GEOPHYSICAL SERVICES
LIMITATIONS OF REPORT

1. This report was prepared for the exclusive use of the owner, architect, and engineer for evaluating the project as it relates to the technical aspects discussed herein. It can be made available to prospective contractors for information on factual data only and not as a warranty of subsurface conditions included in this report. Unless other contractual agreements were made, the services described in this report were carried out in accordance with the Terms for Geotechnology's Services that were attached to the proposal.

2. Geotechnology endeavored to perform the survey in accordance with generally accepted practices of other consultants undertaking similar studies at the same time and in the same geographical area. The findings and conclusions stated herein must be considered not as scientific certainties, but rather as professional opinions concerning the significance of the limited data gathered during the course of the survey. No warranty, express or implied, is made.

3. The geophysical analyses and conclusions contained in this report are based on the site conditions, project layout, grid size, geophysical data, and interpretive procedures described herein and are for preliminary planning purposes only. Geotechnology can make no interpretation as to the presence of underground features at locations beyond the survey lines.

4. Geophysical exploration methods are non-intrusive, indirect, and potentially influenced by a variety of natural or man-made conditions. The potential for detecting the presence or absence of underground objects or voids is based on the quality of the recorded data as limited by site conditions, and on the interpretation of the data received; hence, there will always be the potential of not observing a subsurface object or void or interpreting the presence of a subsurface object or void where one does not exist.

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GEOPHYSICAL SURVEY FOR VOID DETECTION
FORT CALHOUN POWER STATION
BLAIR, NEBRASKA

Prepared for:

HDR ENGINEERING, INC.
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St. Louis, Missouri

Geotechnology, Inc. Project No. J019386.03

October 24, 2011

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GEOTECHNOLOGY INC
FROM THE GROUND UP

VIA EMAIL: Patrick.poepsel@hdrinc.com

October 24, 2011

J019386.03

Mr. Patrick Poepsel, P.E.
HDR Engineering, Inc.
8404 Indian Hills Drive
Omaha, Nebraska 68114-4049

Re: Geophysical Survey for Void Detection
Fort Calhoun Power Station
Blair, Nebraska

Dear Mr. Poepsel:

Presented herein are geophysical survey results for the above referenced site. This work was conducted in general accordance with the Geo Subcontractor Services Agreement dated August 22, 2011, Amendment No. 1 dated September 23, 2011, and Amendment No. 2 dated October 7, 2011. Geotechnology performed ground penetrating radar (GPR), seismic refraction and refraction microtremor to evaluate the potential presence of voids at the subject site. This report includes a description of the geophysical methods and survey results.

It is a pleasure to be of service to you on this project. If you have any questions or comments, please contact the undersigned at (314) 997-7440.

Very truly yours,

GEOTECHNOLOGY, INC.

Douglas W. Lambert
Senior Project Manager - Geophysics

Glen L. Adams
Senior Geophysicist

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J019386.03

GEOPHYSICAL SURVEY FOR VOID DETECTION
FORT CALHOUN POWER STATION
BLAIR, NEBRASKA

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GEOPHYSICAL SURVEY FOR VOID DETECTION
FORT CALHOUN POWER STATION
BLAIR, NEBRASKA

1.0 INTRODUCTION

1.1 Site Description. The site consists of approximately 100 acres within the Missouri River flood plain, including main plant buildings, switch yards, and auxiliary office and training buildings. A site location map is presented on Plate 1. Voids are suspected to have developed beneath concrete slabs within the facility due to recent flooding around the site. Geotechnology performed ground penetrating radar (GPR), seismic refraction and refraction microtremor (ReMi) to explore subsurface conditions and interpret the presence of possible voids based on the geophysical data.

1.2 Scope of Work. The scope of work included mobilizing a GPR unit, seismic refraction/ReMi equipment and personnel to the site. GPR and seismic data were collected at locations selected by the client. Data were processed and interpreted for the presence of potential voids. Small diameter drill holes were performed to corroborate the GPR data at selected locations. Results are reported herein.

