PRELIMINARY EVALUATION AND ANALYSES OF THE U.S. DEPARTMENT OF ENERGY GEOTECHNICAL DATA FOR THE WASTE HANDLING BUILDING SITE AT THE POTENTIAL YUCCA MOUNTAIN REPOSITORY

Prepared for

U.S. Nuclear Regulatory Commission
Contract NRC–02–02–012

Prepared by

Sarah H. Gonzalez
John A. Stamatakos
Katherine R. Murphy
H. Lawrence McKague

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

June 2004

ABSTRACT

This report provides a preliminary evaluation of geotechnical data presented in the U.S. Department of Energy (DOE) report “Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project” (Bechtel SAIC Company, LLC, 2002). The geotechnical data include borehole geologic data, seismic velocity and density profiles, and strain dependent shear modulus and damping measurements. The DOE intends to use these data to develop seismic design response spectra and representative time histories for the surface facilities area. The seismic hazard for the Yucca Mountain site and associated ground motion levels have been calculated for a hypothetical Yucca Mountain hard rock site known as Point A. However, these calculations do not account for the overlying layers of tuff and alluvium on which the surface facilities are to be constructed. The presence of these overlying layers may result in significant amplification of ground motion levels at the surface.

A three-dimensional geologic model was developed in EarthVision® (Dynamic Graphics, 2002) the geologic data provided in Bechtel SAIC Company, LLC (2002). This model was used to help assess the DOE geologic cross sections which were also presented in Bechtel SAIC Company, LLC (2002), and to identify inconsistencies in the geologic data. Additional faults may be needed in the eastern part of the study area to account for some of these inconsistencies. In addition, a number of lithologic profiles were selected from the EarthVision model to represent the variable geologic conditions at the potential Waste Handling Building site. These lithologic profiles form the basis of ground response models. Ground response modeling was performed to evaluate the geotechnical data in Bechtel SAIC Company, LLC (2002) and help determine which data were most significant to ground amplification. Lithology based velocity and density profiles were then created for each of these selected profiles. The geotechnical data were generally found to be sufficient to develop velocity and density profiles for ground response modeling. Preliminary ground response modeling results showed that ground motion amplification was most sensitive to velocity inputs and layer thickness. In contrast, density had a very small effect. Strain dependent shear modulus and damping curves are not well constrained at higher strain levels (above approximately 0.1 percent). However, ground motion amplification was relatively insensitive to the range of dynamic property curves used in modeling at the 10^{-4} hazard level.

CONTENTS

FIGURES

Figure Page

FIGURES (continued)

Figure Page

TABLES

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety. The report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

The authors thank S. Hsiung for technical review and B. Sagar for programmatic review of this report. The authors also appreciate A. Ramos for providing word processing support C. Cudd and P. Mackin for editorial support in the preparation of the document.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Data analyses presented in this report are documented in Scientific Notebook Number 644. Data used to support conclusions in this report are taken from documents published by U.S. Department of Energy contractors and supporting organizations; the respective source of these non-CNWRA data should be consulted for determining the level of quality assurance.

ANALYSES AND CODES: Maps and related Geographic Information System data were generated and plotted by the software ArcView GIS© Versions 3.1 (ESRI, 1998) and Version 3.2a (ESRI, 2000), which are commercially available software that are maintained in accordance with CNWRA Technical Operating Procedure TOP–018. Ground response analyses were conducted using ProShake®, Version 1.11 (EduPro Civil Systems, 2001), which is also a commercially available software that is maintained in accordance with CNWRA Technical Operating Procedure TOP–018. The three dimensional geologic model was created in EarthVision® Version 7.0.1 (Dynamic Graphics, 2002), also under control at the CNWRA.

REFERENCES

Dynamic Graphics. “EarthVision.” Version 7.0.1. Alameda, California. 2002.

ESRI. “ArcView GIS©.” Version 3.2a. Redlands, California: ESRI. 2000.

———. “ArcView GIS©.” Version 3.1. Redlands, California: ESRI. 1998.

EduPro Civil Systems. “ProShake.” Version 1.11. Sammamish, Washington. 2001.

1 INTRODUCTION

1.1 Purpose

The potential high-level waste repository site at Yucca Mountain, Nevada, is located in a tectonically and seismically active region of the western United States. Seismic analyses are therefore important to both preclosure safety analysis and postclosure performance assessment. The preclosure seismic safety analysis requires a reasonable representation of the potential vibratory ground motions at the Yucca Mountain site that could arise from earthquakes in the region. Assessment of ground motions that could impact the Yucca Mountain surface facility installations are an important consideration in the safety analysis. Current design plans for the surface facility installations place them above a thick sequence of alluvium and tuff in Midway Valley. Midway Valley is located to the east of the potential repository within Yucca Mountain.

Amplification of earthquake energy is a well-known phenomena at sites built on unconsolidated soil. Ground response modeling is used to account for soil amplification effects. These ground response models take earthquake time histories or response spectra, selected to represent the seismic hazard for the underlying bedrock, and transform them into the equivalent time histories or response spectra at the top of the soil column. The amplification of earthquake energy as it propagates from bedrock through the soil column is largely a function of physical properties of the soil; specifically velocity, density shear, modulus reduction, and damping. Detailed information about the physical properties of the material above bedrock is needed to develop reliable ground response models.

This report provides a preliminary evaluation and analyses of geotechnical data as possible inputs to the U.S. Department of Energy (DOE) preclosure seismic safety analyses. In particular, this report reviews geotechnical data presented in the DOE report “Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project” (Bechtel SAIC Company, LLC, 2002). The purpose of this review is to determine whether the data presented in Bechtel SAIC Company, LLC (2002) adequately characterize the Yucca Mountain site such that vibratory ground motion levels for preclosure seismic design and performance assessment will be adequate and technically defensible.

This report supports two program objectives. First, results of the evaluation and analyses of the DOE geotechnical data coupled with the analytical methodologies described herein provide the U.S. Nuclear Regulatory Commission (NRC) staff with the necessary technical bases to support issue resolution with the DOE during the prelicensing period. The goal of issue resolution during this prelicensing period is to assure that the DOE has assembled sufficient information for the NRC staff to conduct a license application review. Second, our evaluation and analyses of the geotechnical data in Bechtel SAIC Company, LLC (2002) will form part of the technical bases for staff review and assessment of the preclosure seismic safety assessment contained in a potential DOE license application for the Yucca Mountain repository, if and when the DOE submits such an application to the NRC. Within this second objective, the analytical methodologies described in this report are consistent with the review methods established in the Yucca Mountain Review Plan (NRC, 2002).

In addition to a review of the data for completeness and accuracy, the evaluation of the geotechnical information in Bechtel SAIC Company, LLC (2002) was accomplished by independent analyses of the geologic and geotechnical data followed by the development of a suite of sensitivity studies designed to identify which of the geotechnical input data are most significant to ground response modeling at the surface facility installations. This report is organized in several sections that reflect the nature of this review.

- Chapter 2 provides a review of the geological data from the boreholes and associated DOE structural cross sections provided in Bechtel SAIC Company, LLC (2002). In this Section 2.2 of Chapter 2, we describe the development of a three-dimensional EarthVision® model constructed using the geologic data. The model represents the layered, tilted, and faulted stratigraphy in Midway Valley, incorporating the alluvium, nonwelded volcanic units that postdate the Tiva Canyon Tuff, and moderately to strongly welded volcanic units of the Tiva Canyon Tuff. Construction of the three-dimensional EarthVision® model allowed us to recognize possible inconsistencies in the geologic data or geologic interpretations provided in Bechtel SAIC Company, LLC (2002). The three-dimensional model also provided us with the basis for lithologic profiles discussed in later sections of the report.

- Chapter 3 provides a review of the geotechnical data obtained from the boreholes, surface geophysical measurements, and dynamic laboratory testing. In these sections we also develop a suite of velocity, density, and dynamic property inputs based on the geotechnical data provided in Bechtel SAIC Company, LLC (2002). These inputs are directly correlated to the lithologic units in the three-dimensional EarthVision® model.

- Chapter 4 provides a preliminary sensitivity study of the geotechnical data provided in Bechtel SAIC Company, LLC (2002). We begin to identify the data most important to ground amplification, using stratigraphic profiles extracted from the three-dimensional EarthVision model. Layers within these stratigraphic profiles are assigned the material property inputs developed in the previous chapter.

- Chapter 5 provides a summary of preliminary observations and conclusions drawn from the data review and sensitivity studies. We consider our observations and conclusions preliminary because DOE site characterization activities are ongoing, and the DOE has not yet provided response spectra or seismic hazard results for the surface facility installations. Therefore, comparisons of our analyses with DOE site response results are not yet possible.

1.2 Scope

The scope of this report is limited to an evaluation of geotechnical data for volcanic and alluvial strata reported in Bechtel SAIC Company, LLC (2002); including:

- Stratigraphy
- Shear-wave velocity (V_S) profiles
- Compression-wave velocity profiles (V_P)
- Low-strain Poisson's ratio
- Low-strain shear modulus and damping

- Shear modulus reduction and damping as a function of shear strain
- Density

These geotechnical data were collected at four locations within the Yucca Mountain site:

- Waste Handling Building area
- North Ramp and Main Drift of the Exploratory Studies Facility
- The crest of Yucca Mountain
- Fran Ridge borrow area

The DOE intends to use these data to develop Preclosure seismic design response spectra and time histories for Preclosure seismic performance assessment. Because the majority of the geotechnical data contained in Bechtel SAIC Company, LLC (2002) were collected from the proposed Waste Handling Building site, our evaluation and analyses are focused on the data collected from this location. DOE has recently provided details on a revised surface facility design (DOE, 2004) that includes areas of Midway Valley beyond what was designated as the proposed Waste Handling Building site in Bechtel SAIC Company, LLC (2002). We note that the proposed Waste Handling Building site area is encompassed within the revised surface facility layout presented in DOE (2004) and thus, all of the geotechnical information reviewed and evaluated in this report are applicable to the revised DOE surface facility area. In addition, we only assessed data used as inputs to the ProShake® ground response calculations which are V_S, density, and shear modulus reduction and damping as a function of shear strain. The scope of this report is also limited to analyses of Preclosure safety and operations. Review of the geotechnical data with respect to Postclosure performance will be addressed separately.

2 GEOLOGIC DATA

2.1 Geologic Setting

Yucca Mountain comprises a several kilometer thick accumulation of volcanic tuff deposited on an irregular surface of eroded and deformed Paleozoic and Precambrian basement composed of highly faulted and folded sedimentary and metasedimentary rocks. The tuff originated from a series of Middle to Late Miocene (15–9 million years) calderas that collectively form what has been defined as the southwestern Nevada volcanic field. Sawyer, et al. (1994) provide the most recent comprehensive regional stratigraphy of the Miocene volcanic rocks in the Yucca Mountain region. Rocks of the Paintbrush Group, principally Tiva Canyon Tuff (12.7 million years), make up the main surface exposures of Yucca Mountain, whereas the repository horizon is within the underlying Topopah Springs Tuff (12.8 million years). The Paintbrush Group tuff rests on a sequence of older tuff, including the Prow Pass and Bullfrog members of the Crater Flat Group. Younger tuffs related to the Timber Mountain Group are locally exposed at Yucca Mountain in topographic lows between large block-bounding faults. Alluvium and colluvium, mainly derived from erosion of the Miocene tuff exposed on fault-bound ridges, also fill the topographic lows and basins.

Faults at Yucca Mountain are north to north-northeast trending, forming fault-bounded north-south ridges that are crossed by occasional northwest-trending, dextral strike-slip faults (Day, et al., 1997, 1998). Faults dip almost uniformly to the west and separate blocks of gentle to moderate east-dipping tuff. Fracturing of the volcanic rocks at Yucca Mountain started soon after deposition of the volcanic tuff about 11–13 million years ago. The first fractures of the volcanic rocks were probably cooling fractures (also commonly referred to as cooling joints). Soon after deposition of the tuff, tectonic and gravitational forces caused additional fracturing of the tuff. Cooling, tectonic, and unloading fractures constitute the naturally occurring fracture system at Yucca Mountain (Dunne, et al., 2003). Because the region is still tectonically active and eroding, both tectonic and unloading joints continue to form and reactivate.

At the proposed Waste Handling Building site in Midway Valley, the subsurface strata consist of alluvium overlying moderately and densely welded pyroclastic flows of the Tiva Canyon Tuff and nonwelded bedded tuff of the post-Tiva Canyon Tuff and the pre-Rainier Mesa Tuff. Table 2-1 provides a summary description of the lithologic units encountered in the boreholes and used to develop the three-dimensional EarthVision® model. The proposed Waste Handling Building site is cut by several north-northeast to north-northwest trending normal faults. The largest of these is the Exile Hill fault splay, which has significant down-to-the-northeast displacement. In general, the bedded nonwelded tuffs are confined to the hanging walls of the normal faults. Because of the faulting, the underlying stratigraphy generally dips about 25° to the east-southeast, although locally some beds dip back to the west-northwest within several of the small grabens that form between normal faults or on relay ramps that form between enechelon segments of normal faults.

2.2 Three-Dimensional Geologic Framework Model

A review of the geologic data was conducted using data from the Bechtel SAIC Company, LLC (2002) to create a three dimensional geologic model in EarthVision (Dynamic Graphics, 2002). The data used to create the EarthVision® model were geologic cross sections, and where

Table 2-1. Summary Description of Lithologic Units Under Proposed Waste Handling Building Site in Midway Valley		
Unit Name	**Unit Symbol**	**Lithology**
Quaternary Alluvium	Qal	Poorly to well-cemented tuffaceous alluvium with mixture of layered gravel and cobble of clasts of densely welded ignimbrite in a matrix of smaller fragments of nonwelded tuff and silty sand.
pre-Rainier Mesa Bedded Tuff	Tmbt1	Bedded and reworked tuff with up to 10 percent pumice
Tuff unit “x”	Tpki	Nonwelded pyroclastic flow with 10–30 percent pumice clasts
post-Tiva Canyon bedded tuff	Tpbt5	Devitrified and reworked fallout tephra and tuffaceous rocks and interbedded paleosols
Crystal rich member of the Tiva Canyon Tuff	Tpcrn	Moderately to densely welded crystal rich pyroclastic flow, some pumice fragments but no lithophysae.
Upper lithophysal zone of the Tiva Canyon Tuff	Tpcpul	Moderately to densely welded crystal poor upper lithophsal zone. Up to 20 percent lithophysae. Moderately to intensely fractured
Middle nonlithophysal zone of the Tiva Canyon Tuff	Tpcpmn	Densely welded crystal poor pyroclastic flow. Moderately to intensely fractured
Lower lithophysal zone of the Tiva Canyon Tuff	Tpcpll	Densely welded crystal poor pyroclastic flow with up to 20 percent lithophysae, slightly fractured.
Lower nonlithophysal zone of the Tiva Canyon Tuff	Tpcpln	Densely welded crystal poor pyroclastic flow. Moderately to intensely fractured

appropriate, borehole data provided in Bechtel SAIC Company, LLC (2002). The boreholes used in construction of the EarthVision model are shown in Figure 2-1. For the purposes of this report, faults identified in Bechtel SAIC Company, LLC (2002) were numbered. Refer to Figure 2-1 for fault locations and numbers. Faults and stratigraphic layers were defined in the EarthVision® model by points derived directly from cross sections in Bechtel SAIC Company, LLC (2002). The fault data points were gridded in EarthVision®, and additional points were added as necessary using the editing tool in EarthVision®'s three-dimensional viewer. The locations of extra points were determined visually according to our understanding of the fault shape. The tops of stratigraphic layers were defined by points derived directly from the cross sections and borehole data in Bechtel SAIC Company, LLC (2002). The stratigraphic data

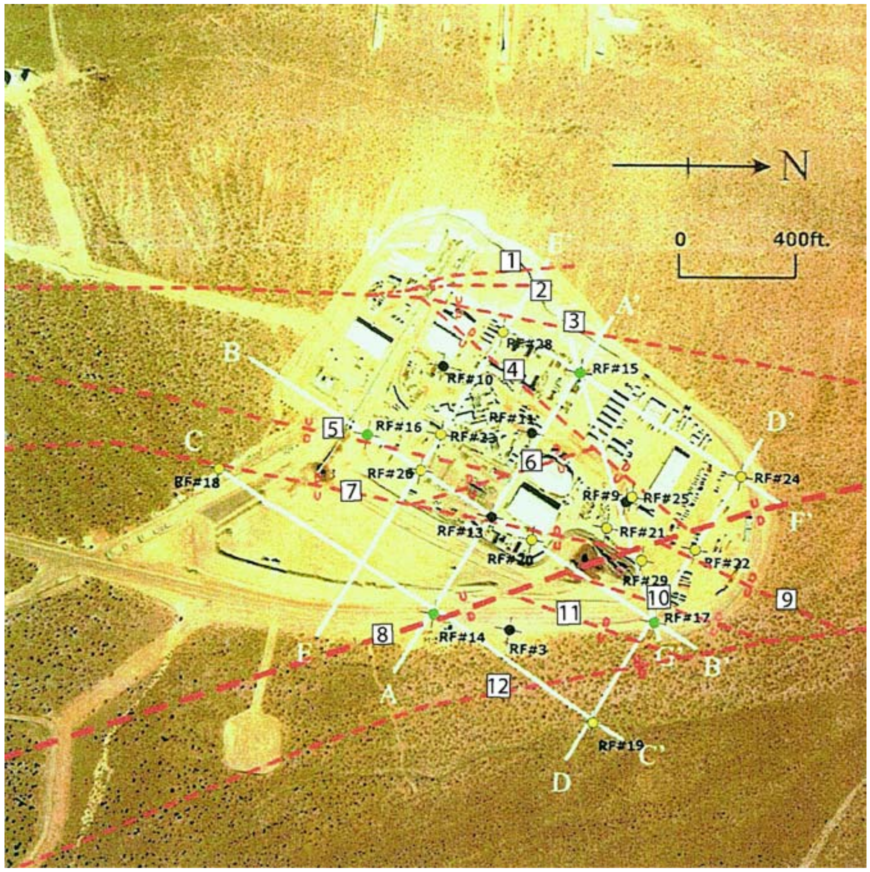

Figure 2-1. Faults From Bechtel SAIC Company, LLC (2002) are Numbered to Facilitate References to Specific Faults. Images are Taken from Figure 224 of Bechtel SAIC Company, LLC (2002). Also Shown are Boreholes RF#3, RF#9–11, RF#13–26, and RF#28–29.

points were gridded in EarthVision®. A digital elevation model of the area was used to define the topography. In our EarthVision® model (Figure 2-2), nearly all faults cut the Quaternary alluvium and the topography. This is due to complications associated with creating the computer model and does not indicate that we believe there to be alluvial fault scarps in the proposed Waste Handling Building area. Future work will ensure that faults do not break the surface of the model.

2.3 Evaluation of the DOE Geologic Data

Construction of the three-dimensional model shows that sufficient geologic data exist to develop a geologically viable model of the subsurface at the proposed Waste Handling Building site. Although we note several aspects of the model and input data that can be improved, we conclude that the model is sufficiently well developed that we can use it to derive necessary stratigraphic profiles for the ground response modeling section of this report.

