Effectiveness of MASW Detecting Abandoned Lead/Zinc Mines in Southeastern Kansas

Summary

Fractures and voids within near-surface rock layers can pose a stability risk to any surface structure. Confident detection and 3-D mapping of voids or open fractures prior to roof failure/ collapse and the resulting surface expression allows the risk such features pose to people and property to be reduced or possibly eliminated. Abandoned lead-zinc mines along State Line Road south of Baxter Springs, Kansas, have been suggested to represent a potential risk to surface structures in the area. Extensive drilling in the immediate area has provided excellent ground truth but lacks the lateral resolution necessary to map the subsurface expression of these structurally weak zones and voids which are a likely byproduct of mining. The mine works of interest are in an area where Mississippian Limestone acts as both the source and roof rock. Overlying the limestone is a clay layer 10 to 15 ft thick. For the purposes of this study, this geologic setting can be represented as a two-layer acoustic model.

Surface wave profiling using MASW could provide a very quick and relatively accurate image of the upper 100 ft to 150 ft of the subsurface. Considering the sensitivity of surface waves to shear wave velocity, changes in the dispersive characteristics of surface waves in many cases directly correlates to changes in rock stiffness. Abrupt changes in shear wave velocity are expected at the boundary between voids (water or rubble filled) and consolidated bedrock. As well, fractured or highly altered zones where competent rock is broken up and replaced by unconsolidated sediments and/or fluids produce obvious changes in the shear wave velocity field. This study will focus on the following goals and objective: 1) feasibility of MASW (a continuous non-invasive surface-wave imaging technique) to distinguish drill confirmed void areas from competent rock, 2) vertical and horizontal resolution potential at this site, 3) potential of 2½-D profiling, 4) effects of surface vs. spike geophone coupling, 5) detectability of fractures/ faults, 6) evaluation of effective depth of imaging, 7) generation of a subsurface map of the shear wave velocity field, and 8) allow confident interpretations of void areas in the upper 100 to 150 feet. This study will be designed to both develop an accurate shallow subsurface image and study optimization and limitations of delineating lateral changes in shear wave velocity using surface waves.

Introduction

Surface waves have traditionally been viewed as noise on multichannel seismic data designed to image targets significant to shallow engineering, environmental, and groundwater studies (Steeples and Miller, 1990). Recent advances in the use of surface waves for near-surface imaging have incorporated spectral analysis techniques (SASW), developed for civil engineering applications (Nazarian et al., 1983) with multi-trace reflection technologies (CDP) developed for petroleum applications (Mayne, 1962). Combining these two uniquely different approaches to acoustic imaging of the subsurface allows high confidence, non-invasive delineation of horizontal and vertical variations in near-surface material properties (MASW) (Park et al., 1996; Xia et al., 1999; Park et al., 1999).

Surface wave imaging has shown great promise detecting shallow tunnels (Figure 1), bedrock surface (Figure 2), remnants of underground mining (Figure 3), and fracture systems/karst (Figure 4). Extending this imaging technology to include lateral variations in lithology has required a unique approach incorporating SASW, MASW, and CDP methods. Integrating these techniques provides a 2-D continuous shear wave velocity profile of the subsurface. Signal enhancement resulting from determination of a dispersion curve using up to 60 closely spaced receiving channels and the calculation of a dispersion curve every 4 ft to 8 ft or so along the ground surface provides a unique, relatively continuous view of the shallow subsurface. This highly redundant method enhances the accuracy of the calculated shear wave velocity and minimizes the likelihood of irregularities associated with an occasional erratic dispersion curve corrupting the data analysis or interpretation.

The objective of this research program is to determine the feasibility of this relatively new technology to delineate lateral variations in shear wave velocity within consolidated sediments. These variations should be detected as anomalously low velocity zones within otherwise relative uniform materials. This site study will be divided into two phases: 1) testing and evaluation and 2) sitewide mapping to delineate the three-dimensionality of any voids and/or fractures (Figure 5). The testing stage will involve forward modeling and on-site acoustic wavefield studies. This testing stage may require a day to acquire the two profiles and as much as a week to determine penetration depths, a generalized velocity model, and feasibility of distinguishing velocity changes that correlate to borehole data within the limestone. The second stage (if determined necessary or useful) will attempt to delineate the entire area of interest in a pseudo three-dimensional sense (2½-D). This stage will require the deployment of as many as six more profile lines optimized (based on available drill data and the results of the second phase) to allow the areal trends and extent of any interpreted anomalous zones (voids or fractures) in the upper 150 ft at this site to be mapped.