2.0 GROUND PENETRATING RADAR (GPR) SURVEY

2.1 GPR Method. GPR is a geophysical technique in which a broadband electromagnetic (EM) signal is transmitted into the ground. The EM signal travels through underlying materials and is reflected by subsurface features. The magnitudes of the reflections are based on contrasts in dielectric permittivity and conductivity of the subsurface features. Features located below concrete often exhibit distinguishable high-amplitude reflections due to the large dielectric contrast between the concrete and underlying materials including voids, some subgrade materials, and utilities. The reflected signal is recorded with respect to the time required for the signal to travel down and back (two-way travel time in nanoseconds). Data are collected along survey lines and the results are presented in profiles representing reflected radar signal from beneath the survey line. Three dimensional (3D) GPR datasets are generated from parallel 2D profiles. This survey was performed in general accordance with ASTM Method D6432.

2.2 GPR Data Acquisition and Processing. Geotechnology performed the GPR surveys between September 6 and 30, 2011, using a GSSI SIR 3000 GPR system and 400 MHz antenna. 3D GPR data were collected within 54 grids as established by the client. GPR Grids 1 through 11 were collected within the Turbine Building as shown on Plate 2. GPR Grids 12 through 54 were collected in exterior areas as shown on Plate 3. Grid locations were established by measuring from existing site features. Data were collected along lines spaced approximately 6 inches to 2 feet apart within each grid. Additional GPR data were collected on a wall within an elevator vault within the Turbine Building, however, the area was too small for complete 3D data collection. The 2D data collected on the wall did not appear to exhibit high amplitude features that would suggest the presence of voids.

The GPR data were processed using Radan Version 6.6. Data processing included gain equalization, vertical normalization, horizontal filtering, and 3D integration of profiles. 3D GPR images are shown on Plates 4 and 5 for depths within approximately one foot of the assumed base of concrete.

2.3 GPR Results. As an initial summary, the GPR method performed well at the subject site, even in the presence of high ground water. This summary can be understood based on an evaluation of the conductivity of subsurface materials. The ability for the radar signal to penetrate the subsurface is based largely on the conductivity of the medium through which the signal travels. Radar signal attenuation increases and depth of penetration decreases with increasing conductivity. Two primary factors contribute to the conductivity of subsurface materials – mineralogy of the matrix and moisture content. Typically, clays and clayey soils limit the penetration of radar signal greater than sand and sandy soils because clay minerals are highly ionic and, therefore, more conductive than silica based sands. The presence of moisture will increase the conductivity relative to the conductivity of the soil matrix. At the subject site, the 400 MHz radar signal was observed to penetrate to depths of at least 7 feet, which is reasonably good for this antenna frequency. The presence of sand based soils, even though saturated, allows for reasonable radar penetration. We typically find less than 7-foot depth of penetration in clayey soils with this same radar frequency.

Numerous high amplitude GPR reflections, possible voids, are evident in the data. Many were observed within one foot below the base of concrete and some were observed at greater depths, ranging between 2 and 8 feet. The high amplitude anomalies observed for various depths were mapped and are shown on the grids presented on Plate 6 and in Appendix A. Individual GPR features are identified by grid number and sequential letter.

While distinct high amplitude reflectors can be observed, the source of such reflectors could also be related to features other than voids, such as large gravel, clay, or other variations in materials within the subsurface. A total of 76, ½-inch diameter holes were drilled between September 27 and 29, 2011, to evaluate subsurface conditions at the locations of various high amplitude GPR reflectors. After drilling each hole, a fiberglass probe was advanced by hand to ascertain subgrade materials and conditions. The locations of the drill holes are shown on Plates 5 and 6 and in Appendix A. The drilling results are summarized in Table 1. The drill holes are identified by grid number followed by hole number for that grid. Actual void space was encountered at one location, Drill Hole G33-1, where a 22-inch void was observed immediately beneath the pavement. Further investigation at this location by HDR indicated that our drill hole was placed over a utility duct. Elsewhere, the fiberglass probe could be easily inserted to depths ranging between approximately 2 inches and at least 48 inches at 56 drill hole locations. In these cases, the subgrade material appeared to be comprised of soft silt or silty clay. At the remaining locations drilled, the probe was advanced no more than 2 inches using greater effort. The limited amount of ground truthing and use of the more simplistic probing method was chosen due to project schedule. High amplitude features observed at depths greater than approximately three feet were not ground truthed because of the greater amount of time required to core a large diameter hole and drill with a rig or hand auger. We recommend that the deeper high amplitude features be explored by performing borings or test pits.

GPR is a tool that can help locate voids or other areas of concern within designated survey areas, however, the high amplitude GPR features presented in our report are non-unique. They may represent voids, clay, large gravel, metal, or other material with electrical properties that contrast with the overlying pavement or surrounding material. The assumption could be made that the observation at the point of drilling/probing represents the condition of the entire area covered by that high amplitude feature. However, the amplitude and response cannot be correlated between GPR grids or even features within grids.