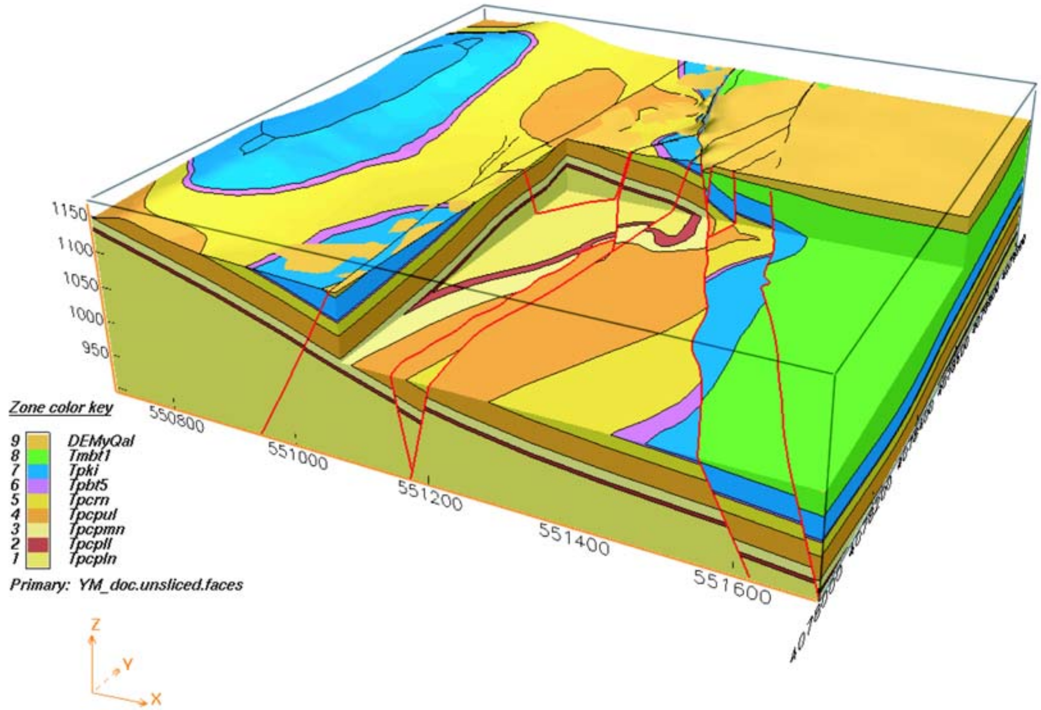

Figure 2-2. The EarthVision® Model of the Proposed Waste Handling Building Site. No Vertical Exaggeration.

In construction of the three-dimensional model, we note the following with respect to the geologic data and cross-sections provided in Bechtel SAIC Company, LLC (2002):

- In the Bechtel SAIC Company, LLC (2002) cross sections, all faults terminate below the Quaternary alluvium, implying that faulting in this part of Yucca Mountain ceased in the Pliocene, prior to at least 2 million years ago. While faulted Quaternary alluvium was not found in the alluvial test pits, the test pits are not located across major faults. The model could easily be modified to accommodate other interpretations of post Pliocene faulting.

- Along its trace, Fault 10 appears as both a normal and reverse fault in the Bechtel SAIC Company, LLC (2002) cross sections. Drafting errors in cross section D-D' (Figure 2-1) may be the origin of this problem. In Bechtel SAIC Company, LLC (2002) faults in the D-D' cross section dip to the southeast, although slip direction arrows seem to indicate that the faults dip northwest. A presentation by Lung (2002) contains some of the same or very similar cross sections, and most faults in his cross section D-D' dip to the northwest. The northwest dip is more logical, leading us to believe that the southeast dip may have been a drafting error in Bechtel SAIC Company, LLC (2002).

- Along its tract, Fault 12 appears as both a normal and reverse fault, which can be seen in the EarthVision® model (Figure 2-3 and Figure 2-4). The problem with Fault 12 could

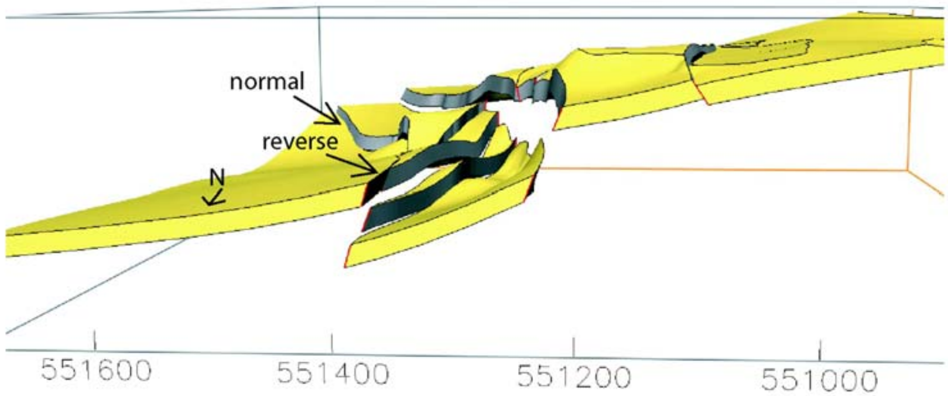

Figure 2-3. East-West Slice of EarthVision® Model Layer Tpcrn Showing Change in Displacement Along Fault Surface. View Is to the South with No Vertical Exaggeration. Coordinates are UTM, Zone 11.

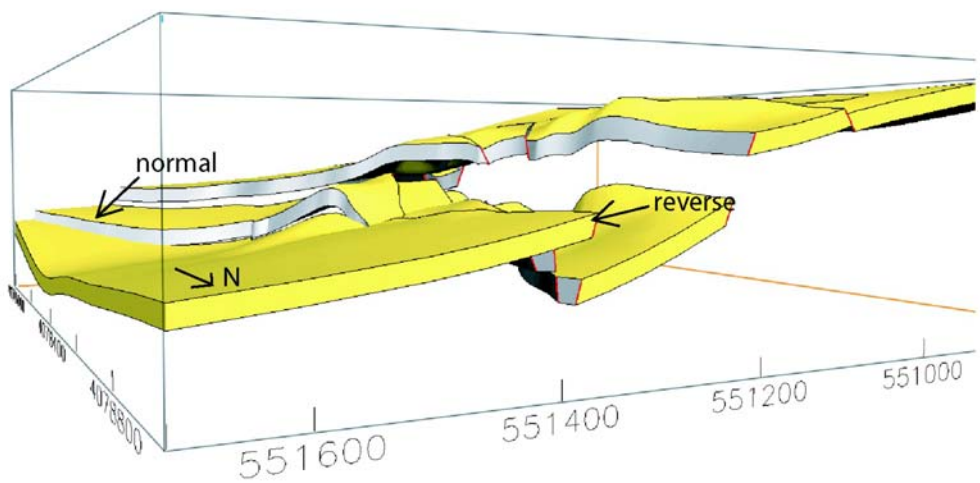

Figure 2-4. Oblique View of the Tpcrn Layer in the EarthVision® Model Showing the Change in Displacement Along Fault 12. View is to the South-Southwest With No Vertical Exaggeration. Coordinates are UTM, Zone 11.

be alleviated by the addition of a normal fault in the far eastern part of the model, perhaps outside the proposed Waste Handling Building site.

- Faults 1, 2, 3, and 4 have very small offsets [Figure 2-5 and Bechtel SAIC Company, LLC (2002) cross sections A, E, F, and G]. It is unclear why faults were interpreted by the DOE in these locations. Also, it is unclear why Faults 1, 2, and 3 are interpreted to be reverse faults. The interpretation in Bechtel SAIC Company, LLC (2002) that Fault 3 is a major structure spanning the entire study area should be reexamined, since the fault appears to have only a small of offset.

- A structural high in the southeast indicates a possible missing fault (Figure 2-6). The structural high could be explained as a relay ramp fault connecting displacement along the two segments of Fault 12.

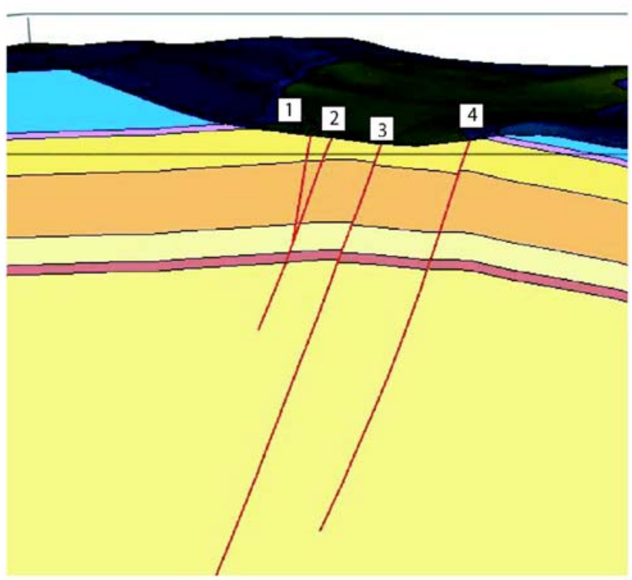

Figure 2-5. EarthVision® Model Exhibiting the Small Offsets of Faults 1, 2, 3, and 4. View Is to the North With No Vertical Exaggeration. Model Is Sliced at Northing 4078481. See Figure 2-1 For Map View of Fault Locations.

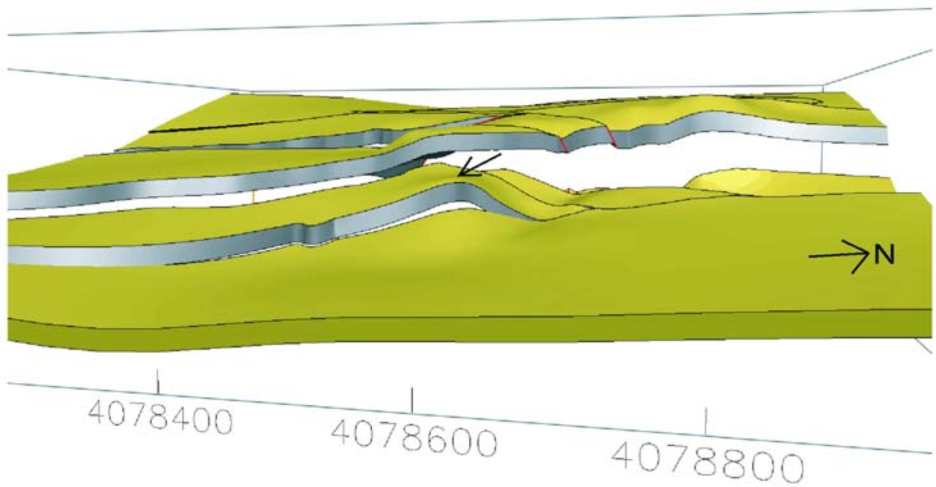

Figure 2-6. The Structural High Near Fault 12 is Indicated by a Black Arrow. A Fault on Either, or Both, Sides of This Structural High Could Explain its Presence. Stratigraphic Layer Shown is Tpcrn. No Vertical Exaggeration.

3 VELOCITY, DENSITY, AND DYNAMIC MATERIAL PROPERTIES DATA

3.1 Subsurface Velocity Data at the Proposed Waste Handling Building Site

As described in Bechtel SAIC Company, LLC (2002), three methods were used to acquire subsurface shear-wave (V_S) and compression-wave (V_P) velocity data at the Waste Handling Building site:

- Conventional downhole seismic surveys from 16 boreholes, designated UE–25RF#13 through UE–25RF#29.[1] Locations of the boreholes are shown in Figure 3-1.

- Downhole suspension seismic surveys from 15 boreholes, RF#15 through RF#29. Locations of the boreholes are shown in Figure 3-1.

- Spectral analysis of surface waves surveys. A total of 40 spectral analysis of surface waves surveys were carried out at locations distributed throughout the proposed Waste Handling Building site. Locations of the survey lines are shown in Figure 43 of the Geotechnical Report (Bechtel SAIC Company, LLC, 2002).

3.1.1 Conventional Downhole Seismic Surveys

In the conventional downhole seismic surveys, V_S and V_P were measured at selected depths (1, 2 or 3 m [3, 5, or 10 ft] intervals, depending on the borehole depth) in each borehole from sources generated at the surface. Shear waves were generated from successive sledgehammer blows to the ends of a large horizontal wooden beam with steel end caps located within a few meters of the borehole. The beam was coupled to the ground by driving the front tires of a vehicle onto it. Blows to opposite ends of the beam produced opposite polarity ("positive" or "negative") shear wave pulses. Compression waves were generated by vertical sledgehammer blows to a steel plate on the ground, also located within a few meters of the borehole. Wave signals were recorded by a three-sensor array of orthogonal geophones, one vertical and two horizontal. The sensor was then lowered or raised in each borehole in set depth increments between each reading. To maximize recording of V_S amplitudes, the geophone array was aligned within each borehole so that one of the horizontal geophones remained parallel to the wooden shear-wave beam.

The data were processed using digital 100, 200, and 400 Hz low pass filters. The degree and type of filtering varied from borehole to borehole depending on signal quality and noise. Travel times were then calculated from the signals. The first arrivals of the compression waves were used to determine travel-times. The average time of the peak arrival or maximum peak and trough (for "positive" and "negative" polarity) was used to assess the travel times for the shear waves. These travel-times were then adjusted to compensate for the slight offsets of the sources from the boreholes. The adjusted compression and shear wave velocities were then plotted as a function of receiver depth. Linear regressions were then fit graphically to observed linear trends in the travel-time data. Figure 3-2 shows an example of the velocity fits to the data

---

[1] For simplicity, the UE–25 prefix will be omitted from the borehole names. Instead, the boreholes will be referred to as RF#13 through RF#29.

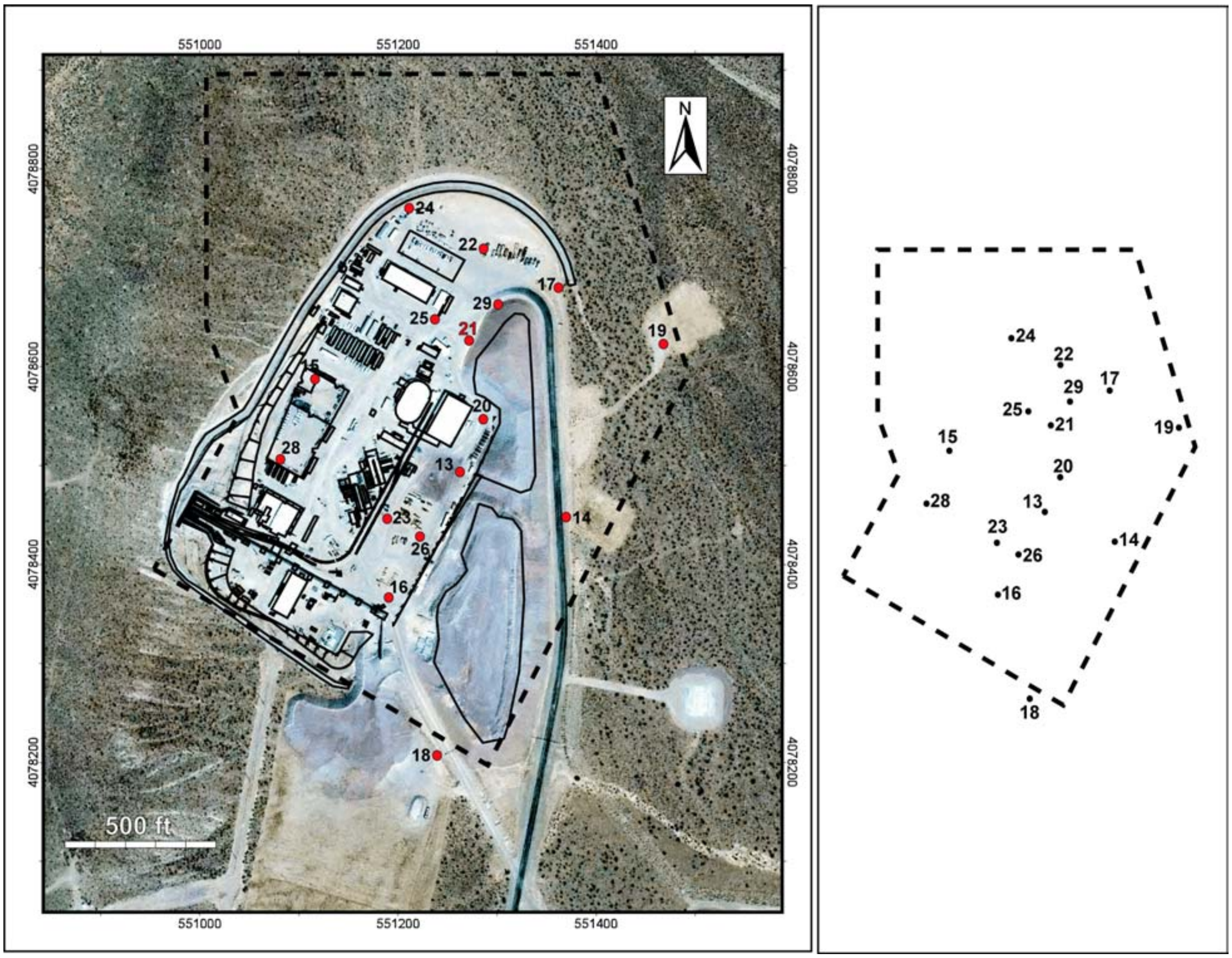

Figure 3-1. Air Photo of the Proposed Waste Handling Building Site with Overlay That Outlines the Current North Portal Surface Facilities. Dashed Line Outlines the Proposed Waste Handling Building Site. Red Circles Show the Locations of Boreholes Used in the DOE Site Investigation. For Clarity, the Insert to the Right of the Image Also Shows Borehole Locations and the Outline of the Proposed Waste Handling Building Site.

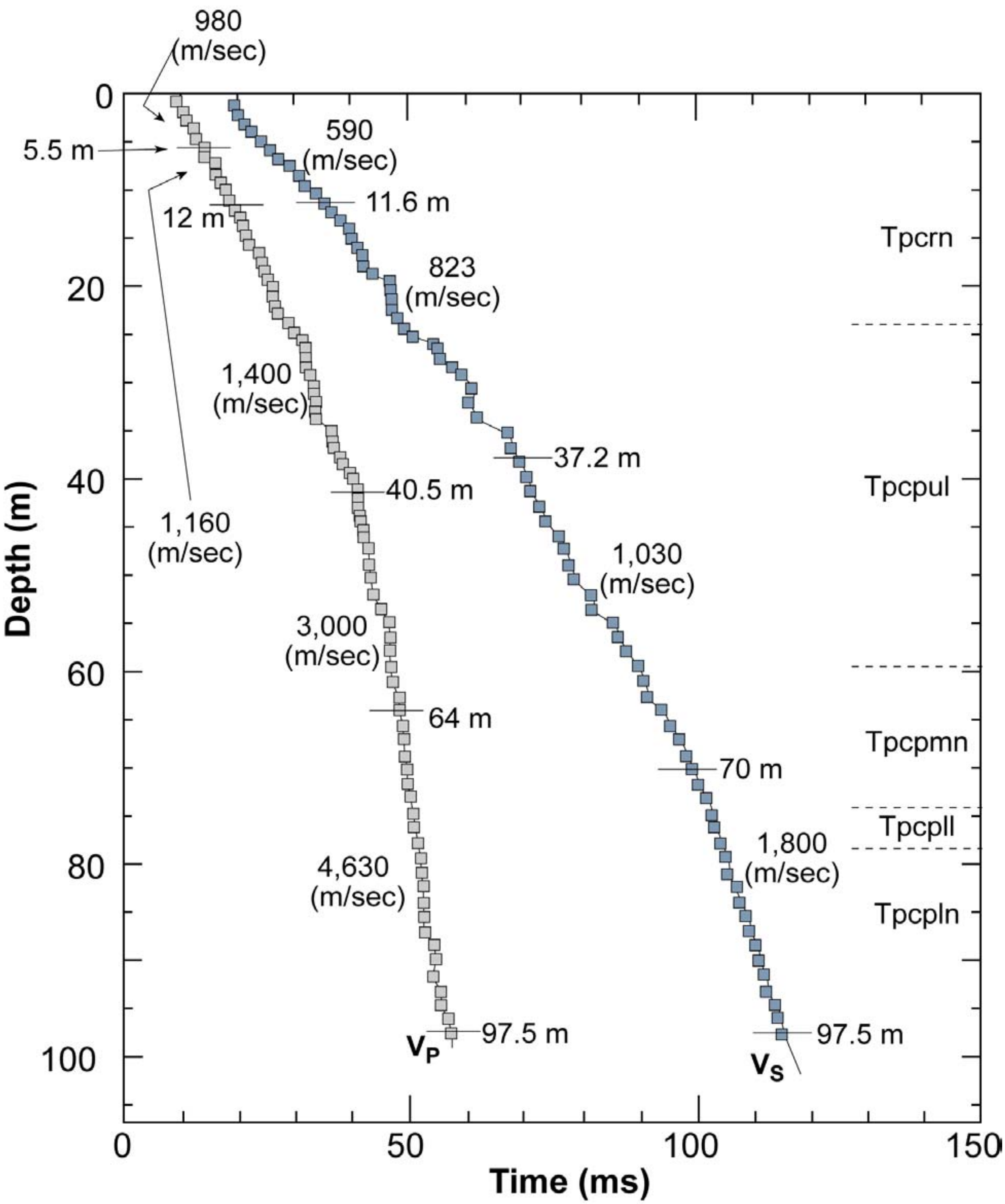

Figure 3-2. DOE Velocity Data from Down Hole Measurements at Borehole RF#15, The Velocity Intervals and Values Are Noted. The Data Were Scanned and Then Regraphed from Figure V-3 in Bechtel SAIC Company, LLC (2002).

for RF#15. The slopes of these trends defined the shear and compression wave velocities. Results for the conventional downhole surveys across the proposed Waste Handling Building site show that V_S generally increases with depth from approximately 200 m/s [~656 ft/sec] near the surface to greater than 1,800 m/s [~5,706 ft/sec] in the densely welded layers of the Tiva Canyon tuff. V_P also increases from approximately 600 m/s [~1,969 ft/s] near the surface to nearly 3,200 m/s [~10,499 ft/s] in the densely welded layers of the Tiva Canyon tuff. As observed in many of the borehole data, strong contrasts in velocity occur across mapped stratigraphic interfaces. Yet, not all interfaces and velocity contrasts are coincident, nor are all the observed steps in shear- and compression-wave velocity profiles. These complexities suggest that in some cases the generated wave paths from the sources to the receivers followed complex paths through the rocks. The complexities noted in the results are not surprising given the nature of the underlying strata, which include partially and sometimes highly cemented alluvium overlying fractured volcanic tuff with large vertical and lateral variations in composition and degree of welding.

