Reducing Uncertainty in the Seismic Design Basis for the Waste Treatment Plant, Hanford, Washington

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ABSTRACT

The seismic design basis for the Waste Treatment Plant (WTP) at the Department of Energy’s (DOE) Hanford Site near Richland was re-evaluated in 2005, resulting in an increase by up to 40% in the seismic design basis. The original seismic design basis for the WTP was established in 1999 based on a probabilistic seismic hazard analysis completed in 1996. The 2005 analysis was performed to address questions raised by the Defense Nuclear Facilities Safety Board (DNFSB) about the assumptions used in developing the original seismic criteria and adequacy of the site geotechnical surveys. The updated seismic response analysis used existing and newly acquired seismic velocity data, statistical analysis, expert elicitation, and ground motion simulation to develop interim design ground motion response spectra which enveloped the remaining uncertainties. The uncertainties in these response spectra were enveloped at approximately the 84th percentile to produce conservative design spectra, which contributed significantly to the increase in the seismic design basis.

A key uncertainty identified in the 2005 analysis was the velocity contrasts between the basalt flows and sedimentary interbeds below the WTP. The velocity structure of the upper four basalt flows (Saddle Mountains Basalt) and the interlayered sedimentary interbeds (Ellensburg Formation) produces strong reductions in modeled earthquake ground motions propagating through them. Uncertainty in the strength of velocity contrasts between these basalts and interbeds primarily resulted from an absence of measured shear wave velocities (Vs) in the interbeds. For this study, Vs in the interbeds was estimated from older, limited compressional wave velocity (Vp) data using estimated ranges for the ratio of the two velocities (Vp/Vs) based on analogues in similar materials. A range of possible Vs for the interbeds and basalts was used and produced additional uncertainty in the resulting response spectra.

Because of the sensitivity of the calculated response spectra to the velocity contrasts between the basalts and interbedded sediments, DOE initiated an effort to emplace additional boreholes at the WTP site and obtain direct Vs measurements and other physical property measurements in these layers. One corehole and three boreholes have been installed at the WTP site to a maximum depth of 1468 ft (447 m) below ground surface. The three boreholes are within 500 ft (152 m) of and surrounding the high level waste vitrification and pretreatment facilities of the WTP, which were the Performance Category 3 (PC-3) structures affected by the interim design spectra. The corehole is co-located with the borehole closest to the two PC-3 structures. These new measurements are expected to reduce the uncertainty in the modeled site response that is caused by the lack of direct knowledge of the Vs contrasts within these layers.

INTRODUCTION

The U.S. Department of Energy (DOE) is constructing a Waste Treatment and Immobilization Plant (WTP) to treat and vitrify underground tank waste stored at the Hanford Site in southeastern Washington State (see Fig. 1.) The WTP comprises four major facilities: a pretreatment facility to separate the tank waste into high level waste (HLW) and low-activity waste (LAW) fractions, a HLW Vitrification facility to immobilize the HLW fraction in borosilicate glass, a LAW Vitrification facility to immobilize the LAW fraction in borosilicate glass, and an Analytical Laboratory to support operations of the three treatment facilities.

The Hanford Site and WTP are situated on a sequence of sedimentary units (Hanford and Ringold Formations) that overlie the Columbia River Basalt Group (CRBG). The CRBG is a sequence of flood