3.0 SEISMIC SURVEYS

3.1 Seismic Methods

Refraction. The seismic refraction method involves generating compressional seismic waves (p-waves) at the ground surface using an impact source. The seismic waves travel from the source through the subsurface along a variety of paths including refracting along interfaces between soil and rock layers having different seismic velocities. The seismic waves return to the ground surface where they are recorded at various distances from the source using geophones and a seismograph. Seismic velocity calculations are made by analyzing the differences in elapsed time from the source to each geophone. The resulting profile is a representation of p-wave velocities of the soil and bedrock directly beneath the survey line. This survey was performed in general accordance with ASTM Method D5777, with the exception of data modeling and interpretation which were performed using tomographic methods for greater velocity detail. Tomographic methods are not addressed within the ASTM standard.

Refraction Microtremor (ReMi). The ReMi method is used to develop shear wave velocity profiles. ReMi surveys are conducted by passively recording background surface waves (microtremors) that are generated by passing vehicles, equipment, airplanes, etc. The surface seismic energy produced by the noise sources travels across the ground surface and is received by geophones placed in a linear array. The seismic energy detected at the geophones is recorded using a seismograph and is transformed into a phase velocity spectrum for analysis. Shear wave velocity profiles are constructed by analyzing surface wave phase velocities and frequencies, and performing inversion modeling.

3.2 Seismic Data Acquisition.

Refraction. Seismic refraction data were recorded between September 19 and September 22, 2011, along 5 lines, indicated as Lines 1 through 5, as shown on Plate 3. The survey locations were established along lines parallel to each side of the main structure. Lines 2 and 3 were both established, approximately 30 feet apart, on the east side of the building to provide additional data in this area over the water intake structure. The water intake/circulation structure is approximately 75 wide, 30 feet high and trends east-west between the main building and the intake structure/Missouri River to the east at a depth of approximately 1.5 feet at the location of the seismic lines (based on client supplied information).

Seismic refraction data were recorded using two, 24-channel Seistronix RAS-24 engineering seismographs. Lines 1, 2, 3, and 5 were recorded using forty-eight geophones placed at 10-foot intervals along each survey line resulting in survey spread lengths of 470 feet. Due to limited space, Line 4 was recorded using 30 geophones spaced at 10-foot intervals resulting in a survey spread length of 290 feet. A total of 2,170 feet of seismic data were collected. Seismic source impacts, or "shots", were acquired at eleven to fourteen locations along each line, which included end shots, off-end shots, and multiple mid-spread shots. An truck-mounted Propelled Energy Generator (PEG) was used to generate the seismic energy by striking a metal plate on the ground surface. Generally, 10+ successive impacts were made on the metal plate at each shot point. The seismographs were used to "stack" the recorded data from each impact. Stacking the recordings enhanced source signals and reduced the effects of spurious noise in each recording. Noise levels at the facility were very high during data acquisition, which negatively impacted data quality even with stacking. Field tests and preliminary processing were performed during data collection to assess the severity of the noise. Frequency filters were applied with some success for subsequent processing.

ReMi. ReMi data were collected using two Seistronix RAS24 engineering seismographs and the same 10-foot geophone spreads used to collect the refraction data. The ReMi data were collected along Lines 1 through 5 at the locations shown on Plate 3. Data for each ReMi survey was acquired by collecting approximately 15 background microtremor "noise" recordings using a time window (sampling length) of 30 seconds each. The primary microtremor source for the survey was vehicular traffic and construction activities from within the plant.

3.3 Seismic Data Processing.

Refraction. Profiles of seismic p-wave velocities were generated based on the arrival times of the seismic waves. Rayfract™ software (Intelligent Resources, Inc.) was used to process the seismic refraction data and produce tomographic velocity sections based on predictive modeling of the first break arrivals and subsurface ray paths. Researchers at Oak Ridge National Laboratory and the U.S. Army Environmental Center favorably reviewed this program, among others, for performing well in many situations where lateral or vertical velocity gradients exist, such as the subject site.[1] Profiles for Refraction Lines 1 through 5 are shown on Plates 7, 9, 11, 13, and 15, respectively.