3.1.2 Suspension Seismic Surveys

The suspension seismic surveys were accomplished using a OYO Model 170 P-S suspension logging system, which consists of a solenoid source driver, located near the bottom of the tool, and two biaxial geophones, each with one vertical and one horizontal sensor. The two receivers (near and far) were located in series along the instrument, one approximately 2 m [7 ft] and the other approximately 3 m [10 ft] above the source. The energy pulses generated by the solenoid source are coupled to the borehole wall and the surrounding rock or soil through fluid in the borehole (water or drilling mud). The energy is coupled back from the borehole wall to the geophones through the same fluid. Logging was conducted by raising the instrument package from the bottom of each borehole to the surface. Velocity measurements were made at approximately 0.5 m [1.6 ft] intervals. Each measurement consisted of two horizontal shear wave readings (one “normal,” one “reversed”) and one vertical compression wave reading. Up to eight measurements could be stacked at each elevation to improve signal-to-noise ratios. Arrival times for V_P were picked from the first break in the wave amplitude vertical sensor. Arrival times for V_S were picked from the reversal in the waveform based on a comparison of the normal and reverse pulses.

Because the logging tool has two sensors, the suspension surveys yield two sets of velocity results (Figure 3-3). One set (receiver-to-receiver) is based on the difference in shear-wave travel-time from the source to the near and far receivers and the known distance between receivers. The second set (source-to-receiver) is based on the travel time from the source to the near receiver, and the known distance between the source and the near receiver. In general practice, the receiver-to-receiver results are usually considered more reliable because they are easier to interpret and are considered to produce higher resolution. However, the compression waves were often difficult to recognize at the far receiver in the receiver-to-receiver results because of wave attenuation and damping. For example, much of the compression wave receiver-to-receiver data for RF#15 was not included because of large scatter in the input wave forms (Figure 3-3a). Thus, the source-to-receiver data were considered in Bechtel SAIC Company, LLC (2002) to provide more complete coverage of the subsurface strata. In addition, Bechtel SAIC Company, LLC (2002) deemed the source-to-receiver data more appropriate for ground motion analyses because wave velocities are averaged over the relatively larger distance between the source and near receiver compared to the smaller distance between receivers. This effectively reduces the noise introduced by very thin high or low velocity layers.

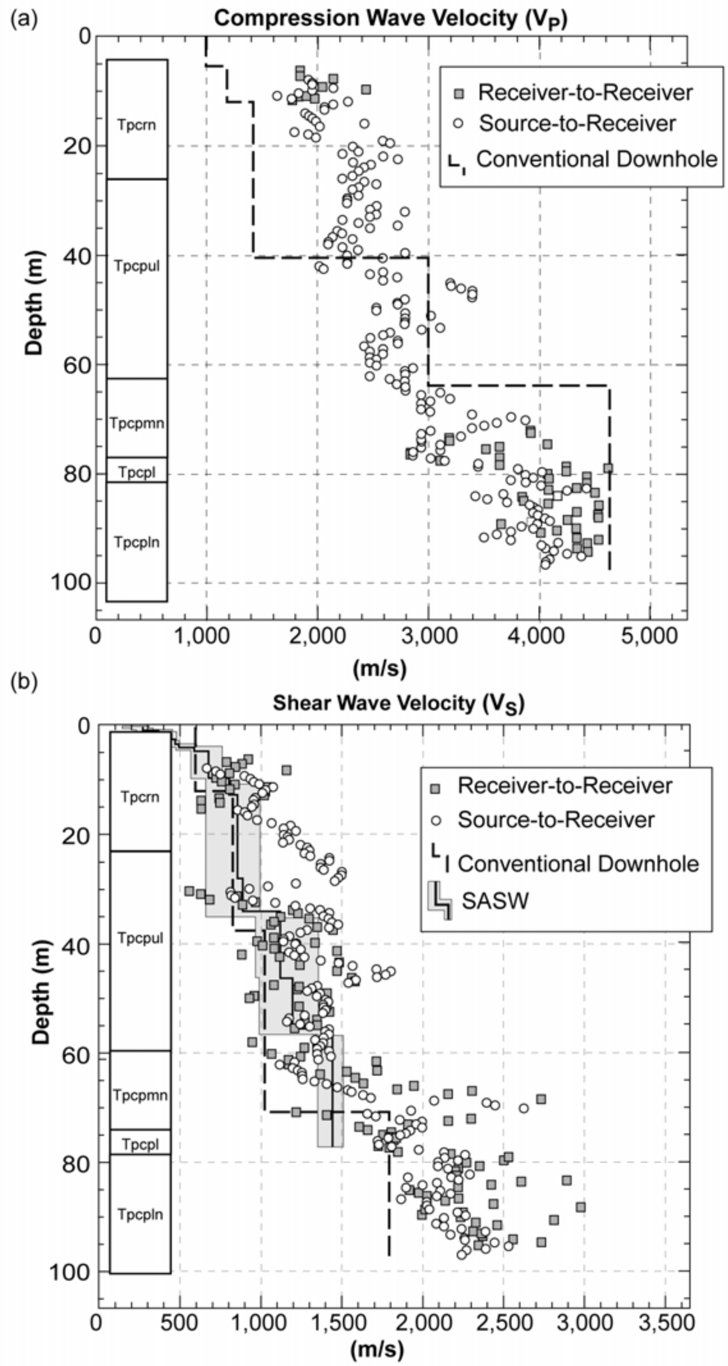

Figure 3-3. Comparison of Compression Wave Velocity (V_p) Shown in (a) and Shear-Wave Velocity (V_s) Shown in (b) from Conventional Downhole, Source-to-Receiver Suspension, Receiver-to-Receiver Suspension Methods for Borehole RF#15. V_p and V_s Data Were Scanned and Regraphed from Figures VII-3 and VII-19 in Bechtel SAIC Company, LLC (2002). The Spectral Analysis of Surface Waves Profile Shown in (b) Is the Area 2 Composite Profile Which Was Scanned and Regraphed from Figure 93 in Bechtel SAIC Company, LLC (2002).

Overall, the results from the suspension surveys from all boreholes are similar to those from the conventional downhole surveys in that V_S increases from approximately 200 m/s [656 ft/sec] near the surface to greater than 1,800 m/s [5,906 ft/sec] in the densely welded Tiva Canyon tuff. V_P increases from approximately 600 m/s [1,969 ft/s] in the alluvium to nearly 3,200 m/s [10,499 ft/sec] in the densely welded Tiva Canyon tuff.

Both downhole and suspension survey results included uncertainties in averaged V_S and V_P values that reflect the variable nature of the host rocks and soils (such as composition, fracture density, and vein material), complexities in the source ray paths, and natural and cultural noise.

In the conventional downhole measurements, a relatively large volume of material is sampled because the source remains at the surface and away from the borehole as the receiver array is moved vertically within the borehole. This can to mute variability in V_S or V_P from local effects (they are effectively integrated out). However, the signal-to-noise ratio in the downhole surveys increase as the receiver is moved down the boreholes and away from the source at the surface because the input waveform is dulled by attenuation and damping. In addition, there is user subjectivity in the conventional downhole results because the velocity trends are picked from observed inflections in the slope of the recorded velocity profiles. For example, in the velocity picks from the conventional downhole profiles for RF#15 shown in Figure 3-2, a large velocity contrast was picked by the DOE contractors at a depth of approximately 70 m [230 ft], where V_s is shown to increase from 1,024 m/sec [3,360 ft/s] to 1,798 m/sec [5,899 ft/s]. However, an equally valid interpretation is that this change in slope occurs closer to a depth of 60 m [197 ft]. In this alterative interpretation, the conventional profile would then more closely match the V_s profile from the source-to-receiver data as shown in Figure 3-3b, and the large change in velocity will move closely match the change in lithology between the middle lithophysal and lower nonlithophysal units of the Tiva Canyon tuff.

In contrast, the strength of the input waveform remains relatively uniform in suspension surveys because the receiver and source remain at fixed distance from each other for all measurements in the borehole. In this method however, local factors such as patches of fractured rock or vein fillings strongly influence a single measurement and thus contribute substantially to the overall variability in the measurements because only a small volume of material is sampled by each measurement. As indicated in Bechtel SAIC Company, LLC (2002), some smoothing of the suspension data was therefore necessary to compensate for these local effects.

3.1.3 Spectral Analysis of Surface Waves Surveys

The spectral analysis of surface waves method relies on the dispersive characteristic of Rayleigh waves as they propagate through a layered medium because of changes in the material properties of the underlying rocks or soil, including shear wave velocity and stiffness. Spectral analysis is used to separate the waves by frequency and wavelength to arrive at individual or composite dispersion curves. Forward modeling is then used to develop one-dimensional V_S profiles and associated dispersion curves that reasonably match the observed Rayleigh wave dispersion. V_P is not modeled by this method.

Spectral analysis of surface waves surveys were performed at 40 surface locations producing 35 spectral analyses of surface waves profiles within the proposed Waste Handling Building site (Bechtel SAIC Company, LLC, 2002). Spectral analyses of surface waves surveys were conducted using either common-receivers midpoint geometry or fixed source configuration in which the receivers were progressively spaced up to a maximum of approximately 60 m [197 ft]. Wavelengths from approximately 1 m [3 ft] up to 300 m [984 ft] were generated at the source. In theory, the maximum depth that shear wave velocities can be determined using the spectral analysis of surface waves method is half the longest wavelength. Thus, the arrangement of receivers and wavelengths used allowed dispersion data to be collected to depths of approximately 150 m [492 ft]. To generate energy with the requisite spectral frequencies, four sources were used (i) a handheld hammer striking the ground; (ii) a sledgehammer striking the ground; (ii) a bulldozer operated back and forth a distance of several meters, and (iv) a Vibroseis truck (for three very deep profiles, spectral analysis of surface waves profiles 35, 36, and 37).

V_S from spectral analysis of surface waves profiles is comparable to the downhole and suspension results except at very shallow depths, less than approximately 6 m [20 ft] where the spectral analysis of surface waves readings indicate much slower V_S (e.g., Figure 3-3b). Because these differences are only observed in the very shallow surface layers, these differences are not considered significant to the overall site response modeling.

3.2 Density Data at the Proposed Waste Handling Building Site

To acquire density data, Schlumberger Limited ran wireline caliper and gamma-gamma density tools in seven boreholes within the proposed Waste Handling Building site. In general, the holes were in good gage with only occasional enlargements greater then 2.5 cm [1.0 in]. Preferential elongation occurs occasionally in some holes over short distances. Elongations of greater then 2.5 cm [1.0 in] are rare {RF#16, 57.9 to 7.01 m [190 to 200 ft]}. Only a few elongations are greater then 3.8 cm [1.5 in] and they only occasionally result in a corresponding lower density value {RF#25 at 61m [200 ft]}. These deeper enlargements occur over intervals of a few feet, and the corresponding lower density would have a minor effect on the integrated density for the lithologic unit.

Because of drilling, the boreholes were left with a residual mudcake coating on the wall. To correct for the mudcake, a dual-detector density tool was used. This is a well-established practice used in many borehole drilling applications. No calibration data were supplied for either tool in the report; however, the relatively consistent density values between holes suggest the tools were adequately calibrated, although this was not verified.

In general, the rocks beneath the proposed Waste Handling Building site have relatively low densities. Densities as low as 1.6 Mg/m^3 [99.9 lb/ft^3] are measured in Tpki unit (tuff unit “x”), which is nonwelded tuff containing up to 30 percent pumice clasts. Densities in the alluvium and the other nonwelded to moderately welded tuffs range near 2.0 Mg/m^3 [124.9 lb/ft^3]. Densities of up to 2.4 Mg/m^3 [149.8 lb/ft^3] were measured in the nonlithophysal units of the densely welded Tiva Canyon Tuff. The density values derived from the gamma density logs appear to be adequate to use in the assessment of the seismic hazard analysis at the proposed Waste Handling Building site because they are based on well-established techniques and incorporate relatively consistent results from boreholes distributed across the proposed Waste Handling Building site.

3.3 Evaluation of the DOE Velocity and Density Data

DOE provided a comprehensive set of velocity data from three established geophysical techniques and density data from seven boreholes. Based on review of these data, we conclude that they are sufficient to develop ground response models of the proposed Waste Handling Building site. Note, however, that additional velocity and density data for the areas of Midway Valley outside the current Waste Handling Building site that the DOE plans to use for additional surface facilities, such as the aging-facility pads north of Exile Hill (DOE, 2004).

Despite noted differences in V_S among the three measurement methods (conventional downhole, suspension, and spectral analysis of surface waves); overall results in terms of velocity trends are comparable (Figure 3-4). Of the four data sets for velocity, we used the source-to-receiver suspension data because they were most easily correlated with stratigraphy. In Bechtel SAIC Company, LLC (2002), the suspension results are presented within small enough depth interval that we could bin the data within each stratigraphic unit. In contrast, the conventional downhole V_S and V_P profiles were developed from eyeball fits to linear segments of the data without regard for stratigraphic position or lithology. These processed velocity data and smoothed spectral analysis of surface wave data do not easily lend themselves to correlation with stratigraphy.

Detailed plots of the density and velocity data indicate that lithology may be an important factor in the development of site response models. In Figures 3-5 a, b, and c, density and velocity data are sorted by lithology.

The circles and error bars shown in Figure 3-5 are the mean values and standard deviations reported for each lithology in each borehole where the data were obtained. These data were taken from Tables VII-2, VII-3, and 12 in Bechtel SAIC Company, LLC, 2002). The thick black line and shaded area are the weighted mean and standard deviation of the weighted mean for each lithologic unit.

The weighted mean for each lithology was calculated as:

$$\overline{X} = \frac{\sum_{i=1}^{m} \left(\overline{x}_i \times n_i\right)}{\sum_{i=1}^{m} n_i}$$

where $\overline{X}$ is the weighted mean value of V_s, V_p, or density for the lithology, $\overline{x}_i$ is the average value of V_s, V_p, or density as measured in the i^{th} borehole, and n_i is the number of measurements of V_s, V_p, or density in the i^{th} borehole for all total of m boreholes.

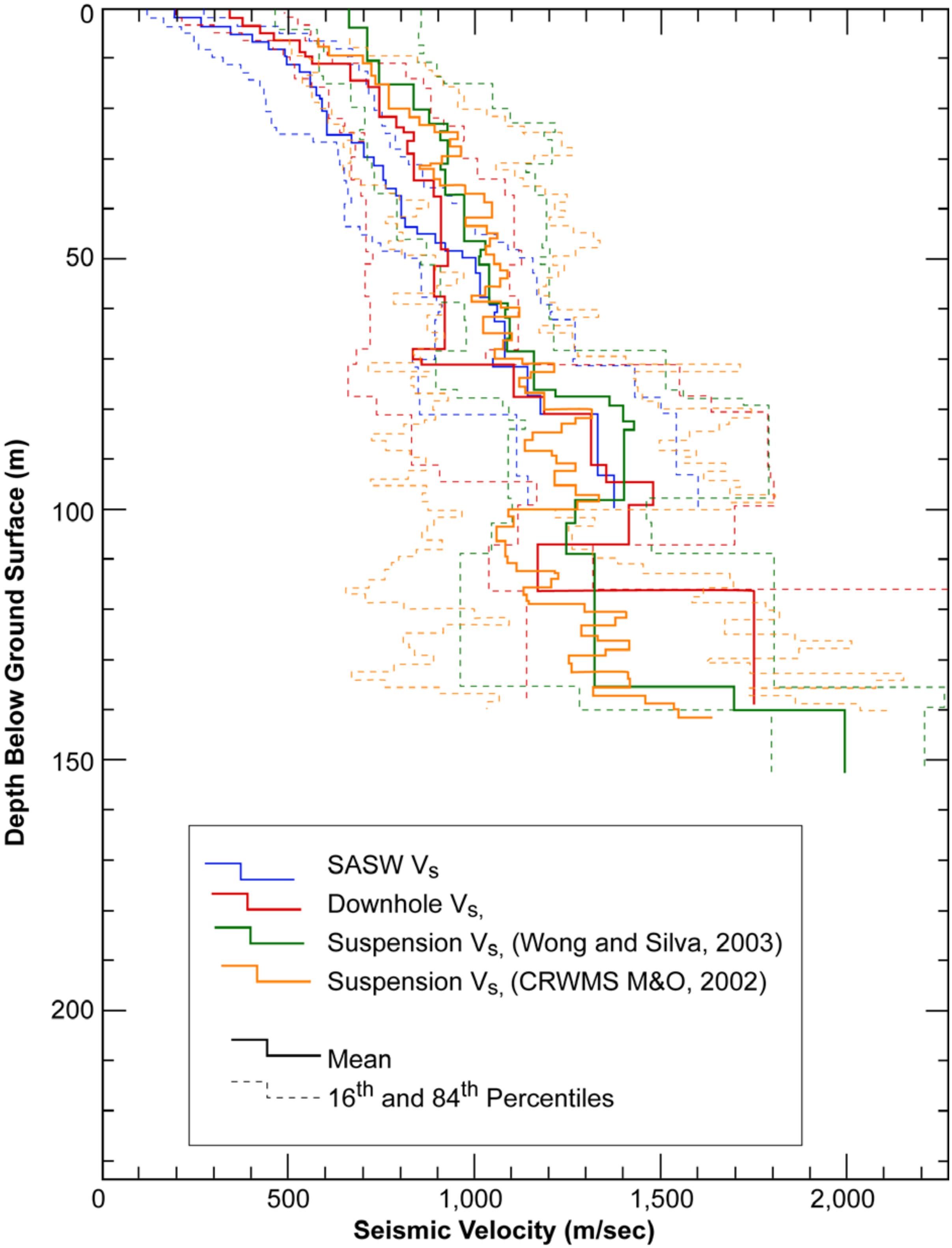

Figure 3-4. Composite Shear-Wave Velocity Profiles Based on the DOE Data from Conventional Downhole, Suspension Surveys, and Spectral Analysis of Surface Waves Results

