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Attachment 2

Project Report, "Dynamic Profile," TXUT-001-PR-007, Revision 2

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COMANCHE PEAK
PROJECT REPORT

DYNAMIC PROFILE

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1.0 PURPOSE AND OVERVIEW

This document describes the methodology and data used to develop the Dynamic Profile for Comanche Peak Nuclear Power Plant Units 3 & 4 (CPNPP 3 & 4). The dynamic profile is provided as input to the ground motion studies for determining the Ground Motion Response Spectra (GMRS) and Foundation Input Response Spectra (FIRS) and consists of shear- and pressure-wave velocities and associated dynamic properties for the defined profile.

The profile is defined as the interval extending from near surface to seismic basement (defined by the depth at which a shear wave velocity of 9200 ft/sec and greater is reached) and is divided into the shallow profile and the deep profile. The shallow profile extends from near surface to about 550-ft depth and is characterized from borings, geophysical logs including suspension velocities, and laboratory test results. The deep profile extends from about 550-ft depth to seismic basement and is characterized from regional geologic maps and well data including core and geophysical logs. The resulting Dynamic Profile is composed of representative velocities and material properties including index, strength, and damping percentages.

Appendix 2 describes a sensitivity analysis performed to test the non-linear behavior of the site-specific profile including the input data and results.

2.0 DEVELOPMENT OF SHALLOW AND DEEP STRATIGRAPHY

The shallow stratigraphy was developed from geotechnical borings and geophysical logs. The deep stratigraphy was developed from information in the published literature and data from regional oil and gas wells.

2.1 Shallow Stratigraphy

One hundred and forty-five geotechnical borings (excluding cluster, off-set, and monitoring well borings) were drilled as part of the subsurface exploration activities for CPNPP 3 & 4 (Figure 1). A detailed description of the data and methodology for developing the shallow stratigraphy is provided in calculation TXUT-001-FSAR-2.5-CALC-004, *Engineering*

Stratigraphy. Velocity data for the shallow profile was acquired from 15 of the geotechnical borings (Figure 1). The velocity profile was developed through a correlation of velocity measurements with the engineering stratigraphy. A detailed discussion of the analysis is provided in the calculation TXUT-001-FSAR-2.5-CALC-003, *Shallow Velocity Profile Development Slope Method.*

Comparison of the geophysical data logs and the geotechnical boring logs provided the basis for developing the stratigraphic model at CPNPP 3 & 4. Suspension shear (V_s) and pressure (V_p) wave velocity, natural gamma radiation, and resistivity measurements, provided in GeoVision Report 6573-01 (GeoVision, 2007), were used to define stratigraphic units identified within the geotechnical boring logs. Ten major stratigraphic units were identified within the subsurface at CPNPP 3 & 4 between the ground surface and about 550 ft below ground surface (elevation 294 ft). As shown in Figure 2, these 10 units are divided among three geologic formations, in order of depth: the Glen Rose formation, Twin Mountains formation, and the Mineral Wells formation.

The Glen Rose formation is the uppermost formation encountered and outcrops at the surface of the site and within surrounding drainage cuts and exposures. The Glen Rose limestone was divided into engineering stratigraphic units A through E (E1 to E3). Based on the borings drilled for CPNPP 3 & 4, the Glen Rose formation has a thickness of 169 to 228 ft. This variable thickness is primarily due to topographic differences between borings. The upper portion of the Glen Rose (units A and B) is composed of alternating thin to massive beds of limestone and shale, with shale becoming more prevalent towards the basal portion of the section. The bottom portion (units C through E) is composed of a thick section of limestone that alternates between packstone and wackestone and has several thin shale interbeds, such as unit D (see Figure 2).

A lithologic transition from limestone to sandstone marks the boundary between the base of the Glen Rose and the top of the Twin Mountains formation. The sandstone at the top of unit F, which is composed of limestone, shale, and sandstone, marks the gradational contact between the two formations. The Twin Mountains formation is primarily composed of interbedded sandstone and shale, ranges from 217 to 242 ft in thickness, and encompasses most of unit F and all of units G through I. Units G and I are composed of sandstone, and unit H is primarily shale with sandstone interbeds. Only one borehole (B-1012) was drilled deep enough (550 ft) to encounter the basal conglomerate of the Twin Mountains, Unit I, and the Pennsylvanian Mineral Wells formation. The top of the Mineral Wells formation was encountered at an elevation of 455 ft in depth (389 ft in elevation). The Mineral Wells formation is noted in this boring as a massive shale with interbeds of sandstone and is consistent with regional lithologic descriptions.

