TECHNICAL SESSIONS

MONDAY P.M.

3:30-4:00
A Protocol For Selecting Appropriate Geophysical Surveying Tools Based On Engineering Objectives and Site Characteristics, by Neil Anderson, Steve Cardimona and Allen Hatheway

Engineering geophysical techniques measure specific physical parameters and are routinely applied to highway-related problems. The engineer responsible for site investigation should ensure that geophysical technique(s) employed provide cost-effective information about physical properties of interest at the required levels of spatial resolution and target definition. As an aid to the highway engineer, we present tabularized information about some commonly employed geophysical methods, and a generalized approach for evaluating their utility. Our discussions are intended to be informative - not exhaustive. For more rigorous treatments of the geophysical techniques the reader is referred to the selected bibliography. The engineer engaged in survey design is strongly encouraged to work with a knowledgeable geophysicist.

4:00-4:30
Electrical Resistivity Techniques for Subsurface Investigation, by Steve Cardimona.

Geophysical resistivity techniques are based on the response of the earth to the flow of electrical current. With an electrical current passed through the ground and two potential electrodes to record the resultant potential difference between them, we can obtain a direct measure of the electrical impedance of the subsurface material. The resistivity of the subsurface, a material constant, is then a function of the magnitude of the current, the recorded potential difference, and the geometry of the electrode array. Depending upon the survey geometry, the data are plotted as 1-D sounding or profiling curves, or in 2-D cross-section in order to look for anomalous regions. In the shallow subsurface, the presence of water controls much of the conductivity variation. Measurement of resistivity is, in general, a measure of water saturation and connectivity of pore space. Resistivity measurements are associated with varying depths relative to the distance between the current and potential electrodes in the survey, and can be interpreted qualitatively and quantitatively in terms of a lithologic and/or geohydrologic model of the subsurface.

4:30-5:00
Case Studies in Pile Dynamic Analysis (PDA), by Suzanne McNaughton

TUESDAY A.M.

8:30-9:00
Subsurface Investigation Using Ground Penetrating Radar, by Steve Cardimona

The ground penetrating radar geophysical method is a rapid, high-resolution tool for non-invasive investigation. Ground penetrating radar records microwave radiation that passes through the ground and is returned to the surface. The radar waves propagate at velocities that are dependent upon the dielectric constant of the subsurface, and reflections are caused by changes in the dielectric constant that are due to changes in the subsurface medium. A transmitter sends a microwave signal into the subsurface, and the

time it takes energy to return to the surface relates to the depth at which the energy was reflected. Thus, interpretation of this reflected energy yields information on structural variation of the near subsurface. Ground penetrating radar transmitters operate in the megahertz range, and the choice of source signal peak frequency helps to determine the expected depth of penetration and resolution. Higher frequency sources will offer greater vertical resolution of structure but will not penetrate as deep as lower frequency sources. The choice of appropriate source will be target and project-goal dependent. Data are most often collected along a survey profile, so that plots of the recorded signals with respect to survey position and travel-time can be associated with images of geologic structure as a function of horizontal position and depth. Ground penetrating radar can be collected fairly rapidly, and initial interpretations can be made with minimal data processing, making the use of ground penetrating radar for shallow geophysical investigation quite cost-effective.

9:00-9:30

GPR As A Tool For Detecting Problems In Highway-Related Construction, by Scott Lewis.

Three case studies utilizing GPR for highway related projects are presented. Methods, investigation approach, results, strengths and weaknesses of GPR in each situation, and improvement recommendations for similar efforts in the future are discussed. The first case involves GPR for the evaluation of possible construction deficiencies related to cracking observed in a newly constructed soundwall. Efforts at void location within the soundwall were mostly unsuccessful due to antennae resolution, although two potential voids were imaged. Although rebar posed difficulties in allowing the GPR signal to penetrate the wall, the rebar imaging itself gave indications of construction weaknesses. Correct antennae orientation allowed the location of some soundwall bond beams. Zones of excess concrete and missing bond beams were detected. The second case involves the use of GPR for void detection and delineation caused by washout from an old brick-lined sewer beneath pavement that shows varying signs of subsidence. A secondary purpose of this study was also the delineation of the sewer itself. Used in conjunction with two punch cores taken through the pavement for control, the GPR was able to delineate the washout zone and the location of the sewer quite well. The third case involves a GPR survey of a concrete bridge approach slab in which the purpose was to evaluate possible construction deficiencies. Variations in the concrete and rebar mat, relative to a baseline of data collected in the nearby vicinity, and are seen as

9:30-10:00

Enhancing Geotechnical Information With The GPR, by Marc Fish

To learn how well a ground penetrating radar (GPR) could supplement or replace conventional test borings a research project was initiated through the Federal Highway Administration's Priority Technology Program. The objective of the research was to determine if the GPR could distinguish between and accurately determine the depth to different soil layers, the water table, bedrock, bedrock fractures, subsurface voids and river bottom profiles within different locations throughout New Hampshire. GPR profiles were obtained at locations between test borings or at locations where test borings could not be done because of environmental concerns, time constraints or difficulties with drill rig access. A total of seventeen geotechnical projects used the GPR as either the sole source of subsurface information or as a supplement to conventional test borings. One site investigated bedrock fractures within a roadway rock cut. Two sites investigated the profiles of a river bottom. Three sites investigated potential subsurface voids. Nine sites investigated soil and bedrock depths One site investigated an old stream channel location, and one site investigated the depth to the ground water table. This paper discusses the success and failures of using the GPR at these seventeen project sites. It includes what criteria were used to determine if the GPR could be used on a particular project, the GPR techniques employed, and the verification processes for the GPR results.

BREAK

10:30-11:00

Identification And Delineation Of Sinkhole Collapse Hazards in Florida Using GPR and Electrical Resistivity Imaging, by Michael Garman

Sinkhole development is a geological hazard affecting the northwest quarter of the Florida Peninsula. New sinkhole frequencies are highest in the central and west central areas of the State. New sinkholes form more frequently when both the water table is low and heavy rainfall occurs. With record low water tables after 3 years of drought in the Spring of 2001, new sinkholes became a significant geologic hazard in some parts of the State and affected many major roads.

