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Geology and Geophysics
Subsurface Exploration   Non-Destructive Evaluation

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March 13, 2020
via. Email (5 Pages + Attachments)

Yeh and Associates, Inc.
391 Front Street
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Attention: Mr. Judd King, P.E., G.E.

Re: **Summary Report**
Seismic Refraction Survey for Bedrock Investigation
At Reservoir No. 2 Replacement Water Tank Site
San Luis Obispo, California

INTRODUCTION

This report summarizes the seismic refraction survey completed by Advanced Geoscience, Inc. at referenced site. This survey recorded seismic waves generated on the ground surface to prepare subsurface velocity profiles for investigation of bedrock structure and rippability. The data from this survey was also used to generate a seismic shear-wave velocity profile for the site to estimate the average shear-wave velocity of the upper 30 meters (Vs30).

The seismic refraction tomography data were recorded by Advanced Geoscience during a one-day field program completed on March 4, 2020. The refraction data were recorded along two survey lines designated as Lines 1 and 2 (shown on the site map in Figure 1). The data underwent computer processing to prepare 2D subsurface profiles showing seismic compressional-wave velocity layering in the upper ±50 feet. Additional multi-channel analysis of surface waves (MASW) data was also recorded along the center of Line 1. The MASW data underwent computer processing to prepare a 1D profile of seismic shear-wave velocity layering for Line 1.

The following provides a summary of our field survey procedures and methods of data processing and evaluation. A concluding section discusses the results of this seismic velocity profiling, the correlation of this velocity layering to the rippability charts for

Caterpillar excavation equipment, and the Vs30 estimated from the shear-wave velocity profile.

FIELD SURVEY

Advanced Geoscience set up two survey lines across the site designated as Lines 1 and 2 (shown in Figure 1). Line 1 was positioned along a straight-line, northwest-to-southeast traverse through the marked center points of the proposed water tanks locations. Line 2 was positioned approximately perpendicular to Line 1 between the proposed tank locations.

The seismic data were recorded using a multi-channel Seistronix EX-6 data acquisition system. This recording system was connected to geophones (seismic motion detectors) positioned in the ground surface at 10-foot intervals along the survey lines. Line 1 was set up with 60 geophone positions for 590 feet of data coverage, and Line 2 was set up with 42 geophone positions for 410 feet of data coverage. The geophones were 4-Hertz (lower-cutoff frequency), vertically-aligned velocity transducers.

The refraction tomography data were recorded from ten to thirteen seismic energy "source points" positioned along each survey line. The source points started 5 feet off the start of the geophone lines and continued at 40 to 50-foot intervals between the geophone positions. The last source point was positioned 5 feet off the end of the geophone lines.

The seismic energy was generated using a 60-pound, man-portable weight drop. The weight drop was used to make four or more impacts on a metal plate placed on the ground surface. At each source point, the recordings from the multiple impacts were summed together to increase the amplitude of the seismic wave arrivals.

The center portion of Line 1 was also set up with a separate geophone line to record MASW data to generate a 1D seismic shear-wave velocity profile. The center of Line 1 was used for this data recording because the topography was mostly homoclinal. To record this MASW data a 42-channel geophone line spaced 6-feet apart was set up between stations 200 and 446 feet on Line 1. The energy source points for this data recording were positioned at offsets of 6 and 48 feet from the first and last geophone positions.

The distance stationing set up along Lines 1 and 2 was marked by stakes on the ground surface at the beginning and end of the survey lines and at 50-foot intervals. This stationing along Line 1 was located on the site map by its intersection with the two surveyed stakes marking the center points of the two proposed water tanks. Line 2 was located relative to Line 1 by its intersection point (stations 290 feet on Line 1 and 110 feet on Line 2) and its measured compass azimuth.

DATA PROCESSING AND EVALUATION

The seismic data quality was generally good. The field records showed seismic wave arrivals from subsurface refraction patterns at most all of the geophone locations.