2.1.1 Correlation of the CPNPP 3 & 4 and CPSES 1 & 2 Stratigraphy

Qualitatively, the stratigraphic units identified in the Comanche Peak Steam Electric System Units 1 & 2 (CPSES 1 & 2) FSAR are very similar to the stratigraphic units picked for the current COLA investigation for CPNPP 3 & 4. Figure 3 shows the relative location of CPSES 1 & 2 to CPNPP 3 & 4. Construction photographs from CPSES 1 & 2, shown on Figure 4, show distinct beds of limestone and shale within the vertical exposures. The exposures of the Glen Rose formation documented in these photographs exhibit flat-lying (no apparent dip) limestone and shale beds of various thicknesses. Descriptions provided within the CPSES 1 & 2 FSAR correspond with descriptions of engineering layers A, B1 and B2, and C from the CPNPP 3 & 4 site.

Velocity data provided in the Dames & Moore Cross-Hole Data Report, *Generalized Subsurface Profile and Seismic Wave Velocities,* was also used to compare the site stratigraphy between CPSES 1 & 2 and CPNPP 3 & 4. Figure 5 compares the engineering stratigraphy layers of CPSES 1 & 2 and CPNPP 3 & 4, plotted at their respective elevations. The elevations of each engineering layer in CPSES 1 & 2 were found to differ by an average of 10 ft, or horizons in the profile from CPSES 1 & 2 have elevations about 10 ft below the elevations of the same horizons beneath CPNPP 3 & 4. Regional dip of the area is roughly 25 ft per mile to the southeast (Sellards et al., 1932). Given that CPNPP 3 & 4 are approximately 2000 ft NW (or updip) of CPSES 1 & 2, the difference is explained by and is consistent with the regional dip of the units. This comparison was then used as a basis to compare the stratigraphy between the site locations as well as to compare velocity profiles developed from independent measurements and techniques.

2.2 Deep Stratigraphy

A variety of regional information was used to determine the deep stratigraphy for CPNPP 3 & 4. Stratigraphic and velocity data were acquired from published literature and regional oil and gas wells. Figure 6 shows the location of wells used to determine deep stratigraphic units (summarized in Table 1 and Table 2) and the two wells that provided velocity data. Figure 7 shows the interpreted stratigraphy and V_p logs for two regional wells used to develop the deep profile.

The resulting deep stratigraphic profile (summarized in Table 3) begins in the lower Pennsylvanian Strawn group, which contains the Mineral Wells formation, the deepest unit defined as part of the shallow profile in Section 2.1. The remainder of the Strawn Series is lithologically similar to the Mineral Wells and consists of shales and intebedded sandstones and limestones. Included within the Strawn Series are the Garner and Millsap Lake formations. Below the Strawn is the Atoka Group which includes the Atoka Sand, the Smithwick Shale, and the Big Saline Conglomerate. The top of the Atoka Group, the Atoka sand, is shale interbedded with sands and limestones. The sandstone layers have an average thickness of about 30 ft (Thompson, 1982). To the north and west of the study area, the upper portion of the Atoka Group includes the Caddo Reef, a massive limestone. In Sommervell County, however, located closer to the Ouachita thrust belt, deposition was more terrigenous (Thompson, 1982). Beneath the Atoka sand, the Smithwick is primarily a black shale, with a thickness that varies from 300 to 600 ft (Sellards et al., 1932). Below the Smithwick shale, the Big Saline Conglomerate has a variable thickness and pinches out just southeast of the site, so that at CPNPP 3 & 4 it has a projected thickness of only about 40 ft. Underlying the Atoka Group is the Marble Falls limestone. The upper portion of this unit is a dark-colored fossiliferous limestone (Sellards et al., 1932). The lower portion of the Marble Falls is interbedded dark limestone and gray-black shale, sometimes referred to as the Comyn Formation (Montgomery et al., 2005), and sometimes considered part of the Barnett Shale (Rathje & Olsen, 2007), which is stratigraphically below the Marble Falls. The Mississippian

Barnett Shale (250 to 1000 ft thick, regionally) represents a gas source and reservoir in the region. The Barnett Shale unconformably overlies the top of the Ellenburger Group throughout most of the Fort Worth Basin, though in the northeastern portion of the basin the Upper Ordovician Viola and Simpson limestones intervene (Montgomery et al., 2005). The Cambrian to Ordovician Ellenburger limestone and a thin underlying clastic sequence rests unconformably on metamorphic basement in the Fort Worth Basin and was deposited in a passive continental margin setting (Montgomery et al., 2005).