Government agencies in Florida routinely use geophysics as part of a geotechnical evaluation of sinkholes after a collapse has occurred. Ground penetrating radar (GPR) and electrical resistivity imaging (ERI) are important tools for detecting and evaluating the subsurface dimensions of buried depressions, caves, and/or raveling soil pipes associated with ground surface collapse. The images that are provided by these geophysical methods, combined with test boring data, are used to evaluate the volume of the karst feature and to determine the cost effectiveness and best method of remediating the collapse. Three case studies from Florida are described in the following paragraphs.

Case studies show the important role of GPR and ERI in the evaluation of sinkholes affecting roadways. However, these case studies also draw attention to the fact that geophysical investigations are not performed during the planning of roads and their associated retention basins. Sinkhole precursors such as buried depressions, raveling soil pipes, and cavities are readily identifiable by the appropriate geophysical survey. When performed prior to construction, the roads and retention basins can be relocated to avoid adverse conditions or roads can be designed to bridge sinkhole prone locations.

The cost analysis is simple. The Thonatosassa Road buried depression could have easily been identified as part of a GPR survey that cost about $10,000.00. The road could have been moved to the side approximately 15 feet or built to bridge the 27-foot diameter throat. Instead over $250,000.00 from an emergency budget was spent to stabilize the feature while several lanes of the road were closed. In the Mariner Boulevard example, an improperly located retention basin caused millions of dollars of damage. The buried depressions beneath the retention basin could have been easily identified by a $1,500.00 GPR survey, allowing the retention basin to be moved to another location.

11:00-11:30

GPR and EM Surveys to Detect and Map Peat and Permafrost, by Roark Smith

Ground penetrating radar (GPR) and electromagnetic terrain conductivity (EM) surveys were performed to detect and map peat layers and frozen ground at a proposed landfill site near Fairbanks, Alaska. Geotechnical test pits showed the presence of peat layers and discontinuous permafrost across the site, prompting a concern that differential settlement could disrupt the leachate collection system that was to be installed beneath the landfill refuse. A geophysical pilot study was undertaken to better assess the extent of peat and frozen ground and thus the potential for settlement. GPR and EM were selected because they are shallow-focus, high-resolution techniques that provide for rapid real-time subsurface scanning and continuous data coverage along a survey line. Thus, the techniques could be used to fill in the data gaps between the test pits. It was expected that GPR would image the electrically conductive peat layer, and frozen ground would exhibit low conductivity that could be readily detected by the Geonics EM31. In addition, the test pit data provided an exciting opportunity to “ground truth” the geophysical data and accurately assess the effectiveness of each method for detecting peat permafrost. A particular objective of the pilot study was to determine if GPR could be used to assess the thickness of peat layers.

11:30-12:00

Preliminary Results of Cavity Mapping Using EM Induction to Aid Highway Design, by Momoh Mallah.

An Electromagnetic (EM) induction survey was carried out in and around the Forestiere Underground Gardens for a proposed interchange, construction project. The aim was to locate underground rooms and tunnels, associated with the gardens. Inside the gardens, a 14m X 9m grid was set up on the surface over known locations of rooms and tunnels. Three other grids measuring 30m X 20m were surveyed within the vicinity. Data were collected mostly on a 0.5m grid. A multi-frequency electromagnetic profiler was used to collect data across 6 frequencies ranging from 1770 to 19950 Hz. Contoured plots were generated from this survey and verified the efficacy of this method for location of the tunnels and rooms. These results are to be used as a standard for interpreting results from other areas. One of the anomalies from the gardens, coincidental with a 1.5-inch steel pipe on the surface, was further investigated at our facilities in order to resolve ambiguity. An area with no obvious surficial metallic debris was chosen and a grid established. This grid was surveyed with and without a similar 1.5-inch diameter steel pipe on the ground. Results showed that the pipe on the surface was not detected, thereby confirming our original interpretation.

TUESDAY PM

1:30-2:00

Determination of Granular Material Deposit Volumes, by Steve Cardimona.

University of Missouri Rolla, Department of Geology and Geophysics utilized the ground penetrating radar and differential GPS (DGPS) tools to investigate thickness of fine gravel sized milled rock over natural ground throughout a large area of previous mine workings near Joplin, Missouri. Using a 400MHz-frequency radar antenna, UMR achieved signal penetration sufficient for this study and data quality was high. Clearly evident in the data is the interface between the milled rock and clay soil. An average radar velocity for all sites was obtained by calibrating the radar signals with one point of available ground truth and the time-to-depth conversion was determined from this. The average depth to the soil layer across all the sites varied from 27cm to 96cm. DGPS was used to map both the areas and GPR survey lines. The GPS data provided the elevation profiles and areas necessary to calculate three-dimensional volumes of the material. The techniques described in this report can be employed for estimating the volume of the granular deposits that is essential for determining available fill material for roadway construction projects.

2:00-2:30

Ground Penetrating Radar (GPR): A Tool for Monitoring Bridge Scour, by
Doyle J. Webb, Neil L. Anderson, Tim Newton and Steve Cardimona

The University of Missouri-Rolla (UMR) and the Missouri Department of Transportation (MoDOT) acquired ground-penetrating radar (GPR) profiles across streams at ten different bridge sites in Southeast and central Missouri. The intent was to determine whether GPR is an effective tool for monitoring bridge scour (i.e., estimating water depths and identifying in-filled fluvial scour features). The interpretation of the acquired profiles indicates that the GPR tool can be used to accurately estimate water depths in shallow fluvial environments (<20 feet). In some instances, in-filled (paleo) scour features can also be imaged and mapped. GPR has certain advantages over alternate methods for estimating water depths. GPR can provide an essentially continuous profile-type image of the stream channel and the sub-water bottom sediment along the route selected. The GPR antennae are non-invasive and can be moved rapidly across (or above) the surface of a stream at the discretion of the operator. The GPR tool does not need to be physically coupled to the water surface and can be operated remotely, ensuring that neither the operator nor equipment need be endangered by floodwaters.

2:30-3:00

Efficient Large-Scale Underground Utility Mapping Using A New Multi-Channel GPIR System, by Ralf Birken.

