	FUGRO CONSULTANTS, INC. **COVER SHEET** *Foundation Velocity Report*	**PR No.: PGEQ-PR-16** **Revision: 1** **Page 1 of 33**

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CCCSIP DCPP P- and S-Wave Foundation Velocity Report

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1	Purpose is clearly stated and Report satisfies the Purpose.	✓		
2	Methodology is appropriate and properly applied.	✓		
3	Assumptions are reasonable, adequately described, and based upon sound geotechnical principles and practices.	✓		
4	Input was authorized and correctly incorporated into the Report.	✓		
5	Software is properly identified and applied; and validation is referenced, or included, and acceptable.	✓		
6	Detailed Discussion is complete, accurate, and leads logical to Results and Conclusions.	✓		
7	Results and Conclusions are accurate, acceptable, and reasonable compared to the Input and Assumptions.	✓		
8	If commercial software, such as EXCEL, MATLAB, IDL, or Mathcad, was used, equations and other entries have been checked as necessary to ensure correct results.	✓		
9	References are valid for intended use.	✓		
10	Appendices are complete, accurate, and support text.	✓		

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ABBREVIATIONS AND ACRONYMS

1D	one-dimensional
2D	two-dimensional
3D	three-dimensional
CCCSIP	Central Coastal California Seismic Imaging Program
DCPP	Diablo Canyon Power Plant
FCL	Fugro Consultants, Inc.
ft/s	feet per second
IMASW	Interferometric Multichannel Analysis of Surface Waves
km	kilometer(s)
kV	kilovolt(s)
m	meter(s)
ms	millisecond(s)
m/s	meters per second
NAD 83	North American Datum of 1983
NAIP	National Agriculture Imagery Program
NRC	U.S. Nuclear Regulatory Commission
ONSIP	Onshore Seismic Interpretation Project
PG&E	Pacific Gas and Electric Company
QA	quality assurance
s	second(s)
Vp	acoustic-wave velocity
Vs	shear-wave velocity

1.0 INTRODUCTION

This project report was prepared to provide P- and S-wave velocity measurements within and around the protected area of the Diablo Canyon Power Plant (DCPP), as part of the Pacific Gas & Electric Company (PG&E) Central Coastal California Seismic Imaging Project (CCCSIP).[1] The primary purpose of developing a three-dimensional (3D) acoustic-wave velocity (Vp; also called P-wave) model within the protected area is to support seismic-reflection processing; this report focuses on additional processing to produce 3D grids of both Vp and shear-wave velocity (Vs; also called S-wave) that encompass the existing structure foundations.

This work is considered a nuclear safety-related activity. Thus it was conducted in strict conformance with the Fugro Consultants, Inc. (FCL) NQA-1 Quality Assurance (QA) program. All work performed by FCL and its subcontractors was reviewed and approved by the PG&E management and QA teams. The 3D Vs and Vp foundation mapping effort was conducted at the request of Dr. Stuart Nishenko, PG&E Geosciences Department, with PG&E QA oversight by Ms. Marcia McLaren. This report, with incorporation of PG&E and independent reviewer comments, will represent the final deliverable associated with the foundation velocity element (task 6) of CWA No. 3500959480 issued to FCL.

1.1 Project Management

The project was directed by PG&E, with primary responsibility for project execution assumed by FCL. Numerous other contractors and subcontractors were tasked with portions of the data collection effort, as shown in the organizational chart (Figure 1-1).

FCL was responsible for assisting PG&E Geosciences and the DCPP in developing and executing a seismic-reflection program to map and characterize active and potentially active faults in the DCPP vicinity. The FCL QA responsibilities were performed under CWA No. 3500905574 with the PG&E Geosciences Department.

1.2 QA Management

FCL qualified and trained all personnel involved in data collection and processing activities under the FCL QA Program, and work was performed in accordance with project-specific QA documents, namely, work instructions prepared by FCL. Pre-work and in-progress surveillances and audits were performed by FCL QA manager Clint Eldridge. All FCL work and QA review were performed and accepted under the QA program.

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[1] The CCCSIP work is being done by PG&E to comply with the California Energy Commission (CEC) recommendation, as reported in the CEC's November 2008 report titled *An Assessment of California's Nuclear Power Plants: AB 1632 Report*, that PG&E use three-dimensional seismic-reflection mapping and other advanced geophysical techniques to explore fault zones near the DCPP.

2.0 PROJECT SCOPE

This report presents analyses and conclusions focused on estimating Vs and Vp depth and elevation profiles within a 3D volume and along Profiles A through D spanning the DCPP foundation area (Figure 2-1). The analyses used active-source seismic data from the onshore CCCSIP data collected in 2011[2] and 2012[3] in the region within and adjacent to the DCPP. GeoTomo, of Houston, Texas, used its validated TomoPlus software to conduct 3D first-arrival tomography analyses in accordance with work instruction 2234-WI-23 (*Process Seismic Data with TomoPlus Software to Produce 2D and 3D Tomographic Models*, most current revision) to provide 3D Vp constraints for seismic-reflection processing over a large area that contains the DCPP foundation. The shallow-resolution limits of the larger-scale 3D Vp constraints are assessed using simplified one-dimensional (1D) data analyses of first-arrival-time data in the DCPP foundation area and two-dimensional (2D) data analyses of three seismic lines in the DCPP area. Surface-wave-dispersion data are used to estimate Vs depth at six locations in the DCPP foundation area.

These new Vp and Vs data are compared to existing shallow downhole seismic Vp and Vs estimates from four boreholes (Blume and Associates, 1969) located within the DCPP foundation area between the two containment structures and the turbine building (Figure 2-2). This region within the large extent of the largest DCPP structures (the turbine building and two containment structures and the area between them) could not be accessed with seismic sources and receivers during the 2012 3D seismic survey. Consequently, shallow (20–40 feet, 6–12 meters [m]) 3D velocities within these regions are not directly constrained by the 3D tomography. For this report, existing pre-construction velocity measurements are used to constrain shallow velocities in this area. Since pre-construction shallow velocities are used to constrain shallow velocities in the central region of the DCPP dominated by embedded structures, the 3D velocity estimates in this report correspond to current topographic grade and natural ground velocity conditions. The results obtained following detailed analyses of manual arrival-time picks and surface-wave dispersion velocities are compared to the TomoPlus 3D high-resolution velocities to develop shallow Vp-depth adjustments and Vp/Vs-depth relations that ensure that estimated 3D Vp and Vs velocities in the DCPP foundation area represent appropriate shallow-velocity profiles.

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[2] PGEQ-PR-02, rev. 1, CCCSIP Onshore SRP—Bird Seismic Systems Data Report, and PGEQ-PR-04, rev. 0, 2011 PG&E Onshore Seismic Reflection Program, Nodal Seismic Data Report.

[3] PGEQ-PR-14, rev. 0, CCCSIP Onshore 2012 Data Report.