An AutoCAD file topographic site map showing the proposed tank locations was first used to determine the coordinates and elevations of the geophone stationing set up on the sloping ground surface along Lines 1 and 2. This distance stationing which was tied to the tank center points was corrected for steeper topographic slope (at beginning and end of Line 1 and the entire length of Line 2) to more correctly position this stationing in map view as shown in Figure 1. The corrected position of this stationing placed on this map in AutoCAD was then used to prepare a spread sheet of coordinates and elevations to interpolate the coordinates and elevations for each geophone position set up along Lines 1 and 2.

The RAYFRACT seismic refraction tomography software developed by Intelligent Resources, Inc. (www.rayfract.com) was used to generate seismic compressional-wave velocity depth profiles along Lines 1 and 2. This refraction tomography modeling procedure is generally more capable of imaging sharper lateral velocity variations due to bedrock structure than other refraction data modeling methods. This procedure also more correctly shows changes in subsurface velocity layering with increasing depth, associated with the transition from unconsolidated alluvium to upper-weathered bedrock to less-weathered, more-indurated bedrock.

The refraction field records were input into RAYFRACT to graphically pick first arrival times ("first breaks") for refracted waves traveling through the surface layer and into deeper higher-velocity layers. These time-distance data were used together with the geophone coordinates and ground surface elevations to conduct refraction tomography imaging of the subsurface seismic velocity layering. RAYFRACT used the Delta TV (turning ray-based) method to generate an initial 2D velocity-depth model. This initial model was then refined to produce a closer fit to the arrival time data using the Wavepath Eikonal Traveltime (WET) tomographic inversion method with 40 iterations with a maximum velocity 5,000 m/sec. The best-fit velocity-depth models were then gridded and color contoured with SURFER (written by Golden Software, Inc.) to show estimated vertical and lateral velocity variations.

Figures 2 and 3 show the resulting seismic compressional-wave velocity profiles for Lines 1 and 2. These profiles are displayed as elevation versus distance measured along a horizontal plane, with a horizontal scale of 1 inch= 40 feet and a vertical scale of 1 inch= 20 feet for two-fold (x2) vertical exaggeration.

The MASW data records from Line 1 underwent processing using the computer program SurfSeis developed by the Kansas Geological Survey (www.kgs.ku.edu/software/surfseis/). These data records were used to generate surface-wave amplitude displays of phase velocity versus frequency. These displays were used to pick dispersion curves for the fundamental-mode, Rayleigh wave. The dispersion curves were then used to conduct a least-squares inversion to calculate one-dimensional (1D) models of shear-wave velocity (Vs) layering near the center of Line 1. After preparing 1D Vs profiles for the source points on both ends of Line 1 it was determined that the profile generated from the source points on the southeast end of the line provided the best 1D model. Therefore, this 1D Vs profile from the southeast source points was used to represent the Vs profile beneath the center of Line 1.

Figure 4 shows this resulting 1D seismic shear-wave velocity profile for Line 1. The upper 130 feet of this velocity versus depth profile is also shown in Figure 2 on the compressional-wave velocity profile for Line 1.

The 1D shear-wave velocity layering in Figure 4 was used to calculate an estimated Vs30 for the site. This calculation was made using the following formula in accordance with the International Building Code (IBC 2000 and later editions) which places a slightly heavier weight on the lower shear-wave velocity layers (Park, 2013).

$$Vs\,30 = \sum D_i \,/\, \sum (D_i / Vs_i)$$

For i=1 to Number of Layers to 30 m

D_i = Layer Thickness Vs_i = Shear-Wave Velocity of Layer

Based on this calculation the estimated Vs30 for this site is reported as 2,741 ft/sec.

DISCUSION OF RESULTS

The 3,000 ft/sec compressional-wave velocity contours (highlighted by the color cyan) on the velocity profiles for Lines 1 and 2 (Figures 2 and 3) are interpreted as the upper surface of the partially intact, weathered Franciscan Formation bedrock. This bedrock unit in this area is described as Franciscan Melange (KJfm) composed mostly of fragmented rock masses embedded in a matrix of metasandstone, and Franciscan Metavolcanic rocks consisting primarily of greenstones (greenschists) metamorphosed from basalt, as shown on the Geologic Map of San Luis Obispo prepared by Wiegers (2010).