Witten Technologies Inc. (WTI) non-invasive Ground Penetrating imaging Radar system (GPiR system) improves on standard ground-penetrating radar (GPR) by using a 16-channel radar array and advanced signal processing routines to produce three-dimensional (3D) images of the subsurface and 3D maps of underground utilities. The array in the GPiR system, which covers a 6-foot (2-meter) swath on the ground and can be towed by a vehicle at speeds up to 2 miles/hour, collects enough data in one pass to form a 3D-radar image beneath its track.

Additional features of the CART systems are a very precise geometry control and advanced signal processing and visualization software. During the GPiR data collection a self-tracking laser theodolite is following a prism mounted on the CART system collecting precise positioning information. In city environments the positioning has typical accuracies of better than 1 centimeter. The raw GPiR data are filtered with custom pre-processing algorithms and merged with the geometry data. The subsequent migration of the data produces high-resolution 3D radar images of the subsurface, which are interpreted for the 3D locations of infrastructure lines present. The final products can be large-scale maps, custom 11 by 17-inch depth-slice plots, custom 3D images, depth-slice movies or 3D CAD drawings in widely used formats. These visualizations clearly show the complexity of the subsurface infrastructure environment in large cities.

The combination of those features allows the GPiR system to be used efficiently for large-scale underground utility mapping. This is demonstrated with results from a pilot project in which the GPiR system was used to map buried utility conduits and other shallow structures on a large-scale in New York City. In four nights of surveying an area of approximately 120 000 sq ft (nearly 3 acres) was covered including a geodetic survey of surface features (curbs, street signs, valve covers, manhole covers, etc.) in the survey area to provide a local reference grid for the radar images. Small subsets of the large areas were analyzed in more detail.

BREAK

3:30-4:00

Integrated Geophysical Investigation of Abandoned Landfill, Grandview Triangle Area, Kansas City, Missouri, by Galih Agusetiawan, Neil Anderson and Steve Cardimona

The University of Missouri-Rolla (UMR) acquired a suite of geophysical data (magnetic and electromagnetic) across an abandoned landfill in the Grandview Triangle (GT) study area, Kansas City, Missouri for the Missouri Department of Transportation (MoDOT) as part of a broader geotechnical characterization of site. The primary objective was to identify and locate any large, metal objects (vehicles, tanks, etc.) within the landfill, which could potentially collapse/compact under the weight of the overpass and vehicle traffic. A secondary objective was to determine if any large metallic objects (such as fuel tanks) remain buried within the abandoned fuel station sites immediately adjacent to the landfill. Due to increased traffic volume at the junction of I-470, I-435 and Hwy 71 (Grandview Triangle), south Kansas City, a highway extension and a new overpass are planned. A section of this new overpass will overlie over an abandoned landfill. Landfill records are poor. Essentially, all that remains are aerial photographs showing the progression of the construction at or around the site. There is no formal account as to the exact nature of the garbage that was used to fill the land. Similarly, there are no documented records indicating that all fuel tanks were removed from the abandoned fuel station sites.

Inasmuch as the new overpass will extend across the abandoned landfill, MoDOT engineers are concerned about the nature of the material previously deposited on site. Large, under-compacted metallic refuse is of particular concern, as these objects may collapse under the increased pressure from the thickened overburden, concrete support pylons, and vehicle traffic. (Anecdotal reports suggest the burial of a school

bus at this site.) There is also concern that fuel tanks could be buried on the abandoned fuel station properties. The geophysical study of the landfill and fuel station sites appears to have been successful. High-amplitude, complementary anomalies were identified on the magnetic and electromagnetic data sets. Two of these anomalies could be generated by buried fuel tank on the fuel station properties. At least one prominent geophysical anomaly from the abandoned landfill site could be generated by a small, buriedvehicle. These anomalous features will be tested (by excavation or drill) later this Fall, and the nature of causative features will be determined.

4:00-4:30
Geophysical Methods For Mapping Abandoned Mines, by Tom Lefchek

4:30-5:00
Non-Invasive Geophysical Methods Applied To Sanitary Landfills: Solid Waste Management Unit 059, by Neil Anderson.

Magnetic Field Strength, Multifrequency EM induction, and GPR surveying were conducted to qualitatively characterize a suspected former landfill as part of the Environmental Assessment phase of a proposed road construction project at Fort Leonard Wood Military Reservation in Missouri. Preliminary field observations were unable to substantiate the existence of a shallow sanitary landfill where a series of subtle geomorphological features (parallel trenches and crests) suggested that 'earth-moving' activity possibly associated with the operation of a landfill had occurred. No historical records documented the existence of such activity. A subsidence study determined that the cross sectional settlement in the suspect area was found to be less when compared to that of an adjacent established landfill and laboratory tests. Hence, conventional subsidence techniques may not be useful in cases where post-landfill activity has altered the former landfill's surface.

The use of non-invasive complementary magnetic, electromagnetic, and ground penetrating radar methods were useful in mapping boundaries and depths of trash zones as follows: 1) The magnetic method detected distinct peak variations (nT) in the Earth's total magnetic field due to ferromagnetic anomalies associated with ferrous trash remnants in the in the shallow subsurface. 2) The electromagnetic method using 4 kHz out of phase (quadrature) EM data detected increased conductivity in the trench features where there was more capacity of the orthent to hold moisture. 3) Using a 400 MHz antenna, unfiltered GPR data detected changes in dielectric constants where buried refuse was interpreted through hyperbolic diffraction's and strong lateral variations not likely caused by natural sedimentary features.

WEDNESDAY A.M.

