvement in other applicable technologies both in price and capability and have potential to enhance or compliment GPS technology, such as micro-electro-mechanical systems (MEMS). Multi-sensors are being configured and efficient software developed to collect and store track position and track quality data on a GIS database. For the purpose of track alignment and displacement the stored data can be retrieved at any time and processed to produce valuable data for track maintenance operations. Incorporating the time period between surveys, the rate of track movement can easily determined at any point along the surveyed track, which can be a useful indicator of track superstructure, substructure or geological anomalies.

CONCLUSIONS

This small-scale study has shown the usefulness of HADGPS for railway track superstructure and substructure monitoring. Accurate track position collected with a relatively inexpensive GPS platform set-up and employing a data smoothing algorithm (B-Spline) the speed of data collection (5 to 15 mph) did not unduly influence data accuracy. However, these surveys were conducted on a short section of track (1,400 ft) without the need to compensate the data for change in super-elevation and GPS signal interruption. Therefore, there is considerable research effort required to apply this technology (sensor) for large-scale monitoring operations. Future research will involve refining the data smoothing algorithms and developing efficient software to collect, store and process the data. The geometric data needs to be presented in a format suitable for engineers engaged in track alignment and maintenance operations.

ACKNOWLEDGMENTS

The authors acknowledge the funding provided by the Federal Rail Administration and West Virginia Department of Transportation. Resources and administrative assistance from the Nick J. Rahall Transportation Institute, Marshall University; and the CSX and Norfolk Southern railway companies for their generous assistance in providing resources and rail track sites for investigation.

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TABLE 1: Horizontal Component of GPS Data

Speed of Hy-Rail GPS Survey	Data Repeatability (Accuracy) cm	New Survey Point to Baseline Distance		New Survey Line to Baseline Distance	
		Mean cm	From Initial 139.33 cm	Mean cm	From Initial 139.33 cm
5 mph	1.37 (0.54 ins)	139.15	0.18 cm (0.39 ins)	139.02	0.31 cm (0.12 ins)
10 mph	0.77 (0.38 ins)	139.27	0.06 cm (0.02 ins)	139.10	0.23 cm (0.09 ins)
15 mph	1.35 (0.53 ins)	139.06	0.27 cm (0.11 cm	138.83	0.50 cm (0.20 ins)
Average	1.16 cm (0.46 ins)		0.7 cm (0.07 ins)		0.35 cm (0.14 ins)

TABLE 2: Vertical Component of GPS Data

Speed of Hy-Rail GPS Survey	Data Repeatability (Accuracy) cm
5 mph	1.93 cm (0.76 ins)
10 mph	2.42 cm (0.95 ins)
15 mph	2.19 ins (0.86
Average	2.18 cm (0.89 ins)

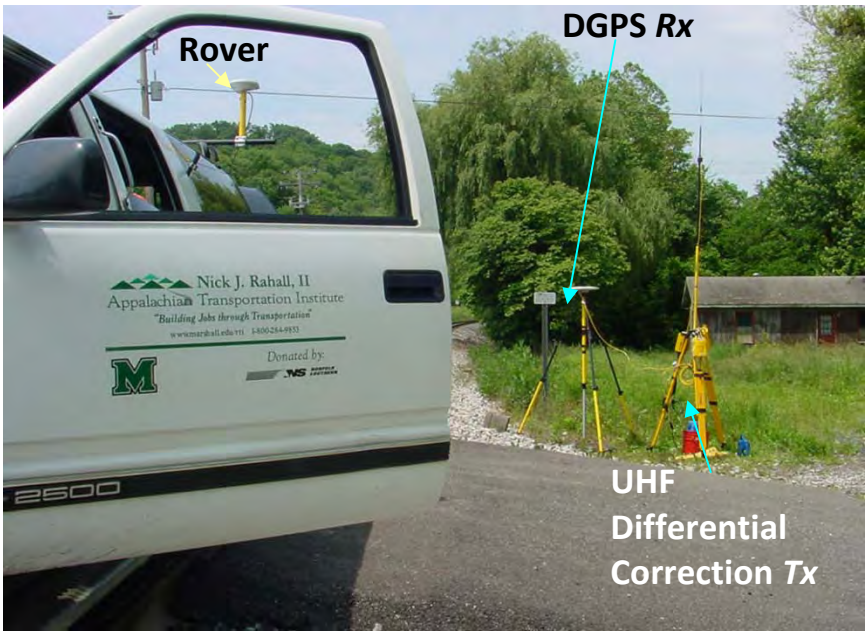


Figure 1: Photo of HADGPS and Hy-Rail Setup

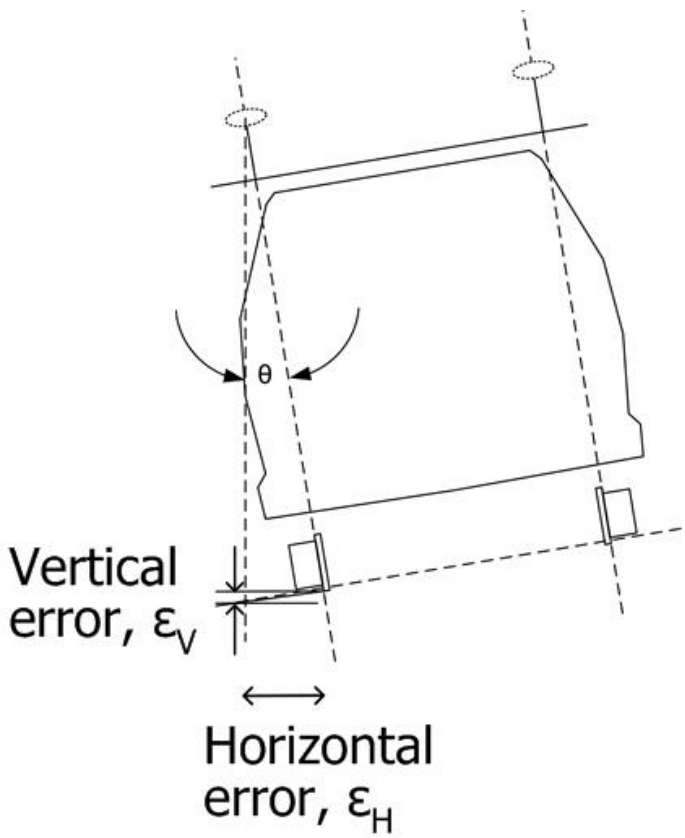


Figure 2: Error Due to Super Elevation of Track

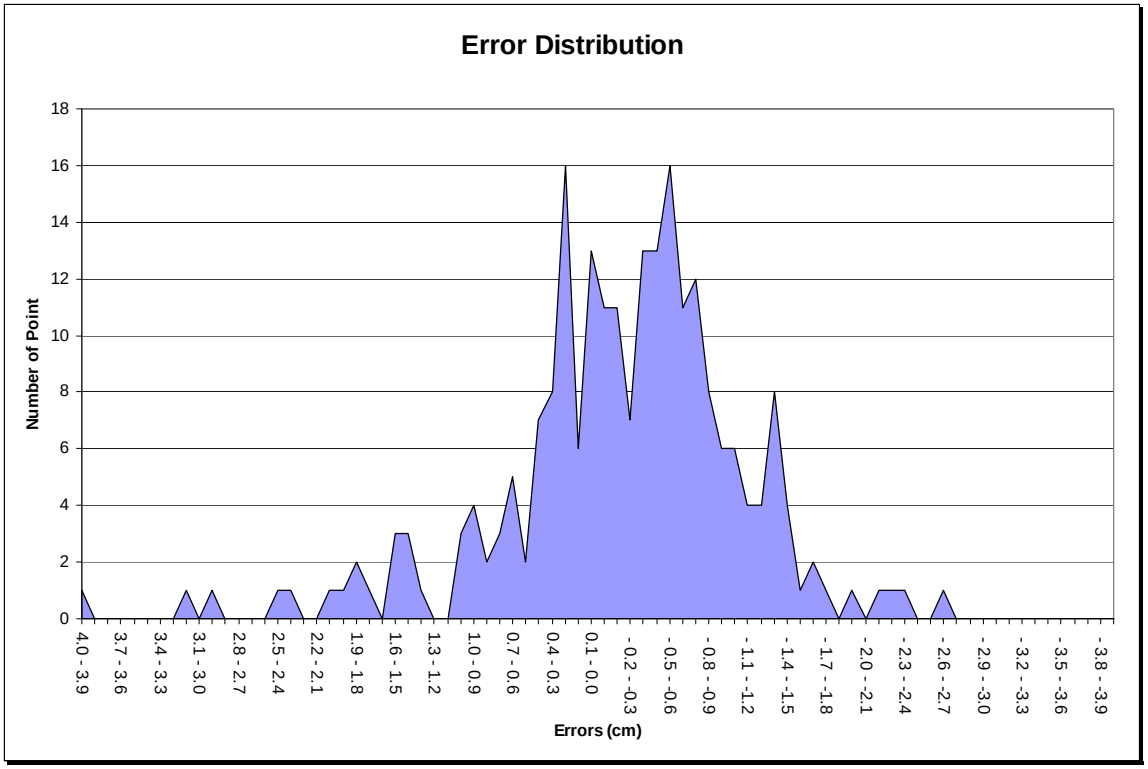
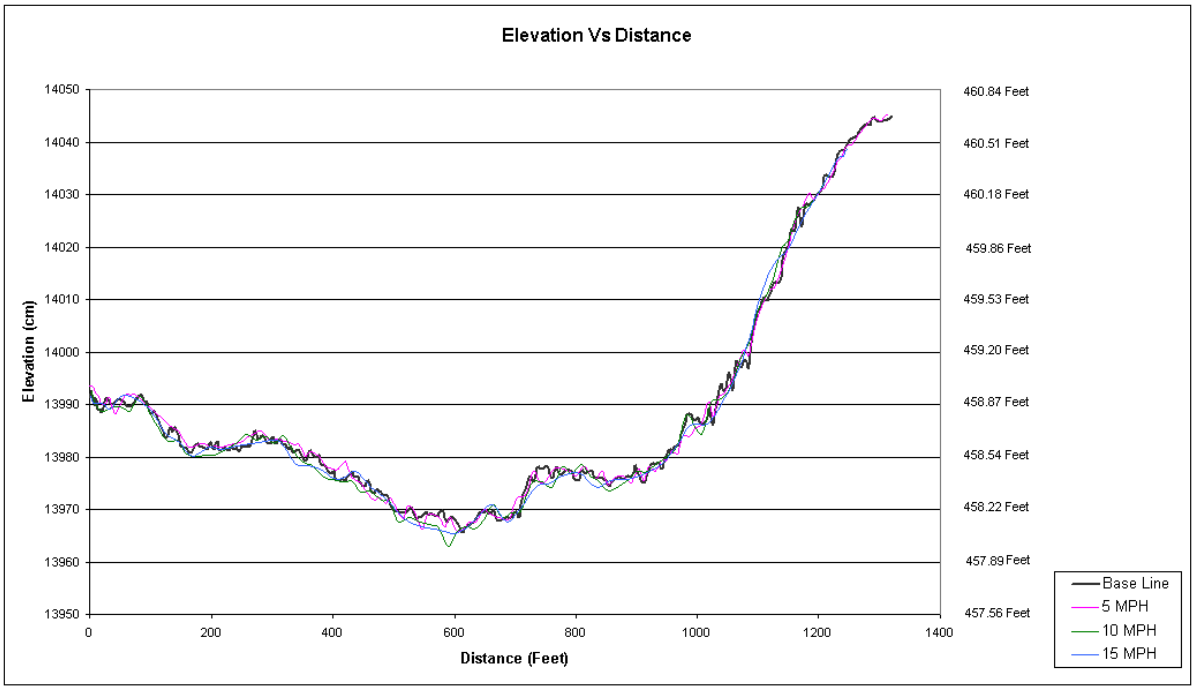


Figure 3: Error (Gaussian) Distribution Curve for New Survey Point To Baseline GPS Data



Appendix F: A Study of Rail Track in Area of Ground Movement

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ABSTRACT

Maintaining mainline active rail track in good condition is critical for continued productive and safe use. Thus several railway track sites along the banks of major rivers with histories of ground movement are being studied. The paper presents results of the geophysical survey of one site, 1,200 feet in length, located 100 feet from the Ohio river. The focus is on evaluating track bulk moisture characteristics in track substructure. A geophysical survey consisting of ground penetrating radar, seismic, gravity, very low frequency and resistivity measurements were conducted. A high accuracy differential global positioning system surveying technique was used to determine elevation profile and vertical settlement of the track.