Below this 3,000 ft/sec velocity contour the velocities within this bedrock unit increase rapidly with depth to the ±8,500 ft/sec contour interval. This 8,500 ft/sec contour interval on both Lines 1 and 2 appears to be near the upper surface of the much harder, unweathered bedrock rock units beneath this area.

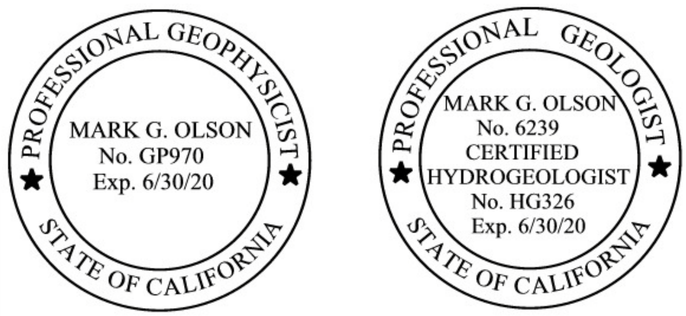
The 1D shear-wave velocity profile overlay on Line 1 (in Figure 2) also shows higher 3,500+ ft/sec shear-wave velocity layering starting near this 8,500 ft/sec compressional-wave velocity contour interval beneath the center of Line 1. The depth of this 3,500+ ft/sec shear-wave velocity layer supports our interpretation of the positioning of this much harder bedrock unit. Based on our experience, shear-wave velocities in this 3,500 ft/sec range are associated with the harder indurated rock conditions.

Figures 2 and 3 also display the seismic compressional-wave velocity ranges for the rippability of metamorphic schist bedrock which is the rock type we used for the Franciscan Formation bedrock in this area. These velocity ranges are superimposed on the same color velocity scales used for Lines 1 and 2 and are based on the graphs in the Caterpillar Handbook of Ripping, 12th Edition (Caterpillar, Inc., 2000). This evaluation shows that the bedrock unit above elevation 520 feet is mostly rippable for the Caterpillar the D8R through D11R equipment.

The Vs30 estimate of 2,741 ft/sec was compared to the National Earthquake Hazard Reduction Program (NEHRP) seismic site classification which is based on shear-wave velocity ranges. This Vs30 is within the range of 2,500 to 5,000 ft/sec for Site Class B for rock conditions (Park, 2013).

Advanced Geoscience appreciates this opportunity to be of continued service to Yeh and Associates, Inc. and their clients. If you have any questions or additional requests concerning these seismic refraction surveys please contact the undersigned.

Sincerely,
Advanced Geoscience, Inc.