8:30-9:00
Overview Of The Shallow Seismic Reflection Technique, by Neil Anderson

The shallow seismic reflection technique is relatively straightforward from a conceptual perspective. Essentially, we generate a high-frequency, short-duration pulse of acoustic energy at the earth's surface, and measure the arrival times and magnitudes of "echo pulses" that are reflected from subsurface horizons (i.e., water table, bedrock, lithologic and facies contacts, etc.) and returned to the earth's surface. Ideally, the travel times and magnitudes of these recorded "echoes" can be used to create a 2-D or 3-D velocity/depth model of the subsurface. If borehole lithologic control is available, a geologic image of the subsurface can be generated. In practice however, the reflection seismic technique is complex - mostly because the echoes (reflected energy or seismic events) of interest are contaminated by both coherent and random noise. To compensate, sophisticated acquisition and processing methodologies have been developed to enhance the relative amplitude of the reflected events of interest. Many of these methodologies are site and target

dependent. The interpretation of reflection seismic data is also a complex process, and as much an art as a science. Interpreted velocity/depth models can be unreliable because of either inaccurate velocity control or incorrect seismic event identification.
Similarly, seismic amplitudes can be misinterpreted because of gain distortions. Forward seismic modeling and the inclusion of external geological and geophysical constraints are often the key to successful interpretations, and the development of a reasonable subsurface geologic image. The potential user should bear in mind that the quality of reflection seismic data is technique, site, and target dependent. Interpretable data will not be generated if improper acquisition and/or processing techniques are employed. In certain instances, interpretable data cannot be recorded (using cost-effective conventional methodologies) because of adverse site conditions, or because the target characteristics (i.e., small size, lack of anomalous attributes, etc.) preclude its delineation.

9:00-9:30
Collecting Shallow CMP Siesmic Data With Automatically Planted Geophones, by Kyle Spikes

Shallow-seismic reflection imaging in the 2 to 20 m range requires dense spatial sampling. Geophones must be planted individually by hand along the entire length of the survey line at 5 to 50 cm intervals. This acquisition geometry requires intense manual labor, resulting in high cost and substantial time in the field for a shallow-seismic reflection survey. To lower expenses and time in the field, the geophones need to be planted in a more time-efficient method. Currently, 72 geophones are being planted automatically and simultaneously by bolting them to four pieces of rigid channel iron. Two hydraulic cylinders working in tandem are then connected to each segment of channel iron. All eight cylinders are mounted on a trailer, which provides the platform for moving the geophone array. Planting 72 vertical geophones by hand typically requires three people to work for 15 minutes. Using the hydraulically powered geophone-planting apparatus, the same task can be accomplished in less than 90 seconds. Differences are negligible between common midpoint (CMP) data collected with conventionally planted geophones and CMP data acquired with automatically planted geophones, allowing the same subsurface information to be extracted from each. Therefore, automated shallow-seismic reflection surveying is likely to be developed in the near future.

9:30-10:00
Near Surface Three Component Seismic Data Acquisition, by Matthew Ralston.

Multi-mode analysis of the full vector wavefield has the potential to provide engineers and geophysicists with near-surface soil properties such as unit thickness', stratal geometry, soil strength, compressibility, and pore-fluid content. Acquisition of the full vector wavefield using three-component (3C) receivers, however, is a time-and labor-intensive procedure. The purpose of the current research is to develop a means of acquiring the full vector wavefield in an efficient and cost-effective manner so that the analysis and interpretation of these data might become general practice within the near-surface geophysical community. Our approach has been to rigidly attach arrays of 3C Gal'perin receiver units to lengths of channel iron. The channel iron serves as an acquisition device that eliminates the need to individually plant, connect, vertically level, and horizontally orient each 3C unit. I model the acquisition device as a linear filtering mechanism and approach the resulting crosstalk between receiver mounts as an inverse filtering problem that requires determination of the transfer function of the acquisition device. Coincident acquisition of seismic data using both device-mounted and traditional spike-mounted 3C Gal'perin units provides a means to estimate the transfer function. Application of the inverse of this function to the device-mounted data results in field gathers that are equivalent to those recorded with traditional spike-mounted 3C units.

BREAK

10:30-11:00
Seismic Refraction Interpretation With Velocity Gradient And Depth of Investigation, by Michael Rucker.

Traditional interpretation of seismic refraction data has used a concept of layered horizons or zones where each horizon has a discrete seismic velocity. Software packages are now available that analyze and present seismic velocity as a continuously varying gradient across a grid or mesh. Such packages may utilize optimizing methods coupled with finite element or finite difference concepts to achieve interpretations. The resulting velocity gradient style of interpretation presents very different representations of the subsurface compared to traditional interpretations. These differences include advantages, disadvantages and conceptual challenges in utilizing the results. A profound advantage is an explicit interpretation of depth of investigation defines by the grids utilized in the interpretation. The author has observed that interpretations in geologic environments containing velocity reversals, where an underlying horizon seismic velocity is lower than in the overlying horizon, the velocity gradient method tends to interpret shallow depths of investigation consistent with bottom depths of the higher velocity horizons. In geologic environments with gradually increasing velocities with depth due to increasing confining pressure, such as cohesionless granular deposits, velocity gradient interpretations can be more realistic than forced multi-layer interpretations. Abrupt increases in the gradient velocities inconsistent with confining pressure may be a reasonable indicator of cemented or cohesive materials rather than cohesionless materials. However, the velocity gradient concept tends not to model true abrupt changes, such as discrete soil-rock boundaries with large seismic velocity contrasts, as effectively as more traditional interpretations. Furthermore, rippability criteria developed over the last 30 or more years predates velocity gradient interpretation methods; velocities obtained by gradient methods may not match well with traditional velocity interpretations used to develop those criteria. The author is presently performing interpretations using a combination of both traditional and velocity gradient interpretation to utilize the advantages of both concepts.

11:00-11:30

Seismic Refraction Analysis of Landslides, by Charlie Narwold.

Seismic refraction has proven a useful geophysical tool for investigating landslides. The velocity structure of a landslide mass and the depth to the failure surface are variables that may be estimated using seismic refraction. Data obtained using refraction can aid in determining appropriate mitigation and maintenance practices involving landslides. One method used to interpret seismic refraction data, the General Reciprocal Method (GRM), calculates refractor depths using overlapping refraction arrival times from both forward and reverse shots. The GRM assumes a layered model and is effective when the velocity structure is relatively simple and refractors are gently dipping (<20°). However, the velocity structures of landslides are often complex, involving lateral variations in velocity, steeply dipping refractors, and diffraction's from blocks within the landslide mass. Refraction tomography, another method of interpreting seismic refraction data, is capable of modeling complex velocity structures. Using first arrival picks, refraction tomography develops a best-fit velocity model by iteratively comparing different velocity structures with observed data. In one example, the GRM was effective in modeling a landslide with a simple velocity structure. Based on the model, the landslide appears to be a shallow feature restricted to the uppermost velocity units, consistent with field observations. In a survey of a different landslide, abrupt changes in the depth to the top of the lowermost velocity unit, interpreted to be bedrock, correspond to the mapped edges of the landslide. The apparent vertical displacements in the bedrock are interpreted to indicate the landslide is a deep-seated feature. In another example, velocity models of a landslide generated using tomographic analysis, indicate low-velocity slide material over a steeply dipping, concave up, high velocity unit interpreted to be bedrock. Offsets in the bedrock refractor possibly indicate fracturing and displacement extending into bedrock. In all three examples, seismic refraction surveys and analysis of the data provided information integral to the understanding and treatment of the landslides.