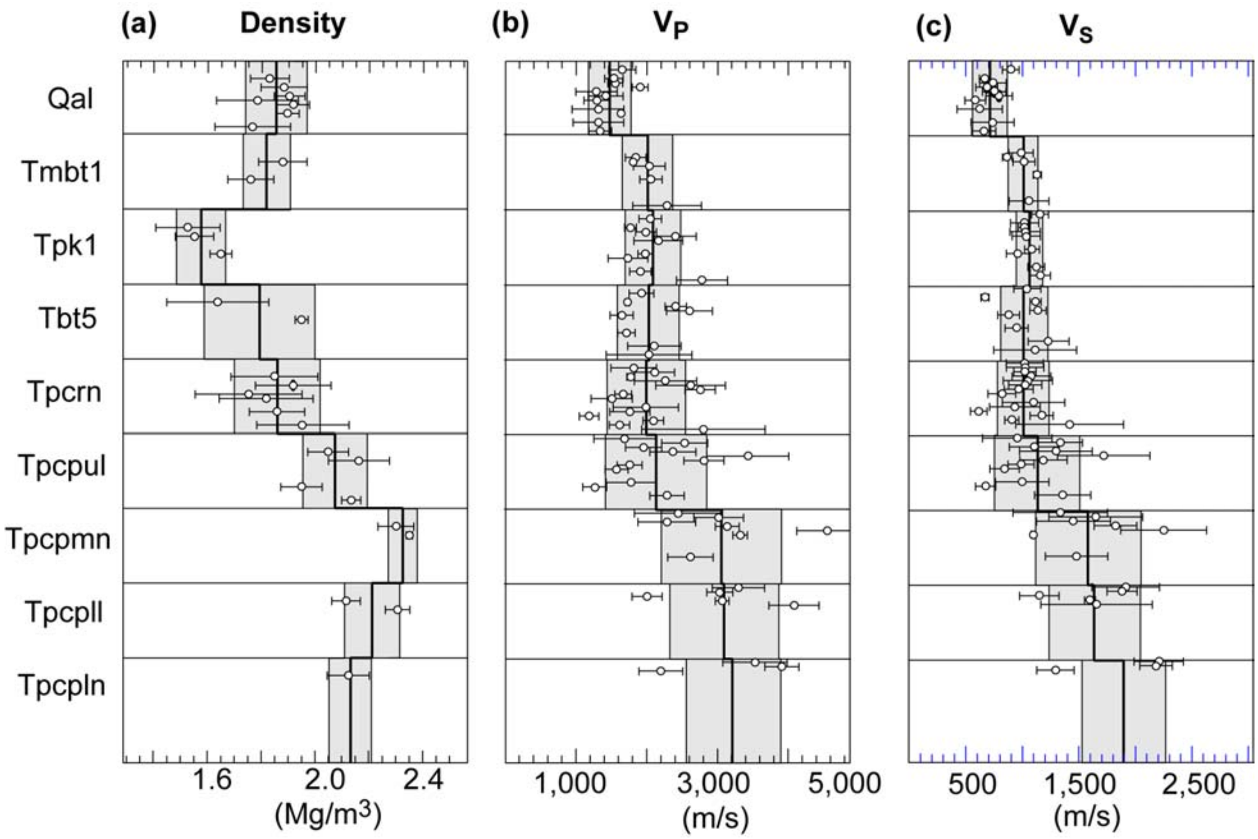

Figure 3-5. Density Shown in (a), V_P Shown in (b) and V_S Shown in (c) Plotted as a Function of Stratigraphy. The Circles With 1-Sigma Error Bars are The Mean Values from Each Borehole Where Velocity or Density Data For That Unit were Obtained. The Thick Black Line With 1-Sigma Shaded Error Band is the Weighted Mean of the Borehole Data.

The shaded area is none standard deviation (σ) about the weighted mean and was calculated as:

$$\sigma = \sqrt{\left[\frac{\sum_{i=1}^{m}\left[\left(\bar{x}_i^{2} + \sigma_i^{2}\right) \times n_i\right]}{\sum_{i=1}^{m} n_i}\right] - \left[\frac{\sum_{i=1}^{m}\left(\bar{x}_i \times n_i\right)}{\sum_{i=1}^{m} n_i}\right]^{2}}$$

The resulting V_S and V_P profiles reveal at least two important layer boundaries, one between the alluvium (Qal) and underlying nonwelded tuff (Tmbt1) and one between the moderately welded upper lithophysal unit (Tpcpul) and densely welded middle nonlithophysal unit (Tpcpmn) of the Tiva Canyon Tuff. Impedance ratios also show large acoustic and shear contrasts across the same two layer boundaries (Table 3-1).

Table 3-1. Impedance Ratios

Layer Boundary	Shear Impedance	Acoustic Impedance
Qal/Tmbt1	0.72	0.75
Tpcpul/Tpcpmn	0.64	0.62

The alternative possibility that velocity and density are largely controlled by depth below ground surface is not supported by these data. Analysis of these data show that velocity and density do not solely depend on depth (Figure 3-6). The data show that within the upper 100 m [328 ft], velocity and density do not increase with depth. Only at depths below 100 m [328 ft] do both density and velocity show large increases. However, these increases are at depths where presence of the densely welded tuff units is more commonly.

3.4 Dynamic Property Data at the Proposed Waste Handling Building Site

Bechtel SAIC Company, LLC (2002) presents combined resonant column and torsional shear test results which were performed to evaluate the dynamic properties of tuff and alluvium from the proposed Waste Handling Building Site. A total of 18 intact tuff specimens and a single reconstituted alluvial specimen were obtained from boreholes RF#14, RF#15, RF#16, and RF#17 which are shown in Figure 2-1.

The resonant column and torsional shear equipment has been developed at the University of Texas at Austin Civil Engineering Department over the past two decades (Bechtel SAIC Company, LLC, 2002). The equipment is of the fixed-free type, with the bottom of the specimen fixed and torsional excitation applied to the top (Bechtel SAIC Company, LLC, 2002). Both resonant column and torsional shear tests can be performed in a sequential series on the same specimen over a shearing-strain range from about 10^{-4} percent to slightly more than 10^{-1} percent (Bechtel SAIC Company, LLC, 2002). The primary difference between the two

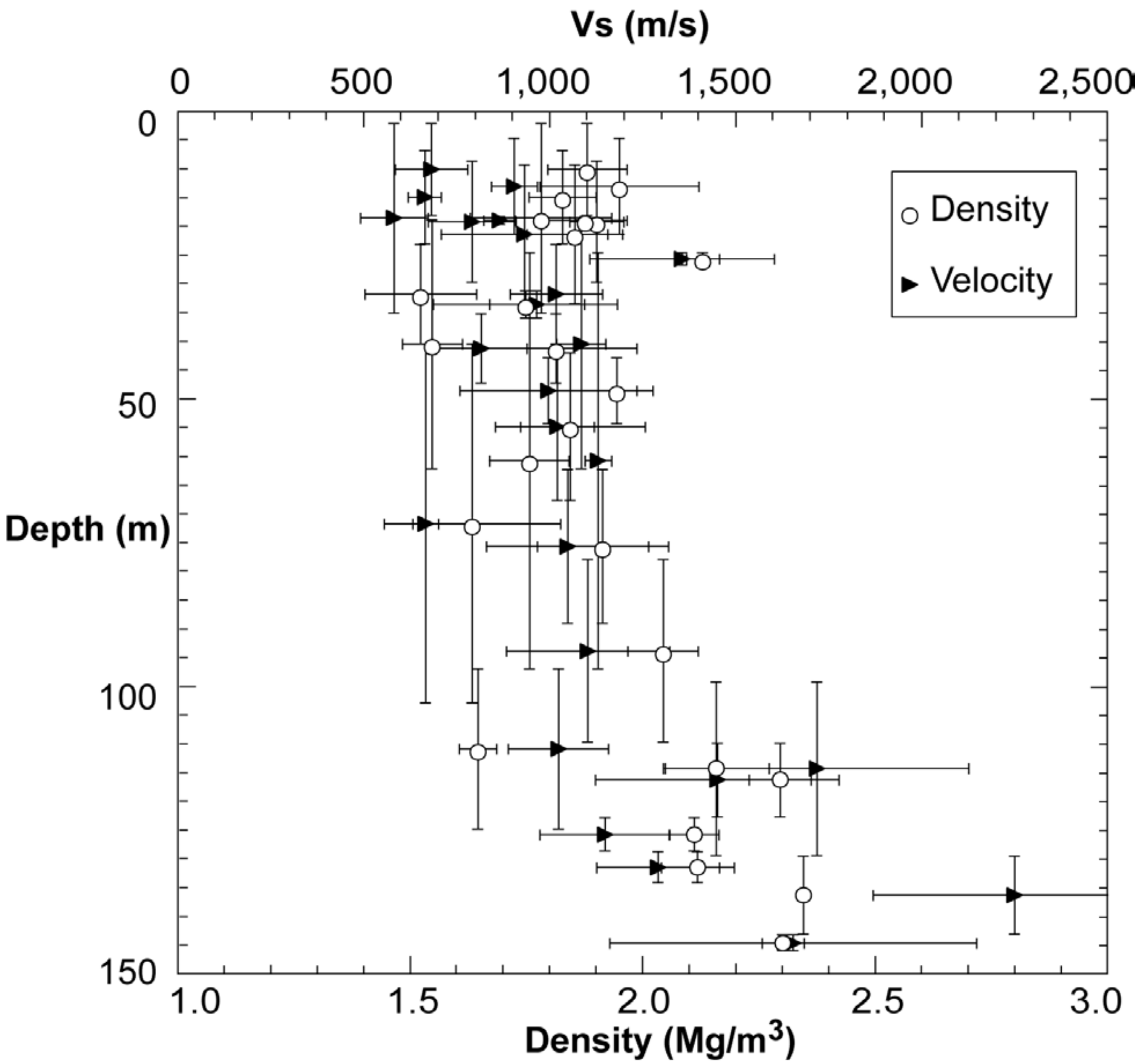

Figure 3-6. Density and Shear-Wave Velocity Plotted as a Function of Depth. The Error Bars for V_s and Density are the 1-Sigma Errors About the Reported Mean Values. The Error Bars for Depth Plot the Depth Range Over Which The Density or V_s Were Measured.

types of tests is the excitation frequency (Bechtel SAIC Company, LLC, 2002). Ten cycles of loading were used in the torsional shear test followed by about 1,000 cycles in the resonant column test (Bechtel SAIC Company, LLC, 2002).

3.4.1 Alluvial Data

Only one alluvium sample (not intact) was collected. Several attempts were made to obtain intact alluvial specimens; however, the material failed during the sampling process. For this reason, the alluvial sample was reconstituted in the laboratory using the standard under compaction method of Ladd (1978).

The normalized shear modulus and damping ratio data for the alluvial sample are shown in Figures 3-7 and 3-8, respectively. Data from both resonant column and torsional shear (first and tenth cycles) tests are plotted. Also plotted for comparison is a standard set of curves for sand (Seed, et al., 1986). The alluvial data generally fall within the range of the standard sand curves.

3.4.2 Tuff Data

A total of 18 tuff samples were collected for testing. Fourteen of these samples were derived by wet-coring specimens with a nominal diameter of 3.97 cm [1.56 in] from each larger-diameter core sample. The remaining 4 tuff specimens were wet cored from 4 of the above 14 tested specimens (Bechtel SAIC Company, LLC, 2002).

Figures 3-9 and 3-10 plot the shear modulus and damping data, respectively, for all tuff samples from the proposed Waste Handling Building. The plots show data from both resonant column and torsional shear tests (first and tenth cycles). A standard set of curves for sand (Seed, et al., 1986) and a standard rock curve, obtained from the ProShake® ground response analysis program (EduPro Civil Systems, 2001) have also been plotted for comparison. In Figures 3-9 and 3-10, data from tuff samples of the same lithologic unit are indicated by the same symbol. Bechtel SAIC Company, LLC (2002) divided the tuff samples into three groups according to dry unit weight. Tuff samples belonging to Groups 1, 2, and 3 data are shown in red, green, and blue, respectively in Figures 3-9 and 3-10. The above grouping was chosen because of the relationship between V_s obtained from resonant column and torsional shear measurements and dry unit weight. A general trend of increasing V_s with increasing dry unit weight was observed.

Group 1 (refer to Table 3-2) includes tuff specimens with a dry unit weight between 2.13 Mg/m^3 [133 lb/ft^3] and 2.35 Mg/m^3 [147.0 lb/ft^3], and V_s between 2,103 m/s [6,900 ft/s] and 2,682 m/s [8,800 ft/s]. This group is primarily comprised of the densely welded tuff units including Tpcpln, Tpcpmn, and the moderately to densely welded unit Tpcpul. No dynamic testing was performed on the densely welded unit Tpcpll.

Group 2 (refer to Table 3-3) includes tuff specimens with a dry unit weight between 1.87 Mg/m^3 [117 lb/ft^3] and 2.11 Mg/m^3 [132 lb/ft^3] , and V_s between 1,524 m/s [5,000 ft/s] and 1,781 m/s [6,500 ft/s]. This group is primarily comprised of the moderately to densely welded tuff units.

Group 3 (refer to Table 3-4) includes tuff specimens with a dry unit weight between 1.2 Mg/m^3 [78 lb/ft^3] and 1.5 Mg/m^3 [94 lb/ft^3], and V_s between 1,036m/s [3,400 ft/s] and 1,433 m/s [4,700 ft/s]. This group is primarily comprised of the nonwelded tuff unit Tpki and also a Tcprn

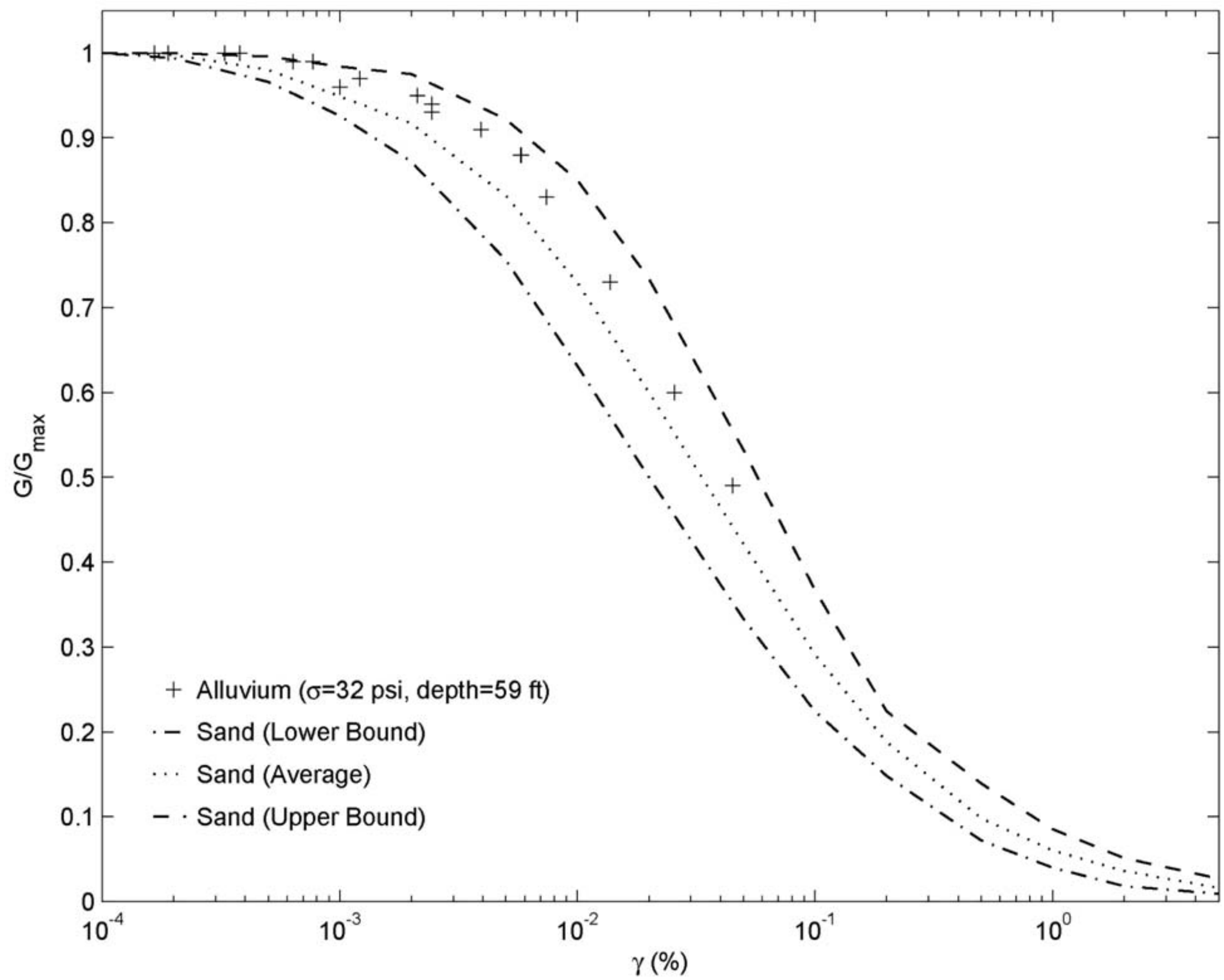

Figure 3-7. Normalized Shear Modulus Results for the Alluvial Sample from the Proposed Waste Handling Building (Modified from Bechtel SAIC Company, LLC, 2002). Also Shown for Comparison Are Average, Upper, and Lower Bound Sand Curves.