The methods for determining stratigraphic elevations of units are listed in order of confidence and are noted in Table 2.

A. The top of the Strawn was measured in wells logged by WLA as the top of the Mineral Wells formation.
B. Using GEOMAP-stated elevations of horizons in the three nearest wells, the attitude of each horizon was determined and the elevation projected to the site location.
C. The CPNPP 3 & 4 site was projected onto the line of section of GEOMAPS cross section through two nearby wells (Squaw Creek and 1-Davis).
D. Horizon elevations determined from GEOMAPS structure contour maps.

For most stratigraphic units, more than one method was available for determining the elevation of a given horizon, and the standard deviation (σ_{top}) of the resulting elevations was used as an estimate of the error. Only a single elevation pick was determined for the top of the Big Saline and the top of the Atoka, thus, the average standard deviation in feet for the other stratigraphic units was applied as an estimate of the error for these units.

3.0 VELOCITY PROFILE DEVELOPMENT

Velocity data used to construct the Dynamic Profile consists of suspension shear (V_s) and pressure wave (V_p) velocities acquired from the 15 borings for the shallow profile; and principally pressure wave and limited shear wave data for the deep profile. The shallow velocity profile was constructed from the 15 suspension borings drilled for the CPNPP 3 & 4 investigation to depths of 150 to 550 ft (GeoVision Report 6573-01, Comanche Peak COL Geophysical Logging Rev 0). The deep velocity profile was constructed from velocity data acquired from wells located 2 to as much as 40 miles from the site (Figure 6). Velocity data for the regional deep profile was provided by the Texas Railroad Commission.

3.1 Shallow Velocity Profile

Development of the site velocity profile is detailed in TXUT-001-FSAR-2.5-CALC-003, *Shallow Velocity Profile Development Slope Method*. This calculation demonstrated the correlation between the engineering stratigraphy developed for the site, and the shear-wave and pressure-wave velocity field stratification. Changes in the wave travel time gradients were demonstrated to correspond with engineering layer boundaries defined by major changes in lithology (primarily limestone, shale, and sandstones). The vertical correspondence of velocity to lithology is also correlated from borehole to borehole throughout the site, demonstrating the continuity of layers across the area.

Layer velocities for every layer, in each boring, were calculated using the inverse of the slope of a line fit through the simulated down-hole travel times through each individual layer. The geometrical means of the representative layer velocity measurements were calculated to develop the shallow velocity profile (Figure 8). Representative layer velocity variations for the shallow velocity profile are provided by transformed standard deviations of the log deviants of each layer.

3.1.1 Comparison of Velocity Methods for the Shallow Profile

The velocities acquired from the 15 suspension log velocities were compared to velocities acquired by other methods at four of the borings, as well as velocities acquired from cross-hole methods at CPSES 1 & 2. Shear wave velocities were obtained by inversion of surface wave dispersion curves (SASW) at B-1000, B-1001, B-1012, and B-2000. Down-hole velocities were also obtained to a depth of about 140 ft in B-1000 and B-2000. This data set of SASW and down-hole provided an independent velocity comparison for about the upper 100 ft of the profile of the companion suspension borings. Cross-hole velocities obtained for CPSES

1 & 2 provided a comparison of independently acquired velocities for most of the shallow profile (about 525 ft depth).

Analysis of the suspension log data showed that engineering layer C exhibited very low variability from hole to hole in terms of its representative layer velocities. The layer C interface was consistently detected by all techniques and provides a standard to compare the velocity results from each method. The results from all velocity measurement methods are shown on Figure 10. This figure shows suspension log data for all 15 borings, the average profile velocities developed from the suspension logs, the geometric mean of the SASW shear wave results along with the geometric mean of the downhole V_s and V_p velocities for layer C and cross-hole data from CPSES 1 & 2.