11:30-12:00

Repeatability of Seismic Refraction Data, by Dennison Leeds.

Two different seismic refraction surveys performed three years apart with different instruments identified a common refractor, even after the ground surface elevation had been reduced 15 meters by construction grading. Preliminary investigations for rippability and earthwork factors were performed using seismic refraction methods in November 1998 at the New Benicia Martinez Toll Plaza site, to be completed

sometime in 2002. A refractor was defined at that time and determined to be unrippable at an elevation of 12 to13 meters. The calculated seismic velocity of the refractor was 2000 m/sec. This refractor was approximately 17 meters below original ground surface. A second seismic refraction survey was performed at the same location in March 2001, after the site had been excavated to a subgrade elevation of 16.5 meters. The results identified a refractor 3.5 meters below the new grade elevation. Its seismic velocity was calculated at 2031m/sec., within 1% of the survey done three years prior. The refractor elevation was determined to be in the same range as the original survey. Both profiles were processed using the same commercially developed seismic processing program and were recorded using the same parameters. LOTB data identifies siltstone bedrock at this elevation. Initial excavation in preparation for tunnel construction at this location confirmed the interpretation of unrippable bedrock.

WEDNESDAY P.M.

1:30-2:00
High Resolution Seismic Reflection Applied To Rock And Soil Subsidence Problems, by James W. Cooksley.

Subsidence of rock and soil masses is commonly associated with cavernous rock formations, but is also experienced over man-made cavities such as mine workings and cavities resulting from broken water lines. If there is reason to suspect the potential of subsidence, high-resolution seismic reflection profiles can provide the imagery necessarily to assess the configuration and depth of the cavity. Furthermore, if subsidence has occurred or is taking place, the horizontal and
vertical extent of the subsidence can be interpreted from the reflection seismic sections. The refection seismic method has been successfully applied to sinkhole studies in Florida and Pennsylvania and to mine subsidence problems in California.

2:00-2:30
Synthetic Reflection Seismic And Ground Penetrating Radar (GPR) Data: The Key To Understanding These Subsurface Imaging Techniques, by Neil Anderson and Steve Cardimona

Forward modeling of reflection seismic data is a computational process through which a geologic (depth/acoustic impedance) model of the subsurface is transformed into a synthetic reflection seismic section (forward model). Forward models are generated both before and after the field acquisition of reflection seismic field data. Models generated before acquisition can demonstrate whether an intended target is likely to generate an interpretable reflection signature, and can also be of assistance in the design of field acquisition parameters. Models generated after data acquisition facilitate the interpretation of the processed reflection data, particularly if the geologic models are generated from "ground-truth" (borehole sonic and density logs).

Forward modeling of ground penetrating radar (GPR) data is in many ways analogous to the modeling of reflection seismic data. The main practical differences are related to the nature and scale of the geologic (or otherwise) model. GPR models depict spatial variations in dielectric constant as opposed to acoustic impedance. Units incorporated into radar models can be as thin as one millimeter (or less), whereas lithologic units incorporated into reflection seismic models seldom have thicknesses of less than one meter.

2:30-3:00
Geophysical Site characterization: GPR And Reflection Seismic Study Of Previously Mined Ground, by Tim Newton.

The University of Missouri-Rolla (UMR) conducted a reflection seismic/ground-penetrating radar survey for the Missouri Department of Transportation (MoDOT) along segments of proposed interstate route 249, near Joplin, Missouri across ground previously mined for lead/zinc. A total of 14,600 lineal meters of shallow reflection seismic data, nine down-hole seismic calibration check-shots, and 15,000 lineal meters of ground penetrating radar (GPR) data were acquired. The seismic data were acquired to map Mississippian bedrock, locate and identify paleo-sinkholes and abandoned mine features, and determine structural geologic trends in the study area. The GPR data were acquired to identify and locate abandoned mine access and ventilation shafts in areas that were overlain by surficial milled ore rock (chat). Pre-construction knowledge of these anthropogenic and natural features will assist in route selection and geotechnical site mitigation, and minimize both the potential for contractor variable site condition claims and the potential for long-term subsidence-related problems. The geophysical survey was successful in meeting MoDOT goals. The interpretation of the seismic data, and corroborative engineering geologic field mapping and drilling, established that the shallow reflection seismic technique can be used in the Joplin area to map bedrock structure (including probable fault lineaments and paleo-sinkholes), locate abandoned, in-filled and/or caved-in open pit mines; and define areas of probable shallow mining activity. The interpretation of the GPR data established that the GPR technique can be used in the Joplin area to locate abandoned mine access and ventilation shafts, even where such shafts are in-filled and overlain by a thin veneer of mill-waste products.

BREAK

3:30-4:00
Crosshole Sonic Testing Of Cast-in-Drill-Hole (CIDH) Piles, by Kim Price

4:00-4:30
Estimate of CIDH Pile Concrete Compressive Strength From Cross-hole Sonic Testing, by Zha Jinxing.

This paper presents preliminary findings from Cross-hole Sonic testing data of concrete compressive wave velocity and laboratory results of concrete compressive strength for nine concrete cylinders from various project sites. Based on the correlation between the modulus of elasticity and compressive strength of concrete specified in ACI Code, Section 8.5.1, Cross-hole Sonic Logging can be utilized to monitor and evaluate the curing of concrete for CIDH piles, in addition to detecting homogeneity or anomalies of CIDH pile concrete. A direct correlation between the compressive strength and the wave velocity is proposed for estimating the compressive strength of CIDH pile concrete. Results of Cross-hole Sonic Logging for a 2133-mm (84-inch) diameter CIDH pile of the Salinas River Viaduct new construction project on State Route 41 in San Luis Obispo County, California are discussed to further delineate anomalies previously identified by Gamma-Gamma Logging and to provide information on concrete curing.