ReMi. SeisOpt®@ReMi™ software (Optim LLC) was used to process the surface wave data and produce shear wave velocity sections. The recorded data for each line was transformed into velocity-frequency spectra from which dispersion curves were selected and modeled to produce a series of one-dimensional velocity models. The one-dimensional models were combined into a single profile for each ReMi line. Profiles for ReMi Lines 1 through 5 are shown on Plates 8, 10, 12, 14, and 16, respectively. The resulting ReMi profiles begin and end approximately 50 feet from the ends of each line because the surface wave evaluation requires a string of geophones to generate a single one-dimensional model.

3.4 Seismic Results. The seismic data were interpreted by comparing the velocity profiles to nearby Borings B-4, B-7, -8, and -9, which were used to establish the types of geologic materials corresponding to the profiled velocities. The stratigraphy at the site is generally comprised of approximately 70 feet of alluvial deposits over limestone bedrock. Weathered shale bedrock was observed in a boring immediately north of the subject survey area. The alluvial deposits are comprised of alternating layers of loose and dense silty sand to sand with silt and occasional layers of clay up to 14 feet thick. Sand and clay each exhibit a wide range of velocities depending on a number of physical parameters such as moisture content, porosity, sorting, and particle packing. Based on the seismic refraction data, alluvium at the subject site exhibits velocities ranging between approximately 1,500 ft/s within the top 20 feet of material and increased with depth to approximately 5,000 ft/s near top of bedrock. Published P-wave velocities for sands range between 1,300 and 6,500 ft/s and clays may range between approximately 3,500 and 8,200 ft/s.[2] Top of bedrock was interpreted to generally coincide with the 5,000 foot/second (ft/s) contour on the refraction data as shown on Plates 10 through 13. Top of bedrock undulated across the site. The shallowest bedrock imaged appeared to be at a depth of approximately 56 feet at the east end of Line 5 and the deepest bedrock imaged appeared to be at a depth of approximately 78 feet at the west end of Line 5.

The circulation structure located between the main plant building and the Missouri River was not imaged in Lines 2 and 3. The data collected along these lines exhibited significant noise from facility activities and exhibited high-velocity shallow energy from the surface pavement, which masked our ability to pick the arrivals related to the shallow circulation structure.

Zones of low velocity were observed in the refraction and ReMi data above and below the top of bedrock as indicated on Plates 9 through 18. These low velocity zones indicate

[1] "An Evaluation of Methods and Available Software for Seismic Refraction Tomography Analysis", Jacob R. Sheehan, William E. Doll and Wayne A. Mandell, JEEG, Volume 10, Issue 1, pp. 21-34, March 2005.

[2] "Acoustics of Porous Media", Thierry Bourbie, Olivier Coussy, and Bernard Zinszner, Gulf Publishing Company, Houston, TX, 1987.

locations at which material is softer and/or less dense and through which the seismic wave travels slower compared to surrounding material. These velocity contours are gradational and illustrate velocity changes between extremes values. These values do not necessarily represent the actual seismic velocities, but rather, illustrate the general trends of velocity changes across the profiles and the general locations and relative differences of the extreme high and low velocities.

Low velocity features within limestone bedrock could be due to the presence of

- karst features such as voids, clay or water filled cavities or solution-widened joints/fractures, or
- zones of weathered or otherwise weak rock compared to surrounding more competent rock.

Low velocity features within the alluvium could be related to

- zones of loose sand as observed in nearby borings, or
- voids, if sufficient overlying cohesive material is present for bridging.

We recommend that the low velocity zones identified on the seismic profiles be further explored using intrusive methods such as borings or test pits. Of particular concern may be the presence of low velocity zones in the proximity of underground structures such as the low velocity zone observed at a depth of approximately 60 feet on Line 2 beneath the circulation structure and the low velocity zones in the vicinity of the fire protection pipes located north of the circulation structure (centered at line distance 330 and depth 20 feet) and the raw water pipe waste disposal pipe and fire protection pipe located south of the circulation structure (centered at line distance 100 feet and depth 10 feet. In addition, the low velocity zone centered at a distance of approximately 350 feet along Line 3 and a depth of approximately 45 feet corresponds reasonably well to a velocity inversion observed on the ReMi profile.

Portions of seismic Lines 2 and 3 coincide with some GPR grids. Although the GPR depth of investigation is shallow (approximately 8 feet and less) compared to the seismic data, a correlation was evident at one location. The shallow low velocity feature on Seismic Line 2, centered at a line distance of approximately 330 feet and depth of 20 feet, may correspond to a high amplitude GPR feature on Grid 17.