The representative profile velocities for layer C were 5685 ft/sec for the shear-wave and 11324 ft /sec for the pressure-wave velocities. These velocities demonstrate low variability (5596–5803 V_s and 10952–11709 V_p at the two-sigma range for the log deviates) between borings. For comparison, the shear wave velocities for layer C from the four SASW inversions ranged from 5000–5250 ft /sec, which represents an approximately 10 percent lower result but which more closely approximates the cross-hole shear wave velocities for this layer. The down-hole data suffered from a low signal-to-noise ratio in the shallow portion of section. However, the down-hole shear wave velocity for layer C in B-1000 was 5456 ft/sec, which closely matches the integrated profile velocity for this layer obtained from the suspension log data. In contrast, the down-hole shear wave velocity obtained from B-2000, 4415 ft /sec, is significantly lower than the other techniques and is probably in error because of the poor data quality. Comparison of the cross-hole and suspension log data throughout the rest of the section indicates that they are in general agreement but show local variations on the order as those discussed above. The largest discrepancy appears to be layer E2, which shows lower shear- and pressure-wave results. Similar variations on the order of about 10% are seen in the pressure-wave inter-method comparison.

The shallow profile velocities compare well with both the SASW and down-hole velocities acquired within companion suspension log borings as well as with the velocities acquired from the cross-hole survey completed for CPSES 1 & 2. The correlation of velocity gradient with the engineering stratigraphy and the lateral continuity of the engineering units suggests that the suspension log data provides reproducible measurements for the shallow profile. Thus, velocities acquired from the 15 suspension log borings have been used to define the shallow velocity profile (Figure 8) as provided in Table 4.

3.2 Development of Regional Deep Velocity Profile

Velocity data for the deep profile was obtained from the Bureau of Economic Geology, the University of Texas-Austin, and the Texas Railroad Commission. Velocity data used to develop the deep velocity profile (Figure 10) came from the two nearest wells with available data (Figure 6)—the Quicksilver 1-Officers Club well (located 7 miles to the ENE in Hood County) and the Sun 1-Hallmark well (located about 40 miles to the west in Erath County). The Officers Club well provided V_p and V_s data from an elevation of -4900 to -8900 ft including the Smithwick Shale, the Big Saline Conglomerate, the Marble Falls Limestone, the Barnett Shale and the Ellenburger Limestone. The Sun Hallmark-1 well provided V_p data from an elevation of 1100 ft to -2500 ft including the Strawn Series, the Atoka Sand, the Smithwick Shale, the Big Saline Conglomerates, the Marble Falls and the Barnett Shale. In addition, boring B-1012 from the geotechnical study at the site penetrated the Mineral Wells formation of the Strawn Series and provided V_p and V_s data which was applied to the entire Strawn Series, given that lithology is homogenous throughout (see stratigraphic discussion in Section 2.2).

Harmonic mean velocities were calculated for each stratigraphic unit using the relation $V = \Sigma d_i / \Sigma (d_i/v_i)$; where d is the distance between two measured velocity, v, data points. Harmonic mean V_s and V_p values (Table 3) for the Strawn came from the Mineral Wells formation data from boring B-1012, the V_s and V_p values for the Smithwick Shale, the Big Saline Conglomerate, the Marble Falls Limestone, the Barnett Shale and the Ellenburger Limestone were calculated from the Quicksilver 1-Officers Club well data, and the V_p value for the Atoka Sand was calculated from the Sun 1-Hallmark well data. The Atoka Sand is the only unit which did not have V_s data, and so a V_s value was estimated using a linear regression of the V_p and V_s data from the other units in Officers Club well (Appendix 1). In cases where there was more than one velocity log available for a given unit, the resulting harmonic velocities differed by generally less than 10%. For example, the Mineral Wells formation (part of the Strawn Series) logged at boring B-1012 has a harmonic velocity of 10485 ft/sec and the Strawn Series logged in the Sun Hallmark well has a harmonic velocity of 11188 ft/sec, a difference of about 6%.

For the velocity data error analysis, standard deviations from the harmonic mean of V_p and V_s within each stratigraphic unit were determined. The V_s standard deviation for the Atoka unit (which did not have V_s measurements) was calculated by applying the same proportion from the V_p standard deviation to the harmonic mean V_s value (e.g., $\sigma_{Vs} = V_s * (\sigma V_p / V_p)$).