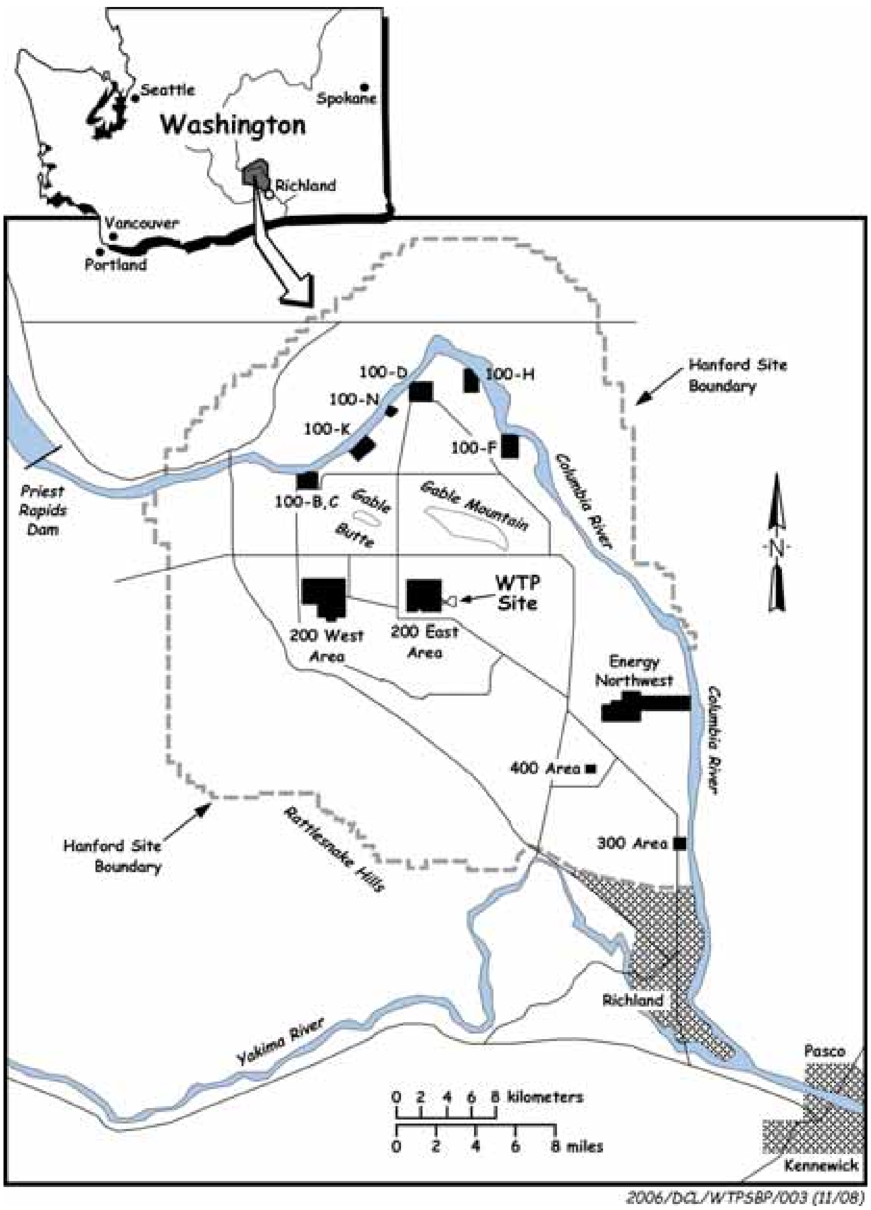

Fig. 1. Location of the Waste Treatment and Immobilization Plant (WTP) site.

basalt flows that erupted between 17 and 6 million years ago from fissures or vent systems in Oregon, Washington, and Idaho, and forms the main bedrock of the WTP. The upper four basalt flows (Saddle Mountains Basalt) were laid down over a period of time which allowed sediments of the Ellensburg Formation to accumulate between basalt layers. The general stratigraphy of geologic units of interest below the WTP is shown in Fig. 2.

The seismic design basis for the WTP was established in 1999 based on a probabilistic seismic hazard analysis completed in 1996 [1]. The Defense Nuclear Facilities Safety Board (DNSFB) subsequently initiated a review of the seismic design basis of the WTP. In March 2002, the DNFSB staff questioned the assumptions used in developing the seismic design basis, particularly the adequacy of the site geotechnical surveys, and subsequently raised additional questions about the probability of earthquakes,

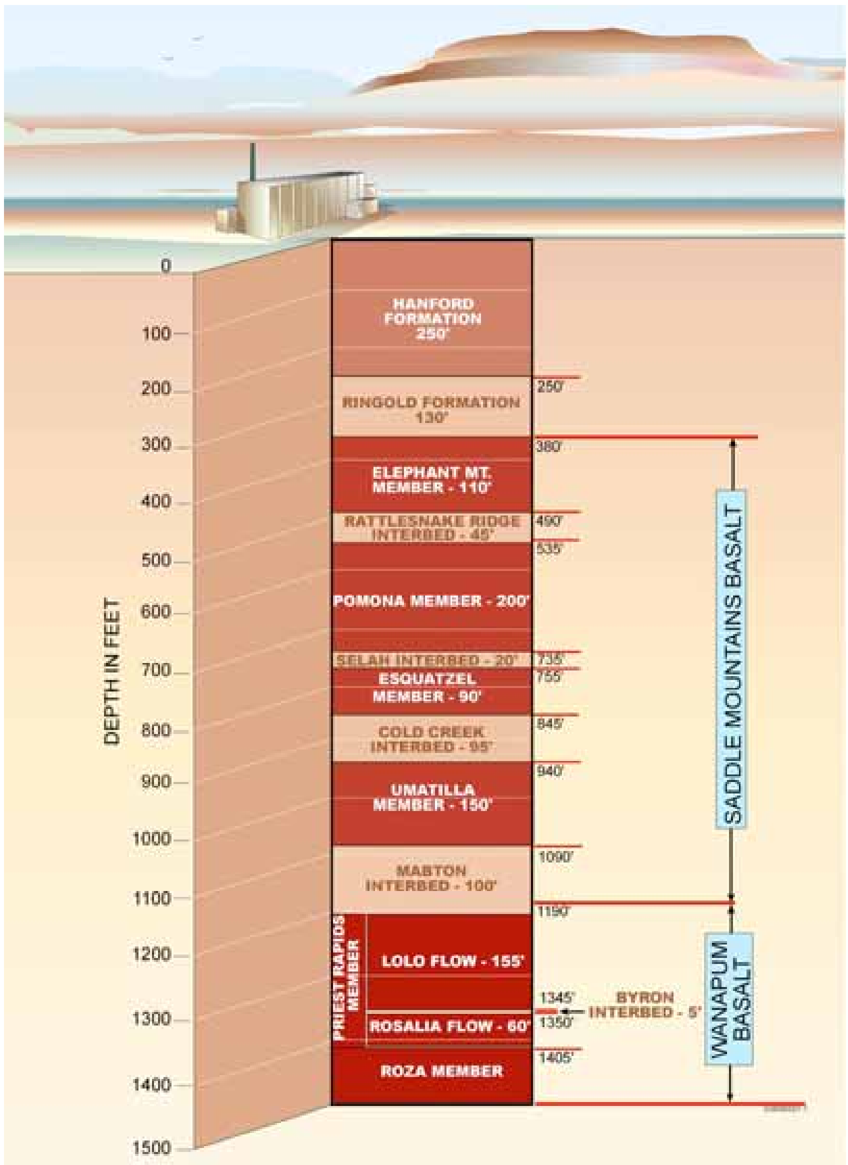

Fig. 2. General stratigraphy and approximate depths below ground surface of geologic units of interest below the WTP.

adequacy of the "attenuation relationships" that describe how ground motion changes as it moves from its source in the earth to the site and large uncertainty in the extrapolation of soil response data from California to the Hanford Site. Between 2002 and 2004, the DOE Office of River Protection (ORP) responded and resolved many of the questions raised, and developed a plan to acquire additional site data and analysis to address remaining questions. The key features of this plan were 1) acquiring new soil data down to about 500 ft (152 m), 2) reanalyzing the effects of deeper layers of sediments interbedded with basalt (down to about 2,000 ft [610 m]) that may affect the attenuation of earthquake ground motions more than previously understood, and 3) applying new models for ground motions as a function of magnitude and distance at the Hanford Site.