3.0 3D TOMOGRAPHY

Three stages of 3D tomographic inversion use acoustic-wave first-arrival-time picks from CCCSIP data to develop a high-resolution 3D Vp tomographic grid for the 2012 Phase 1 region that encompassed the DCPP foundation area (Figure 2-2). Each stage of 3D tomographic inversion is discussed in detail in the *2011 Onshore 2D Data Processing Report* (PGEQ-PR-08). These 3D tomographic Vp inversions are designed to provide critical constraints needed for seismic-reflection processing. The 3D tomography provides an initial 3D interval velocity model for the top several kilometers of the crust on topography for migration-velocity analyses and provides statics for all receiver and source positions.

The seismic-reflection data-acquisition geometry is designed to accomplish seismic-reflection imaging objectives at a variety of scales, from higher-resolution imaging in the top several kilometers in the DCPP area to imaging to the base of the seismogenic crust throughout the larger CCCSIP onshore area. The seismic-reflection data acquisition mostly uses station and source spacings of 32.8 or 98.4 feet (10 or 30 m) in the 2012 Phase 1 area containing the DCPP. A smaller source-and-receiver spacing of 16.4 feet (5 m) is only intermittently accomplished in small areas west and north of the main DCPP foundation footprint (Figure 3-1).

This seismic-reflection data-acquisition geometry is not optimal to estimate shallow geotechnical 3D velocity structure, particularly velocities to depths of approximately 33 feet (~10 m) or less below surface topography. Typical DCPP shallow velocities are approximated well by a lower-velocity ($V0$) thin intermittent soil and strongly weathered zone of thickness z underlain by a higher-velocity zone ($V1$). The maximum distance that first arrival times associated with the shallow lower-velocity weathering zone will be observed is often referred to as the crossover distance, *Xcross* (Dobrin and Savit, 1988):

$$Xcross = 2 * z * \sqrt{\frac{V0+V1}{V1-V0}} \qquad (3\text{-}1)$$

Table 3-1 shows the values of *Xcross* as a function of $V0$, $V1$, and z for ranges of Vp values typical of those found in pre-construction seismic measurements near the center of the DCPP (Blume and Associates, 1969).

Table 3-1. Xcross as a Function of V0, V1, and z

V0 (m/s)	V1 (m/s)	Z (m)	Xcross (m)
1,000	2,500	3	9.2
1,000	2,500	6	18.3
1,000	2,500	9	27.5
747	1,737	4	12.7
747	1,737	8	25.3
747	1,737	12	38.0

Table 3-1 illustrates that for a station spacing of 98.4 feet (30 m), no first-arrival data are available to observe first arrivals at offsets less than the crossover distances of 90–125 feet (27.5–38 m) that would completely constrain the surface-layer velocity (V0) as the thickness of the surface layer approaches 32.8 feet (10 m). Even a 32.8-foot (10 m) station spacing will not provide first-arrival constraints on V0 for surface low-velocity layer thicknesses of 9.8–16.4 feet (3–5 m) because the nearest-offset first arrivals are observed at distances equal to or greater than the ~10 m crossover distance (Table 3-1). As Figure 2-2 shows there are no seismic sources or receivers within the area spanned by the turbine building to the west and the region between the turbine building and the two containment structures. Thus, the 3D tomography does not constrain shallow (20–40 feet, 6–12 m) 3D velocities within this central portion of the DCPP foundation. Consequently, additional detailed first-arrival Vp and surface-wave-dispersion Vs analyses of 16.4-foot (5 m) station-spacing data from specific instrument deployments in the DCPP area along with existing pre-construction DCPP shallow-velocity measurements (Blume and Associates, 1969, 1978) are used to constrain shallow velocities in the central DCPP foundation area. Since the additional shallow velocity constraints from the central DCPP foundation area (Blume and Associates, 1969, 1978) predate construction and most of the 2012 near-offset source-receiver paths within the central DCPP area are outside of the large DCPP structure foundation areas, the 3D DCPP velocity model estimates in this report represent natural (pre-construction) ground conditions. These higher-resolution shallow velocity measurements are used to determine adjustments to the 3D tomography velocities so that estimated Vp and Vs derived from the 3D velocity model are representative of shallow-velocity pre-construction natural ground velocity conditions throughout the DCPP foundation area (see Section 5.3 for additional information).

3.1 GeoTomo First-Break Picking

First-break picking is the groundwork for travel-time-based velocity inversions. When the signal-to-noise ratio of the field data is low, picking first breaks requires significant manual checking. Five specific factors of the DCPP data make picking first breaks challenging, particularly at small offsets.

1. For long source-receiver distances, the soft soil surface weakens the signal sharply.
2. DCPP is a very noisy environment, with turbines and cooling systems producing strong mechanical vibrations and 230-kilovolt (kV) and 500 kV electrical transmission lines producing constant but slightly amplitude-varying and frequency-modulated noise.
3. The irregular source-receiver geometry within the DCPP area required to accommodate large structures, security zones, and other restricted entry areas produces data gaps in source-receiver offset. These gaps cause large zones where first breaks cannot be picked; the automated first-break-detecting algorithm is designed for regular binned-offset (conventional) 2D and 3D seismic-reflection-acquisition geometries.
4. A small Vibroseis source (the 17,000-pound EnviroVibe, manufactured by Industrial Vehicles International) was used in the DCPP area because of restrictions on vibrations produced during seismic sourcing (2234-PI-07, rev. 0, *Vibration Control Plan for Onshore High Energy Seismic Surveys*), so it is difficult to pick first breaks close to the areas of the largest facilities where steady-state mechanical vibrations as large as 1% g occur adjacent to the turbine building.
5. Some areas of the DCPP contain substantial thicknesses of foundation concrete that produce fast, near-offset first breaks. In these areas, the first breaks reflect the as-built conditions, not conditions on natural ground.

Based on the above considerations, the configured workflow enables the automatic picker to take advantage of the known DCPP geometry and available DCPP subsurface-velocity information (Blume and Associates, 1969; URS/Blume and Associates, 1978). Initially, we use the best velocity model estimated from the initial large-scale 3D inversion of 2011 and 2012 CCCSIP data (Figure 3-2) and the previous site velocity measurements (Blume and Associates (1969; URS/Blume and Associates, 1978) to calculate synthetic travel times that provide picking-window guidance for first-break detecting. Then an iterative process is used where updated synthetic travel times after velocity inversion produce improved picks. The improved picks are used to update the velocity model. This process is repeated iteratively until the synthetic travel times and picked travel times are consistent and overlay on the seismic data first breaks. In this sense, first-break picking is not a preliminary step of inversion; it is also a part of the iteration loop that updates the velocity model and travel times until synthetic travel times are consistent with the observed travel times.