INTRODUCTION

Maintaining railway track located on the embankments of rivers has proven to be a significant challenge due to the associated ground movement. Thus studies are being conducted on sections of mainline track on the banks of the Ohio and Kanawha Rivers in West Virginia. The sites continue to experience ground movement toward the rivers, which has resulted in significant track maintenance and ballast replacement costs. The results of one section of rail track alongside the Ohio River are presented.

The track substructure should permit drainage, anchor the track superstructure, distribute and transfer loads to the underlying roadbed, and facilitate track alignment. The track ballast and sub-grade interface is also a key stability and design factor (Hay). Excessive track deflection leads to ballast deterioration due to inter-particle abrasion, formation of water and ballast pockets, muddy-pumping track, and permanent deformation or settlement. Stable track requires clean, compacted and well-graded ballast; firm and well-drained sub-grade; as well as quality ties.

Replacing the millions of tons of degraded ballast to maintain the rail track safe and productive is a substantial cost. Numerous techniques have been tried to reduce the associated costs, such as applying recycled ballast with a reinforcing composite layer to extend the track life. Ballast reinforcement can reduce the rate of track settlement by effectively increasing the track foundation bearing capacity, resulting in reducing maintenance costs. Monitoring ballast

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degradation and stability is a key factor in extending track life and enhancing rail track stability and operation safety.
In order to predict rail track deterioration it is important to understand the dynamic interaction between the train and track. For example, ballast decay can be evaluated with imaging sensors (Kantor) and computer modeling (Iwnecki) can realistically simulate the dynamics of track use. Predictive models based on experimental work (Thomas) have indicated that track deterioration is critically dependent on rail vehicle acceleration and ballast pressure. Ballast settlement is directly related to haul tonnage rate (tons per year), average train velocity, axle load, rail track structure and type of sub-grade.

Structural Geology of the Region

The site of the study is located 100 feet from the Ohio River, in the western part of West Virginia. The Appalachian Plateau covers the western two-thirds of the state and is mostly Pennsylvanian with some Permian rocks. The whole region is overlain by Quaternary Alluvium. The Appalachian Plateau is a high plain about 1100 to1200 feet above sea level. Erosion has been a predominant influence, leading to sharp v-shaped stream valleys. The Jackson-Mason-Putnam area is located in the Appalachian basin. All sites are on colluviums overlying bedrock of alternating sandstone and shale. Ground truth values have been taken from borehole data at the site, provided by the rail road companies. Most of the cores were drilled at the sides of the track and a few at the center of the track. The borehole data for the site indicate thicknesses of ballast/sub-ballast 5 to 18 feet and depth to bedrock 30 to 50 feet.

Rail Track Maintenance History

The track structure sections under investigation consist of steel rails and wood ties supported by mostly granite ballast. Over the past twenty years records indicate that considerable general slope and rail track movement has occurred alongside the river banks. Therefore extensive track maintenance and repair has been carried out, involving rebuilding the ballast to previous track levels and often adding considerable fly-ash to the river bank and track where required. At the site, tie-backs (bolts), concrete retaining walls and vertically placed steel rails where used to reinforce the ground beneath the rail track. Therefore, each site evaluated has specific conditions of ballast thickness, sub-surface constituents and depth to bedrock, which also varied along the test section length. The zone of the greatest ground movement has occurred from the 180 feet to 900 feet mark (see Figures 1 and 4).

RESULTS FROM RAIL TRACK SITES

Due to the operational difficulty of shutting down mainline track to obtain borehole data the study has focused on geophysical techniques. The long-term study of the site has involved establishing a baseline “geophysical foot print” Gravity, Seismic, resistivity and VLF methods. The geophysical survey will be repeated every one to two years.

Seismic Data

For the seismic investigation twelve geophones were used, each spaced ten feet apart. Five seismic sources were activated for every set-up. To cover the 1,200 feet track section nine layouts were conducted resulting in data collected from 540 (12x5x9) seismic traces. The resultant inverted model output was graphed. The results of the seismic tests for the site are shown in Figure 1. The three layers 1, 2, 3 at the two sites defined as follows: Layer 1 consists of loose railway ballast, mostly granite and some old limestone ballast; Layer 2 comprises the transition from ballast to mixture of ballast, ash fill and some clay; and Layer 3 is comprised of stiffer ash/clay transitioning to natural clay. The range of seismic velocities for the site are consistent with values from the ASTM standard D 5777-00 (ASTM):

Gravel	1,500 to 3,000 ft/sec
Clay (saturated)	3,000 to 9,000 ft/sec
Limestone	7,000 to 20,000 ft/sec

GPR Data

In this clay dominated sub-grade the electromagnetic (EM) energy of the GPR attenuates readily. The GPR data shown in Figures 1 was collected using a 250 MHz (Noggin) antenna. The transform-EKKO software that accompanies the Noggin 250 Plus Smart card was used to post-processing the data.

Gravity and VLF Data

See Figure 1. The gravity measurements taken for the site were not corrected for elevation change as the sections were level. Generally, the data collected was filtered using a low-pass filter to eliminate part of the noise that is contributed by the very shallow layer (between the surface and two feet deep). The filtered data was then used to obtain a best fit simple model. Low gravity reading could be interpreted as topographic lows, fault zones with low density contrast (mass deficiency). An ABEM WADI VLF instrument was used to take measurements. The instrument used a low frequency radio station centered at 23.7 kHz, and read one point every 10 feet, from 0 to 1,200 feet for each section. The instrument records directly the ratio between the vertical and horizontal component of the electro-magnetic (EM) field in percentage terms for the real and imaginary components of the EM field, produced by a radio transmission and received by the instrument antenna. A Hjelt filter was used to process both the real and imaginary components, and then plotted. The VLF data is very sensitive to fractures and underground water.

Vertical Track Movement

Using a track surveying technique devised by the authors the track sites are surveyed routinely. The key component of the technique is a high accuracy differential global positioning system (HADGPS). Figure 4 shows the data collected from two surveys of the site and indicates the magnitude of vertical movement between June and September 2003. It appears that the

largest vertical movement recorded coincides with the lowest part of this section of track, at the 250 feet location.

TRACK BED MOISTURE

Terrain Resistivity

Track substructure moisture has a deleterious effect on track durability resulting in higher maintenance costs. Terrain conductivity and resistivity have proven to be very good indicators of bulk moisture. Soils, unconsolidated sediments and rocks are composed of principally silicate minerals which effectively act as insulators. For most soil and rock the bulk resistivity is a function of porosity, moisture content, fluid salinity and clay content. An increased presence of clay corresponds to a lower bulk resistivity and causes the resisitivity to become frequency dependent. When water is added to clay the concentration of ions at the surface is increased. A diffuse layer is created resulting in a high bulk conductivity (or lower resistivity). Resistivity changes in the ground according to changes in bulk moisture content, void-, pore-water chemistry, clay content and inter-connected clay content. Resistivity surveys are slow and tedious, and limited to a surface that is amenable to the insertion of the metal electrodes. In this case the surface of the railway track is ballast. The electrodes are driven into the ballast. The contact between the ballast material and electrodes is generally poor. The data collected from the top ballast layer were processed with low-band pass filters, thus filtering the very high resistivity values at the immediate ballast surface .

Resistivity Data

The Tripole (TRP) survey was performed using an electrode separation of 10 feet, which is consistent with the other geophysical methods. The TRP is a resistivity method that samples three target depths: 3.4, 6.7 and 10 feet simultaneously. Four electrodes are configured so that current and potential electrodes are interchanged by an external control switch. The raw data was passed through a low-band pass filter. The pseudo-sections of the filtered TRP data for the length of the track site (1,200 feet) are shown in Figure 2. Three lines of resistivity data were collected: along the center-line of the rail track, and on lines a distance of 5 feet and parallel to the track center, on the hillside and the riverside.

Cross-sections (resistivity tomographs) were graphed at 120 feet intervals from the data. Figure 3 shows three cross-sections of track resistivity for distances 120, 240 and 360 feet, which show the track moisture conditions at the lowest point of 1,200 feet track site (see Figure 4).

DISCUSSION OF RESULTS

The initial phase of a long-term study of ground movement and its influence on mainline rail track, on the embankments of major rivers, has focused on using non-invasive geophysical technologies and a high accuracy differential global positioning surveying system. The seismic and GPR data, in Figure 1, which are similar in principle provide a good indication of the

variation in the track substructure matrix, which has been influenced by various degrees of ground movement over the last century. The VLF and seismic indicate a fault near the 1,000 feet location; the seismic, GPR and gravity data indicate considerable migration of ballast material: which is confirmed by fifteen-year old core samples. By measuring small changes in gravity it is possible to detect ground density variations. Air and water filled voids are generally less dense than the surrounding materials. Also changing thickness of sub-surface layers (lithology) and nearness of bedrock resulting in bulk density changes can be detected.
The HADGPS kinematic survey technique developed has permitted the collection of position data of the rail tracks at speeds of up to 15 mph with accuracies of 0.47 ins and 0.87 ins for the horizontal and vertical components respectively. Recently collected vertical or elevation data in Figures 4 shows that the greatest vertical movement of the track occurs at the lowest point on the track section.

Following several days without rain in the area there was light rain the day prior to taken the resistivity measurements. The resistivity data was collected in one day. The resistivity data was passed through a low-band pass filter. The electrode contact with the ballast materials was not as good as that of a typical soil matrix. The validity of using this type of resistivity survey in ballast material is currently being confirmed. Resistvity data is being compared with EM 31 and EM 38 terrain conductivity data (not presented). The low resistivity values (Figures 2 and 3) at this low point indicate the high values of bulk moisture in the track substructure which can be expected following natural drainage conditions. Also, the hillside of the track, for the length of the track section. Appears to have a higher moisture content (lower resisitivity) than the center of the track and the riverside. This may indicate that water runoff from the hillside is being captured to some extent by the track structure and drainage ditch.