In 2004 and 2005, the Pacific Northwest National Laboratory (PNNL) led efforts for DOE-ORP to address features 1 and 2 of the plan by collecting site-specific geologic and geophysical characteristics of the WTP site and conducting modeling of the WTP site-specific ground motion response. New geophysical data were acquired, analyzed, and interpreted with respect to existing geologic information gathered from other Hanford-related projects in the WTP area. Information from deep boreholes was collected and interpreted to produce a realistic model of the deeper rock layers consisting of the interlayered basalts and sedimentary interbeds. The earthquake ground motion response was modeled, and a series of sensitivity studies was conducted to address areas in which the geologic and geophysical information has significant remaining uncertainties. This effort culminated in 2005 with issuance of an updated seismic response analysis for the WTP site [2, 3]. The updated seismic response analysis used existing and newly acquired seismic velocity data, statistical analysis, expert elicitation, and ground motion simulation to develop interim design ground motion response spectra which enveloped the remaining uncertainties. The uncertainties in these response spectra were enveloped at approximately the 84^{th} percentile to produce conservative design spectra, which contributed significantly to the increase in the seismic design basis (see Fig. 3).

A key uncertainty identified in the 2005 analysis was the velocity contrasts between the basalt flows and sedimentary interbeds below the WTP. The velocity structure of the upper four basalt flows and the interlayered sedimentary interbeds produces strong reductions in modeled earthquake ground motions propagating through them. Uncertainty in the strength of velocity contrasts between these basalts and interbeds primarily resulted from an absence of measured shear wave velocities (Vs) in the interbeds. For this study, Vs in the interbeds was estimated from older, limited compressional wave (Vp) data using estimated ranges for the ratio of the two velocities (Vp/Vs) based on analogues in similar materials. A range of possible Vs for the interbeds and basalts was used and produced additional uncertainty in the resulting response spectra.

In late 2005, DOE-ORP initiated planning for the Seismic Boreholes Project (SBP) to emplace additional boreholes at the WTP site and obtain direct Vs measurements and other physical property measurements in these layers. The goal was to reduce the uncertainty in the response spectra and seismic design basis, and potentially recover design margin for the WTP. PNNL was selected to manage the SBP, with oversight from DOE-ORP and the U.S. Army Corps of Engineers (USACE). The priority of the SBP activities was elevated in 2006 as a result of fiscal year 2007 congressional authorization that limited fiscal year 2007 expenditures for the WTP until "…the date on which the Secretary of Energy certifies to the congressional defense committees that the final seismic and ground motion criteria have been approved by the Secretary …"[1]

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[1] John Warner National Defense Authorization Act for Fiscal Year 2007. Public Law 109-364 (H.R.5122 ENR), Sec. 3120, Limitations on Availability of Funds for Waste Treatment and Immobilization Plant.

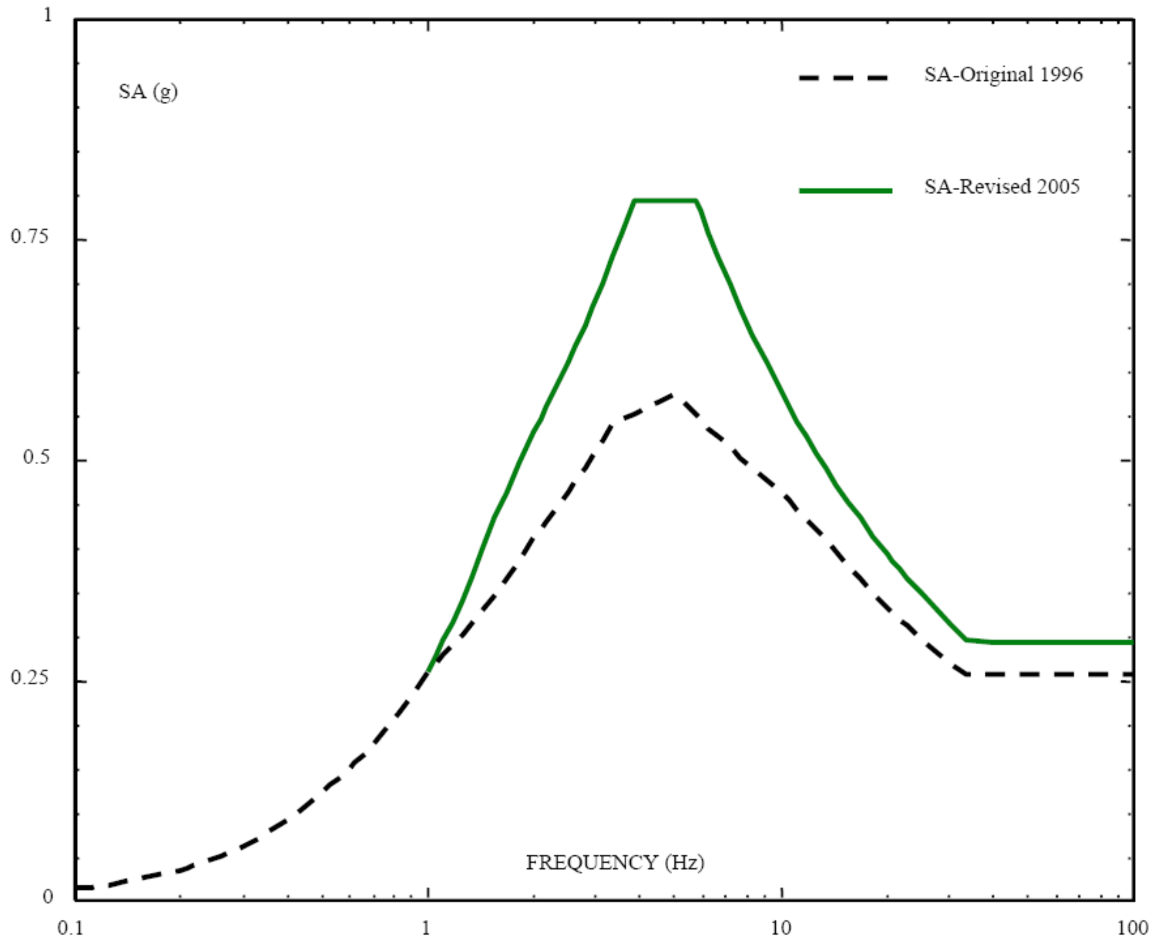

Fig. 3. Original 1996 and revised 2005 horizontal design spectra at 5% damping [2]