3.2.1 Depth of Seismic Basement

At an elevation of about -3973 ft, the Marble Falls limestone records a V_s of about 10520 ft/sec. Though this unit is sufficiently fast to be considered seismic basement ($V_s > 9200$ ft/sec, shown with a grey bar in Figure 9), it is underlain by the seismically slow Barnett Shale. The top of the underlying Ellenburger limestone is mapped at an elevation of about -4443 ± 73 ft, which has a V_s of about 10906 ft/sec and is the best estimate for the top of seismic basement beneath CPNPP. This unit is sufficiently thick regionally, and the nearby Officers Club well indicates greater than 3000 ft of material with shear wave velocities greater than 9200 ft/sec. Thus, basement is defined as the top of the Ellenburger formation for CPNPP 3 & 4.

4.0 DYNAMIC PROFILE DEVELOPMENT

The shallow and deep stratigraphy were combined to develop a layered model representative of the CPNPP site extending to seismic basement. Both aleatory and epistemic uncertainties were evaluated and formed the basis for assigning variability on both stratigraphic control as well as the dynamic properties developed for each layer.

4.1 Profile Construction

The shallow and deep profiles, as described above, were combined by coupling the Strawn Group using the Mineral Wells formation, which is the deepest stratigraphic unit logged at CPNPP 3 & 4, and the shallowest unit characterized for the deep profile. Table 4 provides a summary of the Dynamic Profile including stratigraphic top elevations and associated velocities, as discussed in Sections 2.0 and 3.0, and material properties, as described in the following sections. Dynamic profiles for developing the Ground Motion Response Spectra (GMRS) and Foundation Input Response Spectra (FIRS) are described in TXUT-001-PR-011, *Foundation Interface Report.*

4.2 Stratigraphic Variance and Uncertainty

Site stratigraphy including the shallow and deep layering, shear and compression wave velocities, and dynamic properties are provided in Table 4. The uncertainties associated with the stratigraphy and velocities for the shallow profile are much less than those for the deep profile. Therefore, the range about the mean for the velocities reported in Table 3 has been treated differently.

The shallow profile has been extensively characterized from over 150 geotechnical borings and geologic mapping of the area. The profile has been stratified based on vertical changes in lithology that can be mapped laterally from boring to boring. Standard deviations for the top of each shallow profile layer are less than 2 ft for the upper 200 ft of the profile. The standard deviation for the layers defining the shallow profile from about 200 ft to about 500 ft range from about 1 to 5 ft. Velocity data for the shallow profile acquired from 15 suspension borings demonstrated a strong correlation between the layering and where simulated down-hole travel time gradient "breaks" occurred. The velocity measurements from the suspension log were also compared with down-hole, SASW and cross-hole measurements and were determined to provide the most repeatable measurements. This comparison between various methods was also used to develop the assigned variability as provided in Table 4. Details for development of the layering and corresponding velocities are provided in TXUT-001-FSAR-2.5-CALC-003, *Shallow Velocity Profile Development Slope Method,* and TXUT-001-FSAR-2.5-CALC-004, *Engineering Stratigraphy.*

The deep profile was developed from regional wells and results in a higher uncertainity in both the layering (stratigraphy) and velocity measurements as described above. Shear wave velocity measurements were available from a single well located about 6 miles from the site and was limited to about 4000 ft of data (from about 5000 ft depth to about 9000 ft depth). This data was used to develop a linear extrapolation to estimate shear wave velocity from available pressure wave velocities from other wells to complete the deep profile. Thus the epistemic uncertainty for the deep profile is much greater than the shallow profile.

The deep profile lacks a statistical basis for estimating a robust standard deviation for all layer velocities. The Coefficient of Variation (COV=standard deviation/mean) calculated as 31 percent for the Atoka formation demonstrated the highest COV for all deep profile layers. This is due, in part, to the bimodal distribution of rock types and corresponding velocities within this interbedded sand and shale unit. Nonetheless, the variability was conservatively estimated at 31 percent for all deep profile layers. The velocity range for the shallow profile was defined as 25 percent of the mean velocity of each layer. This range envelopes the suspension log R1-R2 velocities as well as the cross-hole, down-hole and SASW velocities providing a conservative means to capture both epistemic and aleatory uncertainty.