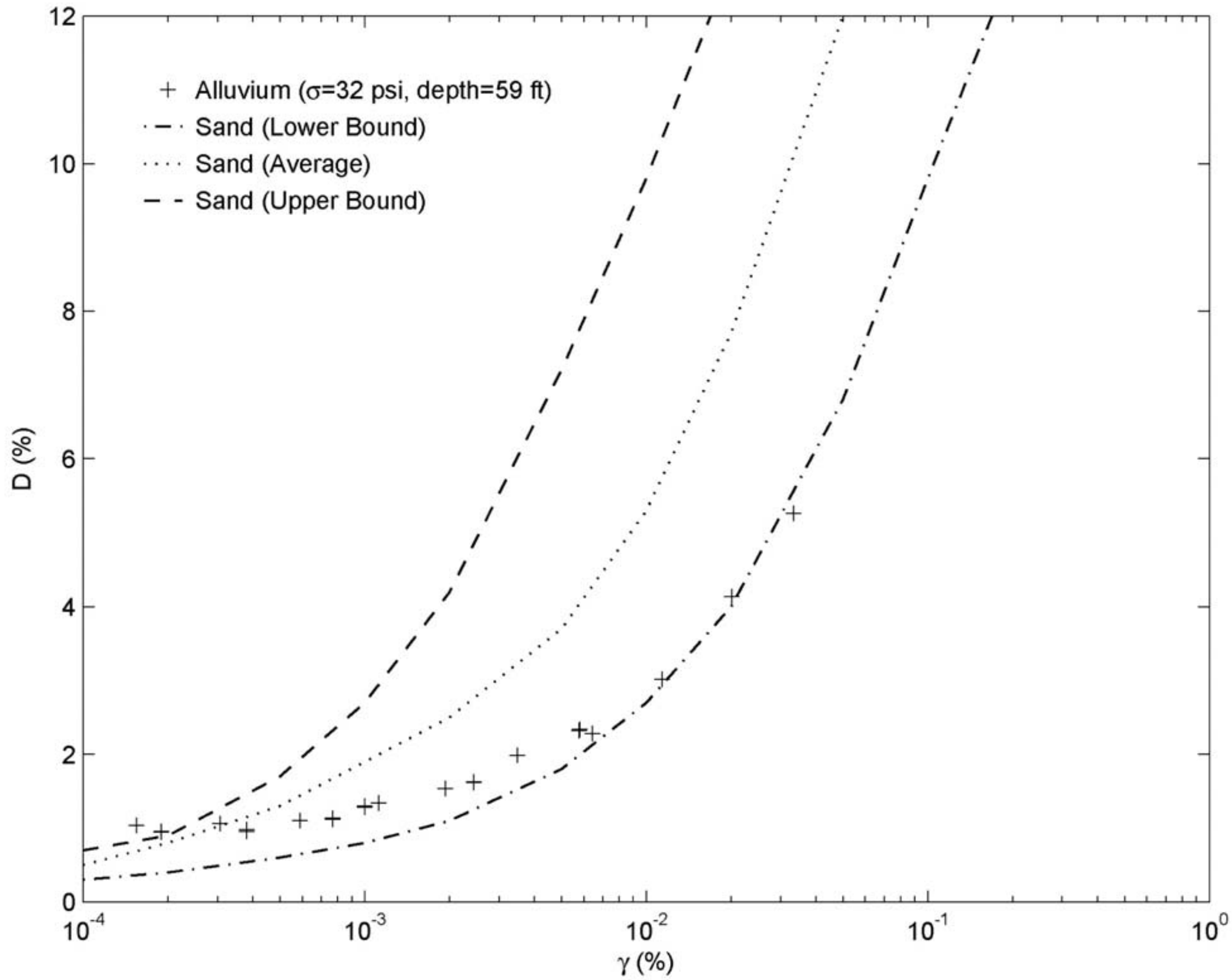

Figure 3-8. Damping Ratio Results for the Alluvial Sample from the Proposed Waste Handling Building (Modified from Bechtel SAIC Company, LLC, 2002). Also Shown for Comparison are Average, Upper, and Lower Bound Sand Curves.

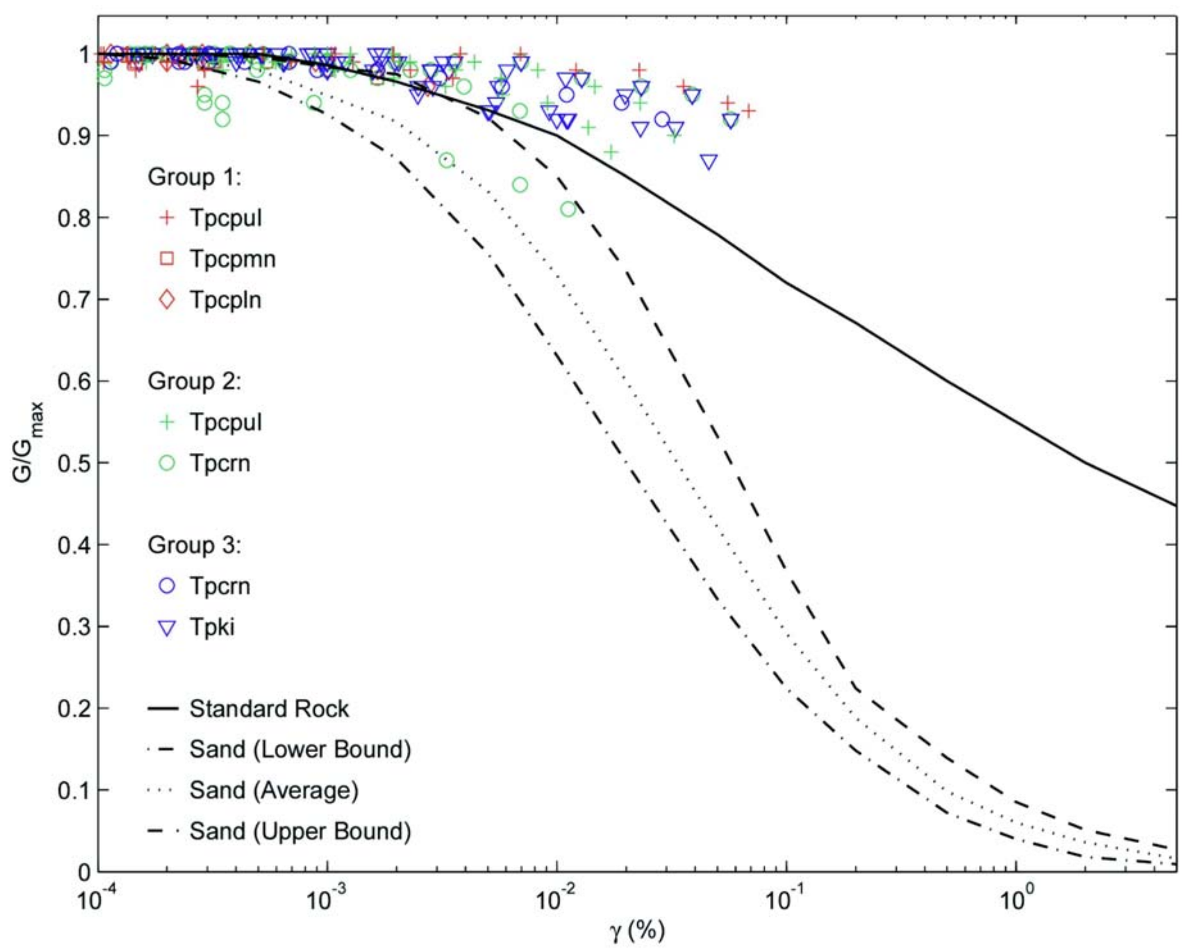

Figure 3-9. Normalized Shear Modulus Data for the Tuff Samples from the Proposed Waste Handling Building (Modified from Bechtel SAIC Company, LLC 2002). Also Shown are Average, Upper, and Lower Bound Sand Curves and a Standard Rock Curve.

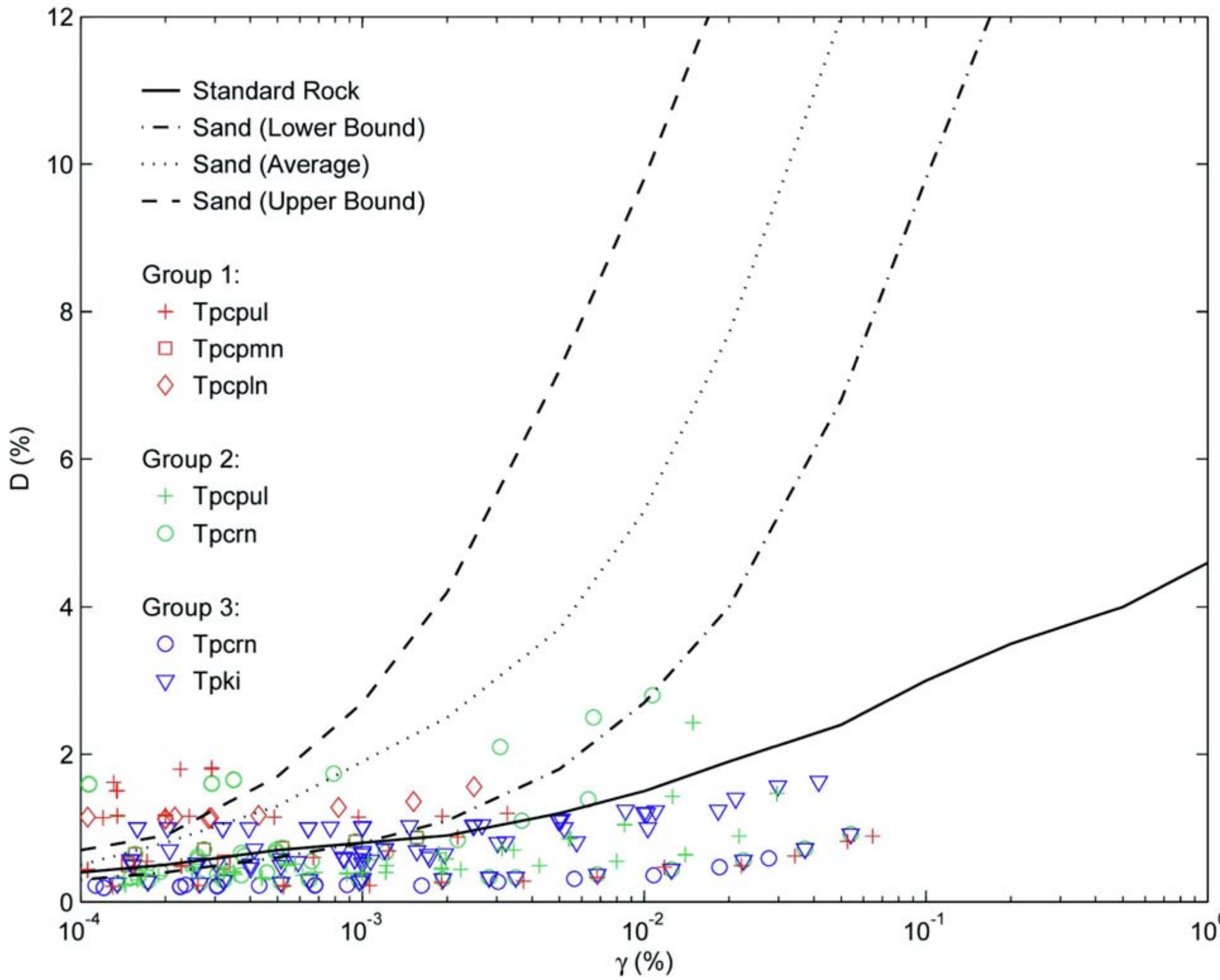

Figure 3-10. Damping Ratio Data for the Tuff Samples from the Proposed Waste Handling Building (Modified from Bechtel SAIC Company, LLC 2002). Also Shown are Average, Upper, and Lower Bound Sand Curves and a Standard Rock Curve.

Table 3-2. Initial Properties of Intact Tuff Specimens With A Dry Unit Weight Between 2.43 Mg/m^3 [133 lb/ft^3] and 2.35 Mg/m^3 [147 lb/ft^3] from Proposed Waste Handling Building Boreholes (Group 1)				
Sample Name	**Borehole**	**Depth**	**Unit**	**Dry Unit Weight**
UTA–23–C	RF#14	110.0 m [361.0 ft]	Tpcpul	2.138 Mg/m^3 [133.5 lb/ft^3]
UTA–23–D	RF#14	121.0 m [397.0 ft]	Tpcpmn	2.339 Mg/m^3 [146.0 lb/ft^3]
UTA–23–G	RF#15	58.67 m [192.5 ft]	Tpcpul	2.321 Mg/m^3 [144.9 lb/ft^3]
UTA–23–T	RF#15	58.67 m [192.5 ft]	Tpcpul	2.315 Mg/m^3 [144.5 lb/ft^3]
UTA–23–H	RF#15	98.15 m [322.0 ft]	Tpcpln	3.329 Mg/m^3 [145.4 lb/ft^3]
UTA–23–J	RF#17	175.4 m [575.6 ft]	Tpcpul	2.246 Mg/m^3 [140.2 lb/ft^3]

Table 3-3. Initial Properties of Intact Tuff Specimens with a Dry Unit Weight Between 1.87 Mg/m^3 [117 lb/ft^3] and 2.1 Mg/m^3 [132 lb/ft^3] from Proposed Waste Handling Building Boreholes (Group 2)				
Sample Name	**Borehole**	**Depth**	**Unit**	**Dry Unit Weight**
UTA–20–B	RF#16	57.76 m [189.5 ft]	Tpcrn	1.937 Mg/m^3 [120.9 lb/ft^3]
UTA–20–C	RF#16	77.27 m [253.5 ft]	Tpcpul	2.007 Mg/m^3 [125.3 lb/ft^3]
UTA–23–B	RF#14	73.61 m [241.5 ft]	Tpcrn	1.994 Mg/m^3 [124.5 lb/ft^3]
UTA–23–R	RF#14	73.61 m [241.5 ft]	Tpcrn	1.893 Mg/m^3 [118.2 lb/ft^3]
UTA–23–F	RF#15	27.0 m [88.7 ft]	Tpcpul	2.106 Mg/m^3 [131.5 lb/ft^3]
UTA–23–S	RF#15	27.0 m [88.7 ft]	Tpcpul	2.041 Mg/m^3 [127.4 lb/ft^3]

Table. 3-4. Initial Properties of Intact Tuff Specimens with a Dry Unit Weight Between 1.2 Mg/m^3 [78 lb/ft^3] and 1.5 Mg/m^3 [94 lb/ft^3] from Proposed Waste Handling Building Boreholes (Group 3)				
Sample Name	**Borehole**	**Depth**	**Unit**	**Dry Unit Weight**
UTA–20–A	RF#16	38.65 m [126.8 ft]	Tpki	1.29 Mg/m^3 [80.8 lb/ft^3]
UTA–23–Q	RF#16	38.65 m [126.8 ft]	Tpki	1.26 Mg/m^3 [78.8 lb/ft^3]
UTA–20–D	RF#16	24.5 m [80.5 ft]	Tpki	1.47 Mg/m^3 [91.5 lb/ft^3]
UTA–23–A	RF#14	31.85 m [104.5 ft]	Tpki	1.50 Mg/m^3 [93.5 lb/ft^3]
UTA–23–I	RF#17	122.0 m [400.2 ft]	Tpcrn	1.38 Mg/m^3 [86.0 lb/ft^3]
UTA–23–S	RF#15	27.0 m [88.7 ft]	Tpcpul	2.01 Mg/m^3 [127.4 lb/ft^3]

sample which is a moderately to densely welded tuff unit. No testing was performed on Tmbt1 samples from the proposed Waste Handling Building site, which is also a nonwelded tuff unit.

The tuff units generally exhibit more linear behavior in comparison to the standard sand and rock curves up to strain levels of approximately 0.01 percent. Beyond these strain levels, the tuff data appear to trend more nonlinearly. There appears to be some variability in dynamic behavior within the data. However, Figures 3-9 and 3-10 do not reveal a strong correlation between the three groups in terms of their dynamic behavior. For example, data for the nonwelded (Group 1) tuff unit Tpki show similar overall dynamic behavior to the densely welded Tpcpul tuff unit (Group 3). One would expect Group 1 samples to exhibit more linear behavior compared to Group 3 samples, because they are more densely welded, and exhibit higher V_s.

3.5 Evaluation of the DOE Dynamic Property Data

Overall Figures 3-9 and 3-10 do not reveal a strong correlation among the three groups' dynamic behavior. There is large uncertainty in the dynamic behavior of the tuff specimens at strain levels beyond 0.1 percent. This is a limitation of the resonant column and torsional shear testing equipment. For some tuff units however, including the densely welded units Tpcpmn and Tpcpln, data are limited to strain levels of approximately 0.003 percent. The large uncertainty in dynamic behavior may be significant for larger earthquake motions which may produce strains beyond these values.

Only one alluvial sample was dynamically tested. Ideally there should be more data to better constrain the modulus and damping curves. The Bechtel SAIC Company, LLC (2002) report refers to additional dynamic testing performed on reconstituted alluvium samples (CRWMS M&O, 1999). Additional dynamic testing was also performed on several tuff units (CRWMS M&O, 1999). These data, however, were not incorporated in Bechtel SAIC Company, LLC (2002) report, and therefore were not available for this review.

4 GROUND RESPONSE CALCULATIONS

The data in Bechtel SAIC Company, LLC (2002) will be used as inputs to develop representative Postclosure and Preclosure time histories for Point B, as well as and Preclosure time histories for Points D and E (refer to Figure 4-1). These time histories are not yet available and Bechtel SAIC Company, LLC (2002) does not contain any of these calculations.

Preliminary ground response calculations were conducted to help quantify the effects of data uncertainty on ground motion amplification. These calculations were performed using the program ProShake® (EduPro Civil Systems, 2001) which calculates the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves (Schnabel, et al., 1972). An equivalent linear procedure is used to account for the nonlinearity of the soil (Idriss and Seed, 1968).

4.1 Inputs to the Ground Response Calculations

Inputs to the ProShake® model include developing a soil column and assigning a velocity, density, and thickness to each layer in the column, including the half-space. Each layer is also assigned a damping and shear modulus reduction curve. In addition, an input time history most to be specified at the top of any layer within the soil profile, or at the corresponding outcrop.

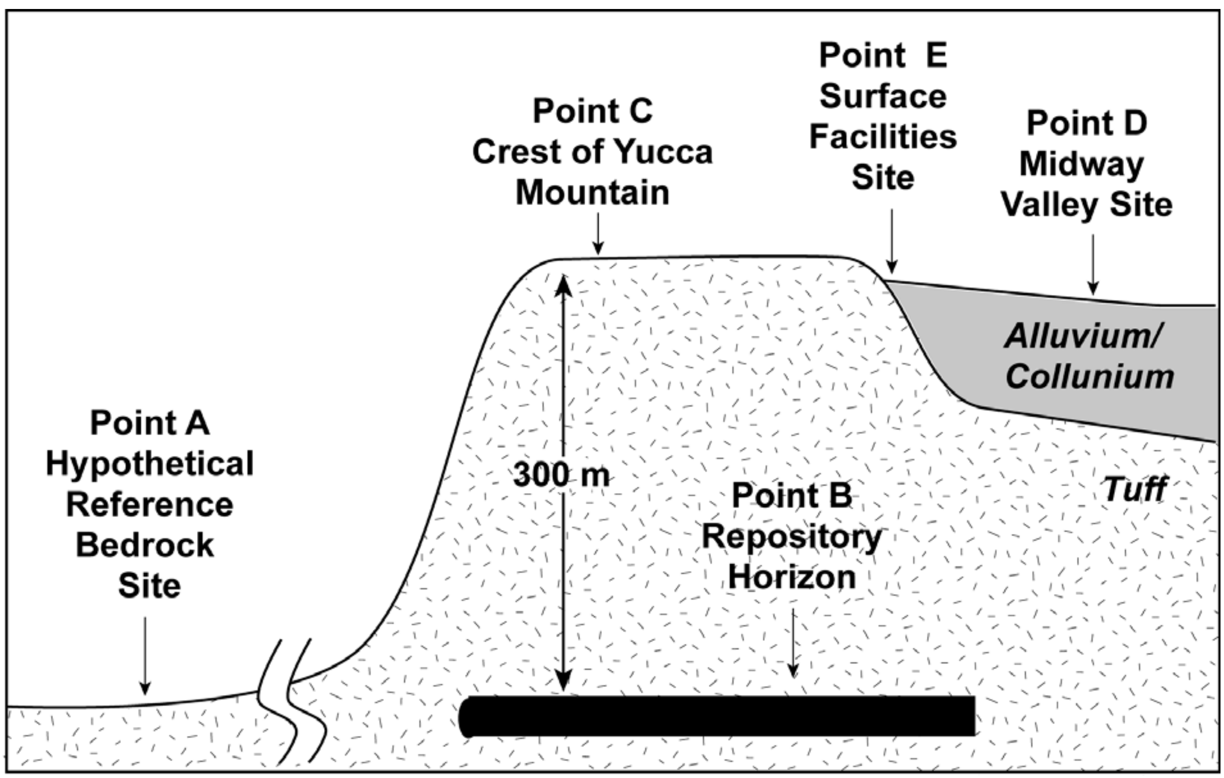

Figure 4-1. Schematic of the Seismic Reference Points At Yucca Mountain (Modified From Stepp, et al., 2001)

4.1.1 Time History Inputs

Four time histories were selected as inputs (Figure 4-2). Corresponding response spectra for these time histories are provided in Figure 4-3. These events were selected because they are similar to events that are representative of the 10^{-4} annual probability of exceedance at the Yucca Mountain site Point A (refer to Figure 4-1). Deaggregation of the mean hazard for an annual probability of exceedance of 10^{-4} at the Yucca Mountain site shows that at intermediate frequencies (5 to 10 Hz), the ground hazard is dominated by earthquakes smaller than M_w 6.5 at distances less than 15 km [9.3 mi] (Stepp, et al., 2001). The sources of these earthquakes are the Paintbrush Canyon, Stagecoach Road, and Solitario Canyon faults (Stepp, et al., 2001). All three faults are normal faults.