APPROACH

The approach to the SBP involved four main elements 1) planning and site preparation, 2) new borehole installation, 3) data collection, and 4) site seismic response analysis. A multi-contractor project team was proposed to plan and implement the project, including providing all health and safety supervision and control, project management and technical direction, interface control, contracting, and environmental compliance. Up to three test boreholes were proposed adjacent to the HLW Vitrification and Pretreatment facilities at the WTP, to conduct downhole logging and obtain adequate data to determine the variability of shear-wave velocities and other physical properties across the footprint of the two facilities impacted by the revised design basis. A single wireline corehole adjacent to one of the test boreholes was also proposed to provide for correlation of the geology to the geophysical logging data. All four boreholes (three "test" or "deep" boreholes and one corehole) were planned to be drilled to a depth of approximately 1300 to 1500 ft (396 to 457 m) below ground surface, so as to penetrate and extend past the four sedimentary interbeds and four basalt members of interest. A suite of geologic and geophysical data collection was proposed to obtain data from the new boreholes critical to reducing uncertainty in the seismic design basis. Finally, new site response modeling and analysis was needed to process the new borehole data and determine the overall impact of reduced uncertainty on the response spectra.

Planning and Site Preparation

To plan and implement the SBP, a project team was established to effectively control all elements of the project. The overall project structure involved a multi-contractor on-site project team that provided technical, project, and field operations direction and oversight. PNNL provided overall management and technical leadership for the project. Energy*Solutions* provided field oversight for all site operations, including technical direction for drilling activities. Fluor Hanford (FH) provided well site geology, radiological controls, and waste management support. Bechtel National, Inc. (BNI) provided access to and supporting facilities on the WTP site. Interfaces between project team members were controlled via contractual relationships between PNNL, Energy*Solutions*, and FH, and via a Memorandum of Understanding between PNNL and BNI.

A drilling plan was developed to guide the installation of the four boreholes [4]. The locations of the boreholes on the WTP site and their designations (C4993, C4996, C4997, and C4998) are shown in Fig. 4. The drilling plan provided a technical basis for subsequent drilling contracts, as well as environmental, health, and safety planning activities. A sampling and analysis plan was also developed and reviewed by external reviewers to document the physical characterization, geophysical logging, in-situ seismic

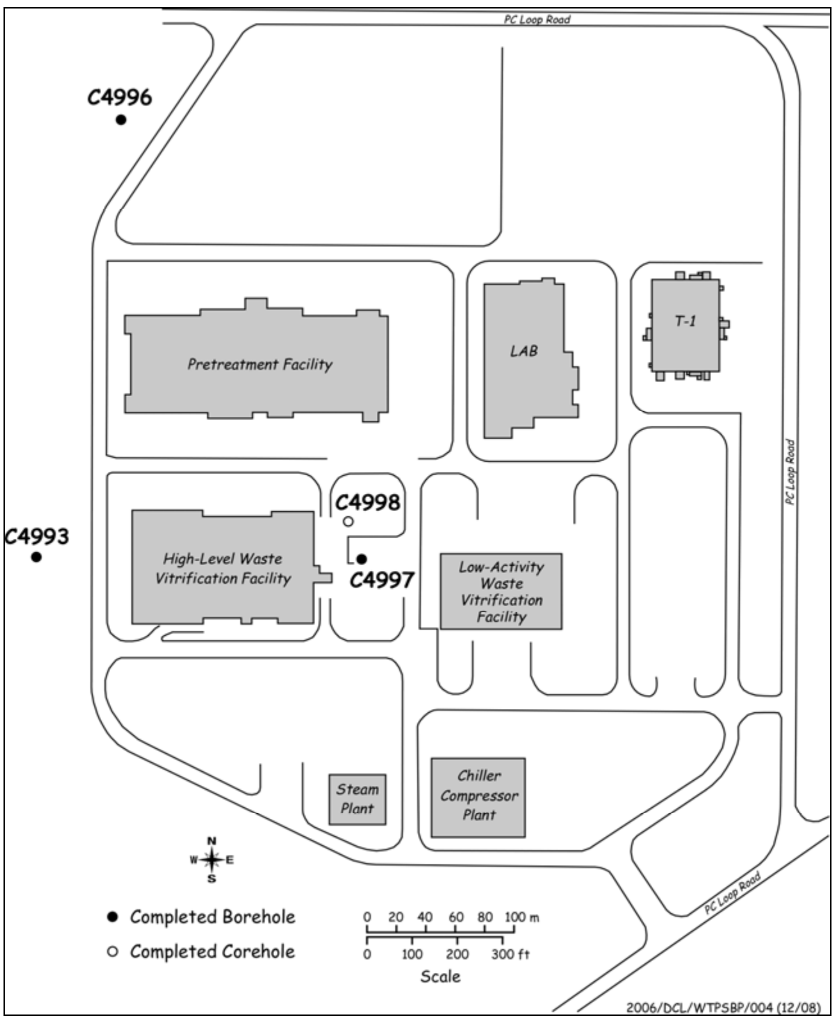

Fig. 4. Seismic boreholes drilled in 2006 at the Waste Treatment plant

velocity and density measurements to be collected, and physical testing of core samples to be performed [5]. Both the drilling and sampling and analysis plans were reviewed by an external review group to assure completeness and adequacy of the technical approach.