3.2 Application of 3D Tomography

The first large-scale stage of tomographic 3D inversion used 22,700,351 active-source acoustic-wave arrival-time picks in a joint inversion with gravity data (Langenheim, 2014) to develop an initial 3D Vp and density model using equidimensional 200-

(easting) by 200- (northing) by 200-foot (elevation) constant-velocity and density cells. The joint travel-time/gravity inversion approach for density and velocity uses the rock-physics relation from Gardner et al. (1974) that relates density to velocity. The joint inversion is formulated as a constrained nonlinear least squares problem and solved using Lagrange multipliers and a preconditioned conjugate gradient iterative algorithm in order to minimize the objective function (Colombo et al., 2013). Details of this tomographic inversion are provided in FCL PGEQ-PR-08 (2014). Prior to joint inversion, inversions are performed separately with the travel-time and gravity data to explore a wide range of velocity and density models and define the best velocity and density models to start the joint inversion.

There are significant residual arrival-time biases after this convergence of the large-scale joint inversion over nearly all source-receiver offsets, indicating the potential for systematic Vp biases (Figure 3-2). The residuals are sorted in each offset bin by an absolute value of the residual to indicate the cumulative fraction (fractile), from zero residual (fractile of zero) to the largest residual (fractile of 1.0). In Figure 3-2, the green region in each offset bin represents half of all the residuals in each offset bin, whereas the 10 percent of the largest residuals in each offset bin are shown in red. To reduce residual biases in the shallower portion of the 3D tomographic model, smaller grid cells and smaller maximum offsets are used in a second, smaller grid-cell-size 3D tomographic travel-time-only inversion.

This second inversion used 9,172,512 active-source acoustic arrival-time picks from the 2012 Phase 1 region (Figure 2-2) at offsets of <15,000 feet, started with the output of the large-scale 3D velocity model in the 2012 Phase 1 area, with velocities interpolated onto finer, non-equidimensional 50- (easting) by 50- (northing) by 10-foot (elevation) constant-velocity cells to a minimum elevation of 1,000 ft below sea level. Inversion of travel-time data in this second higher-resolution inversion allows convergence to a reduced travel-time misfit that has unbiased arrival-time residuals, except at source-receiver offsets of <1,000 feet (Figure 3-3).

To ensure that shallow-velocity biases are minimized, a third highest-resolution 3D tomographic travel-time inversion used 6,380,553 travel times for maximum offsets of <3,000 feet from the 2012 Phase 1 region with 50- (easting) by 50- (northing) by 5-foot (elevation) constant-velocity cells. The resulting arrival-time residuals are unbiased (<0.5 milliseconds [ms]) for offsets >300 feet (Figure 3-4). In contrast, the second inversion has a residual bias of 5 ms at the minimum offset and a residual bias sloping to -2 ms at 1000 ft offset (Figure 3-3).

4.0 EXISTING VELOCITY DATA

Existing velocity data for the foundation area was reviewed from the URS/John A. Blume and Associates (1978) report, *Summary of Geophysical Measurements*. The four shallow uphole velocity profiles DHH-1 to DHH-4 cover areas of the DCPP beneath and between the two containment structures where currently it was not possible to deploy sources or receivers because of the large buildings and restricted areas (Figure 2-2). The uphole-time (referred to as downhole travel-time) data from these four profiles (Figure 4-1) are used to constrain adjustments to the shallow portions of the highest-resolution 3D velocity model in the DCPP region that used 50- (easting) by 50- (northing) by 5-foot (elevation) constant-velocity cells. This is to ensure that the 3D velocities are consistent with the shallow weathering Vp and Vs velocity-depth profiles of natural ground prior to construction and account for the lack of near-offset 2012 data in the central portion of the DCPP foundation (Figure 2-2). Details of the development of adjustments to the tomographic 3D Vp model to produce DCPP-specific 3D Vp and Vs models are presented in Section 5.3.

5.0 ESTIMATION OF SITE-SPECIFIC P- AND S-WAVE VELOCITY PROFILES

The tomographic 3D velocity model provides Vp velocities estimated across a large (~18 × 20 km) area. Subsets of 2012 active-source data from within the DCPP area are analyzed to develop site-specific estimates of 2D Vp tomographic profiles and 1D Vp and Vs profiles using the areas within the DCPP with the densest concentrations of sources and receivers with nominal station spacings of approximately 16.4 feet (5 m) (Figure 5-1) to obtain small offset data to constrain shallow-velocity structure. These site-specific velocity profiles provide the basis for developing shallow-velocity adjustment factors for the 3D tomographic Vp model to produce the calibrated 3D DCPP-specific Vp and Vs models in Section 5.3.

Two-dimensional refraction tomographic processing and Interferometric Multichannel Analysis of Surface Waves (IMASW; O’Connell and Turner, 2011) were used to provide 2D Vp and 1D Vs for comparison to the 3D tomography data. The 2D Vp profiles are from the closest possible deployment of a long-term receiver-cable installation west of the turbine building, the long linear building west of the two circular containment structures in Figure 5-1. Three temporary receiver deployments within the DCPP around the west, south, and north sides of the turbine building and north of the north containment structure represent the closest data to the primary DCPP facilities and provide three areas where 1D Vp and Vs profiles are estimated (Figure 5-1). Surface-wave dispersion processing was used to construct six 1D Vs profiles. Three 2D Vp velocity-elevation sections where developed using 2D tomography from the three available long-linear receiver groups (Figure 5-1), as discussed in Section 5-1. Six areas provide surface-wave phase-velocity measurements that are located west and north of the containment structures (Figure 5-1) to constrain Vs-depth profiles within the DCPP foundation area, as discussed in Section 5.2.

5.1 Local DCPP Refraction Processing

In accordance with work instruction 2234-WI-145, *P-Wave and S-Wave Velocity Analyses Main Plant Foundations – DCPP*, the P-wave velocities were processed from the 2012 3D data using the validated software Rayfract Version 3.25 by Intelligent Resources Inc. The task included performing 2D Rayfract analyses of three Seistronix cabled-based recording system segments that are part of a single cable (Cable 3) deployment: the north, central, and south sections of the eastern leg of the cable deployment (Figure 5-1). Seismic sourcing was positioned at half stations (stations halfway between geophones in the inline direction) through the three cable segments, and the closest source points in the crossline direction to the geophones were used in the refraction analyses. The three straightest geophone layouts, with the smallest receiver spacing of 16.4 feet (5 m) along a Seistronix cable deployment and regular source spacing at one-station increments through the geophone layouts, were used for the refraction processing (Figure 5-1). Rayfract software 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. Source-receiver pair locations for all three 2D Seistronix cable-recording-system seismic-refraction lines are shown on Figure 5-1.

The Rayfract processing workflow is as follows:

1. Read SEG-Y data and geometry.
2. Pick first arrivals and assign first-arrival quality.
3. Build an initial velocity model.
4. Apply 2D first-arrival travel-time tomography.
5. Output final models and data sets.

Seismic-refraction analyses of the seismic data can provide strong constraints on near-surface velocities (statics) and velocity structure. The refraction method includes analyzing the differences in elapsed time between the shot and the detection of the first-arriving seismic waves at various distances from the source. A reconstruction of subsurface velocity structure is made based on the first-arrival times of the seismic energy at the geophones. Seismic-refraction analyses require picking of first-break arrival times and subsequent tomographic inversion of the first-break arrival times to recover the velocity structure that accounts for observed arrival times on topography. Rayfract is used for picking the first breaks at individual traces.