Mark G. Olson
Principal Geologist and Geophysicist

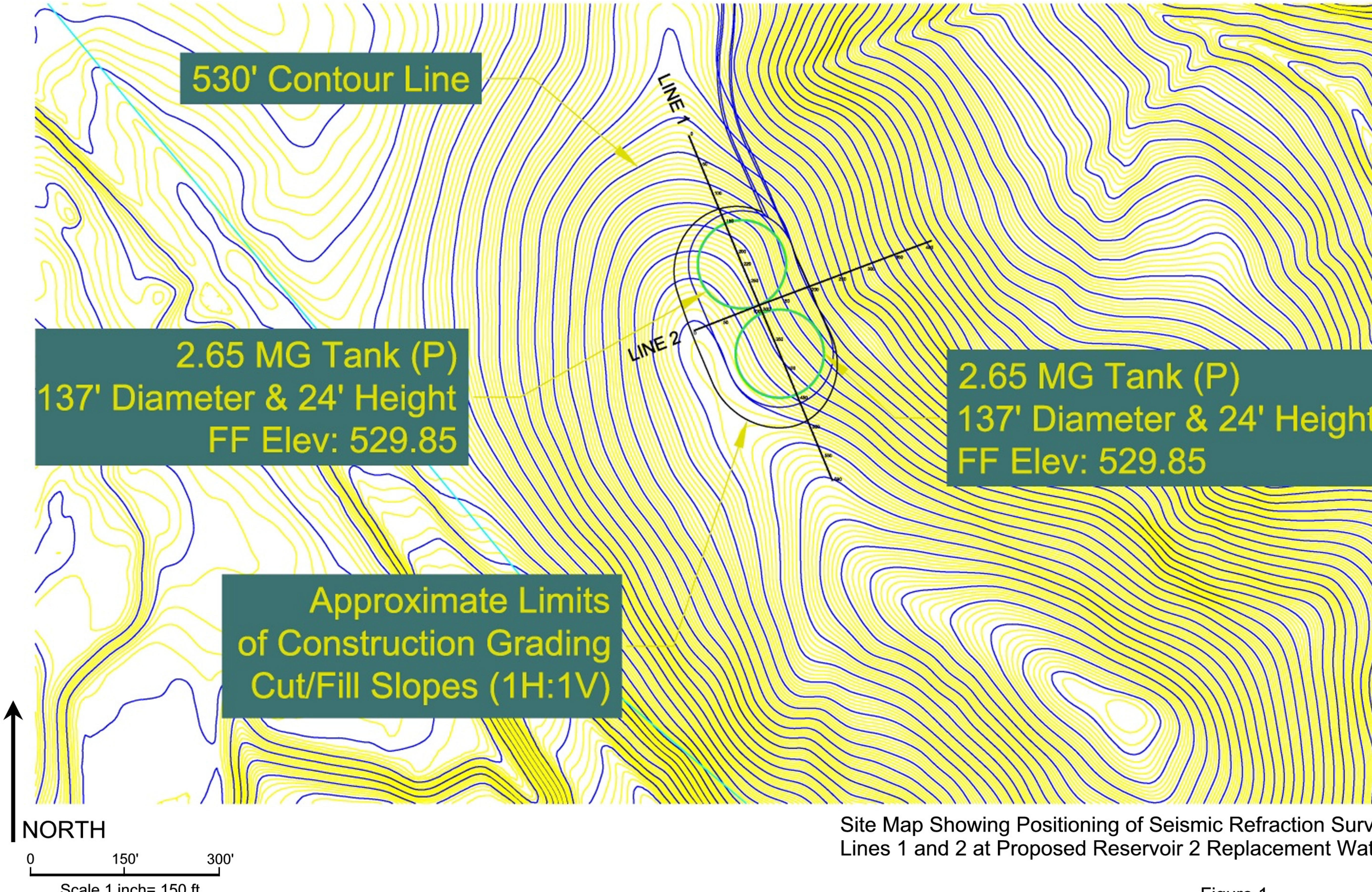
Attachments:

Figure 1 Site Topographic Map Showing Locations of Survey Lines 1 and 2
Figure 2 Line 1- Seismic Refraction Compressional-Wave Velocity Profile
Figure 3 Line 2- Seismic Refraction Compressional-Wave Velocity Profile
Figure 4 Line 1- MASW 1D Seismic Shear-Wave Velocity Profile

References:

Park, C.B., 2013, MASW for Geotechnical Site Investigation, The Leading Edge, Volume 32, No. 6, Society of Exploration Geophysicists, June, 2013.

Wiegers, Mark, 2010, Geologic Map of San Luis Obispo 7.5’ Quadrangle, California Department of Conservation, Geological Survey, 2010.



Site Map Showing Positioning of Seismic Refraction Survey
Lines 1 and 2 at Proposed Reservoir 2 Replacement Water Tank Site