Prior to start of drilling operations, key permits and guiding documents were prepared and approved, including National Environmental Policy Act compliance documentation, waste control plan and corresponding data quality objectives, air discharge compliance documentation, excavation permit, project health and safety plan, and a quality assurance project plan.

New Borehole Installation

Installation of the four planned boreholes required several different drilling techniques to address Hanford site-specific geologic conditions and to assure collection of the required subsurface information. Key attributes and requirements of the drilling program were identified in the Drilling Plan and in subsequent statements of work for the drilling contractors, and included:

- Drilling of four surface or “entry” holes and setting of temporary surface casing from ground surface to approximately 20 ft (6 m) into the top of basalt (approximately 380 to 428 ft [116 to 130 m]) below ground surface). Two strings of steel casing of 9-5/8 in (24 cm) and 13-3/8 in (34 cm) outside diameters were specified to maintain borehole integrity, isolate the suprabasalt sediments and unconfined aquifer and eliminate the potential for cross-contamination of aquifers, and provide adequate access to the lower basalts and sedimentary interbeds. Cable-tool drilling with split-spoon and drive barrel sampling was specified for control of any potential contamination, and to assure adequate sample collection. Blue Star Enterprises Northwest, Inc. of Richland, Washington, was selected to install the entry holes.
- Drilling of one wireline corehole using 3-1/2 in (8.9 cm) core rods with a rotary diamond core drilling rig. The corehole was drilled down the center of an entry hole from the top of basalt at approximately 380 to 428 ft (116 to 130 m) below ground surface (bgs) to a maximum depth of 1400 ft (427 m) bgs. Retrieved core enables detailed characterization of the geology below the WTP, and provides samples for laboratory testing. Layne Christensen Company of Salt Lake City, Utah, was selected to install the corehole.
- Drilling of three deep boreholes using a 7-7/8 in (20 cm) drill bit with a mud rotary drilling rig. The deep boreholes were drilled down the center of the three entry holes from the top of basalt to a maximum depth of 1468ft (447 m) bgs. The 7-7/8 in (20 cm) diameter borehole provided adequate size for deployment of the required downhole logging tools. Drilling through the sedimentary interbeds was identified as a key concern. Lost circulation (loss of drilling fluids to the formation) and caving of the borehole wall were identified as serious problems and did develop as drilling advanced. Placement of cement across the trouble zones was required prior to advancing the borehole. WDC Exploration and Wells of Woodland, California, was selected to install the three deep boreholes.

Data Collection

The characterization effort within the deep boreholes included 1) downhole measurements of the velocity properties (including uncertainties) of the suprabasalt, basalt, and sedimentary interbed sequences, 2) downhole measurements of the density of the subsurface basalt and sediments, and 3) confirmation of the geometry of the contact between the various basalt and interbedded sediments through examination of retrieved core from the corehole and data collected through geophysical logging of each borehole. Additional laboratory dynamic testing of the suprabasalt sediments, basalts, and sedimentary interbeds was also performed to evaluate nonlinear response to strong earthquake ground motion. The characterization effort was guided by the sampling and analysis plan and referenced standards and procedures.

Measurement of Vs and Vp was obtained using two techniques – suspension logging and downhole logging.

- Suspension logging, or P-S logging, uses a downhole shear- and compression-wave source joined to two biaxial receivers (i.e., geophones). The suspension logging system, manufactured by OYO Corporation, is suspended in the borehole by a cable. The source motion creates a high frequency (1000 Hz) impulsive seismic wave that propagates through the borehole fluid and surrounding soil and rock, and is detected by the two receivers on the opposite end of the downhole system assembly. Measurements were taken every 1.6 to 3.3 ft (0.5 to 1.0 m) from the top of basalt to the bottom of the borehole. GEOVision Geophysical Services, Inc. of Corona, California, was selected to perform the suspension logging.
- Downhole seismic logging uses shear- and compression-wave sources at the ground surface, and one or more receivers downhole to detect the seismic waves at depth. The receivers are deployed down the borehole by cable and clamped against the borehole wall to measure seismic wave propagation through the subsurface formation rather than the borehole fluid. Two types of sources were used – impulsive and vibratory. Impulsive sources were effective for measurements in the top 600 to 700 ft (183 to 213 m). A large 60,000 lb (22 metric ton) tri-axial vibratory source (aka T-Rex) operating at 10 to 50 Hz was required to effectively measure Vs and Vp below 700 ft (213 m). Measurements were taken at intervals in the borehole of approximately 6 to 10 ft (2 to 3 m). Redpath Geophysics of Murphys, California, and University of Texas at Austin were selected to perform the downhole logging.

A suite of geophysical logs was also performed to support confirmation of the contact between basalt and interbed sediments, evaluate straightness and the condition of the borehole wall, and evaluate the magnetic deviation as function of depth. Specific geophysical logging methods used included:

- Gyroscope surveys to assess the straightness of the borehole. Energy*Solutions* of Richland, Washington, performed the gyroscope surveys.
- Acoustic televiewer and mechanical four-arm caliper surveys to assess the condition of the borehole wall and diameter or gauge of the borehole. Energy*Solutions* of Richland, Washington, performed the televiewer and caliper surveys.
- Magnetic field survey to assess the local deviation of magnetic north within each borehole as a function of depth. Deviation of magnetic north measurements supported the downhole orientation of Redpath Geophysics seismic velocity logging tools. Wellbore Navigation, Inc. of Tustin, California, was selected to perform the magnetic field surveys.
- A suite of open borehole geophysical surveys including gamma-gamma, gamma-density, caliper, neutron porosity, full wave sonic, and dual induction resistivity were made in the three deep boreholes. The combination of geophysical survey techniques provided data to help confirm the geometry of the contact between the various basalt and interbedded sediments. COLOG of Lakewood, Colorado, was selected to perform this suite of geophysical surveys.