First-break picks were of good quality because either two synchronized EnviroVibes or a single Hemi-60 vibrator were used as energy sources; these seismic sources provide good signal-to-noise ratios over the < 330 foot (100 m) maximum offset range of the three profiles on Figure 5-1. Rayfract provides estimates of 2D Vp from topography, based on these first breaks and the recording geometry. Rayfract uses a “Wavepath Eikonal Traveltime” tomography approach that iteratively improves a subsurface 2D velocity model by tracing rays along multiple signal propagation paths, contributing to one first break based on the Fresnel volume. The computation ends once the arrival times predicted by the velocity model fit the picked first-break arrival times to within a first-break arrival-time typical picking uncertainty of 3–4 ms.

The 2D Vp tomographic profiles from the three Seistronix recording system cable segments (Figure 5-2) provide constraints on shallow weathering-velocity profile characteristics close to the sea cliffs and along the southern side of the entrance to Diablo Creek along the western and northern sides of the DCPP facility (Figure 5-1). To better understand the first-order shallow-velocity profiles further inland, 1D Vp-depth profiles are developed from the three 2D cable segments used in the 2D tomographic analysis plus three inland Sigma recording system receiver groupings and sources west and north of the DCPP turbine building (Figure 5-1). Seismic data from the six receiver groups in Figure 5-1 are used with nearby Vibroseis source points to estimate 1D Vp depth.

For each receiver-group area, all the seismic traces within each distance bin are summed to improve signal-to-noise ratio to better delineate first arrivals. Offset bins are set at 8.2 foot (2.5 m) increments, with the 16.4 foot (5 m) regularly inline spaced Seistronix cable receivers. The Sigma receivers are more irregularly spaced, with group spacings varying from 16.4-32.8 feet (5 -10 m); therefore, a 16.4 foot (5 m) bin spacing is used with the Sigma data to define the traces that are summed in each distance bin to better resolve first-order arrival times. A strongly varying color scale is used to make weaker arrivals more visible, with the seismic traces ordered by offset bin (Figure 5-3). Two scenarios are picked from each of the receiver area stacks to determine earliest and latest first-break times that could be picked from the data.

The apparent velocities and crossover distances from the fast and slow first-arrival time branches from the six 1D Vp-depth profiles on Figure 5-3 are used with Equation (3-1) to estimate weathering layer thicknesses and first-order bounds on shallow Vp (Table 5-1). These simplified 1D Vp-depth estimates are compared to 1D Vp depth extracted from the 2D tomograms from the three Seistronix cable segments, as well as 1D Vp depth extracted from the 3D Vp-elevation model (Figure 5-4). Representative 1D Vp-depth profiles were extracted from the 2D tomograms over the approximately 100-foot-wide (30.5 m) central regions of the tomograms with the deepest velocity resolution. The 1D Vp profiles are created from distributed 2D and 3D Vp profiles using log-normal averaging at each depth of all the lateral estimates of Vp around the center point of the receiver group.

The 1D Vp-depth profiles are shown on Figure 5-4 as black solid curves, with standard-deviation 1D velocity variability shown as black dotted curves. Representative 1D Vp-depth profiles within approximately 50 feet of the source-receiver groups on Figure 5-1 are extracted from the 3D velocity model to create the corresponding 1D average Vp profiles. The individual Vp-depth profiles from the 3D velocity model are log-normally averaged laterally over depth to create the 3D-velocity-model 1D Vp-depth profiles shown on Figure 5-4 as red solid curves, with standard deviation 1D velocity variability shown as red dotted curves.

The shallow portions of the 1D Vp-depth profiles created from the lateral averages of the 3D-velocity-model Vp-depth profiles (herein defined as “3D-1D profiles”) are consistently fast near the surface relative to the 1D Vp-depth profiles from the higher-resolution 2D tomography and 1D Vp-depth profiles estimated by stacking near-offset into bins (Figure 5-4). The 3D-1D Vp-depth profiles generally converge to comparable velocities with the 2D tomography along the Seistronix profiles at approximately 50 foot depth. In contrast, there is good first-order Vp-depth agreement from the surface down between the 1D lateral-averaged 2D tomographic velocities and the 1D slow-pick velocities Vp-depth profiles estimated by stacking near-offset into bins (top plots in Figure 5-4). The central plots on Figure 5-4 illustrate that 3D estimates of shallow velocity are highest at the surface relative to higher-resolution 2D velocities, but generally, the 3D velocities converge to the 2D velocities at depths of 50–60 feet.

Additionally, the shallowest 1D Vp estimates from the 3D velocity model do not correspond to the slow velocities apparent in the 1D Vp-depth profiles estimated by stacking near-offset into bins. This is particularly evident in the velocity data from the Sigma receiver groups adjacent to the turbine building and north containment structure (lower plots on Figure 5-4). The 2D Vp velocity profiles are considered the most accurate and highest resolution estimates of shallow velocities. Given the large differences between shallow 2D and 3D Vp, adjustments to 3D Vp at depths of less than 50 feet are necessary to produce realistic shallow 3D Vp-depth profiles within the DCPP area. These shallow 3D Vp adjustments are presented in Section 5.3.

Table 5-1. Simplified 1D Fast ($_f$) and Slow ($_s$) Apparent Surface-Velocity ($_0$) and Refractor-Velocity ($_1$) and Weathering-Zone Thicknesses ($_h$) from the Six Source-Receiver Groups on Figure 5-1 as Picked on Figure 5-3

Site	V_{0f} (ft/s)	V_{1f} (ft/s)	h_f (ft)	V_{0s} (ft/s)	V_{1s} (ft/s)	h_s (ft)
Seistronix Northeast	5528	10479	64	2992	10842	72
Seistronix Central	4526	9842	21	2351	8680	39
Seistronix Southwest	5118	980	17	1658	6131	20
Sigma Northeast	10163	NA	NA	2327	10412	15
Sigma Northwest	11072	NA	NA	4389	9348	42
Sigma Southwest	2592	10468	15	2705	7798	40

5.2 IMASW Surface-Wave Processing

FCL’s proprietary QA-validated IMASW Version 2.1.0 software estimates Rayleigh-wave dispersion from linear arrays or distributed receiver groups, and then estimates 1D Vs-depth profiles consistent with the observed dispersion. Six regions of active-source Seistronix and Sigma receiver records from the west and north sides of the DCPP (Figure 5-1) were processed using IMASW, in accordance with work instruction WI-145 *P-Wave and S-Wave Velocity Analyses, Main Plant Foundations—DCPP*. These six 1D Vs-depth profiles provide a foundation, along with other existing DCPP geophysical data, to constrain a Vp/Vs-depth function to convert 3D Vp depth to 3D Vs depth.