Figure 1
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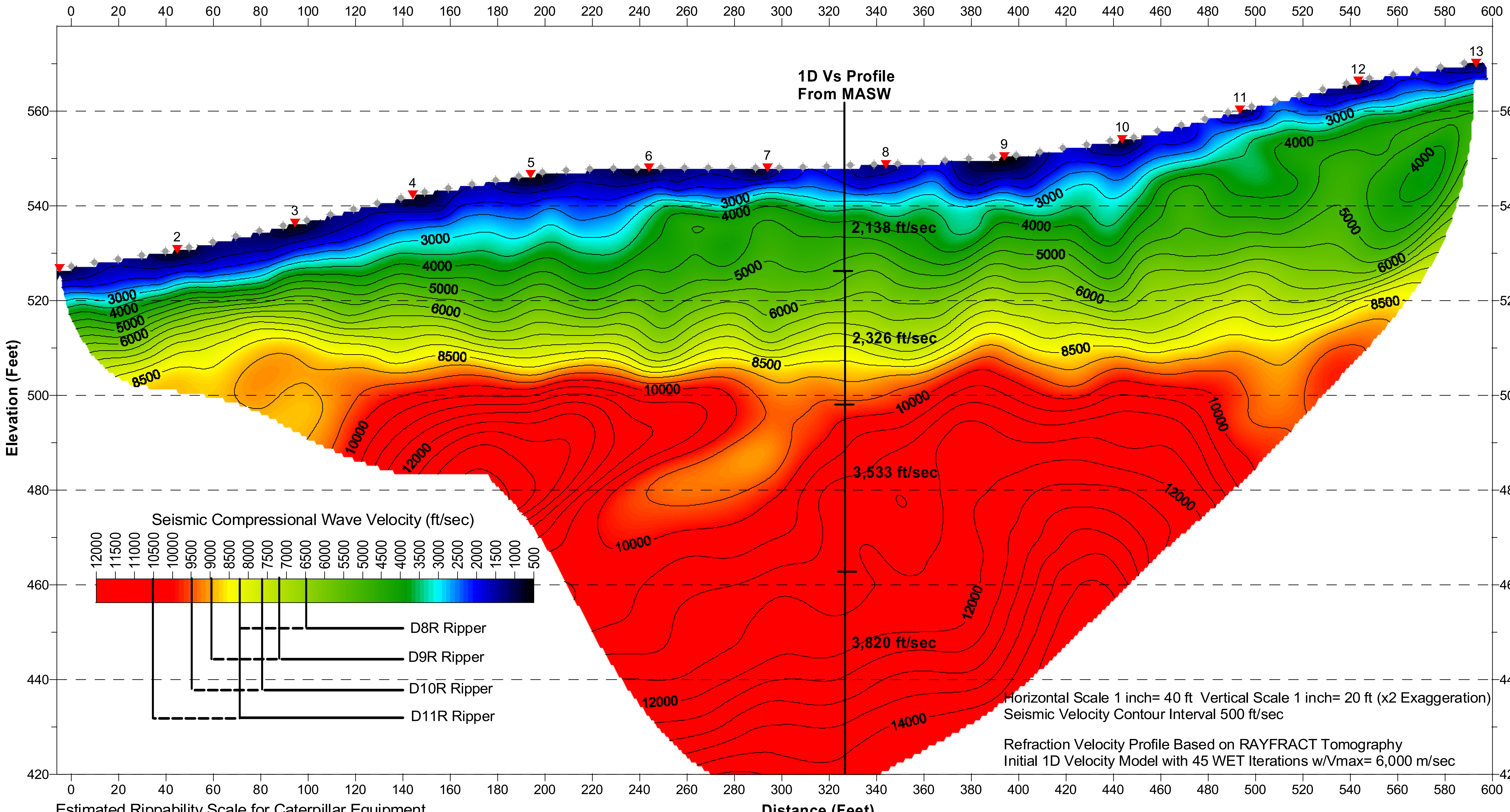
Line 1 Seismic Refraction Compressional-Wave Velocity Profile



Estimated Rippability Scale for Caterpillar Equipment
From Caterpillar Inc. Handbook of Ripping, 12th Edition, Feb. 2000

——— Rippable

- - - - Marginal Rippability

Based on Seismic Velocity Range for Rippability of Metamorphic Schist Rock Type on Caterpillar Charts
For Franciscan Formation (KJfm) Melange and Metavolvanics Mapped in Area

Line 1 Seismic Refraction Velocity Profile
For Bedrock Investigation at Reservoir 2 Water Tank Site
San Luis Obispo, California