A borehole gravity meter (BHGM) was also used to obtain accurate in situ density measurements with resolution of the depth variation of the density within the basalts and sedimentary interbeds. Micro-g LaCoste of Denver, Colorado, was selected to collect the BHGM density data.

Physical samples of basalts, sedimentary interbeds, and Hanford and Ringold formation sediments were collected and subjected to one or more physical testing methods at the direction of the USACE. Selected samples were transferred to the University of Texas at Austin for resonant column/torsional shear, large diameter resonant column, or free-free resonant column tests. Additional Hanford and Ringold formation sediment samples underwent particle size gradation testing at a USACE-selected testing laboratory.

Site Response Analysis

The project will culminate with new site response modeling and analysis to process the new borehole data and determine the overall impact of reduced uncertainty on the response spectra for the WTP site. Geomatrix Consultants of Oakland, California, was selected to update the WTP site seismic response calculations completed in 2005 by incorporating the new geology and geophysical data collected from the WTP site boreholes. In addition, the site response analysis will incorporate new rock-site and soil-site earthquake ground motion models that have been developed and published subsequent to the prior studies [1, 2]. A panel of experts will convene to review the new borehole data and select the range of values of the input parameters to the site response models. A full probabilistic analysis will be completed and the results will support the DOE's identification of final seismic design criteria for the WTP.

PROJECT STATUS

Initial planning for the Seismic Boreholes Project was initiated in August 2005. After issuance of a final drilling plan in March 2006, project planning and project implementation efforts accelerated significantly. Requests for proposals for the entry holes, corehole, and deep boreholes contracts were issued in March, April, and May 2006, respectively. Contract awards were made in May 2006 for the entry holes and corehole contractors, and July 2006 for the deep boreholes contractor. Drilling of the four entry holes began with the first borehole (C4998) on June 12, 2006, and was completed with the final borehole (C4993) on September 5, 2006. Extensive split-spoon and drive barrel sampling of the Hanford and Ringold formations was performed during entry hole drilling of C4997, with additional backup samples collected from C4996 and C4993 entry holes.

Drilling of the corehole through entry hole C4998 began on July 19, 2006, and was completed on September 14, 2006. Wireline coring resulted in collection of continuous core samples from the basalts and sedimentary interbeds with an overall recovery of 99%, which helped to provide the mud rotary drilling contractor and well site geologists with stratigraphic details to help interpret drill cuttings obtained during deep borehole drilling.

Drilling of the three deep boreholes started on July 31, 2006, with deep borehole C4996, and finished on October 12, 2006, with completion of deep borehole C4997. To accelerate installation of all three deep boreholes, three mud-rotary drill rigs were mobilized and operated simultaneously during a portion of the drilling effort. The typical equipment and setup for mud-rotary drilling operations on the WTP site is shown in Fig. 5. While drilling progressed, gyroscope, acoustic televiewer, and mechanical caliper surveys were performed on regular intervals to assess the straightness and condition of each borehole.

Suspension logging of the deep boreholes was performed intermittently as drilling progressed. When drilling in any of the three deep boreholes had advanced through a sedimentary interbed and into the next basalt member, drilling was stopped and Geovision personnel deployed their suspension logging tools into the open borehole to log the recently drilled interval. To limit the potential for interbed sediments to squeeze into the borehole following logging, the borehole interval was cemented, allowed to set, and then re-drilled before advancing deeper. Suspension logging was initiated in borehole C4996 on August 2, 2006, and was completed with the final log of borehole C4993 on October 14, 2006.

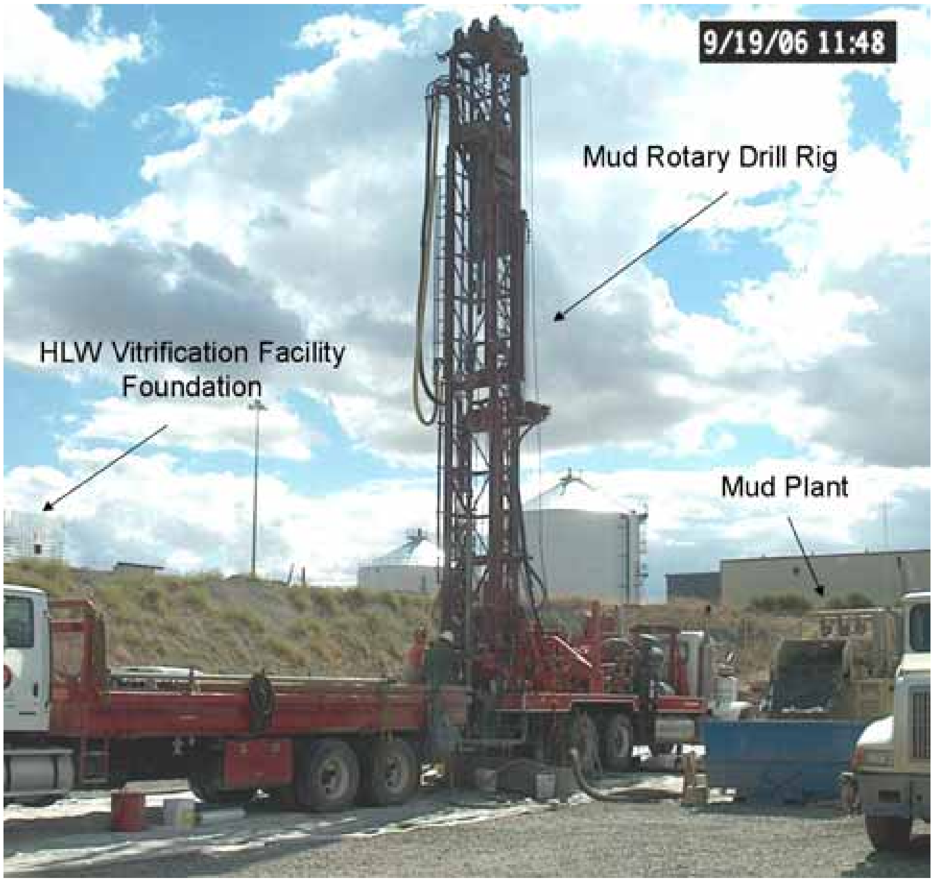

Fig. 5. Mud rotary drilling of borehole C4993.