The applied research proposed here will focus on an area approximately one mile south of Baxter Springs on the Kansas/Oklahoma border. If the scope of this research activity is consistent with the desire of Williams Gas Pipeline Central (WGPC) and Cherokee County, Kansas (CC), the project will commence as soon as a mutually agreeable time can be established between WGPC, CC, and the Kansas Geological Survey (KGS). Each phase of this study will be distinguishable and separated by unique acquisition, processing, analysis, and decision mile-stones. Proceeding from one phase to another will require agreement between WGPC and/or CC and KGS assuming that the results are consistent with ground truth and expectations. Deploy-ment of the initial testing lines will be somewhat dynamic based on accomplishing the objectives and dealing with limitations that appear as the project progresses. All aspects of the program will be discussed and agreed to on-site throughout the testing between representatives of WGPC, CC, and KGS. The actual procedures used to acquire and process these data will evolve as the technique develops, significant characteristics are determined, and the limitations are defined.

Current Procedure

The current operational procedure requires the generation and analysis of an extremely broadband acoustic signal. Lower frequency components are critical to deeper penetration and the imaging associated with deeper targets while high frequency signals will be necessary for detecting smaller anomalies at shallower depths. The primary waveform of interest will be the Rayleigh wave. The dispersive nature of this wave can be related to the shear wave velocity structure of the subsurface. By calculating the dispersion curve (phase velocity as a function of frequency) and then inverting that curve, a shear wave velocity profile can be determined for the area directly beneath the acquisition spread. Acquiring data by progressively moving the source from one station to the next while maintaining a consistent number of receivers and source-to-receiver separation permits the generation of a two-dimensional profile showing the shear wave velocity structure as a function of depth and station location. This shear wave profile can then be analyzed to identify significant changes in shear wave velocity likely indicative of abrupt and large changes in material properties. Laterally non-uniform portions of the velocity profile can be seen most prominently when large variations are observed in the gradient of the velocity field.

Once anomalous velocity zones are detected, a grid of profiles can be laid out and data collected along each profile. This two-dimensional grid provides a 2½-dimensional fence diagram that readily allows interpretation of meandering or spatially extensive features (Figure 6).

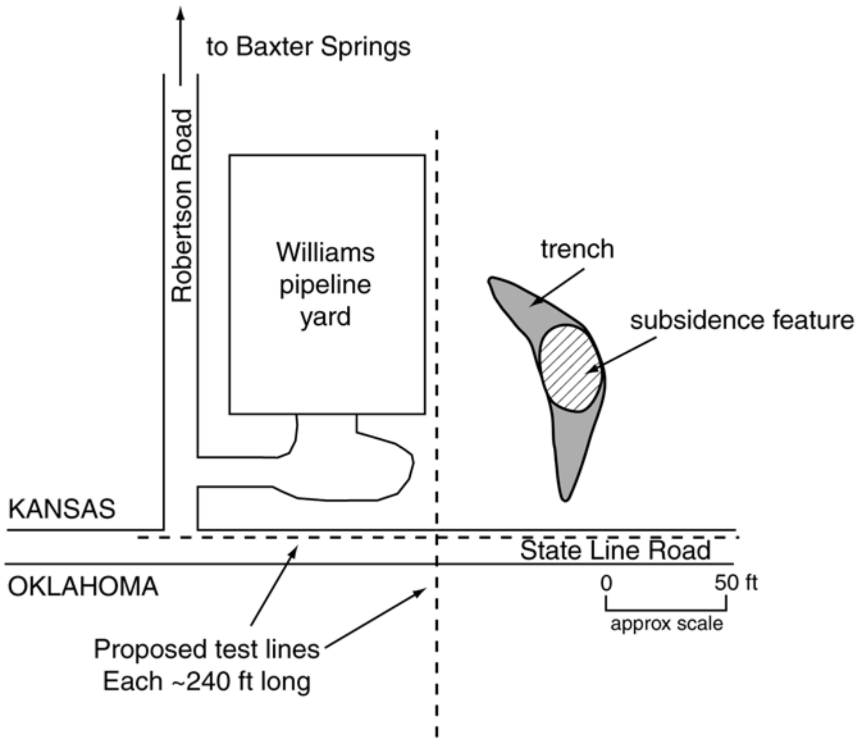
Data will be recorded on a 60-channel Geometrics StrataView seismograph using single GeoSpace 4.5 Hz GS-11D geophones equally spaced along the profile line. Energy for this study will be provided by either a sledgehammer or accelerated weight drop source. The selection of source will be based on depth of interest, velocity structure, and frequency band transmitted by each source type.