4.3 Calculation of Poisson's Ratio

Poisson's ratio (μ) for each stratigraphic layer was calculated from the representative shear (V_s) and pressure (V_p) wave velocity:

$$\mu = \frac{0.5\left(\frac{Vp}{Vs}\right)^2 - 1}{\left(\frac{Vp}{Vs}\right)^2 - 1}$$

For the shallow profile, the Poisson's ratio was derived from the representative velocities calculated for each respective engineering layer (see TXUt-001-FSAR-2.5-CALC-003). Poisson's ratio for the deep profile utilized representative velocities for each of the regional stratigraphic units as described above in Section 3.2. The calculated Poisson's ratio values for each layer were compared to the general rock lithology as described above and are considered to be reasonable estimates.

4.4 Measurement of Unit Weights

Mean total (wet) unit weight values for each engineering layer for the shallow profile (Layer A to Strawn (MW)) was determined from laboratory testing. The number of tests by layer and the range of values is provided in Table 5.

No samples were available for the deep portions of the profile, thus unit weight values were estimated based on principal lithology of each unit and reasonable values were estimated based on engineering judgment. A value of 150 lbs/ft^3 was determined as a reasonable estimate to represent the deep profile.

4.5 Determination of Dynamic Properties

All critical structures are to be founded directly on the limestone (Layer C) or fill concrete. The shallow velocity profile, as described in Section 3.1, demonstrates that the site is underlain by soft to firm rock with velocities ranging from greater than 6000 ft/sec for limestone to 3000 ft/sec and greater for sandstones and shale within the depth interval of about 550 ft below the site. Below 550-ft depth, the shear wave velocity profile, estimated from compression wave velocities obtained from regional wells, is greater than about 7500 ft/sec. The stiffness of these units is expected to behave linearly for low- to high-strain levels. However, to evaluate the site response respective to non-linear properties, the Ground Motion Response Spectra (GMRS) was tested using both linear and non-linear properties assigned for each of the layers described below. Results of this analysis will provide the basis for performing the remaining site response.

4.5.1 Shear Modulus (G) and Damping

Low-strain shear modulus (G) for the shallow profile was calculated from shear wave velocities acquired from the 15 suspension logs (*Shallow Velocity Profile Development*, TXUT-001-FSAR-2.5-CALC-003), applying unit weight values as described in Section 4.3. The deep profile (below 400 ft) was calculated from the estimated shear wave velocities and a unit weight of 150 lbs/ft^3 for all deep layers. Material damping was estimated for each layer of the profile based on the principal lithology. To test the profile for sensitivity to non-linear behavior, a set of degradation curves based on lithology and depth were developed in consultation with Dr. Ken Stokoe. A sensitivity run using these non-linear properties is presented in Appendix 2. For the shallow profile, limestones, shales and sandstones were assigned damping ratios of 1.8, 3.2, and 2.5 respectively. For the deep profile, limestones, shales and sandstones were assigned damping rations of 0.8, 1.0, and 1.0 respectively. See Table 4 for lower and upper bound values estimated for shear modulus (G) *and* G_{max} *and estimated* damping percentages.

The fill concrete shear modulus has been calculated from an assumed mean shear wave velocity (see Appendix 1) and unit weight. The damping percentage of 1.0% is based on judgment and is reasonable for concrete.

The compacted fill has been stratified into three layers characterized by assumed differences in shear-wave velocity, as shown in Table 4. Shear modulus has been calculated from an assumed mean shear-wave velocity for each of the three layers and the assumed unit weight. Low-strain damping percentages were assigned as 1.5 for the upper two layers with the lowermost layer assigned 1.0. Degradation curves for the compacted fill are provided for shear modulus and damping with each appropriate curve listed in Table 4.

5.0 REFERENCES

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6.0 APPENDIX

Appendix 1. Calculation of V_s for Atoka Unit

Appendix 2 Non-linear Sensitivity Study

Table 1. Stratigraphic picks used in estimating deep stratigraphy beneath Comanche Peak Facility.