4:30-5:00
2D, 3D Crosshole Sonic Tomography (CST) Versus Crosshole Sonic Loffing (CSL) For Drilled Shafts, by Natasa Mekic Stall, Robert E. Grimm and Pieter Tackenberg

In recent years, development of NDT methods has been increased and one of the principal objectives for development is a reliable assessment of the integrity or detection of defects of concrete structures. Obtaining accurate and timely information about construction defects is important for major structural stability and safety issues and also for project progress and success. Crosshole Sonic Logging method (CSL) has become the standard method for testing the integrity of concrete structures. Although this method has proven to be valid, the results are difficult to interpret and are often ignored by the project site engineer. Crosshole Sonic Tomography testing and imaging (CST) has better accuracy in providing the geometrical and volumetric information about defects then CSL testing. This improved accuracy is related to geometry of data acquisition along with the larger amount of data collected. All this attributes allow us to produce two- and three-dimensional qualitative and quantitative information about shaft integrity that will

be easier to interpret accurately. In this paper we will present major differences in obtaining the information about shaft integrity when CSL testing was performed versus CST testing using forward and inversion data processing procedure.

THURSDAY A.M.

8:30-9:00
NDT Of Cast And Drilled Hole Piles, by Brian Liebich

9:00-9:30
SPT Energy Measurements With The PDA, by Darin Sjoblom.

The Standard Penetration Test (SPT) has long been the most common method of subsurface sampling for geotechnical exploration. The SPT provides a sample as well as information on the properties of the soil in the form of penetration blow counts. The blow count has been used in many empirical formulas to determine soil properties such as density, shear strength, settlement, and bearing capacity. However, inconsistencies within the testing procedure itself, such as variations in hammer type and operator variables can have a large effect on the results of the test. The Utah Department of Transportation has conducted a series of SPT hammer energy measurements on a number of hammers using the Pile Driving Analyzer (PDA) to correct the results of the SPT test. The hammer energy was recorded for each blow during the SPT test and the average and standard deviation were calculated for each set of blows. The hammer energies were then corrected to a hammer delivering 60% of the theoretical energy for the system using the average recorded hammer energy. The corrected penetration resistance with the energy correction is denoted as N60.

9:30-10:00
PDA Monitoring of Piles End Bearing on Sloping Bedrock, by Jon Bischoff.

Construction of a secondary clarifier on the banks of the Rainy River, Northern Minnesota, required the driving of H-Piles, HP14x102, to sloping, very strong bedrock through thick deposits of soft and medium stiff soils. Pile toe protection was specified to prevent damage to the pile toe and to enable the pile toe to bite into the sloping bedrock surface. Damage to a significant percentage of the piles occurred during a test pile program and driving of production piles. The Pile Driving Analyzer (PDA) was a valuable tool in determining the location on the piles where possible damage was occurring. The PDA results along with extraction of a few piles for visual inspection showed damage was occurring at the toe protection. Based on the site locations where damage occurred, behavior during driving, PDA data and visual observations, the steepness of the sloping bedrock proved to be the primary factor in predicting damage. Modification to the toe protection in the steeper sloping bedrock

BREAK

10:30-11:00
Gamma Density Logging Of Drilled Shafts – Observation & Interpretations, by Michael Rucker.

Integrity testing for commerce placement of many drilled shaft piers has been performed using gamma density measurements. Modern downhole wireline geophysical tools with power winches and computer-based data collection and presentation provide profound improvements over earlier instruments that had to be placed, read and recorded at discrete depth intervals for relatively long time periods. Typically deployed

in PVC or other plastic access tubes, these tools can provide density measurements at depth intervals of 0.1 feet while moving up-hole at about 10 feet per minute. Results of density measurements can be examined immediately on-site, and hard copy can be produced from a standard printer. Access tubes debonded from adjacent concrete are still effective as that integrity testing can be performed long after concrete placement, if necessary. Access tubes can be air or water filled. Density measurement baselines vary slightly if tubes are partially water filled. On occasion, the overall density baseline has been observed to gradually change with depth; interpretation criteria based on statistical variation may need to take such gradual changes into account. Examples of documented flaws in drilled shafts and corresponding gamma density measurements are presented.

11:00-11:30
Two New Non-Destructive Methods To Measure Scour Depth And The Depth Of Unknown Foundations, by Edward Mercado.

Described are two methods for determining the depth of scour at bridge piers and abutments. One method also determines the depth of foundation. Each method has its own unique advantage depending on the river environment. The Parallel Seismic Survey (PSS) is most useful for determining the depth of scour during non-flood stages of a river, even when the scour annulus may be filled in by mud or sand as the flood stage subsides. In addition, the PSS technique also provides information about the depth to the bottom of the foundation, and also can be used for just that purpose. A modified placement of the receiver and source geometry allows determination of both the scour depth and depth of piles in a multiple pile group. A field test of the method provided the depth of scour and depth of foundation to an accuracy of ± 0.3m (1-foot). The Pneumatic Scour Detection System (PSDS) operates on a completely different principal and is designed to provide information about the immediate depth of scour during a flood stage. Its unique advantage is its ruggedness of construction and simplicity of measurement, which allow it to withstand flood-borne debris and is unaffected by water turbulence.

11:30-12:00
Non-Destructive Measurement Of Layer Thickness On Newly Constructed Pavement, by Kenneth Maser.

Accurate measurement of pavement thickness is an essential aspect of the quality assurance of new pavement construction. CALTRANS is seeking a measurement technology to meet this measurement objective through a current research effort. The overall objective of this effort is to determine the average pavement thickness on a newly constructed section to within 0.1" of the true value, without the need to take cores. The effort has been divided into two tasks – one for asphalt pavement and one for concrete pavement. The asphalt task has focused on two adaptations of ground penetrating radar (GPR), one involving the use of an air-launch horn antenna, and one using dual ground-coupled antennas in a common midpoint (CMP) measurement mode. The concrete task is focused on the GPR CMP method, and on adaptations of conventional impact-echo. The work has included laboratory testing on small slabs and simulated pavement materials, testing at research pavement test facilities, and testing on actual roads in service in California. The pavement thickness data has been correlated with thickness results obtained from a large number of cores taken at points in the test areas. The paper will describe the techniques being evaluated, the testing that has been conducted, and the results of correlation with core data.