As previously noted, the GPR data in Figure 1 depicts the limit of the new ballast and old ballast material that has migrated over the years. The profiles (green line) shows a significant migration between the locations 200 and 300 feet and 770 and 870 feet probably due to new ballast being routinely added during track maintenance to level the track following settling. The 200 to 300 feet location coincides with the lowest point of the track section and very high bulk moisture content. The ballast migration could be the result of general hillside ground movement, and water draining and collecting at lower elevation points, and the track structure acting to 'dam' water runoff. Faults or sand channels in the bedrock could also be a factor.

CONCLUSIONS

The geophysical and HADGPS surveying techniques used in this long-term study are generating valuable data and proving insight into the nature and behavior of ground and rail track movement near rivers. The maximum vertical settlement of the track coincides with the lowest elevation point. Track bulk moisture is a significant factor in superstructure and substructure movement. Groundwater characteristics dictated by the rivers water level (stage) and rain event size. Initial data indicate that track settlement and ballast migration may cause pooling water in the track substructure, or facilitate drainage from the track toward the river. The track structure may also retard the progress of surface run-off and groundwater flow.

The resistivity data was collected from electrodes inserted into ballast which generally does not provide particularly good electrode/matrix contact. The data was filtered using a low band pass filter. Research continues at other track sites experiencing similar ground movement.

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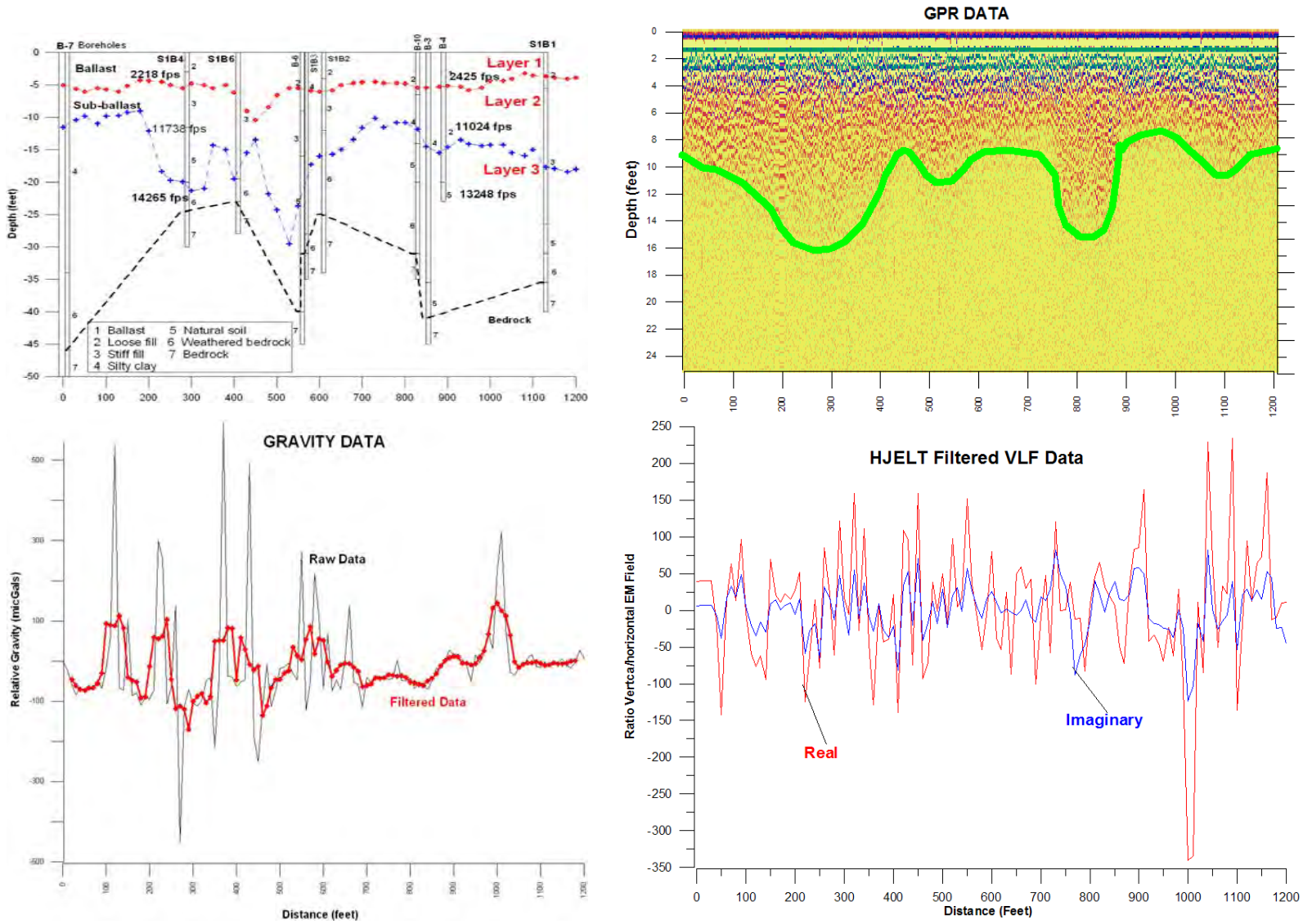