Two of the input time histories were generated from normal faulting events in Europe (Kozani and Umbria Marche), and were recorded on hard rock site at the Kozani-Prefecture and Nocera Umbria Stations, respectively. The remaining time histories (Sylmar and Duarte) were recorded from the 1994 Northridge, California earthquake, which was a thrust faulting event. Each time history (horizontal component) is input at the base of the soil profile (Point A in Figure 4-1) as rock outcropping motions.

4.1.2 Layer Thickness Inputs

The layer thickness inputs used in the ground response calculations are shown in Figures 4-4 to 4-8. These layer thickness inputs correspond to lithologic profiles that were obtained from the three-dimensional EarthVision® model, and were selected to represent the variable geologic conditions at the proposed Waste Handling Building site.

4.1.3 Velocity and Density Inputs

The V_s profiles used in the ground response calculations were correlated with lithology and are shown in Figures 4-4 to 4-8. Large V_s contrasts are observed at two lithologic interfaces: between the Qal and Tmbt1 units and between the Tcpcpul and Tpcpmn units. Mean V_s values were used in the calculations. Three additional profiles, shown in Figure 4-9, were also developed to accentuate variations across the Qal/Tmbt1 and Tcpcpul/Tpcpmn layers, based on the 1-sigma error limits.

The density profiles were also correlated with lithology and are shown in Figures 4-4 to 4-8. Large density contrasts occur at the interface between the Qal and Tmbt1 units and between the Tcpcpul and Tpcpmn units. The mean velocity values in Figures 4-4 to 4-8 were used. Three additional density profiles, shown in Figure 4-10, were developed to accentuate variations in the density within the Tpki unit (tuff unit “x”) and across the Tcpcpul/Tpcpmn interface.

4.1.4 Dynamic Material Properties

No distinctions were observed between dynamic data for the different tuff units. For this reason, all tuff units were assigned identical modulus and damping curves. The shear modulus and damping ratio curves used in the ground response modeling are shown in Figures 4-11 and 4-12, respectively. These curves represent a range of dynamic behavior that is possible within the observed tuff data set.

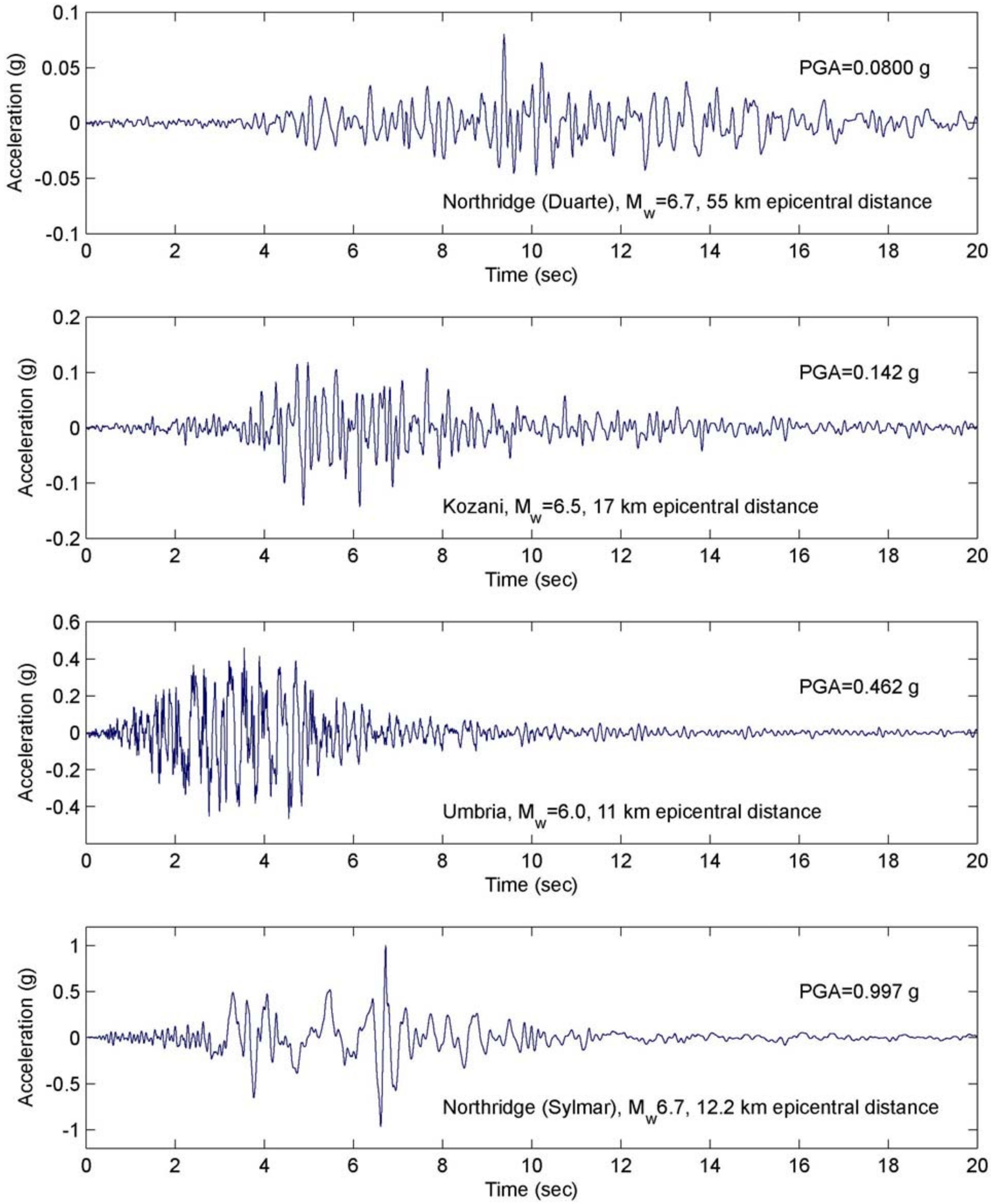

Figure 4-2. Time History Inputs Used in the Ground Response Calculations

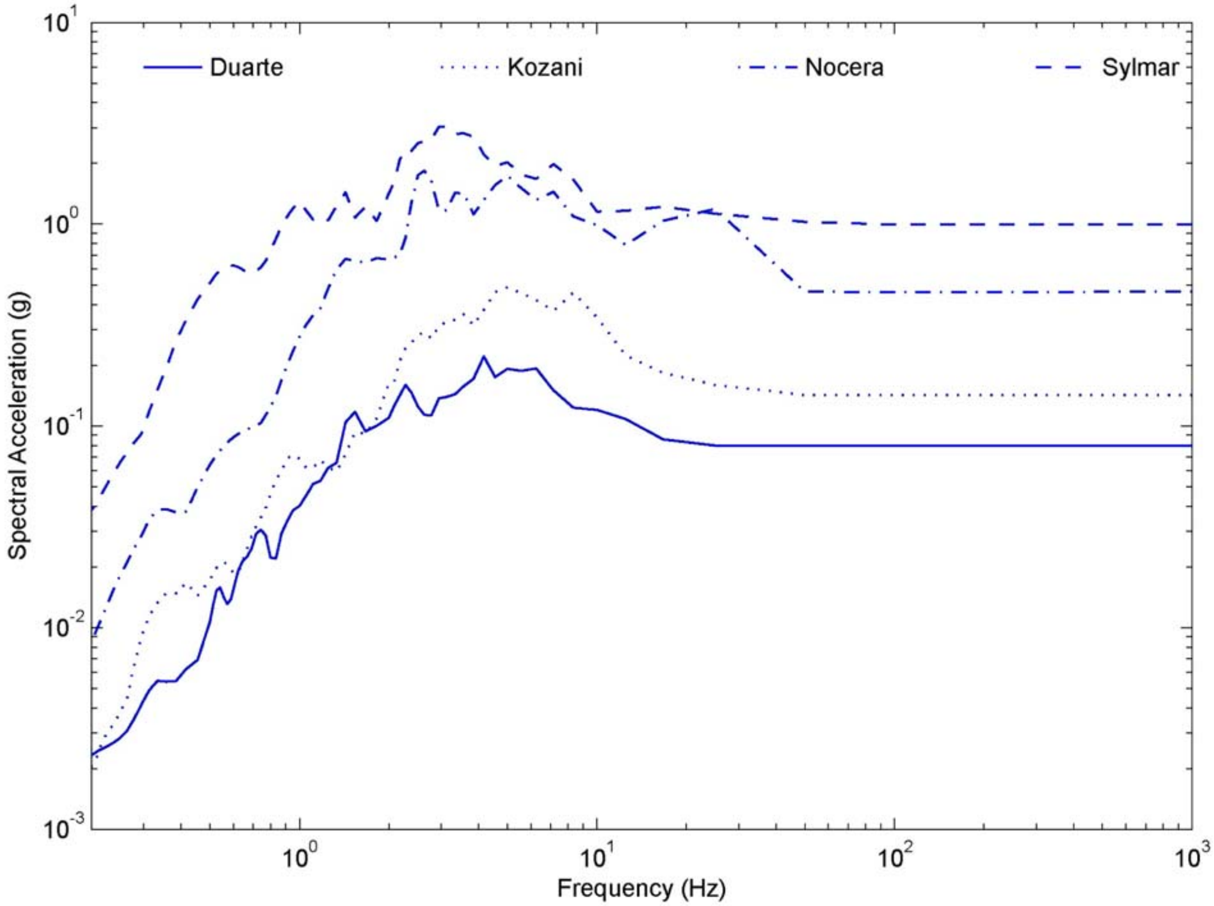

Figure 4-3. Response Spectra (5 Percent Damped) of Input Time Histories Used in the Ground Response Calculations

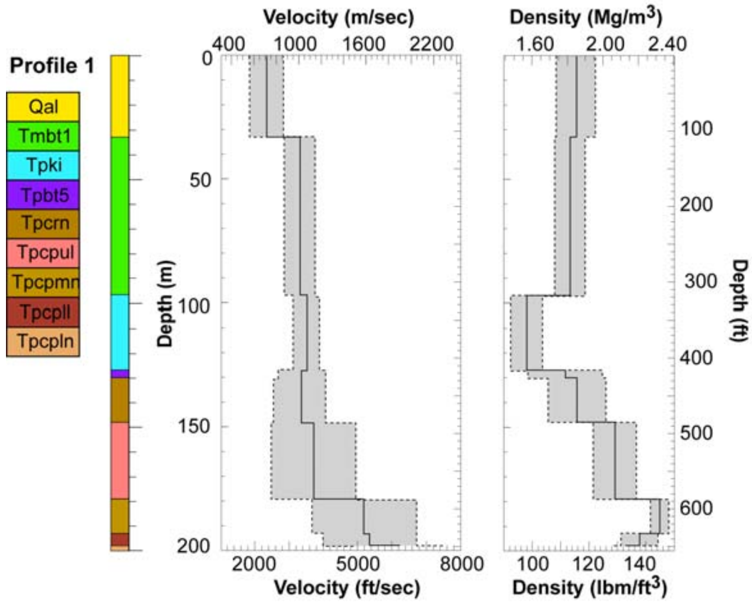

Figure 4-4. Thickness, Velocity, and Density Profile 1 Used in the Ground Response Calculations

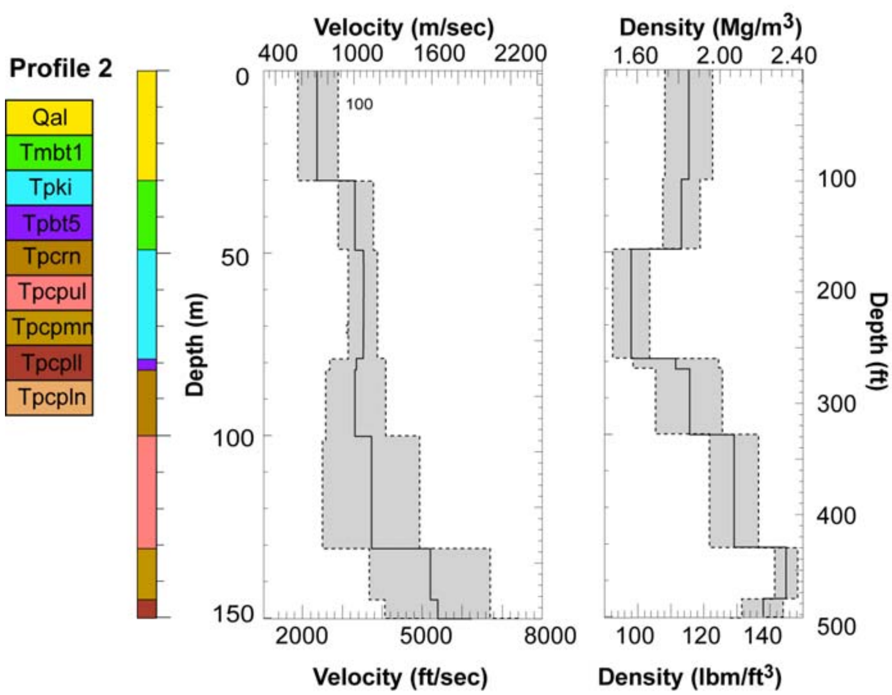

Figure 4.5. Thickness, Velocity, and Density Profile 2 Used in the Ground Response Calculations

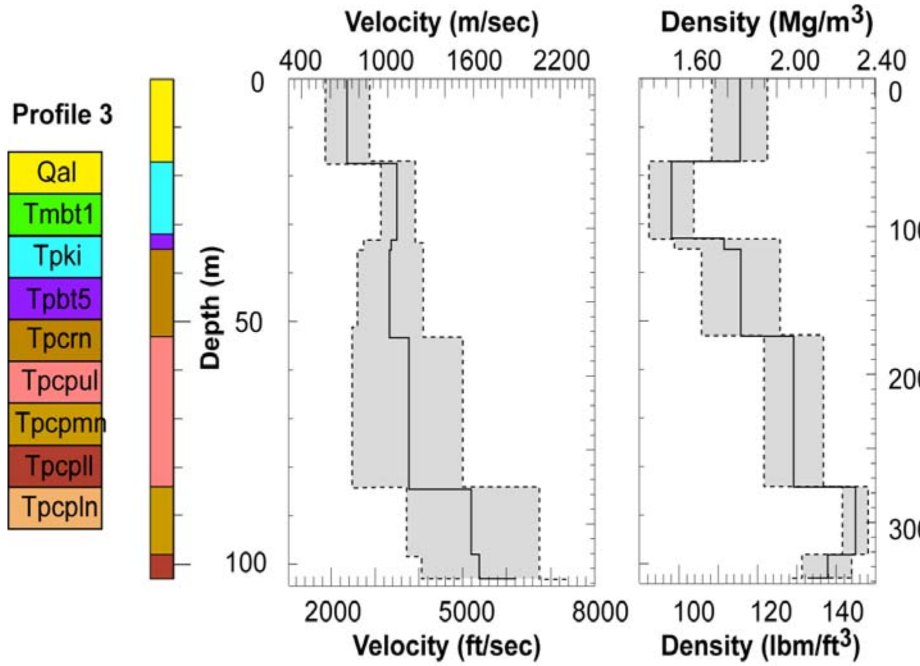

Figure 4-6. Thickness, Velocity, and Density Profile 3 Used in the Ground Response Calculations

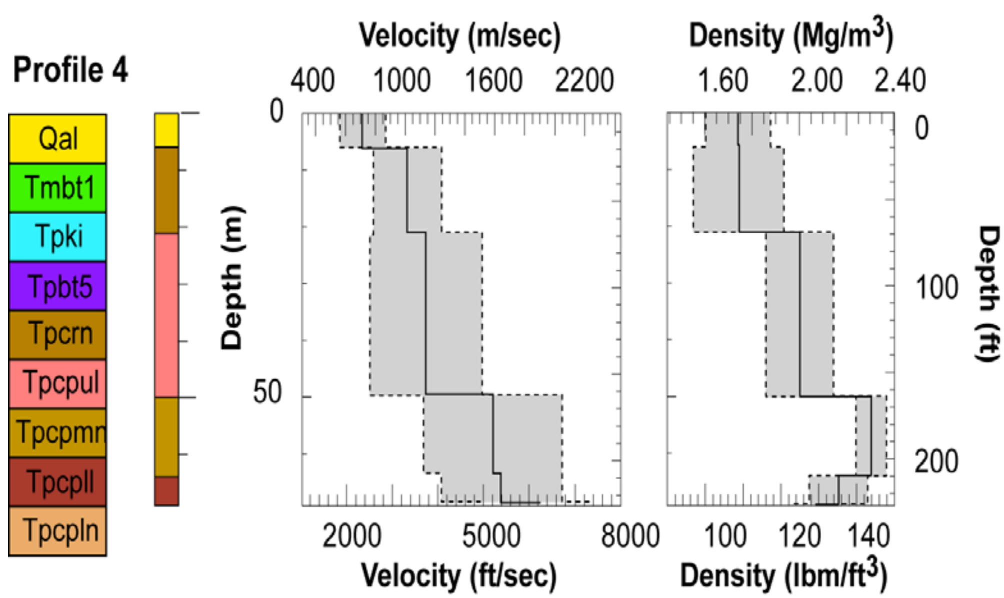

Figure 4-7. Thickness, Velocity, and Density Profile 4 Used in the Ground Response Calculations

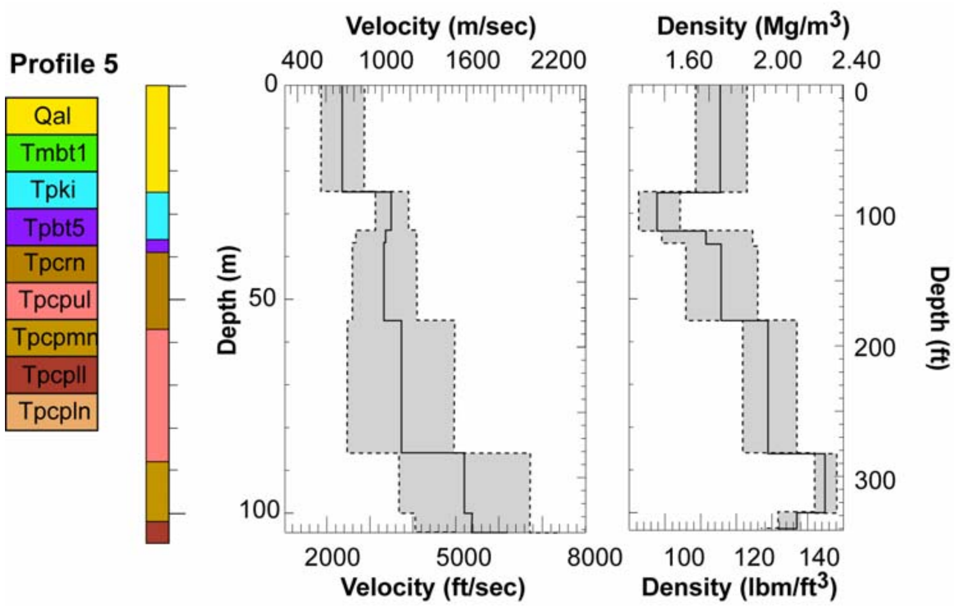

Figure 4-8. Thickness, Velocity, and Density Profile 5 Used in the Ground Response Calculations