The SEG-Y files from each of the six source-receiver groups on Figure 5-1 are read into IMASW and sequentially processed for surface-wave dispersion and velocity inversion. Phase-slowness-frequency (p-f) plots are created for each source-receiver-group region by stacking p-f plots from each of the source points recorded by the receiver group. P-f plots from each of the source points are viewed individually. Individual p-f plots with low signal-to-noise that are dominated by transient DCPP noise sources or higher-mode or aliased energy are removed from the overall stack to improve p-f dispersion image quality. Rayleigh-wave dispersion is well constrained at all six receiver groups (Figure 5-5). The Seistronix source-receiver groups have the cleanest p-f images because they were located farther from 1% g turbine vibrations and other mechanical systems than the Sigma source-receiver groups that are closest to the turbine building (Figure 5-1).

Final p-f plots display only the subset of slownesses and frequencies necessary to identify and pick fundamental-model phase slownesses; larger ranges of slownesses and frequencies are used in the initial p-f calculations. Fundamental-mode Rayleigh-wave phase slownesses are picked along the crest of largest amplitudes represented on Figure 5-5 by the darkest red regions since active-source records are used in all cases; dark blue regions have the lowest amplitudes on Figure 5-5. The picked slownesses on Figure 5-5 are plotted as blue pluses in white circles, with the slowness uncertainties plotted as black pluses in white circles above the picked slownesses to provide slowness uncertainty bounds.

The p-f dispersion and pick uncertainties are used in the IMASW software Monte Carlo inversion module to evaluate 14,000 possible velocity-depth models. There are five individual sequences of Monte Carlo inversion: the first four sequences each evaluate 2,000 velocity-depth models, and the fifth sequence evaluates 4,000 velocity-density models. These are followed by a final (sixth) Monte Carlo inversion. After each individual Monte Carlo inversion sequence, the best 22 models are used in the next Monte Carlo inversion sequence as starting models to generate the next set of 2,000 to 4,000 velocity-depth models. The sixth and final Monte Carlo inversion uses the best 22 velocity-depth models from the fifth sequence of Monte Carlo inversion inputs to find 5,000 final models to quantify 1D Vs-depth statistics, including mean and median models, and 16th and 84th percentile velocities. The velocity inversion algorithm effectively combines aspects of simulated annealing and Monte Carlo inversion as discussed in detail in O’Connell and Turner (2011). Velocity inversions are performed using phase-slowness constraints with strong low-velocity-zone penalty functions to obtain smooth velocity models consistent with the available phase dispersion data.

Vs-depth profile and uncertainties from the Monte Carlo inversions, along with the dispersion fits for the six source-receiver group locations, are shown on Figure 5-6. Lower Vs occurs in the three Seistronix groups near the sea cliffs (top three figure pairs on Figure 5-6). In contrast, the more inland Sigma groups have relatively thin and higher Vs shallow weathering velocities and higher velocities with increasing depth (lower three figure sets on Figure 5-6) relative to Vs depth closer to the coast and Diablo Creek. These six Vs-depth profiles provide Vs-depth constraints to develop the Vp/Vs relations used to convert 3D Vp to 3D Vs, as discussed in the next section.

5.3 Adjustments to the 3D Tomographic Vp Model to Estimate DCPP 3D Vp and Vs

The six IMASW Vs depth profiles discussed in Section 5.2 provide the constraints to estimate a Vp/Vs-depth conversion function that accurately converts GeoTomo Vp depth functions to Vs depth. The four downhole geophysical velocity and arrival-time logs to approximately 50-foot depth in the central containment area of the DCPP that pre-date construction (Blume and Associates, 1969) from Section 4.0 provide constraints to convert post-construction GeoTomo Vp depth to pre-construction ("native ground") Vp depth. The Vp-depth conversion compensates for the extensive distribution of higher-velocity construction materials (e.g., pavement, concrete blocks, piping) that were encountered at the surface and to depths of up to approximately 30 feet during the 2012 data acquisition within the DCPP foundation area, and in areas where receiver offsets were too large to resolve Vp at depths less than 30 feet (Table 3-1).

The first step to develop the Vp/Vs depth function is to create an average GeoTomo Vp depth function representative of the horizontal dimensions and source-receiver paths used for each of the six IMASWVs-depth profiles (Figure 5-1). At each depth the average velocity is calculated from all the GeoTomo profile Vp values using the exponential of the mean of the natural logarithms of all the Vp values at that depth; the natural logarithm standard deviations are also calculated at each depth to facilitate plotting variability of Vp as a function of depth.

A four-parameter three-point linear-gradient Vp/Vs-depth function (Vp/Vs surface value, Vp/Vs value at 5–25 m depth range to define an inflection point, and Vp/Vs value at 150 m depth, with the actual best-fitting depth for the Vp/Vs inflection point in the 5–25 m depth range as the fourth parameter) is evaluated using a grid search approach to find the combination of these parameters that minimizes the misfit to the observed Vs depth profiles (Table 5-2). At each unique four-parameter combination the fit of the GeoTomo Vs depth function obtained using the current Vp/Vs depth function is compared to each of the six IMASW Vs depth profiles to evaluate the fit of each candidate Vp/Vs depth function to the surface-dispersion constraints on Vs depth in the DCPP foundation area (Figure 5-7).

Table 5-2. GeoTomo Vp/Vs Grid Search Parameters, Ranges, and Final Estimates

Parameter	Minimum	Maximum	Increment	Final Model Parameters
Z=0 m Vp/Vs	5.5	7.5	0.05	7.25
Vp/Vs @ inflection	2.4	3.25	0.05	3.2
Z=150 m Vp/Vs	1.65	2.9	0.05	1.75
Z inflection (m)	5 m	25 m	0.5 m	10 m

It is difficult to find a set of parameters that both produces near zero velocity bias across all six sites and also minimizes the maximum range of bias observed at any one site. The final model parameters that achieve the best balance of these two objectives are listed in the right column of Table 5-2. These Vp/Vs parameters result in a slight bias to underestimate Vs in the three sites within the DCPP protected area west of the turbine building and north of containment unit one (Table 5-3). If the velocity bias is reduced with the DCPP protected area sites, then the velocity biases increase substantially for the sea cliffs sites in Table 5-3. An additional parameter to represent a horizontal gradient in Vp/Vs was evaluated but there is not a sufficient distribution of sites to realistically constrain this additional parameter. Consequently, the Vs velocity bias in the DCPP protected area is considered acceptable since it represents a slightly lower (conservative) estimate of Vs for this area. The GeoTomo Vp/Vs parameters in Table 5-2 on average overestimate Vs near the sea cliffs outside of the DCPP foundation area (Seistronix sea cliff road regions in Table 5-3).