Figure 1. Seismic, GPR, Gravity and VLF Data

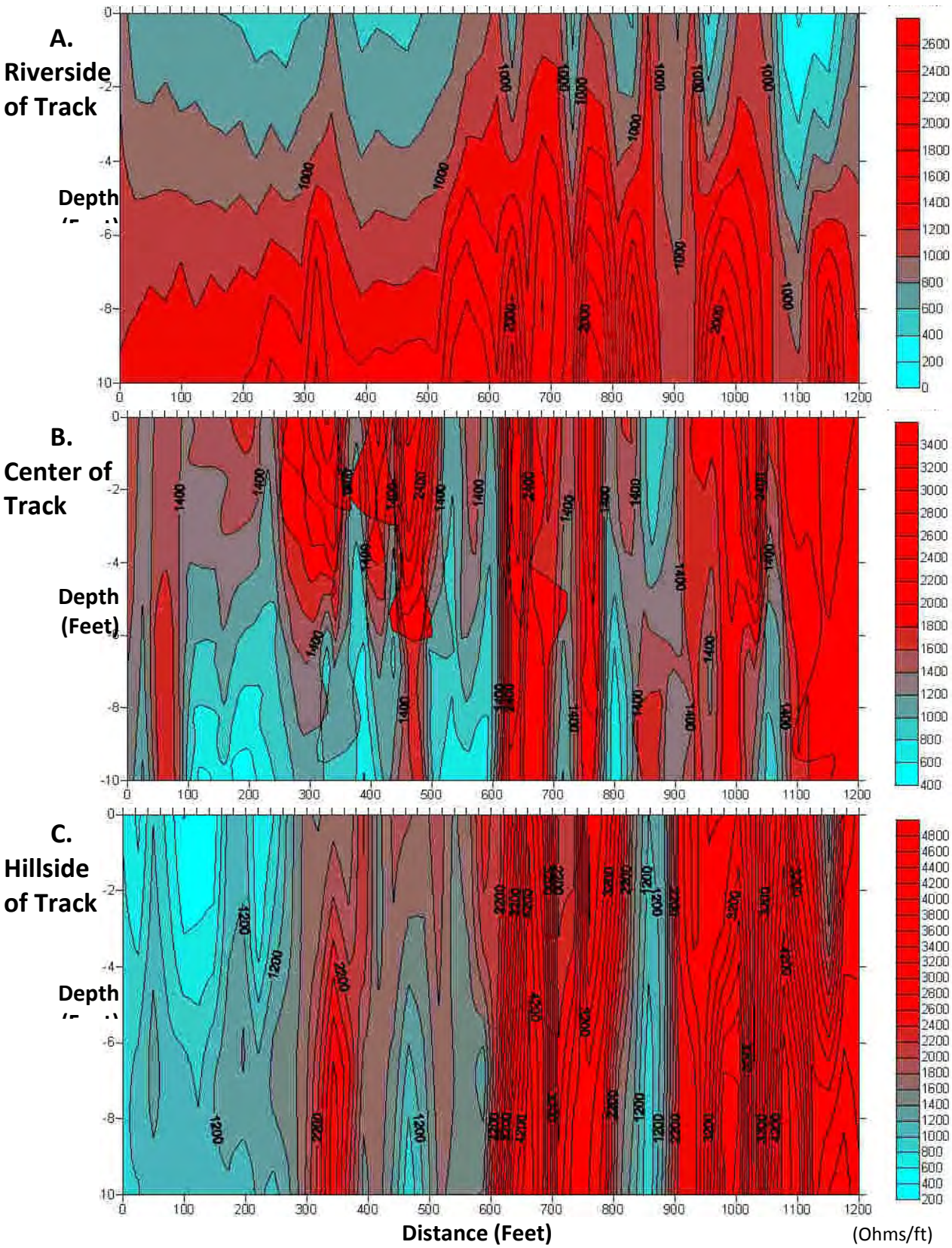

Figure 2. Resistivity Psuedo-Sections Along Rail Track

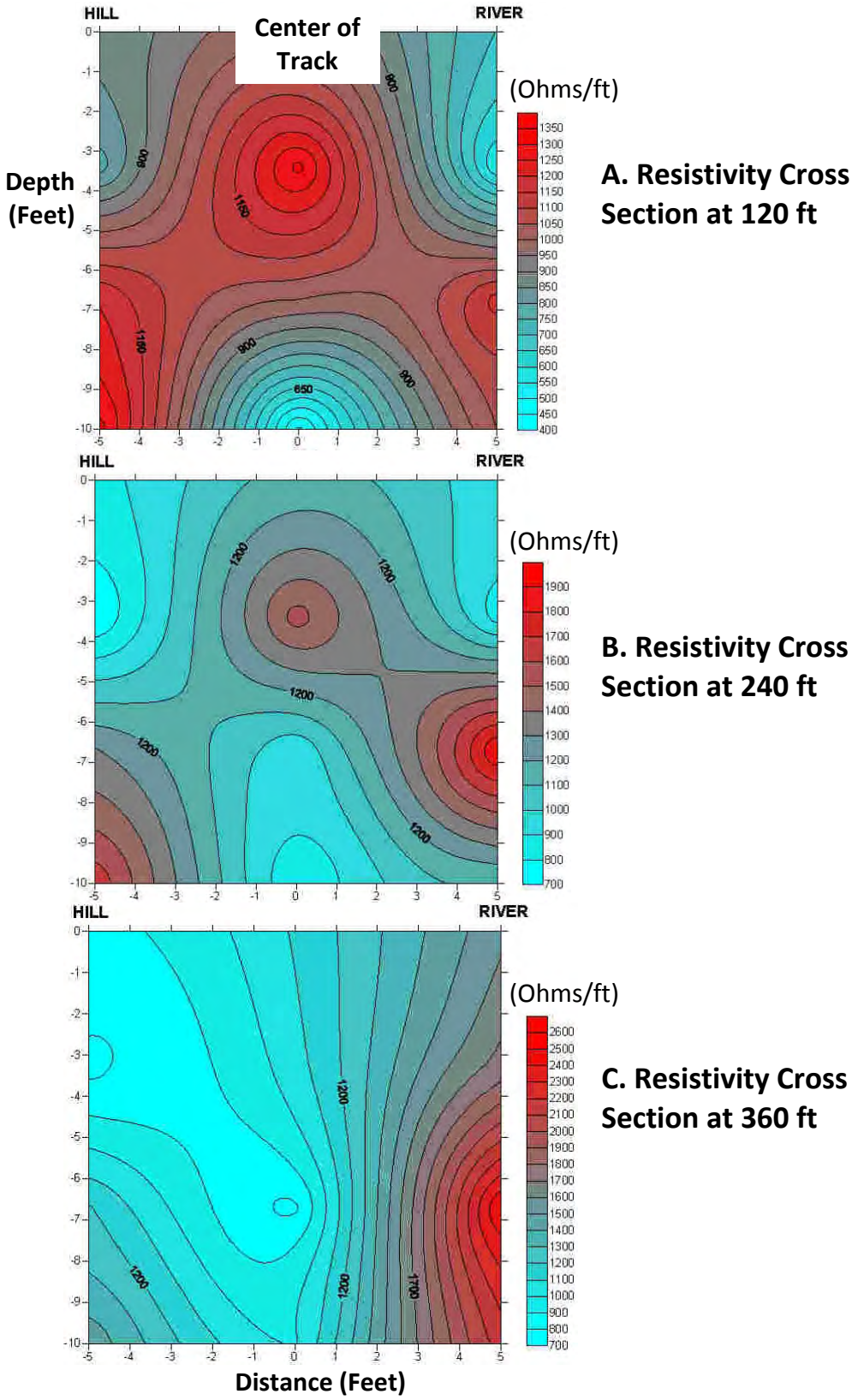

Figure 3. Resistivity Cross-Sections Across Rail Track

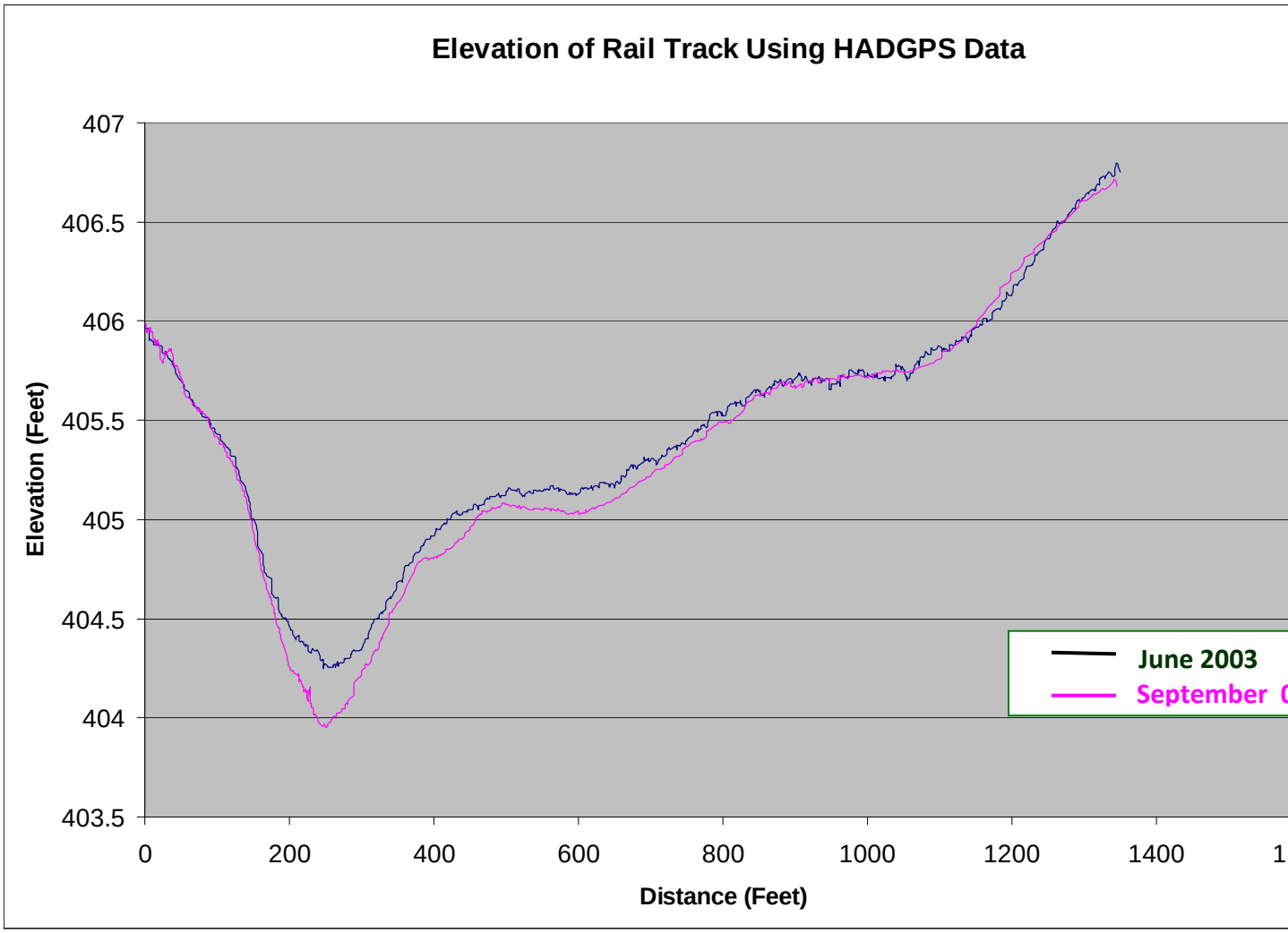
Elevation of Rail Track Using HADGPS Data
407
406.5
406
405.5
405
404.5
404
403.5
Elevation (Feet)
0
200
400
600
800
1000
1200
1400
Distance (Feet)
June 2003
September

Figure 4

Appendix G: Employing HADGPS to Survey Track and Monitor Movement at Curves

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KEYWORDS: HADGPS RTK, track surveying, track shift, monitoring curves.

ABSTRACT
Merging the railway engineer's expertise and innovative application of high-accuracy differential global positioning system (HADGPS) technology precise coordinates of rail track can be acquired, economically. The applications discussed are the rapid surveying of a classification rail yard and measuring track shift at curves, in accordance with Federal Rail Administration (FRA) requirements. Under appropriate conditions, HADGPS RTK is proving to be a promising accurate and economic tool to monitor track position, and measure track shift, to an accuracy of 2 cm.

INTRODUCTION
The demand for high-speed trains in Europe has spurred the development of tools to precisely measure track position and alignment, such as global positioning systems (GPS) that provide high density three-dimensional position data. In the United States, the FRA requirement to identify and accurately locate rail flaws, track sub-structural anomolies and monitor track movement or shift at curves is driving interest in applying accurate GPS technology. For example, HADGPS is being use as a key component of a multi-sensor platform to precisely survey the track (Wildi 1999, Szwilski 2003).

The integration of GPS with geographic information systems (GIS) has also been effectively used in track monitoring, maintenance planning, train tracking and scheduling (Southby 1995). The key to GPS function is a receiver that determines radio signal travel time from an orbiting space vehicle. This provides a psuedorange from the satellite-to-receiver. Determining accurate position data requires a minimum of four satellites. A second receiver, set up on a known position, provides additional corrections to the roving GPS receiver, correcting for various errors that degrade GPS performance. Error sources such as ionospheric and tropospheric delay; satellite clock and ephemeris (orbit) errors are eliminated by using the fixed base station to send the differential between the received signal and known position to the roving receiver. The receiver uses the carrier signal from 5 or more satellites as a "radio yardstick" by determining the integer and fractional number of wavelengths.

Accurate track position data can be obtained using a mobile platform, such as a hy-rail or locomotive. With rover receiver mounted on hy-rail platform data collected has the advantage of being able to conduct surveys in adverse weather and the evening. For both monitoring and surveying of track, HADGPS data is stored in a GIS database. Accurate coordinates from the HADGPS provide location data to monitor movement and adjust track alignment. As the HADGPS samples at a constant rate, surveying at a higher speed results in a lower density of data collected. For example: A HADGPS receiver with a 1 Hz data rate traveling at 50 km per hour collects a data point every 14 meters, and at 10 kph about every 3 meters. By contrast, traditional surveying practices are labor intensive and have produced mixed results in areas of significant ground movement with associated movement of surveying monuments, or with line-of-sight problems.

HADGPS AS A TRACK SURVEYING TOOL

A classification yard located in Alabama (Figure 1), designed and built in the 1950's, was surveyed using a HADGPS technique. The yard design in 1950 called for friction-bearing rail cars, a 56-track hump yard with pneumatic retarders, east and west forwarding yards, a receiving yard, and an engine shop with turntable. Modern rail cars employ roller-bearings which have significantly different resistance characteristics than the traditional friction bearing for which the yard was designed. The original grades were designed to allow the cars to roll off the hump down into the yard and come to a gentle stop or couple to an existing cut of cars with minimal impact. As time progressed, however, these grades changed as the tracks settled and shifted as a result of loading and forces incurred from rolling stock. Occasional maintenance and resurfacing has helped to maintain the original grade. However, it was deemed necessary in 2003 to perform a large-scale re-surfacing of this classification yard due to an increasing frequency of rail car "roll-outs" and decreasing efficiency of the classification operation. These types of overhauls are often delayed or avoided due to the associated costs.

Figure 1. Classification yard in Alabama.

Results

Traditional surveying has taken more than six weeks at similar facilities, while exposing the survey crew to active yard operations. However, employing RTK HADGPS the yard was surveyed in three days, which involved marrying the technical and operational expertise of Norfolk Southern Railway Company (NSR) engineers and the innovative techniques developed by research at RTI, Marshall University. The rapid track monitoring and surveying system, employing HADGPS, was adapted to be synchronous with the car classification operations. Before commencing the RTK data collection, trials were conducted using a hy-rail with rover receiver affixed to test for multi-path error or interference of satellite signal from the nearby mine cars (Figure 2). About half a day was taken to fine tune the HADGPS set-up in the yard.

Figure 2. Testing for multi-path satellite signal error.

The accuracy of data collected by HADGPS surveying system was checked by comparing the data collected to data from traditional leveling conducted on four tracks. Four of the fifty-six tracks surveyed with a traditional level circuit on 33 m (intervals) stations generating several hundred points. Fifty-three of the fifty-six tracks were surveyed with the HADGPS RTK generating a data set of about 27,000 points. The yard redesign team's primary focus was on the vertical data component. The differences between the two data set profiles (nearest point to point) were compared with the differences grouped into four categories: Great (0 to 1.5 cm); Moderate (1.5 to 3.0 cm); Poor (3 to 6 cm); and Bad (greater than 6 cm). The accuracy range of data collected: Great 48%; Moderate 38%; Poor 14% and Bad 2%.