The suite of geophysical logs was performed following completion of each of the three boreholes. COLOG and Wellbore Navigation surveyed each of the deep boreholes between September 28 and October 27, 2006.

Downhole seismic logging of the boreholes was conducted in two principal phases. The uncased "open" boreholes below the steel-cased entry holes were logged first using both impulsive and vibratory shear- and compression-wave sources from the top of basalt at approximately 380 ft (122 m) bgs to the maximum depth of energy penetration - approximately 600 to 700 ft (183 to 213 m) bgs for the impulsive sources and approximately 1200 to 1400 ft (366 to 427 m) bgs for the vibratory source. Downhole logging of the open boreholes was performed over three testing campaigns between October 16 and December 20, 2006. Difficulties were encountered with the vibratory source input signals and the deeper deployment of the downhole geophone system during the first two testing campaigns in October and November 2006. Therefore, a larger wireline truck and heavy-duty geophone probe was loaned from Lawrence Berkeley National Laboratory for use in the final testing campaign in December 2006. The equipment and typical set-up for downhole logging of the deeper basalts and interbeds is shown in Fig. 6.

The second phase of downhole logging was performed using only impulsive seismic sources in the upper portion of boreholes C4998, C4996, and C4993 after the carbon steel temporary casing was removed and either polyvinyl chloride (PVC) or stainless steel casing was installed. A geophone oriented to magnetic north was required to obtain accurate velocity measurements. Therefore, the ferromagnetic temporary carbon steel casing needed to be removed and replaced with nonmagnetic casing. PVC casing was

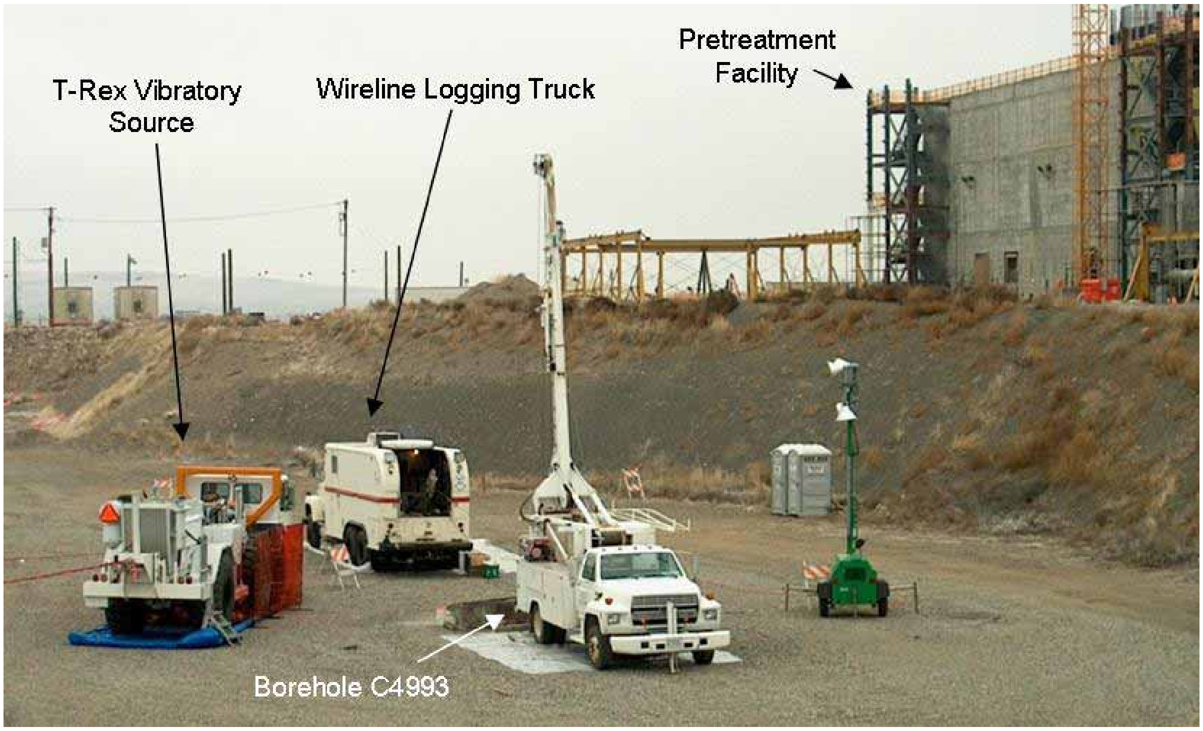

Fig. 6. Downhole seismic logging of borehole C4993 with vibratory source.

installed in the upper 375 ft (114 m) of C4998 in November 2006, and downhole logging completed on December 9, 2006. PVC casing was installed in the upper 547 ft (167 m) of C4996 in January 2007 and downhole logging completed on January 29, 2007. Stainless steel casing was installed in borehole C4993 from ground surface to a total depth of 1411 ft (430 m) bgs in January 2007 and downhole seismic logging of the upper 360 ft (110 m) completed on February 9, 2007.