Table 5-3. Bias of 3D Vs Estimates Relative to IMASW Vs Constraints

Location	IMASW Region	Median Vs Bias (%)
Sea Cliffs	Seistronix Northeast	–7.4
	Seistronix Central East	10.3
	Seistronix Southeast	24.5
	Mean Vs Bias (%)	**9.1**
DCPP Protected Area	Sigma Northeast	–8.8
	Sigma Northwest	–2.0
	Sigma Southeast	–11.2
	Mean Vs Bias (%)	**–7.4**

The shallow 3D Vs-depth estimates derived using the Vp/Vs parameters in Table 5-2 are compared to the Blume and Associates (1969) downhole shear-wave travel times from the four post-excavation, pre-construction boreholes near the center of the DCPP in the top of Figure 5-8; the new Vs-elevation profiles were converted to Vs-depth using topography rounded to the closest 5-foot elevation cell for the comparisons with the Blume and Associates (1969) Vs-depth profile in Figure 5-8. Below 20-foot depth, the mean of 3D Vs-depth estimates (black line on Figure 5-8) is slightly biased toward lower values than the downhole measurement (dotted vertical line on Figure 5-8) and is higher in the top 20 feet (Figure 5-8). The Sigma DCPP receiver groups that provide the Vs depth constraints for the Vp/Vs depth relation were located on developed areas on pavement (Figure 5-1), while Blume and Associates' (1969) downhole sites were located on ground prior to construction (Figure 2-2). The shallow Vs differences in the upper plot of Figure 5-8 are consistent with stiffer material emplaced in the first 10–20 feet during construction relative to original ground.

To constrain the shallowest Vp within the DCPP, we used the mean Poisson's ratio of 0.319 from Blume and Associates (1969) from shallow slow-velocity regions to establish Vp/Vs at the surface and the mean Poisson's ratio of 0.22 at a depth of 32.8 feet. Shallow 3D Vp was adjusted using the estimated 3D Vs to conform to the shallow Blume and Associates (1969) Poisson's ratios using the Vp-depth conversion factors in Table 5-4. The resulting 3D Vp is nearly unbiased relative to Blume and Associates' (1969) Vp below 40 feet (lower plot on Figure 5-8).

Table 5-4. Vp-Depth Conversion Factors for Slow 3D DCPP Vp Model

Depth (feet)	GeoTomo 3D Vp to DCPP Vp Ratio
0	3.74
32.8	1.92
492.1	1

Since the GeoTomo 3D Vp model produces unbiased residuals at 300-foot offsets or more (Figure 3-4), the 3D Vp model is likely unbiased below depths of 50–80 feet based on Equation (3-1) and is consistent with DCPP Vp profiles below 40–50 feet (Figure 5-8). However, the shallow Vp is more uncertain so three 3D DCPP Vp models are produced to account for epistemic uncertainties in shallow Vp:

1. One Vp model is produced with the Blume and Associates (1969) Poisson's ratio constraint imposed (Table 5-4).
2. One Vp model uses the Vp-depth conversion factors of Table 5-5 that produces shallow Vp velocities somewhat higher than the Blume and Associates (1969) and URS/Blume and Associates (1977) shallow constraints.
3. One Vp model uses the original GeoTomo 3D Vp values.

The 3D DCPP Vs model is the same in all three 3D models since a single Vp/Vs function validated using the IMASW velocity constraints (Figure 5-7) was used with the original unmodified 3D Vp model to produce the 3D Vs model. The files and format of the DCPP 3D velocity models are presented in Appendix A.

Table 5-5. Vp-Depth Conversion Factors for Fast 3D DCPP Vp Model

Depth (feet)	GeoTomo 3D Vp to DCPP Vp Ratio
0	2.35
12.8	1.92
472.1	1

6.0 VELOCITY COMPARISON ACROSS DCPP

Four velocity transects are used to illustrate velocity variability within DCPP: two transects oriented through the center lines of the containment structures (A-A′) and the turbine building (B-B′), and two transects (C-C′ to the north, D-D′ to the south) from the sea cliffs inland (Figure 2-2). The resulting Vs-elevation profiles (Figure 6-1) strongly correlate with the age and elevation of marine terraces (PG&E, 2014). The slowest shallow velocities occur in the youngest and lowest terrace next to the coastal cliffs, with shallow velocities increasing with distance from the coastal cliffs and the slopes of Diablo Creek.

To calculate representative values of Vs30 (average shear-wave velocity down to 30 m depth) for the entire DCPP foundation area, the subset of velocity-profile locations along the four profiles encompassing the turbine building and containment structures in Table 6-1 are used to calculate Vs30 for two starting grid cell elevations closest to two structural elevations of DCPP structures. Vs30 starting at a cell top elevation of 62 feet above sea level near the turbine building foundation grade of 61 feet above sea level averages 1,112 ± 200 m/s (3,648 ± 656 ft/s). Vs30 calculated starting at a cell top elevation of 52 ft above sea level near the containment structure foundation grade of 52.7 feet above sea level averages 1,147 ± 190 m/s (3,762 ± 622 ft/s). A second estimate of Vs30 is provided to account for epistemic uncertainty in the estimated Vp/Vs relationship for the DCPP foundation. The second estimate corrects for the bias to potentially systematically underestimate Vs along the eastern containment structure portion of the foundation on average by 7.4% (Table 5-3). This second DCPP Vs30 estimate a profile starting at 52 ft above sea level near the containment structure foundation grade of 52.7 feet above sea level has an average Vs30 of 1238 m/s.

The velocities within the 3D extent of the DCPP foundation and the depth range of calculated Vs30 starting at elevations of 52-62 feet above sea level are generally well constrained by ray coverage (Table 6-2). There are one to two profile locations where there are no ray hits in some 5 ft depth cells within 100 feet of the profile location, but generally there are at least 1-40 ray hits for 30 of the 32 profile locations for all 5 foot depth cells (Table 6-2). For 87.5% (28 of 32) of the profile locations there are at least 6 ray hits within 100 feet of the profile locations in all 5 foot depth cells, with usually at least 20 or more rays at most cell depths (Table 6-2). Three quarters (24 of 32) of the profile locations have at least 57 or more ray hits within 100 feet of the profile locations at all cell depths (Table 6-2). The median number of ray hits is at least 275 or more for all cell depths, with some locations having thousands of ray hits at most cell depths (Table 6-2). Table 6-2 demonstrates that velocity-depth along the velocity profile locations used to calculate average DCPP Vs30 are well constrained by ray coverage over the depth range of the Vs30 estimates.

Velocities are also calculated from the subset of velocity profiles within the 3D extent of the DCPP power block and the DCPP turbine building. The DCPP power block Vs30 values are calculated starting at an elevation of 52 ft above sea level to correspond to the basemat elevation of the power block using the velocity profiles located at the positions listed in Table 6-3. The natural-log-average Vs30 with a 52-foot starting elevation for the DCPP power block from the 11 velocity profiles in Table 6-3 is 1257 m/s ± 102 m/s (4,124 ± 333 ft/s). Ray coverage beneath the DCPP power block is variable with extensive ray coverage over all depths within most profiles except for two Vs-depth profiles that have no ray coverage within a small subset of depth intervals (Table 6-4). Overall there is good ray coverage to define a mean Vs30 for the DCPP power block (Table 6-4). The DCPP turbine building Vs30 values are calculated starting at an elevation of 62 ft above sea level to correspond to the basemat elevation of the DCPP turbine building using the velocity profiles located at the positions listed in Table 6-5. The natural-log-average Vs30 with a 62-foot starting elevation for the DCPP turbine building from the 15 velocity profiles in Table 6-5 is 983 m/s ± 97 m/s (3,078 ± 319 ft/s). Ray coverage beneath the DCPP turbine building is generally extensive except for the small area along the southeast portion of the turbine building represented by profiles B-B' 800 and D-D' 400 that were not accessible with sources and receivers (Table 6-6). Overall, the extensive ray coverage demonstrated in Table 6-6 indicates that Vs30 is well constrained beneath the DCPP turbine building (Table 6-6).