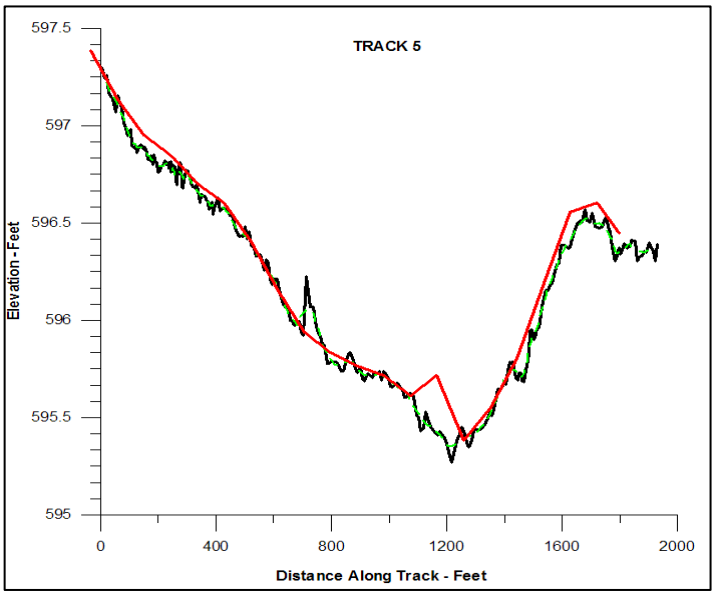


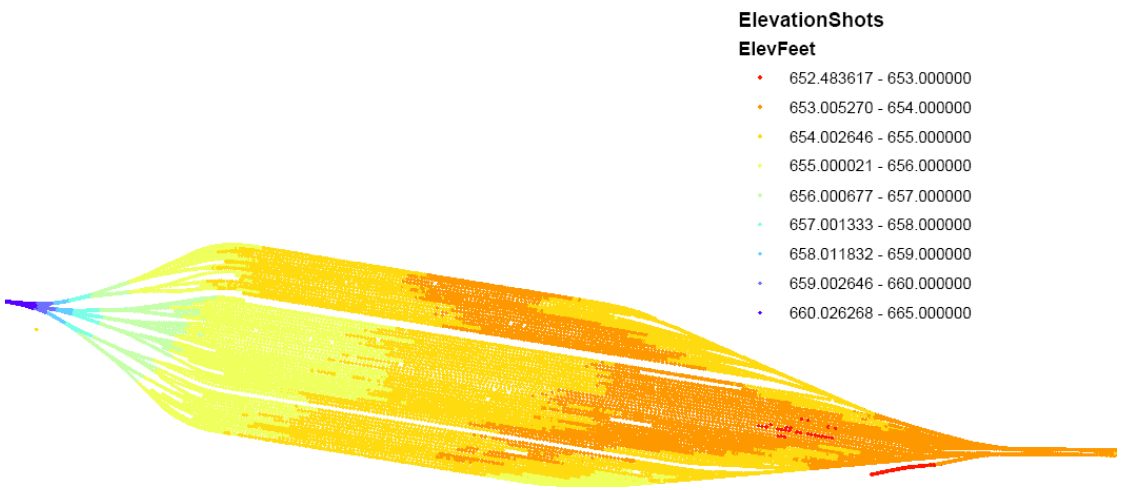
Figure 3. Comparison of traditional leveling (red line) and RTK HADGPS (black line) data, with rover receiver mounted on a locomotive

Figure 3 compares the data from the traditional leveling (red line) and HADGPS RTK collected with the rover located on a locomotive. As the locomotive weighed 127 tonnes, the HADGPS data produced loaded track data, while the leveling produced track elevations in the unloaded state.

Generally, the data required by track design engineers is traditional survey data (northing, easting, elevation) taken in a very specific way. In order to properly analyze the tracks, points of vertical and horizontal curve and tangency are surveyed to the best approximation. Using traditional surveying, where survey collection is slow and point density is kept low in order to increase collection efficiency, office personnel often rely on the field surveyor's "best guess". A method, such as the HADGPS, that takes many points close together (3 m to 5 m spacing) would allow for the use of regression analysis to create a more accurate computer model of existing facilities. Acquiring data of this density using traditional surveying would probably be cost and time prohibitive.

Figure 4: Elevation Profile of Classification Yard.

An unintended benefit to the yard management was the ability to review the HADGPS data imported into a GIS program after the conclusion of the survey. The gradient profile of the tracks produced by the GIS (Figure 4) provided confirmation of anecdotal operational issues.



Immediate feedback to yard management who noticed gradient change anomalies accounting for many operational problems with rollouts and derailments that had occurred over the years.

MEASURING AND MONITORING TRACK MOVEMENT AT CURVES

Recent FRA requirement to measure track shift caused by ambient temperature change has increased the scope of the research effort to develop an accurate and economic tool (HADGPS) to measure and monitor track alignment and movement at curves. Initial research has been conducted using HADGPS to survey track and monitor movement, especially in areas prone to track movement such as alongside rivers and curves. Once a baseline of HADGPS position data is initially established, in a GIS data base, track movement exceptions can be identified on subsequent inspection surveys.

Track movement in the form of buckling became a safety issue with continuous welded rail (CWR) on main line track, and high speed and high tonnage traffics. FRA rules require railroads to monitor curve rail neutral temperature (RNT) in the form of track movement (shift). Current methods of monitoring track movement at curves are: accounting for sections of track added and removed; stakes driven into the ground and measuring the stake to rail distance with a tape; and rail uplift, a rail stress determination technique which involves lifted the track. The FRA has established an Automatic Track Inspection Program (ATIP) that has been successful in detecting of potential accident-causing hazards. With recent trends of heavier equipment and some routes reaching maximum capacity, the need to inspect track rapidly and accurately is increasing. The FRA depends on the ATIP to: assess a railroad's performance-based compliance with the Track Safety Standards (TSS), defect exception analysis, and convenient access to historical data; and support accident and incident investigations.

Results

To date, two data sets have been collected at track curves identified as being prone to track shift. The data was collected in November 2004 and March 2005. The track position data was collected using the mobile HADGPS base station set-up. Figure 5 shows base station set-up in November 2004 (clear) and March 2005 (snow). The data sets include: static points marked on

the rail (Figure 6) just on the designated track curves and the hy-rail (RTK) traveling about 30 km per hour along the whole sections of track of interest. Wooden stakes were also inserted in the ground and its position relative to the inside rail measured with a tape.

Figure 5. Base-station set-up on November and March in New Mexico.

Figure 6. Taking a static HADGPS reading on rail at track curve.

Table 1 shows the two sets of data collected in November 2004 and March 2005. The change in track lateral position, perpendicular to the track, and elevation change is shown for the HADGPS static points on the rail, at the track curves. The changes in track position from the HADGPS RTK hy-rail runs were determined at the static points, to compare the HADGPS static point and RTK Data.

Table 1. Measurement of track movement (shift) using HADGPS static data. Horizontal movement (+) in direction of field side and (-) gauge side. The margin of error is 1 to 2 cm.

Mile Post	**Static Points Data: Position Change, cm**	
	Horizontal	Vertical
200.00	0.8	- 0.2
200.02	0.7	- 0.2
300.28	5.5	4.2
300.40	1.1	3.5
300.50	1.5	3.4
300.60	3.4	4.6
300.70	2.1	4.6
300.85	0.7	4.9

Due to the small temperature difference at the times of the two data collections (November 2004 and March 2005) the change in track position or track shift is small, and mostly fall within the margin of error (horizontal movement 1 to 2 cm) for and static measurements (Table 1) and the HADGPS RTK data shown in Figure 7.

From	To	Grid Azimuth	Grid Distance	Delta Elevation
274	274.00b	140°41'16"	0.008m	-0.002m
274.02	274.02b	355°21'35"	0.007m	-0.002m
274.05	274.05b	200°27'24"	0.013m	-0.003m
274.08	274.08b	38°32'46"	0.012m	-0.005m
274.15	274.15b	1°01'41"	0.028m	-0.003m
274.22	274.22b	316°24'20"	0.023m	-0.007m
274.3	274.30b	256°12'28"	0.022m	0.007m
285.28	285.28d	341°15'20"	0.055m	0.042m
285.4	285.4b	129°35'48"	0.011m	0.035m
285.6	285.6b	281°24'31"	0.034m	0.046m
285.5	285.5b	328°20'18"	0.015m	0.034m
285.7	285.7b	289°53'42"	0.021m	0.046m
285.85	285.85b	124°46'12"	0.007m	0.049m
286.0a	286.0b	359°36'02"	0.011m	-0.045m
285.95a_1	285.95b	240°44'35"	0.005m	0.002m

Figure 7. HADGPS RTK track movement (shift) survey in the mountains.

An objective of the trial was to evaluate the performance of the hy-rail (HADGPS RTK) platform as a track shift inspection tool by comparing the RTK and static data. The research team will return during summer 2005 to collect an additional set of data. However, the range of displacements are consistent and compare well with the small displacements recorded by tape measurements from wooden stakes inserted in the ballast, about 7 meters from the rail. There were indications that a couple of the wooden stakes had moved.

DISCUSSION

The preliminary trails employing HADGPS RTK as a track surveying and monitoring tool has proven to be very promising. As a surveying tool, under the appropriate satellite access conditions, HADGPS has many advantages over traditional surveying. Satellite access is often limited by challenging topography and vegetation. A significant part of this RTL technique is operational: setting up the base station in a strategic location, gaining access to track and track-time, data coolection and processing. There are several improvements that could be made to the process of data collection that can be made from lessons learned through further trials and experience.

Currently the default method to monitor track shift at curves, to satisfy FRA requirements, is tape measurements and wooden stakes. The method is very labour intensive in terms of installing the stakes into ballast then routinely taking and recording tape measurements. Also, wooden stakes inserted in ballast are often disturbed by vehicular impact, ballast movement and maintenance. The HADGPS RTK (hy-rail) is not limited by difficult weather conditions and with satellite access can function in the evening, collecting track position data safely and economically, with an accuracy of about 1 to 2 cm for the horizontal readings.
Another challenge is data display and interpretation, whereby processed data can be presented in an intuitive and easy to understand format. As demonstrated in Figure 6, colour coding is a simple means of showing the degree of track movement i.e the change in track position from data collected by the hy-rail platform in November 2004 and March 2005.

An effort is underway in West Virginia to employ HADGPS, and GIS, as key components of an intelligent transportation system (ITS) infrastructure for the railway corridors. This ITS will permit hundreds of kilometers of track and train traffic to be monitored. Traditionally, the accuracy of RTK position data is limited due the increasing systematic errors with increasing baseline length. At present, RTK positioning errors accumulate at the rate of 1 cm for every 10 km distant from the base station. Additionally initialization times between the rover and base grow with increasing distance. This limitation of HADGPS can be overcome by networking continuously operating GPS reference stations (CORS). An established network for RTK surveying introduces the concept of a Virtual Reference Station (VRS), a reference point established through the network server, and calculated from observations from four or more networked CORS. The networked CORS allow collection of RTK position data up to 40 km from the nearest reference station with the same accuracy and performance of a much shorter baseline (Talbot). Not only does the networked CORS permit the GPS user to increase the rover receiver distance from the reference station, it improves system reliability, and greatly reduces RTK initiation time. The VRS system consists of modeling and networking software, plus communications technology. Though networked CORS provided a goal for long-baseline surveying of rail lines, the focus of this paper employs a portable GPS base station and a roving receiver to survey and monitor track.

CONCLUSIONS AND FUTURE RESEARCH

The railway companies are exploring several alternative methods of performing track surveys and monitoring track shift. In addition to design applications, the need to have accurate and detailed yard maps is growing as the railroads integrate GIS and real-time data driven technologies into rail operations. While not suitable for green-site design where topographic data is best obtained using other methods, the on-track (hy-rail and locomotive) system tested in this trail shows great potential for gathering data in a manner that is both expedient and with little impact on operations in existing high-traffic facilities. These two factors being of utmost importance, the introduction of this technology into industrial applications would be a great boost to railroad design and maintenance data collection.