Gravity-density logging was performed in each of the three deep boreholes C4993, C4996, and C4997 following completion of drilling, but prior to removal of the temporary steel casing and installation of permanent casing in C4993 and C4996. Micro-g LaCoste deployed their BHGM between November 11 and December 10, 2006. Each borehole log required approximately six days operating 24 hours per day to complete.

RESULTS AND DISCUSSION

All planned field data collection was completed in February 2007. Data analysis, site response analysis, and reporting efforts are in progress. Therefore, the primary results of the seismic boreholes project are not scheduled to be available until spring 2007. However, some analysis has been completed and several lessons learned have been identified.

Stratigraphic Characterization

Characterization of the contact between basalt and interbed sediments and corresponding thicknesses of the stratigraphic units has been completed through analysis and interpretation of geophysical logs and well-site geologists' logs from drilling of the corehole (C4998) and each of the three deep boreholes (C4993, C4996, C4997). Results of this characterization are summarized in Table I, and fully

Table I. Thickness of Geologic Units of Interest Below the Waste Treatment Plant.

Stratigraphic Unit	Layer Thickness ft / (m)				
	Predicted[1]	C4993[2]	C4996[2]	C4997[2]	C4998[2]
Backfill/Eolian	165 ± 10 (50.3)	9 (2.7)	4.5 (1.4)	16.8 (5.12)	0.3 (0.09)
Hanford fm. – Sand-dominated facies		150.5 (45.9)	161 (49.1)	149.2 (45.5)	165.7 (50.5)
Hanford fm. – Gravel-dominated facies	100 ± 10 (30.5)	90.5 (27.6)	89.5 (27.3)	91 (27.7)	70 (21.3)
Cold Creek Unit		72 (21.9)	49 (14.9)	62 (18.9)	54 (16.5)
Ringold Fm. – Unit A	100 ± 20 (30.5)	60 (18.3)	45 (13.7)	64 (19.5)	68 (20.7)
Elephant Mountain	85 ± 15 (25.9)	118 (36.0)	105 (32.0)	112 (34.1)	110 (33.5)
Rattlesnake Ridge Interbed	65 ± 10 (19.8)	56 (17.1)	42 (12.8)	47 (14.3)	34 (10.4)
Pomona Member	185 ± 10 (56.4)	186 (56.7)	201 (61.3)	194.9 (59.1)	208.9 (63.3)
Selah Interbed	20 ± 10 (6.10)	23 (7.0)	22 (6.7)	22 (6.7)	22 (6.7)
Esquatzel Member	100 ± 10 (30.5)	95 (29)	96 (29.3)	95 (29)	94 (28.7)
Cold Creek Interbed	95 ± 10 (29.0)	97 (29.6)	98 (29.9)	97 (29.6)	98 (29.9)
Umatilla Member	150 ± 10 (45.7)	161 (49.1)	149 (45.4)	161 (49.1)	157 (47.9)
Mabton Interbed	105 ± 10 (32.0)	98 (29.9)	101 (30.8)	94 (28.7)	101 (30.8)

[1] From [2], Figure 3.2.2
[2] From [7], Table 3.2 and Table 4.1

documented elsewhere [6, 7]. There is some variability in thickness of the geologic units across the four new boreholes; however, this variability is not unexpected, and is in good agreement with predicted values used in the previous WTP analysis [2].

Measurement of Shear- and Compression-Wave Velocities

Analysis of suspension and downhole logging data is still in progress; therefore, comparison of the range of measured Vs and Vp values from the new boreholes to the estimated values used in the 2005 analysis [2] is not yet possible. However, several observations and lessons learned can be made from the data collection efforts.

- Downhole shear-wave seismic logging of the Saddle Mountain basalts and Ellensburg Formation sedimentary interbeds had not been attempted previously. This effort represented a key project technical risk. Testing was required to determine the appropriate combination of source inputs (e.g., impulsive, vibratory, frequency sweep), configuration of receivers (e.g., surface or near surface reference geophones, dual downhole geophones, etc.), and data analysis methods. In addition, the deployability of the downhole geophone system to the required depths in uncased boreholes was unknown.

- Testing of the deployment systems and analysis methods in available cased boreholes was pursued to attempt to mitigate technical risks. However, no boreholes were available for pre-testing that represented the full depth or borehole wall condition to be encountered in the new boreholes. Therefore, the effectiveness of pre-testing was limited.
- Lightweight downhole geophone systems (Fig. 7) using impulsive seismic sources were found to be effective in both cased and uncased boreholes to depths of 700 ft (213 m) or less. The strength of the impulsive signal was inadequate to reach deeper depths within the formation below the WTP. In addition, the lightweight geophone had difficulty consistently deploying to depths below 1000 ft (305 m) in the uncased borehole. The geophone system hung up along the irregular surface of the borehole wall.
- A heavyweight geophone system (Fig. 7) and accompanying wireline truck was required to consistently reach the deeper depths of each of the three deep boreholes. In addition, the T-Rex vibratory source was required to provide an input signal capable of penetrating to depth. Even with the T-Rex source at full signal strength, only compression-wave (P-wave) signals were measurable at the deepest depths (e.g., 1400 ft [427 m]). Shear-wave (S-wave) signals were attenuated significantly below the Cold Creek interbed (approximately 950 ft [290 m]), and lower frequency input signals (30 Hz versus 50 Hz) were required.

PATH FORWARD

Analysis of shear- and compression-wave velocities, densities, and dynamic testing data from the new WTP site boreholes will be completed, and a panel of experts convened to review the results and select the range of values of the input parameters to the site response models. The range of input parameters will be compiled into a “logic tree” representing the input for probabilistic analysis of site response.

Fig. 7. Geophone systems used for downhole seismic logging

Site response analysis will be performed using updated ground motion models and input parameters from the logic tree, and will produce updated design spectra for the WTP site. The result of this analysis is scheduled to be completed spring 2007, and will support the DOE's efforts to certify final seismic design criteria for the WTP.

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