Vs generally increases with increasing distance east (inland) from the coast at depths below the near-surface soil/weathering layer. A Vs-elevation cross section example is provided in Appendix A. Figure A1 in Appendix A shows the cross section location of Figure A3. Figure A3 shows typical Vs variations in cross section from west to east across the DCPP foundation region with Vs generally increasing inland to the east below near-surface soils/weathering velocities. To reveal small-scale details of the Vs-elevation profiles in Figure 6-1, each of the four plots in Figure 6-1 are reproduced at a larger scale on individual pages in Appendix B.

Velocities within the Tertiary Obispo Formation vary substantially over the larger area that contains the DCPP. To put the DCPP foundation velocities in context with respect to velocities found in the larger area surrounding the DCPP, Vs-elevation profiles were calculated at five selected Obispo Formation sites outside the DCPP foundation area that are located within dense seismic-survey source-receiver coverage and generally thick soil cover (Figure 2-1). Consequently, realistic shallow Vp velocities and soil thicknesses of approximately 30 feet are obtained at all five sites (Figure 6-2); these sites do not require the intricate shallow-velocity adjustments of the more sparsely-instrumented DCPP areas because minimum source-receiver offsets are typically only 5 m due to sourcing at receiver half station intervals. A single Vp/Vs value of 2.45 corresponding to a bounding value of Poisson’s ratio of 0.4 for elevations above the water table (Boore, 2007) is used to produce Vs elevation at the five Obispo Formation sites (Figure 6-3).

Obispo Formation Vs30 calculated from an elevation of 62 feet averages 1,000 m/s (3,280 ft/s) across the five non-DCPP sites, comparable to the DCPP foundation 62-foot Vs30 of 1,120 m/s (3,648 ft/s). However, Vs30 at the five non-DCPP Obispo Formation sites is far more variable, ranging from 673 to 1,502 m/s (2,208–4,928 ft/s). Obispo Formation Vs30 calculated from ground-surface topography in these non-DCPP areas of generally deep soil/fill average approximately 275 m/s (902 ft/s); the 3D tomography in these areas shows thicknesses of soil ranging from 30 to 50 feet based on the thickness of velocities <1,371 m/s (4,500 ft/s).

The 3D high-resolution tomography images laterally extensive, relatively thin bodies of high velocity (3,658–6,096 m/s, or 12,000–20,000 ft/s) over an area extending approximately 4 km northwest to 4 km southeast of the DCPP. Tertiary diabase is exposed in numerous outcrops in this area (PG&E, 2014). The locations of thin, high-velocity bodies in the 3D high-resolution tomography correlate one-to-one with subsurface extensions of these diabase outcrops. The 3D high-resolution tomography shows high-velocity bodies beneath and east of the DCPP foundation (Figure 6-1), with Vs exceeding 2,000 m/s (6,562 ft/s); such high Vs in this shallow depth range correlates with sill-like diabase intrusives and associated bedrock alteration.

The 3D DCPP foundation velocity models in Appendix A provide estimates of current grade (topographic) ground seismic velocity conditions across the DCPP foundation area exclusive of modification by embedment of DCPP structures that replaced ground material. As such it is appropriate to modify the 3D DCPP foundation velocity models to reflect as-built conditions in the subsurface using specific information about the 3D subsurface extent of emplaced material and seismic properties of emplaced material embedded below grade.

Table 6-1. Velocity-Elevation Profile Locations Used to Calculate DCPP Vs30

Profile	**Station**	**NAD 83 State Plane Zone 5 Easting (feet)**	**NAD 83 State Plane Zone 5 Northing (feet)**	**Surface Elevation (feet)**
A-A'	200	5708859.9	2275862.8	85.9
A-A'	300	5708898.0	2275770.3	86.3
A-A'	400	5708936.0	2275677.8	90.1
A-A'	500	5708974.1	2275585.3	98.9
A-A'	600	5709012.1	2275492.8	98.5
A-A'	700	5709050.1	2275400.4	98.5
A-A'	800	5709088.2	2275307.9	89.1
A-A'	900	5709126.2	2275215.4	86.4
A-A'	1000	5709164.3	2275122.9	86.3
B-B'	200	5708710.1	2275801.1	87.0
B-B'	300	5708748.1	2275708.7	87.0
B-B'	400	5708786.2	2275616.2	87.1
B-B'	500	5708824.2	2275523.7	87.3
B-B'	600	5708862.3	2275431.2	87.2
B-B'	700	5708900.3	2275338.7	87.4
B-B'	800	5708938.4	2275246.3	87.3
B-B'	900	5708976.4	2275153.8	87.4
B-B'	1000	5709014.5	2275061.3	87.0
C-C'	200	5708671.3	2275527.4	86.9
C-C'	300	5708763.8	2275565.5	87.1
C-C'	400	5708856.3	2275603.5	87.2
C-C'	500	5708948.8	2275641.6	96.7
C-C'	600	5709041.2	2275679.6	108.7
C-C'	700	5709133.7	2275717.6	116.5
C-C'	800	5709226.2	2275755.7	147.1
D-D'	200	5708794.3	2275228.5	87.1
D-D'	300	5708886.8	2275266.5	87.0
D-D'	400	5708979.3	2275304.6	87.3
D-D'	500	5709071.7	2275342.6	95.0
D-D'	600	5709164.2	2275380.7	109.6
D-D'	700	5709256.7	2275418.7	117.0
D-D'	800	5709349.2	2275456.8	149.2

Table 6-2. Ray Hit Count Statistics for the 32 Vs30 Profile Locations in Table 6-1

Cell Top Elevation (feet)	Lowest Ray Hit Count	Highest Ray Hit Count	Median Ray Hit Count	Lowest Ray Hit Count for 30 of 32 Profiles	Lowest Ray Hit Count for 28 of 32 Profiles	Lowest Ray Hit Count for 24 of 32 Profiles
62	0	27111	942	2	22	134
57	2	23269	785	6	51	73
52	3	16776	595	5	31	100
47	4	10105	459	8	22	61
42	3	24019	406	7	29	62
37	1	11584	394	3	41	57
32	0	10113	401	2	35	62
27	0	10338	395	1	28	98
22	0	10556	426	2	6	95
17	0	6112	364	5	21	74
12	0	6717	325	7	35	88
7	0	6252	275	15	102	144
2	0	6485	384	21	105	150
-3	0	7946	485	16	96	229
-8	16	8243	624	22	90	136
-13	7	8734	641	19	94	144
-18	3	10381	791	23	70	230
-23	15	11916	911	58	126	219
-28	16	19716	1073	25	156	217
-33	0	27944	652	19	80	97
-38	1	29269	835	17	39	84
-43	0	19530	463	7	33	76
52	3	16776	595	5	31	100