Developing a technique and technology to measure and monitor track shift at curves is a high research priority for the FRA. Further research work will done of improving the HADGPS RTK technique and sensors located at track curves to measure rail movement with wireless transmission of data Future research project might include using HADGPS measurements to collect data on locomotive motions, determining the magnitude of rocking suspension on particular sections of rail in order to model locomotive reaction to track conditions. Further research will be conducted into the application of HADGPS RTK on a locomotive and hy-rail platform for purpose of derailment analysis.

Work will continue on improving software to efficiently and reliably acquire, store, interpret and display HADGPS RTK data that is easy to understand. The real-time (or near real-time) display of the data is a goal.

ACKNOWLEDGEMENTS

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Appendix H: Rapid Surveying of a Classification Yard Employing High-Accuracy DGPS (RTK)

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ABSTRACT

Faced with a cost and time challenge to survey a fifty-six track classification yard for planned re-surfacing, Norfolk Southern Railway Company (NSR) teamed with a university research group to find a possible solution. Where traditional surveying has taken more than six weeks at similar facilities, the yard was surveyed in three days employing a real-time kinetic (RTK) high-accuracy differential global positioning system, marrying the technical expertise of NSR engineers and innovative technology of RTI[8] at Marshall University. The rapid track monitoring and surveying system was adapted to be synchronous with the car classification operations. The accuracy of data collected by this rapid surveying system is compared to traditional leveling conducted on four tracks.

INTRODUCTION

Modern railroad design engineers and track maintenance managers face many challenges in today's rapidly changing world. Legacy equipment, methods and design, much left over from the golden age of railroading, are constantly trying to keep pace with changing technology that is not designed to accommodate the needs of today's railroaders. This is especially true as engineers try to use modern field survey equipment and Computer Assisted Design (CAD) on a rail infrastructure built using pencil and slide-rule. Gone are the days of twenty person survey crews staking the centerline ahead of the graders. Today personnel are kept to a minimum with a three-person party considered excessive. When Norris Yard (Figure 1) in Irondale, Alabama, was designed and built in the 1950's it was riding the technological wave of the day. It was designed for friction-bearing rail cars and built with a 56-track hump yard with pneumatic retarders, east and west forwarding yards, receiving yard and engine shop with turntable. Fifty years later it is still operating as it did then, improved only by microprocessor controls, skate-retarders and remote control engines on the pull-out end. Also added to the mix are modern rail cars with roller-bearings, which behave differently than the traditional friction bearing for which the yard was designed.

The original design grades were set to allow the cars to roll off the hump down into the yard and come to a gentle stop or couple to an existing cut of cars with minimal impact. Over time, however, these grades have changed as the tracks settled and shifted as a result of loading and forces incurred from rolling stock. Occasional maintenance and resurfacing has

[8] Nick J. Rahall Transportation Institute (RTI), a University Transportation Center (UTC), at Marshall University, Huntington, West Virginia.

helped to maintain and restore the original grades. However, it was deemed necessary in 2003 to perform a large-scale re-surfacing of this classification yard due to an increasing frequency of rail car roll-outs and decreasing efficiency of the classification operation. These types of overhauls are often delayed or avoided due to the associated costs.

ENGINEERING NEEDS

The first step of this type of project is to survey and evaluate the physical condition, horizontal alignment and vertical profile of the tracks. The data is analyzed with regression software and CAD to create track profiles. These profiles are then compared with the tracks in the same group (there are seven groups in Norris Yard) and the original design grades for a quick "first analysis" to identify problem tracks. The results are compared with data from the operations department to further confirm, and/or identify additional, problem tracks or groups. Next, new grades are proposed and a scope of required work is outlined and estimated for time and cost. After final design and staking of the new grades, the re-surfacing can begin. However, the initial surveying phase has traditionally been the most time consuming and costly for the design department, and the principal reason alternative methods of survey data acquisition was considered.

A traditional yard profile survey, utilizing chain and level practices, can be time consuming and expensive. A survey of this scope can take many weeks to perform under traffic and cost up to $50,000. The survey crew is constantly in a battle for foul (track)-time, not to mention weather and additional demands on the time of today's scaled-back workforce. NSR Engineering has found that surveying classification yard tracks utilizing laser survey equipment can be subject to the same constraints as leveling and often produces unreliable vertical data. Line of sight is still required and significant planning is necessary in order to survey all tracks. Lastly, aerial surveying can be cost prohibitive and considered "survey overkill" in some situations. In order to obtain the data NSR's engineering department was seeking in a more timely fashion, a new method needed to be developed.

The data required by Track Design Engineers is traditional survey data (northing, easting, elevation) taken in a very specific way. In order to properly analyze the tracks, points that are more theoretical than physical, such as points of vertical and horizontal curve and tangency, are surveyed to the best approximation. Using traditional surveying, where survey collection is slow and point density is kept low in order to increase collection efficiency, office personnel often rely on the field surveyor's "best guess". A method that takes many points close together (10 to 15 feet spacing) would allow for the use of regression analysis to create a more accurate computer model of existing facilities. Acquiring data of this density using traditional surveying would be cost- and time-prohibitive.

FRA FUNDED RAILWAY RESEARCH ADDRESSES NEEDS

NSR's Design and Construction department received an inquiry from its Alabama Division Engineer regarding the cost for surveying a classification yard in late 2003. Having surveyed a similar facility on another operating division the previous year, the time and cost estimate for a project of this scope quickly raised concerns. Not only was the cost much more than anyone expected, the time frame was too long to meet the Division Engineer's needs. A

brainstorming session ensued in the Design and Construction's break-room with the Chief Engineer during which the many challenges and potential options of surveying a yard were discussed. A member of the design department had attended the 2003 AREMA[9] conference presentation in Chicago and transportation meetings[10] at Marshall University, and became aware of an innovative technology that uses high accuracy DGPS for on-track surveying. As a follow-up the NSR Design and RTI[11] research team discussed the potential of using hi-rail mounted HADGPS to survey the rail yard track. Although this technique had never been attempted before in a rail yard, at least by NS, it promised meet the needs of NSR. The joint endeavor would also provide RTI with an opportunity to evaluate the accuracy of the HADGPS rail surveying technique and fine tune software, while providing a valuable service to the railroad industry. The HADGPS technology is being employed by this research team to survey track and monitor track shift at curves (3), working with various railroad companies.

APPLYING HADGPS (RTK) TECHNOLOGY

Before beginning the yard survey several trail runs were made with the RTI Hi-rail between rows of rail cars to test for multi-path HADGPS errors, see Figure 2. Initially there was concern whether HADGPS rover would receive GPS satellite transmissions while running on an empty track between adjacent ones loaded with rail cars, forming a valley effect. Thus a "multi-path" test was run to evaluate then fine tune the HADGPS, which subsequently functioned well.

During the yard survey a problem was encountered with the hi-rail vehicle attempting to pass through the skate-retarder[12]. As the retarders are designed for large rail car wheels the smaller wheels of the hi-rail vehicle became jammed when it attempted to traverse its first skate. After some brainstorming the surveying equipment was mounted on a 4-axle local engine and the yard HADGPS survey proceeded, collecting data traveling at 10 to 15 mph. However, Murphy's law prevailed as the engine blew a head gasket after traveling for a couple of hours. The equipment was then re-mounted on a yard switch engine which permitted surveying to progress and be completed in three days. This survey included over a hundred static points established throughout the yard with a survey-pole mounted unit. Meanwhile, three NSR Design section employees profiled four sample tracks by the traditional chain and sight level method. This data was compared to the GPS survey elevation data.

In total, four of the fifty-six tracks were surveyed with a level generating several hundred points; fifty-three of the fifty-six tracks were surveyed with the HADGPS (RTK) generating a vertical track data set of about 29,000 points. The design team focused on the vertical data component. The vertical track survey data set to be analyzed from traditional level method was evaluated against the profiles created HADGPS method. At stations (100 feet intervals) the differences between the two profiles (nearest point to point) were measured. These differences were grouped into four categories: Great (0 to 0.04 feet), Moderate (0.05 to

[9] American Railway Engineering and Maintenance of Way Association.
[10] Technical Forum of the Appalachian Coalition for Geological Hazards in Transportation, Center for Environmental, Geotechnical and Applied Sciences; RTI
[11] Nick J. Rahall Transportation Institute
[12] "Skate retarders", or "skates" are installed on the pull-out end of each class track. This mechanical device functions like a 20 feet long friction brake that keeps rail cars from escaping from their assigned track, fouling the ladder, hitting another train or an employee.

0.09 feet), Poor (0.1 to 0.19 feet) and Bad (greater that 0.2 feet). The accuracy range of data collected: Great 48%; Moderate 38%; Poor 14% and Bad 2%. Confident that the data could be further refined and the profiles made more accurate during the design phase using detailed regression analysis, the data was considered adequate for use. Using the product InRoads V8 (Bentley Systems) and Microstation CAD software, profiles were generated, analyzed and problem areas identified. New design profiles were created and then staked in the field using traditional survey methods. Figure 4 shows a further refinement of the vertical data from the HADGPS (RTK) and traditional leveling. The accuracy of the vertical data was determined as the distance (feet) between the leveling data point to the HADGPS running average curve.

In preparation for the track raising and surfacing, ties were replaced, electrical connections to the skate retarders were checked and ballast was stockpiled. Due to scheduling luck, a yard cleaning gang was on site and had the yard tracks swept and debris removed before the surfacing gang arrived. Finally, working one group at a time, the surfacing gang came in and raised the tracks to the set grades (see Figure 3).

LESSONS LEARNED

As a data acquisition experiment this could be judged as success. As in other industries, 'time is money' and the rapid rate that data can be collected for office use using HADGPS (RTK) has many advantages over traditional surveying. However, there are several improvements that could be made to the data collection process that would both speed up the office calculation part of the process and inspire even more confidence in the accuracy of the data. Most of these improvements, though, are likely to be from lessons that can only be learned through experience to enhance what promises to be a viable data collection method.

First, a hi-rail rover with adequate vertical clearance to clear mechanical track obstructions would greatly improve the process and accuracy. An engine is a large piece of machinery that rocks and shakes and is not designed to operate as a stable surveying platform. This vertical error could be seen in the profiled data sets, especially on tracks surveyed in multiple directions (sometimes the rover made multiple passes along a track). While a best-fit alignment is produced during regression, a tighter data set would produce more accurate results.

Second, organization of the data collected could be improved. The point density returned was so high (29,000) that it was hard to organize entries during evaluation. Working with such a large data set taxed the CAD workstations and led to the conclusion that the hardware will have to be upgraded, or the survey data density reduced, in future surveys. In a case like this, each track could be numbered starting with a different series for better organization of data. For example, if running down class track 27, prefix every point name with c27. A series of points would then progress like c270001, c270002, c270003, etc. In addition to being better organized, some regression software can read these point progressions and create alignment and profile data from the order in which they were collected. This would dramatically cut office design time currently spent hand-selecting each track point by point on CAD.