THURSDAY P.M.

1:30-2:00
Revision Of California Test Method – Nuclear Gage Calibration, by Zha Jinxing.

This paper presents details for revisions to California Test Method 111 for nuclear gage calibration. In the current test method, the set of six standard density blocks at California Transportation Laboratory in

Sacramento, California, made of calcareous and siliceous materials, is required for nuclear gage calibration. Disadvantages with the use of the six standard blocks are the great effort taken to perform a nuclear gage calibration and the change in densities of the blocks with time. The proposed revision of the test method introduces a procedure for nuclear gage density calibration based on a set of three metal standard blocks. Principle of calibration, determination of equivalent soil densities of the three metal blocks, statistical results of calibration data, the natural decay of radioactive materials, and the acceptable deviation limit within which the calibration of a gage is valid are discussed. The quality of density calibration data can be evaluated using the correlation coefficient for the linear regression proposed for calibration data analysis. This revision is expected to significantly improve facilitation of the annual calibration procedure of nuclear gages.

2:00-2:30

Application Of The TISAR Technique To The Investigations Of Transportation Facilities And Detection Of Utilities, by Jean-Luc Arsenault and Michel Chouteau

The use of frequency analysis of seismic data for shallow applications has been extensively investigated in the last few years. MASW and other methods related to surface waves, body waves and/or guided waves, are significant examples. Another approach is to use the frequency information within the data, which is the founding principle of the TISAR technique. The acronym TISAR stands for Testing and Investigation using Seismo-Acoustic Resonance. It is based on the analysis of the resonance frequencies of the structures under investigation when energized by an impulsive source. In practice, recording for multiple receiver seismic traces and time and spatial windowing are needed to extract the resonant frequencies; however processing is fairly simple. Numerical modeling has shown it to be fairly indicative of the subsurface geometry and diverse applications have demonstrated its usefulness. In this paper we show the TISAR technique to be very well adapted for very shallow investigations such as the profiling of asphalted road thickness, investigation of concrete slab integrity and thickness, and detection of utilities.

2:30-3:00

Comparison Of Back-Calculated SASW Profiles With Results From Coring And DCP Testing, by Vivek .Khanna and M.A. Mooney

As part of a study into the state of pavements at Oklahoma's General Aviation (GA) airports the Spectral Analysis of Surface Waves (SASW) method was deployed. The main objective of using the SASW method was to provide a reliable, quick, non-destructive determination of pavement layer thickness' and moduli for 71 GA airports. This would enable the determination of pavement structural capacity and an estimation of its remaining life. SASW data was processed using WINSASW software developed by the University of Texas at Austin. Boring logs and sample recovery using coring equipment and a hand auger was also performed at all test sites. Dynamic cone penetrometer (DCP) tests were conducted to a depth of 4 ft in the boreholes after removal of cores. Asphalt concrete (AC) surface layer thickness was generally predicted more accurately than Portland cement concrete (PCC) surface layer thickness by the SASW method. The accuracy of AC surface layer thickness determination fell significantly in pavements with significant longitudinal and transverse (L/T) cracking. For pavements in good condition, the determination of AC layer thickness was within 10% of the actual thickness. For pavements with significant L/T cracking the determined thickness of AC differed from the core thickness by about 20%. Estimation of the base and subbase thickness by the SASW method was more difficult. Estimated base thickness differed from actual base course thickness by 10 – 30%. SASW estimated layer

3:00-3:30

An Investigation on Application of the Tomographic Resistivitiy Method to Concrete Structures, by Michel Chouteau.

Reinforced concrete used for bridge decks and pillars, highways and other transportation facilities experience loss of integrity over time caused by poor initial quality, action of de-icing salts, temperature

changes, fatigue and, above all, delamination caused by corrosion of rebars. Electrical resistivity is sensitive to those losses of integrity. Using 3D numerical modeling we first examine resistivity responses associated with those problems. In the case of rebars, differences occur if they are corroded or not and if cracking or delamination is taking place; resistivity anisotropy is also indicative of rebar distribution and concrete integrity. We also investigate the potential of imaging to recover the resistivity distribution. Finally, the technique is applied to the auscultation of a bridge deck in Montreal and compared with other geophysical and geotechnical data.

BREAK

4:00-4:30
S.I. Analysis. Stability of Landslides, by Hernan Perez

4:30-5:00
A Comparison of Digital Imaging and Laser Scanning Technologies for NDT Rock Mass Characterization, by John Kemeny

Discontinuities in rock masses include faults, joints, bedding planes, and other types of fractures. Traditional methods for obtaining discontinuity data in the field include the scanline survey and cell mapping. In spite of their importance, characterizing rock masses using these field methods is time-consuming, hazardous and prone to errors. Several new technologies offer the possibility of eliminating many of the problems associated with traditional fracture characterization. These include the technologies of digital imaging / digital image processing, and 3D laser-based imaging. These technologies offer the potential for gathering fracture and associated information in a semi-automatic or automatic fashion at a distance from the face. The automated procedures can reduce the errors associated with gathering field fracture data by eliminating human bias and by standardizing the sampling procedure. These automated procedures can also be used to increase the amount of fracture information that is routinely collected in a field survey. Also, by imaging rock faces from a distance, both safety and access problems are reduced or eliminated.