Figure 2
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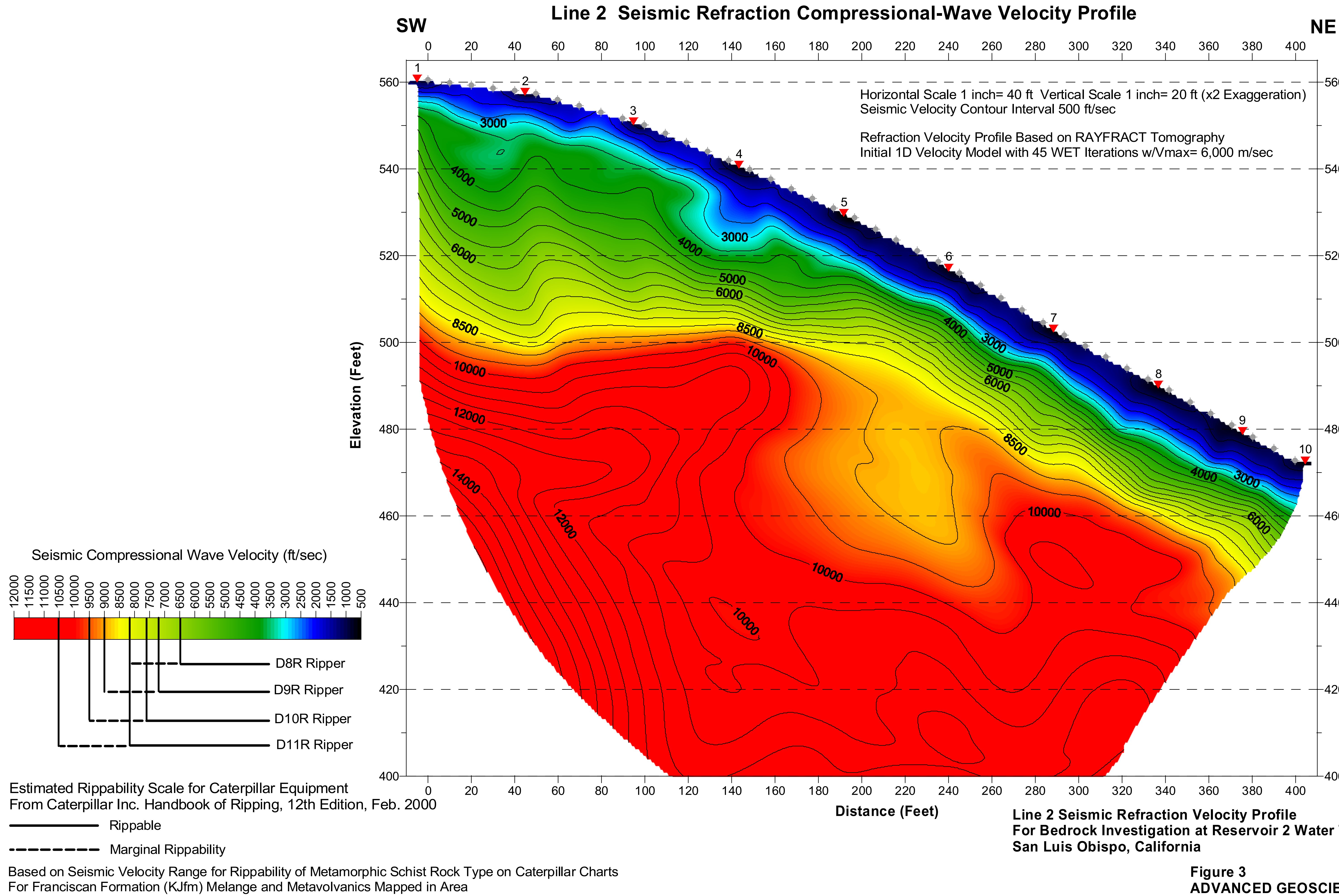

Line 2 Seismic Refraction Velocity Profile
For Bedrock Investigation at Reservoir 2 Water Tank Site
San Luis Obispo, California