Third, a laptop was used to download the HADPGS survey data and display topographic representations of the yard using GIS software. A review of the thousands of survey points

immediately following the conclusion of the survey painted a graphic picture of the yard topography. The instantaneous review by the yard manager and others confirmed anecdotal problem areas and provided yard management confidence in the HADGPS survey technique.

FUTURE EFFORTS

Norfolk Southern Railway Company is currently exploring several alternative methods of performing surveys. In addition to design applications, the need to have accurate and detailed yard maps is growing as the railroads integrate GIS and real-time data driven technologies into rail operations. While not suitable for green-site design where topographic data is best obtained using other methods, the on-track system tested in this experiment shows great potential for gathering data in a manner that is both expedient and has little impact on operations in existing high-traffic facilities. These two factors being of utmost importance, the introduction of this technology into industrial applications would be a great boost to railroad design and maintenance data collection.

ACKNOWLEDGEMENTS

The authors acknowledge the research funding provided by the Federal Rail Administration and guidance from Mahmood Fateh, of the Federal Rail Administration; the Norfolk Southern Railway Company for providing resources and railroad track engineering expertise. Also, gratitude for the administrative assistance from the Nick J. Rahall Transportation Institute, Marshall University.

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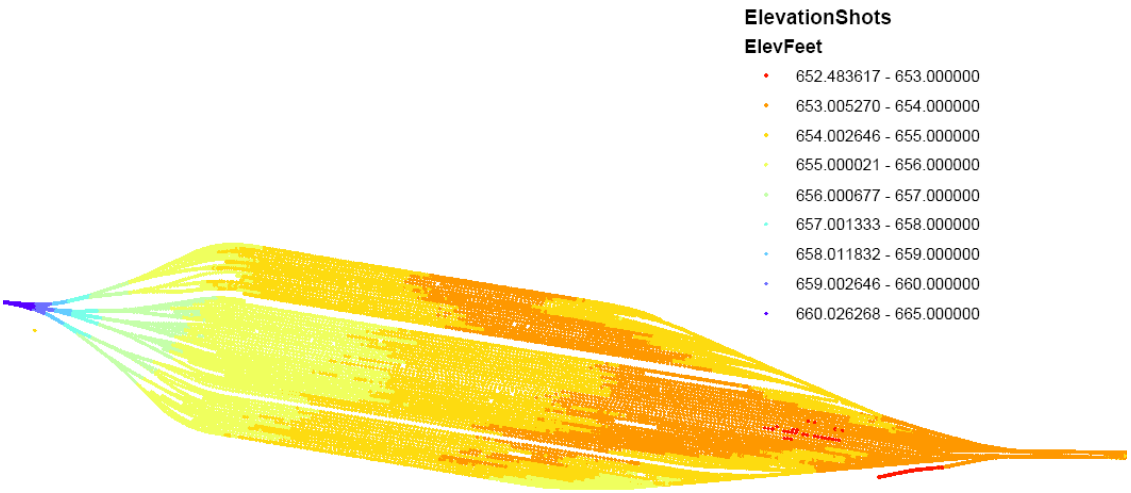
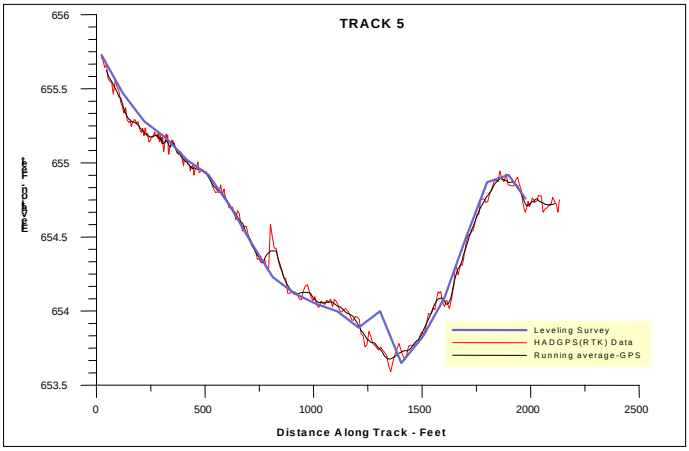
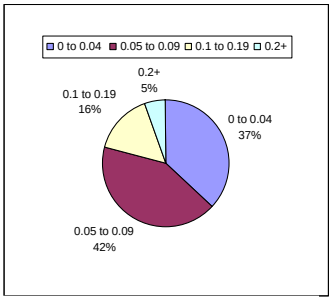
Figure 1: Norfolk Southern Railway Company's Classification Yard, Birmingham, Alabama

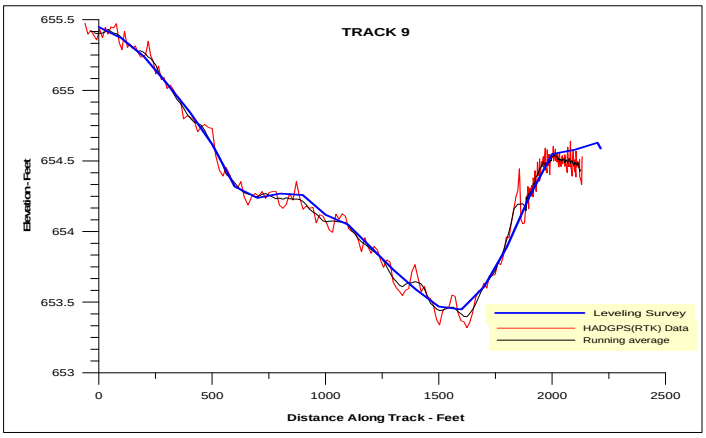
Figure 3: Resurfacing operations

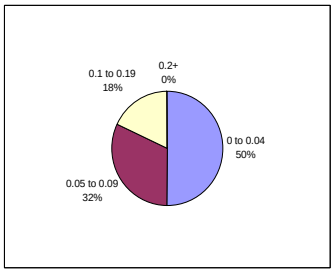


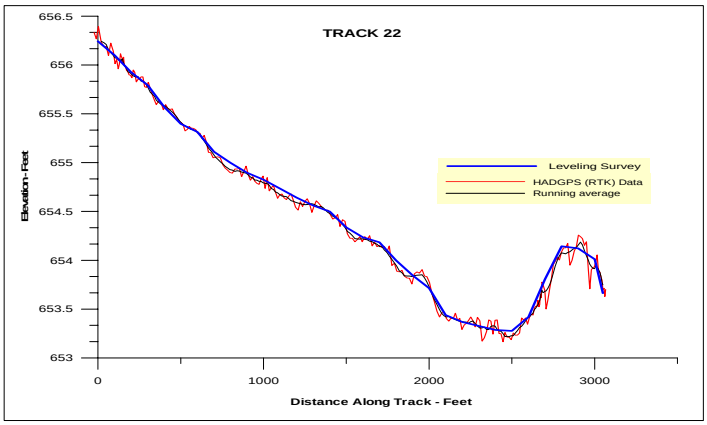




Vertical Data Accuracy - Feet







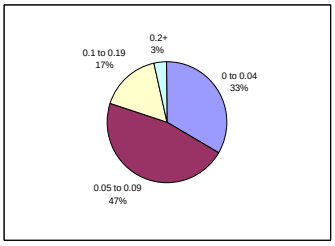


Figure 4: Comparing traditional leveling and HADGPS (RTK) vertical data sets for three tracks. Accuracy of the vertical data is the distance (feet) between the leveling data point and the HADGPS running average curve.

Appendix I: Employing High Accuracy DGPS to Monitor Track Shift

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Abstract

Track shift and buckling caused by ambient and rail neutral temperature changes became a safety issue with continuous welded rail (CWR) on main line track, particularly on high speed and high tonnage track. The Federal Rail Administration (FRA) requires railway companies to measure and monitor track alignment and track shifts at buckle prone curves. The preliminary trials employing high-accuracy differential global positioning system (HADGPS) in real-time kinematic (RTK) mode to measure track shift is producing promising results. HADGPS RTK technology and survey technique can determine track shift to an accuracy of 2 cm on tangent track and 3.5 cm on curves. The application of HADGPS to measure and monitor track movement is relatively new to the United States railway industry.

Introduction

A recent FRA requirements to monitor and measure track shift is the principal driver for this research program. The goal is to develop an accurate and economic tool to measure and monitor track alignment and track shift at curves. To accomplish this goal, researchers have been collaborating with railway companies BNSF, NS and CSX railways to apply HADGPS technology and develop tools that will meet FRA requirements and address their needs. The track shift monitoring technique has evolved by merging the technical expertise of a railway companies and innovative application of high-accuracy differential global positioning system (HADGPS) technology to achieve the economic acquisition of precise coordinates of rail track. Under appropriate conditions HADGPS is proving to be a promising convenient, accurate and economic tool to monitor track position and measure track shift [1,2]. HADGPS also permits classification yards to be surveyed in three days, compared to a typical six weeks using traditional level surveying [3]; and monitor track in areas prone to track movement such as alongside rivers [4].

The current methods to address the FRA requirements to monitor curve movement and shifts in rail neutral temperature (RNT) are: accounting for sections of rail added and removed, reference stakes and tape to measure track movements, and a rail stress determination where the track is lifted (rail up lift). The key to the FRA's Automatic Track Inspection Program (ATIP) success is the detection of potential accident-causing hazards. With recent trends of heavier railroad cars and some routes reaching maximum capacity, the need to inspect track rapidly and accurately is increasing.

GPS Technology

The first United States Global Positioning System (GPS) space vehicles (SVs) were launched in 1978, spearheaded by the Department of Defense (DoD) and could be considered the most successful exploitation by civilians of a military endeavor. There are two global satellite-based navigation systems available at present, with another in the initial stages of implementation. The United States pioneered the technology with a progression of systems dating from 1958, culminating in the Global Positioning System [5].

What GPS Accuracy is Available?
The U.S. GPS provides standard positioning service using each SV to transmit a modulated digital (SPS) code on the satellites L1 frequency. Performance standards are set by the DoD to guarantee global average positioning domain accuracy to ≤ 13 meter horizontal and ≤ 22 meters vertical, with worst case ≤ 36 meters horizontal and ≤ 77 meters vertical. Performance standards are stated with 95% system availability. In order to increase accuracy, there are several methods to augment the errors from the satellite broadcasts. These methods include ground based and space based augmentation systems (SBAS).

1. <u>Space Based Augmentation Systems</u>

The United States Federal Aviation Administration (FAA) put a Wide Area Augmentation System (WAAS) into operation in 2003, in order to meet flight requirements for increased accuracy, availability and integrity for all phases of flight in the National Airspace System. Although designed primarily for aviation users, WAAS provides corrections to the SPS signal to improve positioning accuracies in North America. WAAS consists of twenty-five ground reference stations positioned across the US. Two master stations on either coast collect the reference station data and create a GPS correction message.

2. Ground Based Augmentation Systems

Ground-based augmentation systems are found world-wide, following the international standard ITU-R-M.823 and referred to in the US as the Nationwide Differential Global Positioning Service (NDGPS). NDGPS provides real-time enhancements to the SPS GPS signal. Enhancements to the NDGPS will provide sub-meter accuracy over the continental U.S. and portions of Alaska to support a wide range of navigation and positioning requirements at the federal and state levels. NDGPS currently provides single coverage service over 87% of the continental U.S., Alaska, Hawaii, and Puerto Rico. The NDGPS performance standard is for positioning accuracies of 2 to 5 meters horizontal, within 250 miles of a reference station. Sub-meter accuracies of 10 to 20 cm are possible with special equipment & software. Using the NDGPS requires a radio receiver capable of receiving and processing corrections broadcast between 285 and 325 KHz.