This paper describes a comparison between three methods for field fracture characterization: traditional scanline surveying, digital imaging of fracture traces, and laser-based imaging. The authors have recently developed an image processing technique based on analyzing fracture traces (Post et al., 2001). Preliminary results indicate that high accuracy is possible if traces from two or more non-parallel faces are utilized. This technique is ideal for smooth rock faces but has potential problems on rough surfaces. Laser-scanning devices produce a ?point cloud? consisting of hundreds of thousands of individual distance measurements, the sum of which is a 3D rendering of the surface being scanned. These devices work well on single faces, and are ideal for rough faces where large fracture surfaces are present. On the other hand, laser-canners do not provide useful information on smooth faces (since fracture surfaces are not present). The two technologies, trace image processing and laser-scanning, offer synergies that may allow accurate fracture characterization to be carried out in a wide variety of field conditions. To investigate these synergies, a case study was carried out in Arizona. The case study took place at a blasted road cut in granite. Scanline surveying was also conducted at this site to serve as a baseline. Both the image processing and laser-scanning methods were able to determine the 3D fracture orientations with a reasonable degree of accuracy. The laser-scanning technique was more accurate but at the expense of a more time in the field and additional hours to process the results. Also, laser-scanning requires several minutes to scan, which would create difficulties for certain real-time applications.

FRIDAY A.M.

8:30-9:00
Construction Vibrations, by Justin Henwood.

In the past, specifications for construction vibrations (pile driving, construction traffic, etc.) have been an extension of blast vibration specifications. Blasting forms an excellent foundation for construction vibrations, as it is the most energetic and challenging of vibrations produced by construction activities. As blasting has attracted considerable field experimentation, there is a need to transfer blasting experience to other forms of construction vibrations. In the United States, there have been a very limited number of studies done on non-blasting construction activities producing vibrations, namely construction traffic. in many cases, various state and federal agencies have adopted empirical limits, in terms of peak particle velocity (PPV), in an effort to control construction vibrations. Due to either the frequency of the ground motion or the natural period of the structure, these limits are commonly used where they do not apply. Generally, these empirical limits only apply to common structures, excluding those structures of historical significance. Innovative technology, analytical techniques, and regulations continue to change a discipline that for so long has relied on a PPV of 50 mm/s as an all-encompassing critical vibration level. This paper reflects an effort to research, compare, and condense those regulatory guidelines that currently exist concerning construction vibrations. A case study conducted in the historic district of Georgetown, Colorado is also presented. This nondestructive testing investigation was performed to monitor vibrations and noise caused by construction traffic through the rustic mining town. Test procedures, data analysis, interpretation, limitations, and results will be summarized.

9:00-9:30
An Overview Of The Caltrans Borehole Geophyscial Logging Program, by David Hughes.

Most geotechnical investigations involve drilling and coring to collect samples, measure subsurface properties, and develop lithologic logs. The California Department of Transportation (Caltrans) supports a statewide borehole geophysical logging program to provide supplemental in-situ borehole data. A typical Caltrans borehole logging suite consists of measurements obtained from three sondes, and include caliper,natural gamma, resistivity or induction, and in-situ Compression- and Shear-wave seismic velocity logs. Additional borehole tools that are available, or in development, include acoustic televiewer, borehole deviation, full-waveform sonic, cross-hole radar, and in-situ gamma density logging. Borehole geophysical investigations provide a cost-effective supplement to drilling due to low relative cost, the ability of geophysical methods to look beyond the sidewalls of the borehole, and the collection of in-situ data not available from a standard drilling program.

9:30-10:00
An Overview Of ROSRINE Geophysical Testing, by Clifford Roblee

BREAK

10:30-11:00
Status of the Bridge and Downhole Seismic Instrumentation Installed Through the Caltrans/CDMG Project, by P. Hipley, A. Shakal, V. Graizer and M. Huang

Having instruments in place to simultaneously record the movements of the ground and of man-made structures during seismic events is imperative to advancing our understanding of how these structures react to the ground motions. Caltrans has been working with the California Division of Mines and Geology/CSMIP for several years placing strong motion sensors at bridge and downhole sites to record earthquake induced motion. This project has twelve downhole (subsurface) arrays throughout the state with more downhole arrays to come on line soon. These downhole arrays have sensors as deep as 800 feet and are all located adjacent to instrumented bridge structures. There are 64 bridges instrumented at this time and some large installation projects are currently underway for the San Francisco Bay Area's toll

structures. This paper will discuss the current status of the bridge and downhole seismic instrumentation projects. Geotechnical arrays at La Cienega along I-10 in Los Angeles, Meloland along I-8 in El Centro, near Eureka and the arrays near the Vincent Thomas Bridge in Long Beach represent deep soft alluvium sites. The newly instrumented downhole array in Half Moon Bay represents alluvium over rock. Data recorded by downhole (subsurface) arrays with sensors installed at different depths and geologic layers provide critical information for studies of local site amplification effects any of the bridge strong motion sensors are attached to the foundations to examine the soil/structure interaction during a tremor. Most bridge sites have freefield sensors near by to compare the motions of the bridge to the ground motions. At a few locations, conduits were attached to pile reinforcement to be cast in place in concrete piles. The conduits will be raceways to lock subsurface strong motion sensors at various depths to record the response of these piles to the ground shaking. Other sites have sensors to record translation, rotation and rocking of large bridge foundations.

11:00-11:30

Recent Strong-Motion Data Recorded by Downhole Arrays and Modeling Using Shake Program, by Vladimir Graizer.

Data recorded by downhole (subsurface) arrays with sensors installed at different depths and geologic layers provide critical information for studies of local site amplification effects. California Division of Mines and Geology/CSMIP has been working with Caltrans for several years placing strong motion sensors at downhole arrays. Twelve downhole arrays were instrumented throughout the state with more downhole arrays to come online soon. More than 50 low amplitude recordings from earthquakes with 2.4<M<7.1 were recorded at these arrays. Large (up to 10 cm) long-period (up to 8 seconds) displacements were recorded at the La Cienega, El Centro and Long Beach arrays during the Mw7.1 Hector Mine earthquake at epicentral distances of 200 - 220 km. Use of downhole array data provides an opportunity to identify surface Rayleigh waves at the La Cienega and Long Beach Vincent Thomas Bridge arrays. Surface waves from big earthquakes can produce damage to large structures. Comparison0 of empirical and theoretical site amplification effects at La Cienega and Tarzan were performed using SHAKE91 modeling motion separately in the longitudinal and transverse directions. Data recorded at downhole arrays so far represent low amplitude motions, not exceeding a few percent g. Processed data recorded at the geotechnical arrays are available at the website: ftp://ftp.consrv.ca.gov/pub/dmg/csmip/Geotechnical Array Data adjacent to the pier.