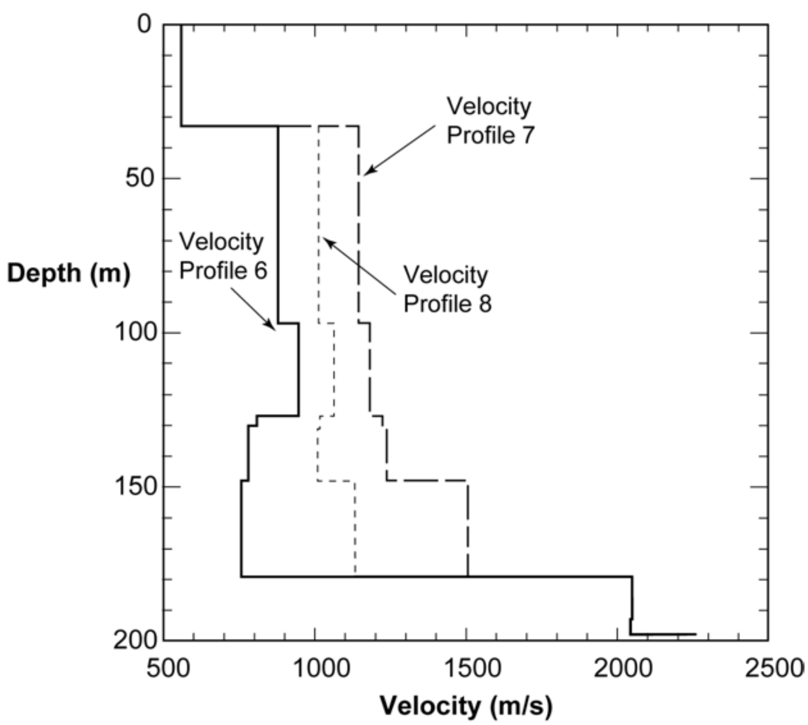

Figure 4-9. V_s Profiles 6, 7, and 8 Used in the Ground Response Calculations

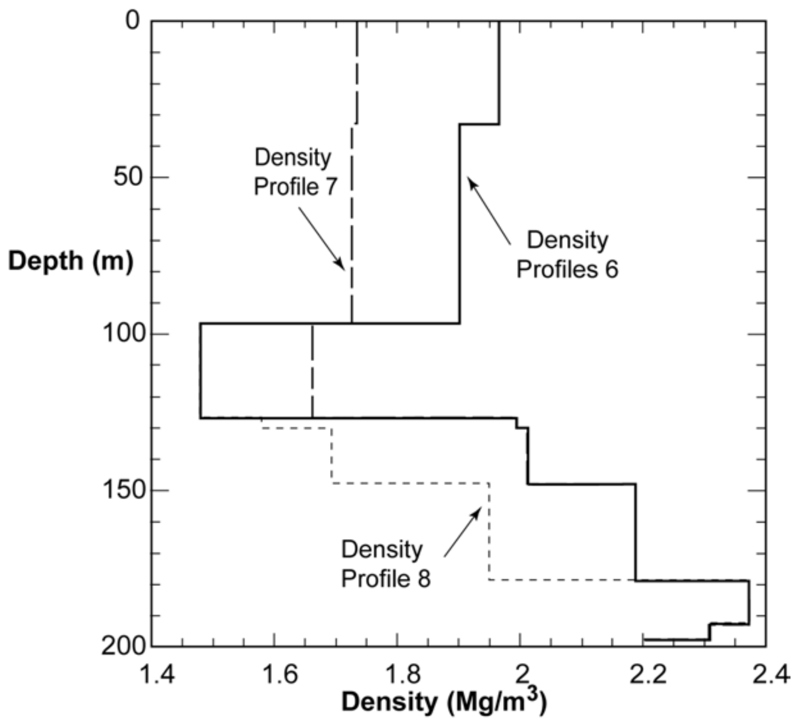

Figure 4-10. Density Profiles 6, 7, and 8 Used in the Ground Response Calculations

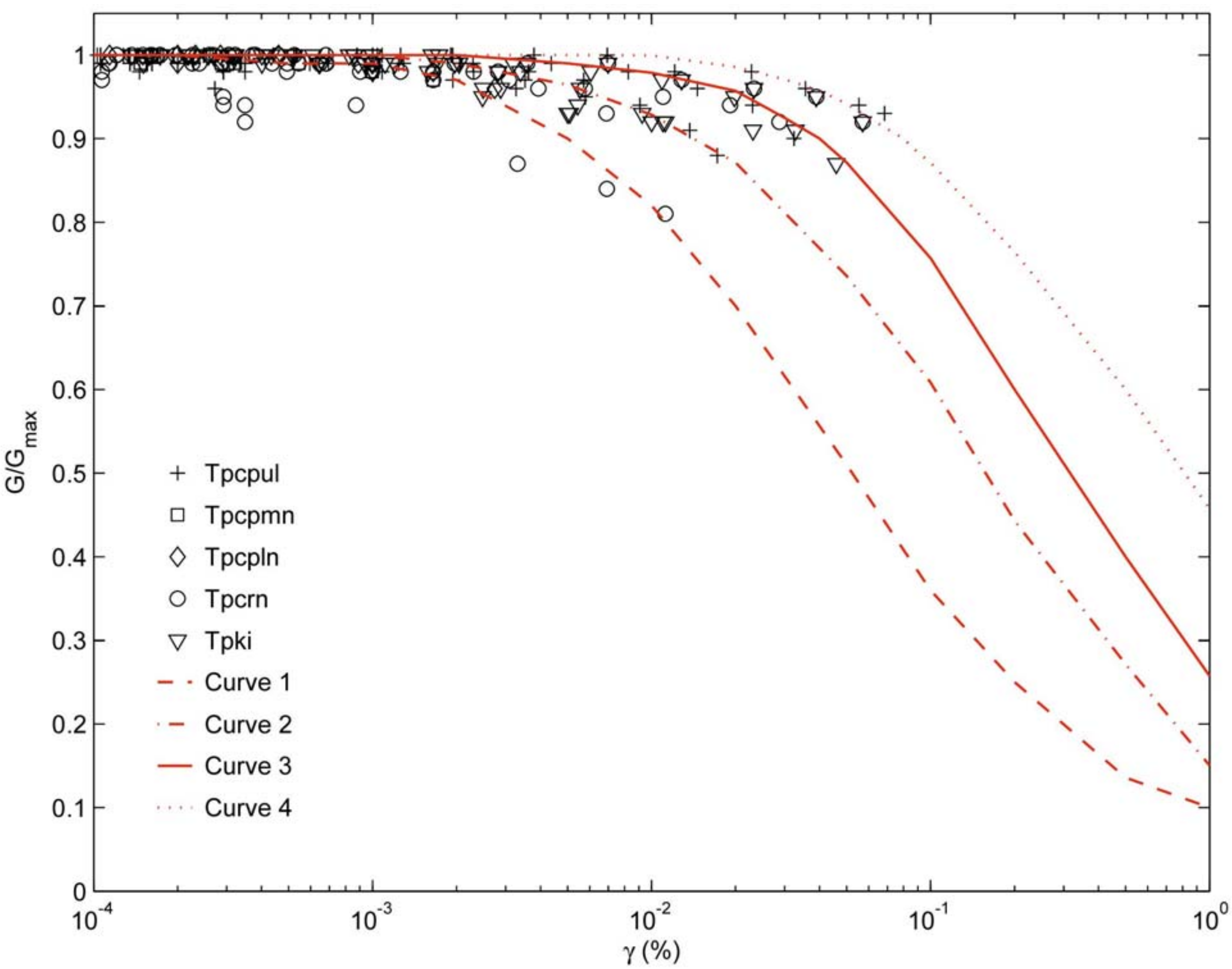

Figure 4-11. Range of Tuff Normalized Shear Modulus Curves Used tor Ground Response Calculations (Modified from Bechtel SAIC Company, LLC, 2002)

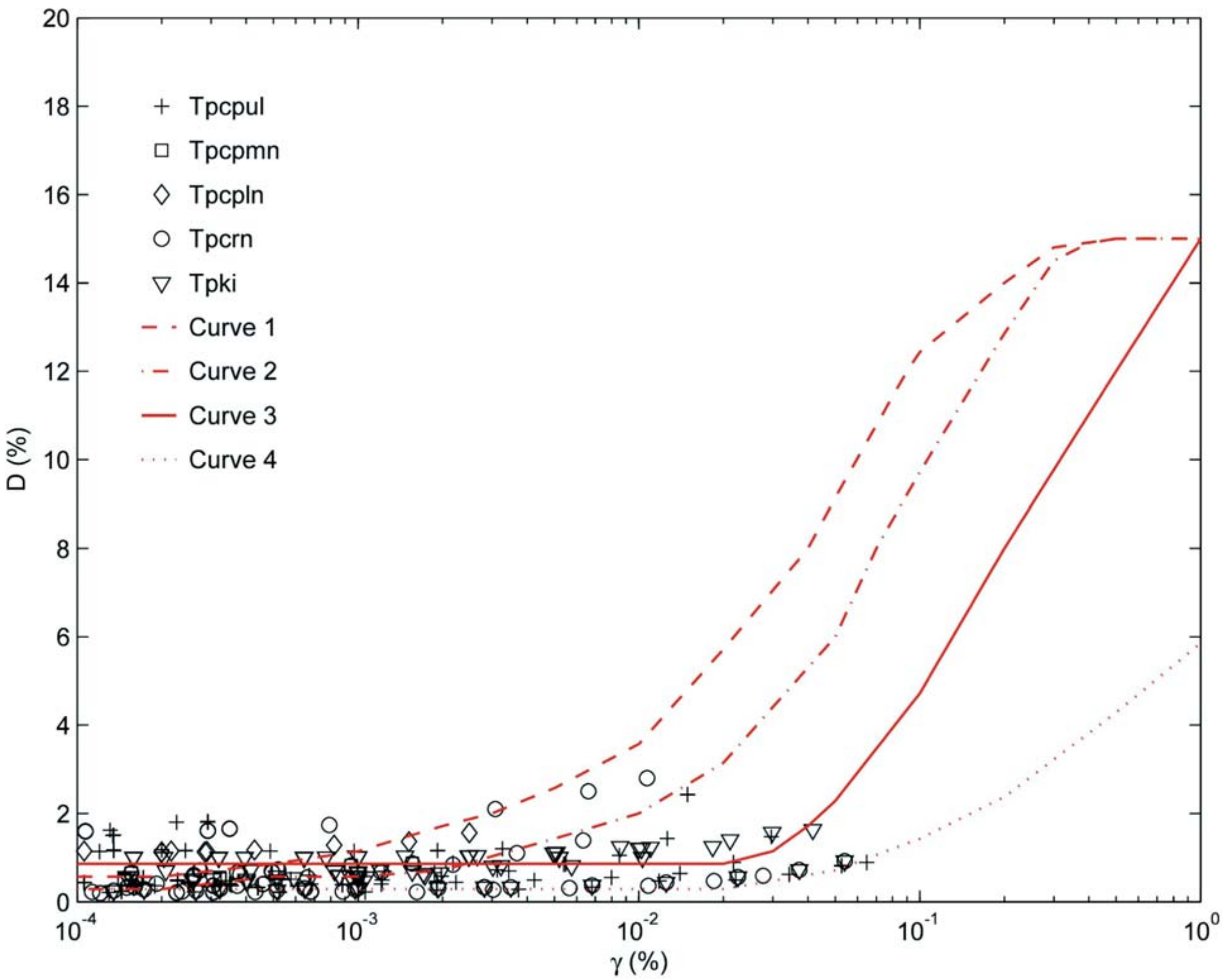

Figure 4-12. Range of Tuff Damping Curves Used for Ground Response Calculations (Modified from Bechtel SAIC Company, LLC, 2002)

4.2 Results and Discussion of Ground Response Calculations

The results from ground response calculations are given in terms of spectral amplification functions which are defined here as the ratio of the soil surface amplitude to the rock outcrop amplitude. Spectral amplification functions for Models 1 to 5 are provided in Figure 4-13. Peak amplitudes and the corresponding frequencies are also provided in Table 4-1. Models 1 to 5 consist of the V_s, density, and thickness profiles of Figures 4-4 to 4-8, respectively. The average shear modulus and damping curves for sand (Seed, et al., 1986) were used for the alluvium. All tuff units were assigned linear material properties with 2 percent damping. The results show that there is significant variability in ground amplification within the Waste Handling Building site. Generally peak amplitudes are within the range of 2.2 to 2.7 (with the exception of Model 4). However, the corresponding frequencies of these peak amplification factors range from 1.5 Hz to 4.3 Hz which may be significant.

Models 6, 7, and 8 have inputs that are identical to Model 1 (which are based on profile 1 in Figure 4-4) with the exception of density. The density profiles used are those from Figure 4-10 which accentuate variations in the density within Tpki unit (tuff unit “x”) and across the Tcpcpul/Tpcpmn interface. The results of these calculations are in Figure 4-14 and Table 4-2, and show little sensitivity to the modified density inputs. Results are very similar to those of Model 1.

In comparison, ground response calculations are very sensitive to V_s. Models 9, 10, and 11 have inputs that are also identical to Model 1 with the exception of V_s. The alternative V_s profiles from Figure 4-11, which accentuate variations across the Qal/Tmbt1 and Tcpcpul/Tpcpmn layers, are used instead of the mean values. The results of these calculations are shown in Figure 4-15 and Table 4-8. Amplification factors are significantly higher than for Model 1.

Models 12 to 15 are identical to Model 1, with the exception of the tuff dynamic property inputs. The tuff units in Models 12 through 15 were assigned the shear modulus and damping Curves 1 (exhibits the most nonlinear behavior) through 4 (exhibits the most linear behavior), respectively (from Figures 4-11 and 4-12). The results are shown in Figure 4-16 and Table 4-4. Overall, there is not a significant difference among results for the range of input curves. There is a small decrease in amplification as more nonlinear dynamic property curves (i.e., Curve 1 in Model 12) are used. As expected, this effect is most noticeable in the larger time history inputs of Sylmar and Nocera Umbra, which produce the largest shear strains. The maximum strain levels (produced by the Sylmar record) levels in these ground response calculations generally fall below 0.2 percent (ranging from 0.12 to 0.19 percent). The maximum strain levels for the other records are significantly lower (modulus and damping curves all have similar values). The sensitivity of the ground response calculations to the input dynamic property curves may be more apparent if larger ground motions are used, as strain levels may become large enough where the modulus and damping curves in Figures 4-11 and 4-12 diverge from one another. This needs further investigation.