Table 6-3. Velocity-Elevation Profile Locations Used to Calculate DCPP Power Block Vs30 Using a Starting Elevation of 52 feet Above Mean Sea Level

Profile	Station	NAD 83 State Plane Zone 5 Easting (feet)	NAD 83 State Plane Zone 5 Northing (feet)	Surface Elevation (feet)	Vs30 (m/s)
A-A'	400	5708936.0	2275677.8	90.1	1212
A-A'	500	5708974.1	2275585.3	98.9	1241
A-A'	600	5709012.1	2275492.8	98.5	1311
A-A'	700	5709050.1	2275400.4	98.5	1306
A-A'	800	5709088.2	2275307.9	89.1	1255
C-C'	400	5708856.3	2275603.5	87.2	1050
C-C'	500	5708948.8	2275641.6	96.7	1229
C-C'	600	5709041.2	2275679.6	108.7	1463
D-D'	400	5708979.3	2275304.6	87.3	1208
D-D'	500	5709071.7	2275342.6	95.0	1272
D-D'	600	5709164.2	2275380.7	109.6	1323

Table 6-4. Ray Hit Count-Depth for DCPP Power Block Vs30 Profile Locations in Table 6-3 For a Starting Elevation of 52 Feet Above Mean Sea Level

Profile	A-A' 400	A-A' 500	A-A' 600	A-A' 700	A-A' 800	C-C' 400	C-C' 500	C-C' 600	D-D' 400	D-D' 500	D-D' 600
Depth (m)	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**
0	729	2633	7777	30	61	686	646	8839	5	31	194
1.524	207	1953	8040	10	61	499	495	4691	8	15	137
3.048	392	1519	8055	29	63	172	610	24019	5	8	112
4.572	125	941	8594	203	57	128	368	11584	3	3	105
6.096	105	657	7852	349	54	108	228	10113	1	2	110
7.62	110	573	6752	380	50	34	188	10338	0	0	116
9.144	95	533	6332	429	46	6	177	10556	0	0	129
10.668	24	419	6112	522	46	21	122	4820	0	5	150
12.192	15	358	6029	1024	77	47	117	3772	0	35	178
13.716	15	316	5438	1835	90	208	129	3697	0	208	155
15.24	21	292	4637	1954	105	362	134	3650	0	295	150
16.764	16	235	5305	2784	96	258	140	3192	0	332	377
18.288	16	253	7953	4067	90	136	129	794	22	396	1278
19.812	7	197	7665	5432	94	19	56	144	164	657	2425
21.336	25	230	7386	6117	140	31	70	3	784	933	3074
22.86	126	267	10061	6923	202	15	159	58	1311	1223	3618
24.384	156	217	11509	7631	324	16	162	89	4320	2461	4137
25.908	148	95	11157	9097	868	9	131	70	11180	5006	5095
27.432	127	47	8924	10531	822	8	99	45	16137	9754	7571
28.956	99	67	8464	15732	7801	2	83	33	16136	13770	8903

Table 6-5. Velocity-Elevation Profile Locations Used to Calculate DCPP Turbine Building Vs30 Using a Starting Elevation of 62 feet Above Mean Sea Level

Profile	Station	NAD 83 State Plane Zone 5 Easting (feet)	NAD 83 State Plane Zone 5 Northing (feet)	Surface Elevation (feet)	Vs30 (m/s)
B-B'	200	5708710.1	2275801.1	87.0	833
B-B'	300	5708748.1	2275708.7	87.0	901
B-B'	400	5708786.2	2275616.2	87.1	974
B-B'	500	5708824.2	2275523.7	87.3	976
B-B'	600	5708862.3	2275431.2	87.2	1028
B-B'	700	5708900.3	2275338.7	87.4	1069
B-B'	800	5708938.4	2275246.3	87.3	1089
B-B'	900	5708976.4	2275153.8	87.4	1056
B-B'	1000	5709014.5	2275061.3	87.0	966
C-C'	200	5708671.3	2275527.4	86.9	804
C-C'	300	5708763.8	2275565.5	87.1	921
C-C'	400	5708856.3	2275603.5	87.2	1045
D-D'	200	5708794.3	2275228.5	87.1	957
D-D'	300	5708886.8	2275266.5	87.0	1052
D-D'	400	5708979.3	2275304.6	87.3	1144

Table 6-6. Ray Hit Count-Depth for DCPP Turbine Building Vs30 Profile Locations in Table 6-5 For a Starting Elevation of 62 Feet Above Mean Sea Level

Profile	**B-B' 200**	**B-B' 300**	**B-B' 400**	**B-B' 500**	**B-B' 600**	**B-B' 700**	**B-B' 800**	**B-B' 900**	**B-B' 1000**	**C-C' 200**	**C-C' 300**	**C-C' 400**	**D-D' 200**	**D-D' 300**	**D-D' 400**
Depth (m)	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**	**Ray hits**
0	1065	552	5091	5323	2241	317	0	7	427	3508	5028	7264	3105	1	2
1.524	1335	505	1012	3085	1768	63	2	6	423	2341	2886	940	3104	5	6
3.048	1588	543	930	1446	984	56	3	4	423	1495	1598	686	3051	16	5
4.572	1516	499	743	1674	1218	42	7	4	423	1125	1602	499	3075	22	8
6.096	1536	633	284	1413	1395	34	7	3	424	961	1444	172	3278	32	5
7.62	1566	487	210	1467	1486	41	8	8	433	697	1333	128	3494	53	3
9.144	1674	513	162	1859	1509	35	4	21	482	633	1224	108	3857	62	1
10.668	1772	409	28	1981	1767	109	4	20	429	634	854	34	4330	98	0
12.192	3729	422	3	1874	1875	219	4	24	440	731	557	6	4935	156	0
13.716	4977	442	16	1575	1947	371	5	74	455	798	356	21	5388	163	0
15.24	6717	291	34	1365	2249	874	7	88	421	784	245	47	5633	166	0
16.764	6252	144	157	952	2384	1402	15	102	405	924	155	208	5760	234	0
18.288	6445	214	406	685	2526	1828	22	110	415	963	286	362	6485	332	0
19.812	7946	257	497	761	2540	2179	25	108	429	1168	590	258	7281	472	0
21.336	5970	309	476	953	2494	2798	56	125	557	1381	962	136	8243	690	22
22.86	3308	305	349	1164	1944	3647	140	129	654	1684	1259	19	8734	1331	164
24.384	815	241	408	1357	1818	4979	267	196	797	2582	1882	31	10381	3326	784
25.908	323	314	97	989	1682	7469	1415	410	931	2871	1556	15	11916	7730	1311
27.432	236	322	25	3125	3128	11755	9980	992	1160	10120	3804	16	12868	19716	4320
28.956	197	82	0	58	80	5457	25650	6822	1422	2260	97	9	5622	27944	11180

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