Space Based Augmentation Systems (WAAS)	2 to 5 meters horizontal accuracy
Ground Based Augmentation Systems (NDGPS)	1 to 3 meters (To 10 cm with special equipment)
Survey grade HADGPS	1 cm ± 1 ppm horizontal 2 cm ± 1 ppm vertical

Table 1: Accuracies of GPS Systems

3. High-Accuracy DGPS and Virtual Reference Stations (VRS)

Most of the initial development of tools to precisely measure track position and alignment, such as global positioning systems (GPS) to provide high density three-dimensional position data, has been in Europe, spurred by the increasing use of high-speed trains. For example, HADGPS is being use as a key component of a multi-sensor platform to precisely survey track [6].

REAL-TIME KINETIC (RTK) METHODS: By counting the number of wavelengths of the SV's L2 carrier wave, the distance between an antenna and SV can be further refined. Carrier-phase differential GPS (CPDGPS), also referred to as real-time kinematic GPS (RTK), uses two or more receivers capable of phase-shift measurements to provide positioning accuracies to 1 cm ± 1ppm horizontal and 2 cm ± ppm vertical. This technique requires signals from at least four SVs be collected simultaneously throughout the measurement process. Dual frequency receivers, those capable of both L1 and L2 band reception, are best suited for this work. Like DGPS, one fixed position receiver is used for broadcasting corrections to the roving unit. The base station broadcasts typically use modulated VHF or UHF FM signal. However with a connection to the Internet, a base station can supply corrections to a rover over the cellular telephone network.

A single base station can provide coverage for an approximate 40 km radius from its position. Beyond 40 km, initialization times and consideration for the ppm error grows. The ppm error indicates that for every million parts distant from the base station, the error increases by one part. For example, a 10 km distance from the base adds an additional 1 cm position error. To overcome this error source, a network of base stations connected to a central server, can provide a virtual reference station (VRS) to the roving receiver. The server uses modeling software to create a VRS located a meter from the user's positions. As the

error grows, the server is able to recalculate a VRS and automatically send a new VRS location to the rover. This reduces error growth from the ppm and reduces initialization times for the rover.

Track Shift Measurement Technique

The track shift measurement technique consists of employing HADGPS receiver mounted on a hy-rail vehicle to collect (GPS) track location data traveling at a speed of 20 to 30 km per hour, then storing the data in a GIS database to establish the initial baseline. The track shift distance is then determined by comparing the track location data on subsequent surveys to the baseline data. Software has been written to compare the data points from the different hy-rail runs and determine the track shift. The track shift can be determined for tangent track and curves. The curve analysis technique requires further improvement.

Coordinates from the HADGPS provide location data for track. As the sampling rate of the GPS is constant, surveying at a higher speed will result in a lower density of data collected. For example, the HADGPS (Trimble 5700) receiver samples every second. Therefore, sampling at 50 km per hour collects a data point every 13.9 meters, at 10 km per hour about every 2.8 meters. Traditional surveying practices are labor intensive and produce mixed results, especially when conducted during inclement weather, in areas of significant ground movement, and in areas where damage occurs to reference stakes. Additionally, traditional surveying requires line-of-site to the target which can be impractical or hazardous for the survey crew.

Under the appropriate satellite access conditions, HADGPS has many advantages over traditional surveying. Advantages: Much longer baselines that traditional optical surveying; use of established national or global coordinate systems (U.S. State Plane, UTM) rather than using a local coordinate system; all-weather, 24 hour surveying possible; aids the transition from a linear referencing system to a geographic one, which is important in developing remote controlled locomotives. Disadvantages: Satellite access is often limited by challenging topography and vegetation; transmitting differential corrections via UHF radio is likewise disadvantaged due to terrain and output power. However, modernization of the civilian GPS signal deals with some of the present limitations with additional digital signals (the L2C) and increased SV signal strength.

A significant part of the RTK technique is operational: setting up the base station in a strategic location, gaining access to track and track-time, data collection and processing. Improvements to the data collection process are expected from lessons learned through further trials and experience. Another challenge is to interpret and display the processed data in an intuitive and easy to understand format.

Track Shift Measurements

Several data sets were collected at track curves identified as being prone to track shift. Data in one area with several curves was collected in November 2004, March 2005 and August 2005, under different ambient temperatures. The track position data was collected using a temporary HADGPS base station set-up. Figure 1 shows base station set-up in November 2004 (clear) and March 2005 (snow). The data sets include: static points marked on the rail (Figure 1) at reference stake measurement locations and with continuous collection from a hy-rail (RTK) traveling about 30 km per hour along the track sections of interest. Steel reference stakes (fence posts) were also driven into the ground and used to measure the distance to the rail with a tape.

Figure 1. Base-station set-up on November 2004 (top left) and March 2005 (top-right) in New Mexico. Static HADGPS point readings (bottom left) taken are taken at strategic intervals around the track curve.

A combination of small temperature difference between data collections (mean temperature 9° C in November 2004; -2° C in March 2005; 18° C in August 2005), and track maintenance resulted in small track shifts. All the HADGPS RTK, static points and reference tape measurements yielded track shift within 7.0 cm. Figures 2 and 3 show the track shift. Track movements are shown color coded: Green 0 to 2 cm track shift; Yellow is 2 to 4 cm shift; Brown is 4 to 6 cm shift; and Red is greater than 6 cm shift. An accuracy of +/- 2 cm for HADGPS static and RTK horizontal readings was typically achieved. Track shift accuracy at curves was typically +/- 3.5 cm. Therefore most of the track shift readings are within or close the margin of error, especially at the curve sites. The RTK measured displacements are consistent and compare well with the small displacements recorded by tape measurements from reference wooden stakes and steel fence posts. There were indications that a couple of the reference stakes had moved.

Discussion

The track sites measured to-date have not yielded significant track shift and are typically within the margin of error for the HADGPS (RTK) surveys. All three methods of measurements: HADGPS-RTK, static reading and reference tape measurements provided consistent results. In at least one curve track movements were detected and corrected by the track maintenance using surfacing equipment to shift the track horizontally to the desired location, in the period between HADGPS-RTK measurements. Overall, the preliminary trials employing HADGPS RTK as a track shift measurement and monitoring tool is proving to be very promising.

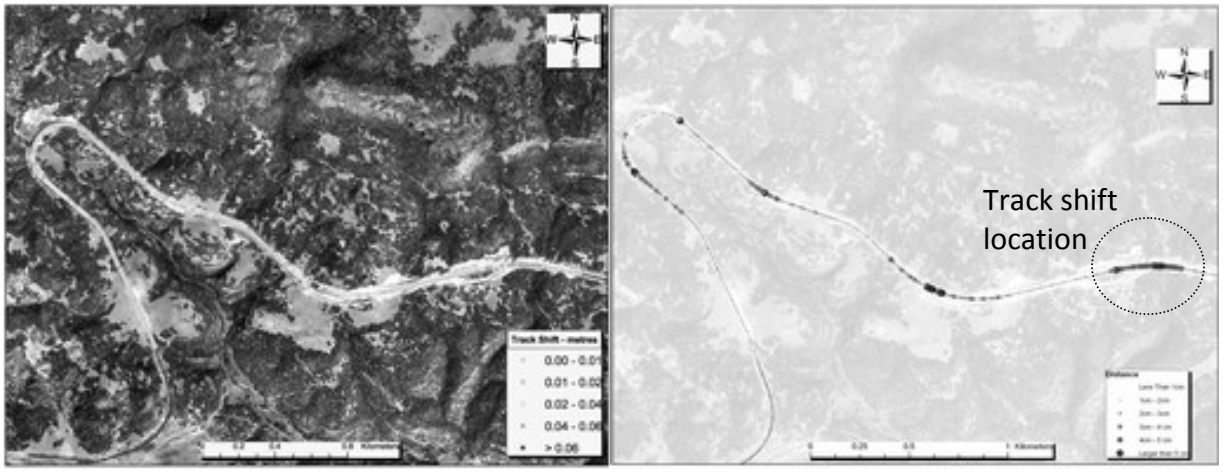

Figure 2. Oak Canyon Curve (usually color) lateral track movement using a color code.

Figure 3. Horse Shoe Curve lateral track movement.

Currently, the common method to satisfy FRA requirement to monitor track shift at curves is taking tape measurements from the rail to steel reference stakes strategically located around the curve. This method of recording tape measurements at each stake is very labor intensive and the stakes can be disturbed by vehicular impact or soil movement. The HADGPS RTK (hy-rail) survey method is not limited by difficult weather conditions. With sufficient satellite coverage HADGPS can collect track position data safely and economically, 24 hours a day 7 days a week with typical accuracy of 1 to 2 cm for the horizontal readings. Satellite visibility may be limited by challenging topography and foliage. Track shift is determined by comparing two sets of track position data taken at different times; a GIS-based technique and software is used to determine the distance the track has moved. Typically a (lateral) track shift accuracy of +/- 2 cm for tangent track and +/- 3 cm for curves is achieved.

A significant part of this RTK technique is operational: setting up the base station in a strategic location, gaining access to track and track-time, data collection and processing. There are several improvements that can be made to improve data processing and measurement procedures based on our experience. Another challenge is improved display of processed data in an intuitive and easy to understand format. As demonstrated in Figures 2 and 3 (black and white photograph), color coding is a simple means of showing the degree of track movement i.e. the change in track position from data collected by the hy-rail platform.

RTK positioning errors accumulate at the rate of 1 cm for every 10 km distant from the base station and initialization times between the rover and base grow with increasing distance. This limitation of HADGPS can be overcome by networking continuously operating GPS reference stations (CORS): the focus of this paper is the employment of a portable GPS base station and a roving receiver to survey and monitor track. An established network for RTK surveying introduces the concept of a Virtual Reference Station (VRS), a reference point established through the network server, and calculated from observations from four or more networked CORS [7]. The networked CORS allow collection of RTK position data up to 40 km from the nearest reference station with the same accuracy and performance of a much shorter baseline [8]. Not only does the networked CORS permit the GPS user to increase the rover receiver distance from the reference station, it improves system reliability, and greatly reduces reading initiation time. HADGPS and GIS are being applied as key components of an intelligent transportation system (ITS) infrastructure for railway corridors permitting the survey of hundreds of kilometers of track on a routine basis.

Conclusions and Future Research

Developing a technique and technology to measure and monitor track shift at curves is a high research priority for the FRA. Further research is scheduled to improve the HADGPS RTK technique; by making the technology system more modular, easy to use and robust. Future work will address more productive means to process the data and precise definition, measurement and modeling of track curves. This includes improving the track shift determination technique. Railway companies are exploring several alternative methods of monitoring track shift. The HADGPS-RTK on-track (hy-rail) system tested in this trial shows great potential for gathering data in a timely and efficient manner with acceptable accuracy. The researchers continue to gain experience applying the HADPGS technology surveying classification yards and other monitoring projects. The further development of this technology will greatly enhance the railroads ability to identify and take corrective action in buckle prone locations thus improving railroad safety and operations.

Acknowledgements

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