Figure 3
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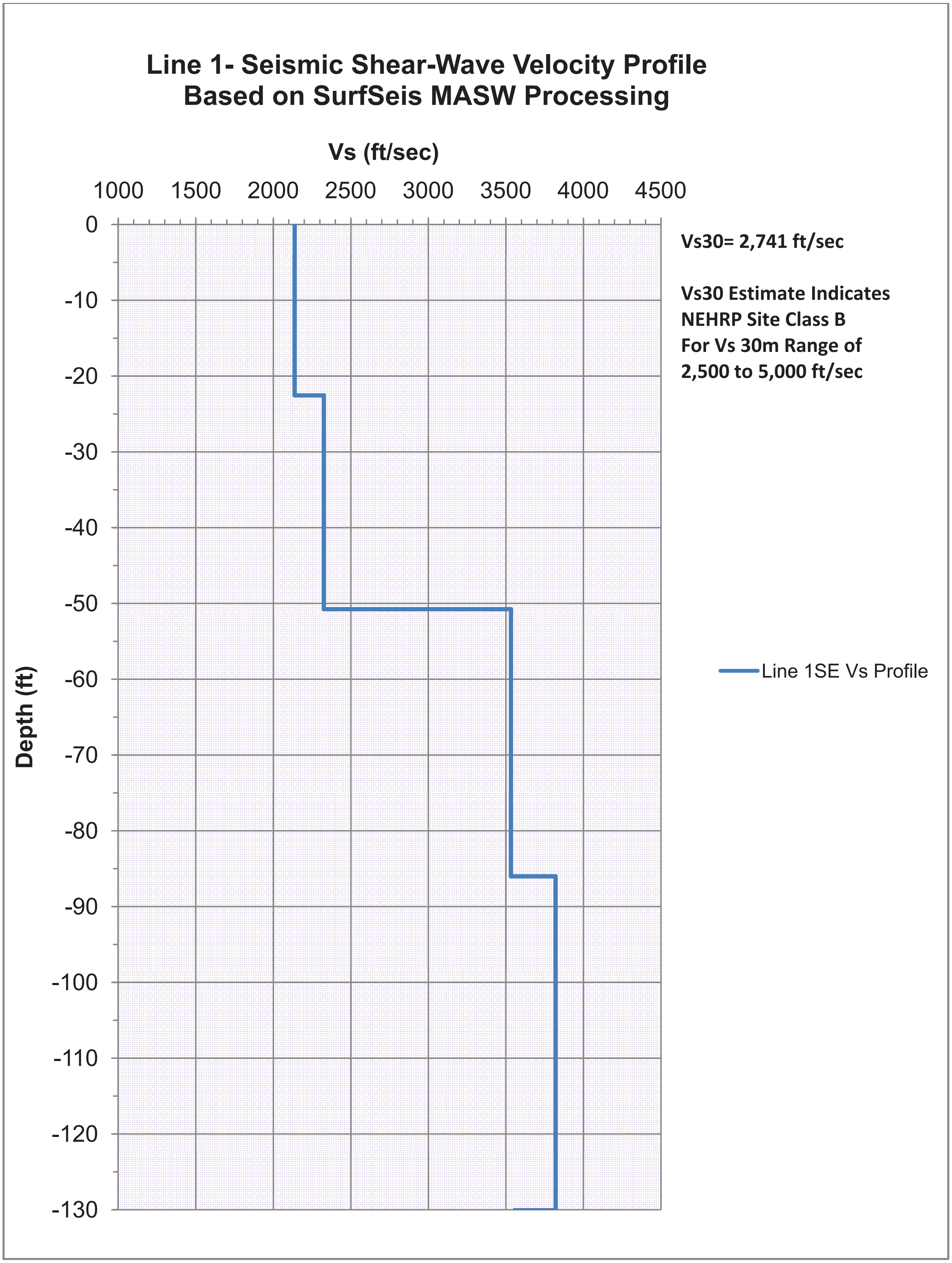

Figure 4

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