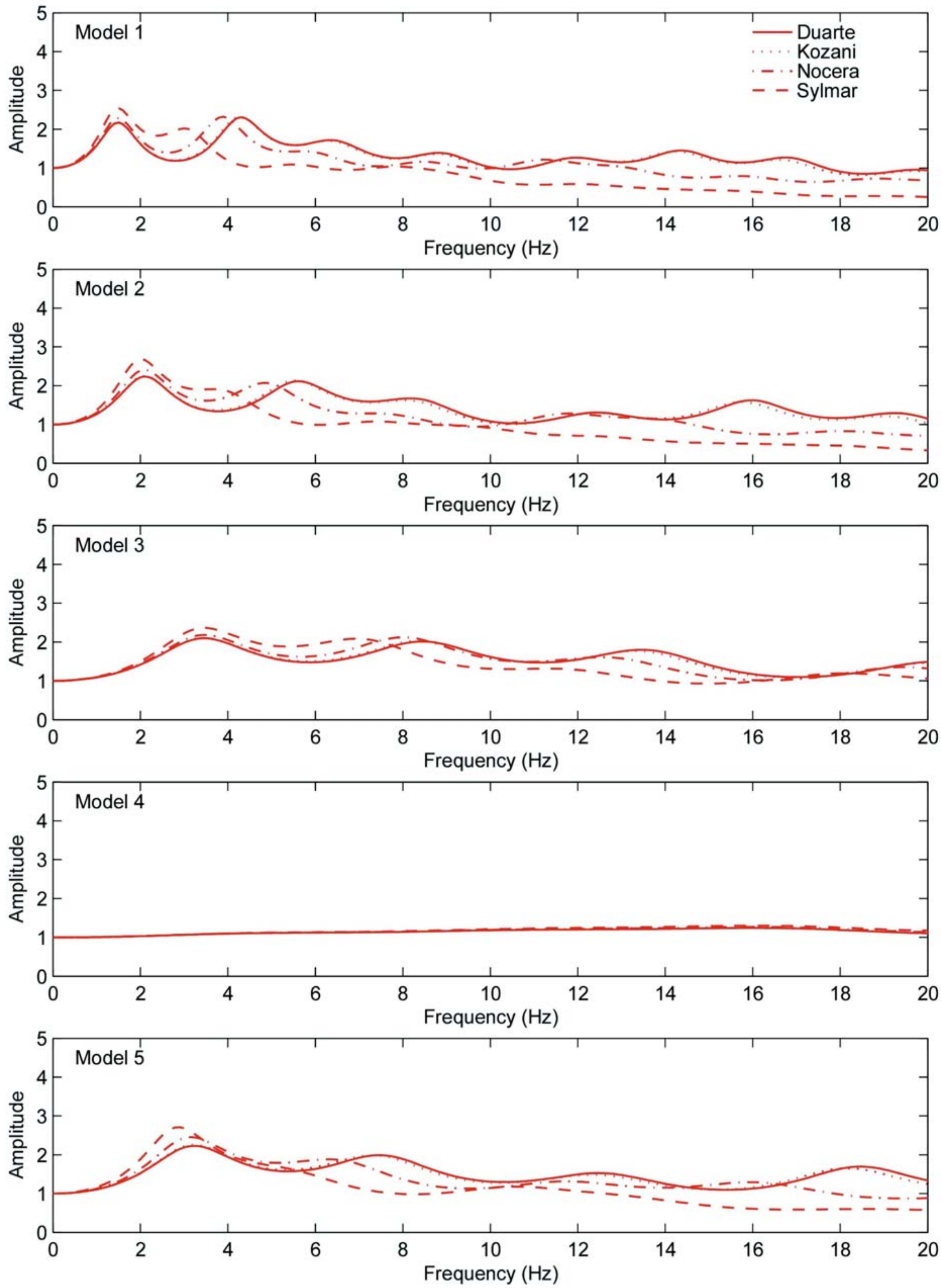

Figure 4-13. Spectral Amplification Functions for Models 1 to 5

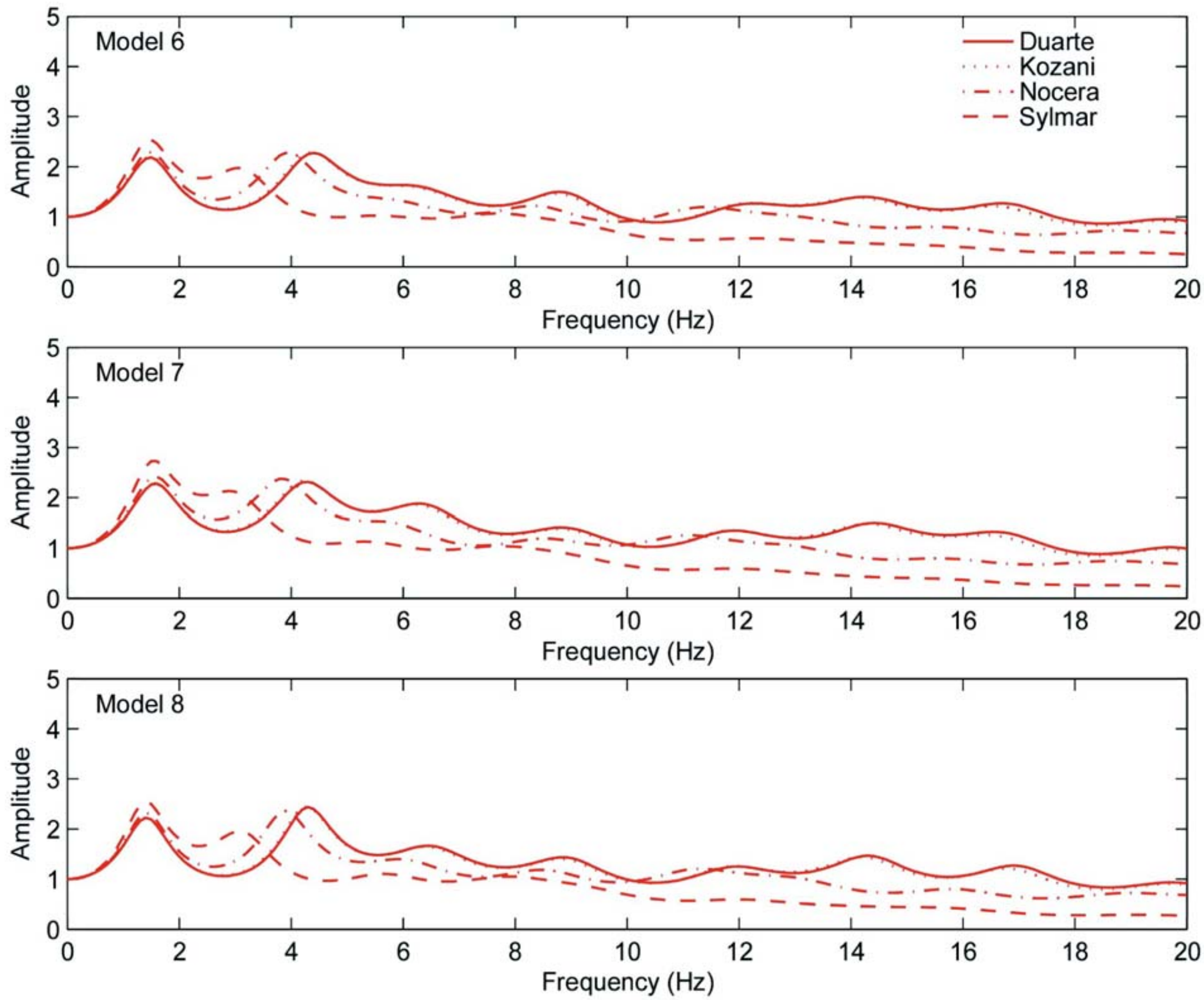

Figure 4-14. Spectral Amplification Functions for Models 6 to 8

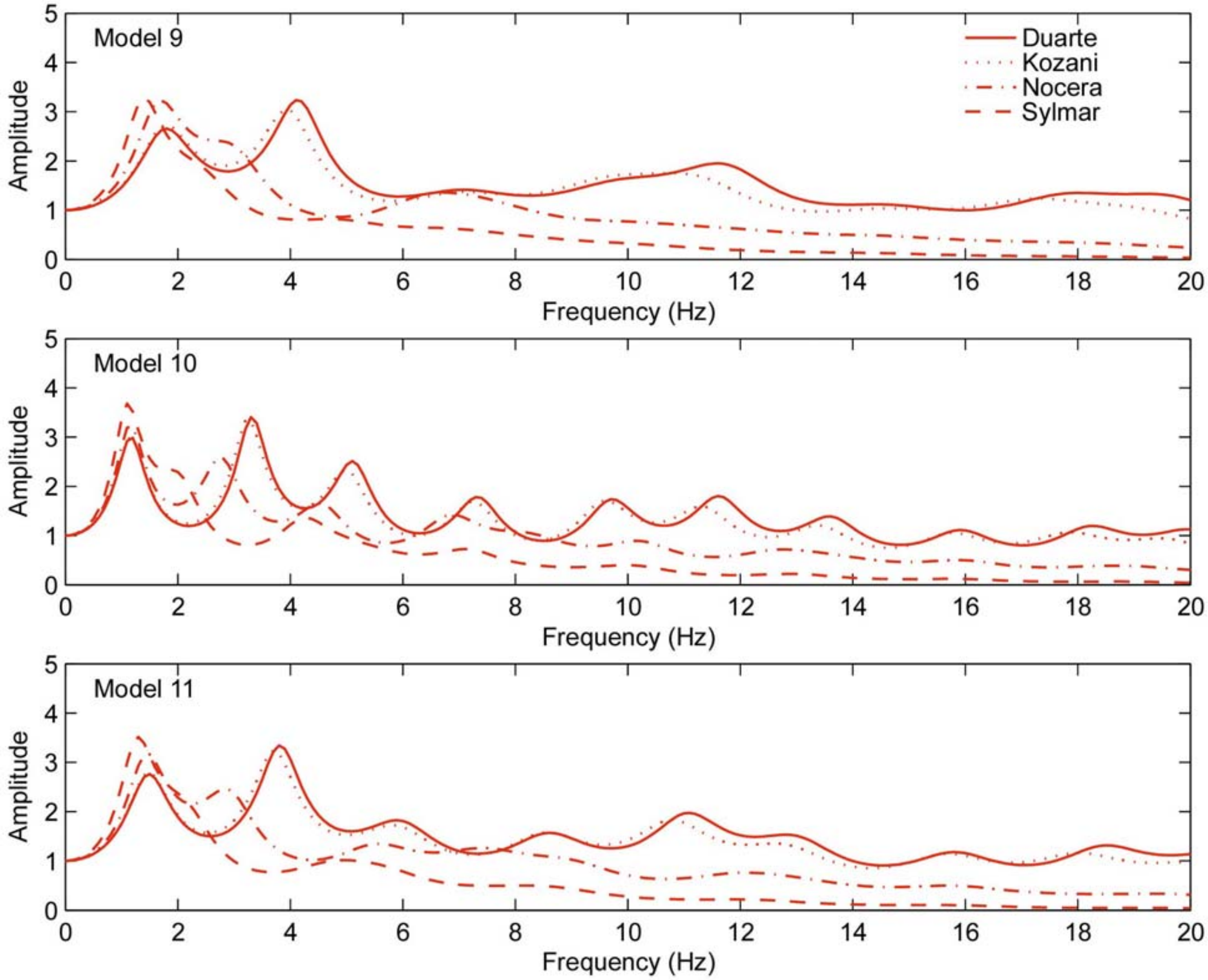

Figure 4-15. Spectral Amplification Functions for Models 9 to 11

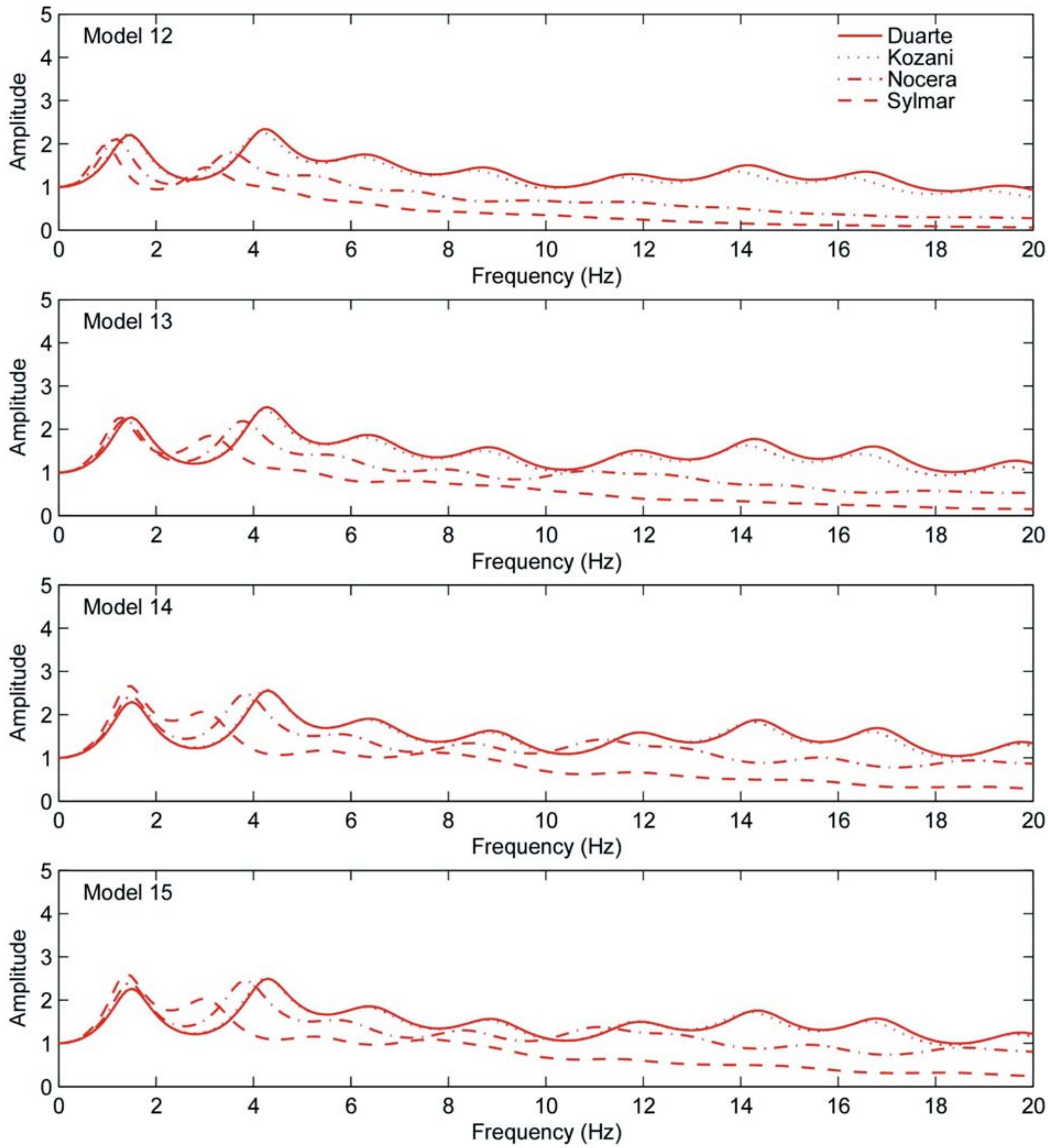

Figure 4-16. Spectral Amplification Functions for Models 12 to 15

Table 4-1. Maximum Spectral Amplification Functions* for Models 1 to 5										
EQ Record	Model 1		Model 2		Model 3		Model 4		Model 5	
	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)
Duarte	2.31	4.30	2.24	2.10	2.10	3.50	1.24	16.00	2.23	3.20
Kozani	2.33	4.30	2.26	2.10	2.11	3.50	1.25	16.00	2.26	3.20
Nocera	2.32	3.90	2.41	2.10	2.18	3.50	1.27	16.00	2.45	3.10
Sylmar	2.55	1.50	2.69	2.00	2.36	3.50	1.30	16.10	2.71	2.90

*Spectral Amplification Functions (SAF_{max})

Table 4-2. Maximum Spectral Amplification Functions* for Models 6 to 8						
	Model 6		Model 7		Model 8	
EQ Record	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)
Duarte	2.27	4.40	2.31	4.30	2.44	4.30
Kozani	2.29	4.40	2.34	4.20	2.45	4.30
Nocera	2.29	1.50	2.42	1.60	2.36	3.90
Sylmar	2.54	1.50	2.73	1.50	2.55	1.40

**Spectral Amplification Functions (SAF_{max})

Table 4-3. Maximum Spectral Amplification Functions* for Models 9 to 11						
	Model 9		Model 10		Model 11	
EQ Record	SAF_{max}	$f_{(Hz)}$	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)
Duarte	3.23	4.10	3.41	3.30	3.34	3.80
Kozani	3.04	3.90	3.33	3.30	3.24	3.70
Nocera	3.23	1.70	3.22	1.20	3.16	1.50
Sylmar	3.28	1.40	3.68	1.10	3.52	1.30

*Spectral Amplification Functions (SAF_{max})

Table 4-4. Maximum Spectral Amplification Functions* for Models 12 to 15								
	Model 12		Model 13		Model 14		Model 15	
EQ Record	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)	SAF_{max}	f (Hz)
Duarte	2.34	4.20	2.51	4.30	2.56	4.30	2.50	4.30
Kozani	2.27	4.20	2.45	4.20	2.57	4.30	2.51	4.30
Nocera	2.11	1.20	2.21	1.40	2.48	3.80	2.45	3.80
Sylmar	1.97	1.00	2.26	1.30	2.65	1.40	2.61	1.40

*Spectral Amplification Functions (SAF_{max})

5 SUMMARY AND RECOMMENDATIONS

The data in Bechtel SAIC Company, LLC (2002) comprise a large subset of the available geotechnical data for the Yucca Mountain site. Overall, the report provides sufficient geotechnical information to support the DOE ground response calculations for seismic preclosure safety analysis. However, the current data are limited to the proposed Waste Handling Building location, and additional data will be necessary to characterize areas currently being considered by the DOE that are outside these boundaries including the aging-facility pads shown north and northeast of the Waste Handling Building site in DOE (2004).

The geologic data from the boreholes and structural sections are sufficient to construct a three-dimensional geologic model from these data. However, in constructing the model, we note several discrepancies with the depiction of faults in the DOE cross sections. For example, the three-dimensional model indicates several additional faults not described in Bechtel SAIC Company, LLC (2002). In addition, several of the faults, in addition to the one identified in Bechtel SAIC Company, LLC (2002), appear to have significant offsets. These offsets are important because nonwelded bedded tuff accumulated on the down-dropped hanging walls of these faults. These nonwelded bedded tuffs have relative slow V_S and thus are important to ground motion amplification.

The velocity and density data collected for the proposed Waste Handling Building site are sufficient for ground response calculations. Based on these data, we show that density, V_S, and V_P are strongly influenced by lithology, and thus that lithology is an important in factor in the development of site response models. As shown in Figure 3-5, the resulting V_S and V_P profiles reveal at least two important layer boundaries, one between the alluvium (Qal) and underlying nonwelded tuff (Tmbt1), and one between the moderately welded upper lithophysal unit (Tpcpul) and densely welded middle nonlithophysal unit (Tpcpmn) of the Tiva Canyon Tuff.

The dynamic data presented in the report are incomplete and may not be sufficient for the DOE to develop reliable ground response models. No dynamic data are presented for strain levels above 0.1 percent. Larger earthquake motions may produce strain levels beyond these values. Data are also restricted to the Tiva Canyon Tuff and younger units. No data are provided for the Topopah Spring Tuff, which is the unit that will house the potential repository. There are also a limited amount of dynamic property data for alluvium. Thus, the development of strain dependent shear modulus reduction and damping curves for ground response calculations is highly uncertain at strain levels beyond approximately 0.1 percent. Additional data need to be collected, particularly at higher strain levels. Alternatively, if equipment limitations prevent this from being done, ground response calculations need to account for these existing uncertainties.

To evaluate the sensitivity of the geotechnical data and to develop a methodology for ground response evaluations, we conducted a limited set of ground response calculations. Based on these analyses, we show that lithologic variations within the proposed Waste Handling Building area have a significant effect on ground motion amplitudes. In particular, we show that the sharp V_S contrasts between the densely welded tuff and the nonwelded bedded tuff and alluvium has a significant impact on ground motion amplification. Future DOE site characterization should focus on the acquisition of V_S data. In contrast, variations in density have a much smaller impact on ground motion amplification. Variations in strain dependent shear modulus reduction and damping curves also showed a small effect on ground motion amplification. However, this may become an issue for postclosure ground response calculations as larger strain levels that are associated with lower annual exceedance probabilities and larger ground motions will be important.

In addition to the geotechnical data presented in Bechtel SAIC Company, LLC (2002), the number and type of input time histories are also important considerations for the ground response calculations. We selected a four of time histories for this investigation, based on criteria from the deaggregation of the mean hazard for an annual probability of exceedance of 10^{-4} (Stepp, et al., 2001). Namely, we selected input time histories from hard rock sites, with moment magnitudes between 6.0 and 6.5. Normal and thrust faulting and strike-slip faulting earthquakes having epicentral distances less than 30 km [18 mi] were also chosen. Ground response calculations are extremely sensitive to the input time histories. A more comprehensive assessment should include a larger number of input time histories to incorporate the natural variability of real earthquakes.

6 REFERENCES

Bechtel SAIC Company, LLC. "Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project." ANL–MGR–GE–000003. Rev. 00. Las Vegas, Nevada: Bechtel SAIC Company, LLC. 2002.

CRWMS M&O. "Preliminary Geotechnical Investigation for Waste Handling Building, Yucca Mountain Site Characterization Project." BCB000000–01717–570500016. Rev 00. Las Vegas, Nevada: CRWMS M&O. 1999.

Day, W.C., C.J. Potter, D.S. Sweetkind, R.P. Dickerson, and C.A. San Juan. "Bedrock Geologic Map of the Central Block Area, Yucca Mountain, Nye County, Nevada." U.S. Geological Survey Miscellaneous Investigations Series, Map I–2601. Scale 1:6000. 1997.

Day, W.C., R.P. Dickerson, C.J. Potter, D.S. Sweetkind, C.A. San Juan, R.M. Drake, II, and C.J. Fridrich. "Geologic Map of the Yucca Mountain Area, Nye County, Nevada." U.S. Geological Survey Miscellaneous Investigations Series, Map I–2627. Scale 1:24,000. 1998.

DOE. "Surface Facility Design." DOE/NRC Technical Exchange on Level of Detail. Las Vegas, Nevada: CRWMS M&O. 2004.

Dunne, W.M., D.A. Ferrill, J.G. Crider, B.E. Hill, D.J. Waiting, P.C. La Femina, A.P. Morris, and R.W. Fedors. "Orthogonal Jointing During Coeval Igneous Defassing and Normal Faulting, Yucca Mountain, Nevada." *Geological Society of America Bulletin*. Vol. 115. pp. 1,492–1,509. 2003.

Dynamic Graphics. "EarthVision." Version 7.0.1. Alameda, California. 2002.

EduPro Civil Systems. "ProShake." Version 1.11. Sammamish, Washington. 2001.

Idriss, I.M. and H.B. Seed. "Seismic Response of Horizontal Soil Layers." *Journal of the Soil Mechanics and Foundations*. Vol. 94, No. SM4. 1968.

Ladd, R.S. "Preparing Test Specimens Using Undercompaction." *Geotechnical Testing Journal*. Vol. 1 No. 1. pp. 16–23. New York City, New York: American Society for Testing and Materials. 1978.

Lung, R. "Borehole Stratigraphy and Test Pits at the Waste Handling Building." DOE-NRC Appendix 7 Meeting. Las Vegas, Nevada: 2002.

NRC. NUREG–1804, "Yucca Mountain Review Plan—Draft Report for Comment." Rev. 2. Washington, DC: NRC. March 2002.

Sawyer, D.R., R.J. Fleck, M.A. Lanphere, R.G. Warren, D.E. Broxton, and M.R. Hudson. "Episodic Caldera Volcanism in the Miocene Southwestern Nevada Volcanic Field: Revised Stratigraphic Framework, $^{40}Ar/^{39}Ar$ Geochronology, and Implications for Magmatism and Extension." *Geological Society of America Bulletin*. Vol. 106. pp. 1,304–1,318. 1994.

Schnabel, P.B., J. Lysmer, and H.B. Seed. "SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites." Report No. UCB/EERC–72/12. Earthquake Engineering Research Center, University of California, Berkeley. pp. 102p. 1972.

Seed, H.B., R.T. Wong, I.M. Idriss, and K. Tokimatsu. "Moduli and Damping Factors for Dynamic Analysis of Cohesionless Soils." *Journal of Geotechnical Engineering*. Vol. 112, No. 11. pp. 1,016–1,032. 1986.

Stepp, J.C., I. Wong, J. Whitney, R. Quittmeyer, N. Abrahamson, G. Toro, R. Youngs, K. Coppersmith, J. Savy, T. Sullivan, and Yucca Mountain PSHA Project Members. "Probabilistic Seismic Hazard Analyses for Ground Motions and Fault Displacement at Yucca Mountain, Nevada." *Earthquake Spectra*. Vol. 17, No. 1. pp. 113–151. 2001.