Reduction of the raw shot gathers into 2-D velocity contours will be accomplished using experience-proven processing and analysis techniques. SurfSeis (a set of processing and display algorithms), developed by the KGS for this imaging technique, will be used in conjunction with a commercial contouring package to produce the interpretable displays. Interpretation will be based on correlating ground truth data (drilling, outcrop observations, trench studies, etc.) with unique features on the velocity field cross-sections. Once the shear wave characteristics of the features of interest can be confidently established it should be possible to locate areas with similar characteristics within the survey area that can be inferred to be of similar nature.

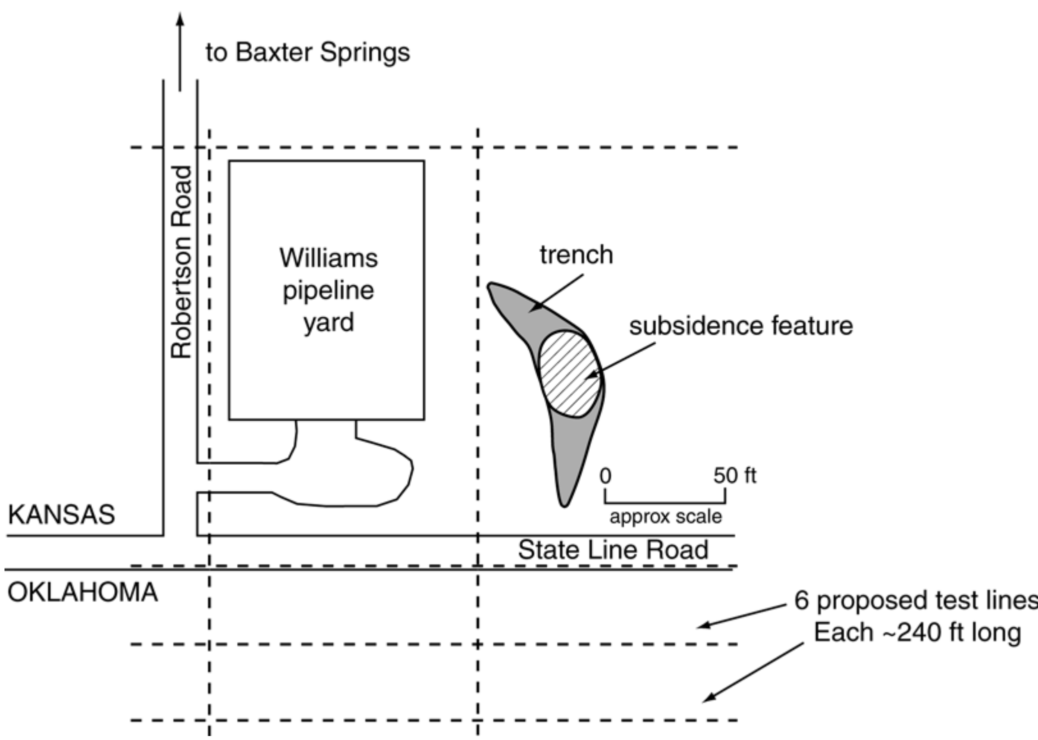
Final Products

The goal of this study will be to detect void features confirmed by drilling prior to surface expression and to delineate the anomalous low-velocity materials likely representative of old mine works and fractures. The results of this study will include a thorough analysis of the technique's feasibility to appraise this unique geologic hazard, an empirically based estimation of vertical and horizontal resolution potential, and an interpretation of the subsurface based on changes in the shear wave velocity field. Ultimately if the technique is effective a subsurface map will be produced which provides the 3-D expression of the voids in this area with an estimation of location accuracy.

PHASE 1



PHASE 2



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