Operator	Taylor	Dallas	Mid-Continent	Kadane	Quicksilver	Davis	Dorchester	Sun	Davis	Mid-Continent
Lease	2-B Cravens	1-Hubbard	Squaw Creek	1-Bunl	Officers Club‡	1-Cousins	1-Davis	1-Hallmark‡	1-Cousins†	Squaw Creek†
Distance from site (miles)	2.4	2.7	4.6	5.1	6.1	6.6	6.7	39.8	6.6	4.6
Unit										
Strawn									90	500
Atoka		-1541	-1564	-1755		-1796		0	-110	-1560
Smithwick			-3614			-3836	-3368	-1000	-3910	-3630
Big Saline	-3743	-3896			-4240			-1779	-4040	-3860
Marble	-3831	-4006	-3856	-4155	-4405	-3979	-3583	-2105	-4040	-3970
Barnett		-4491	-4304	-4585	-4605	-4416	-3973	-2265	-4480	-4320
Ellenburger		-4691	-4514	-4825	-5070	-4633	-4223	-2409	-4690	-4520

‡ Well with velocity data † Measured off GEOMAPS cross section

Table 2. Calculated stratigraphic picks for CPNPP 3 & 4 and standard deviation.

	Method				
	A	B	C	D	σ
Strawn	388		336		26
Atoka		-1814	-980		417
Smithwick		-3809	-3742		34
Big Saline			-3932		
Marble		-3973	-3998	-4060	37
Barnett		-4196	-4384	-4550	145
Ellenburger		-4443	-4588		73

A. Drilled with WLA wells.
B. Projection of GEOMAPS-stated stratigraphic picks in three nearest wells.
C. Projection of stratigraphic picks measured off GEOMAPS cross section.
D. Read off GEOMAPS structure contour maps.
Standard deviation (σ) calculated for each horizon using multiple picks from different methods.

Table 3. Best estimate of deep stratigraphy and velocities

Unit	Lithology	Elevation (ft)	σ_{top}	Thickness(ft)	V_p (ft/sec)	σ_{Vp}	V_s (ft/sec)	σ_{Vs}	Poissons Ratio
Strawn	Shales with few sands and limestones beds	388.1	26	2202	10627	1042	5546	784	0.32
Atoka	Sands and shales interbedded	-1814	63[†]	1995	13921	4278	7642	2375*	0.28
Smithwick	Shale	-3809	33	123	10894	1108	5557	533	0.32
Big Saline	Conglomerate	-3932	63[†]	41	18004	1973	10247	813	0.26
Marble Falls	Limestone	-3973	37	223	19740	999	10520	481	0.30
Barnett	Shale	-4196	145	247	12858	1697	7783	997	0.21
Ellenburger	Limestone	-4443	73	>3000	20382	997	10906	896	0.30

Notes

[†] Reported standard deviation in elevation (σ_{top}) is average of other units' standard deviations.

Strawn unit V_p & V_s values are from Mineral Wells formation logged at CPNPP Units 3 & 4 Boring 1012. Compare V_p value to Sun Hallmark Well harmonic mean of 11188.

Atoka unit V_s values are calculated from regression of other units' V_p and Vs data.

Smithwick unit V_p value reported from Officers Club well. Compare value to V_p harmonic mean from Sun Hallmark well of 11849.

Standard deviation (σ) in V_s estimated from the standard deviation in V_p.

* Standard deviation (σ) in V_s estimated from the standard deviation in V_p.

Table 4. Dynamic properties of subsurface rock materials. Sheet 1 of 4: Lithology and stratigraphy

	Unit	Lithology	Depth from YG[3]	Mean Elv Top (MSL, ft)	Mean Elv σ, Top (ft)	Mean Thickness (ft)
	Fill Concrete	To be placed as needed from top of layer C	N/A	N/A	N/A	-
	Compacted Fill	Fill for excavation	0.0	822.0	N/A	3.0
			3.0	819.0	N/A	17.0
			20.0	802.0	N/A	20.0
	Fill/Residuum	Fill/Residuum/weathered limestone	-	847.0	N/A	-
Shallow Site Profile[1]	A	Limestone (will be removed)	-	834.0	12.1	36.0
	B1	Shale (will be removed)	24.0	798.0	1.8	8.0
	B2	Shale with limestone (will be removed)	32.0	790.0	1.8	8.0
	C	**Limestone (foundation layer)**	**40.0**	**782.0**	**1.8**	**65.0**
	D	Shale	105.0	717.0	1.5	3.0
	E1	Limestone	108.0	714.0	1.6	24.0
	E2	Limestone	132.0	690.0	1.0	34.0
	E3	Limestone	166.0	656.0	1.0	34.0
	F	Limestone with interbedded shales and sand	200.0	622.0	2.2	29.0
	G	Sandstone	229.0	593.0	4.0	80.0
	H	Shale	309.0	513.0	5.2	62.0
	I	Sandstone	371.0	451.0	3.3	63.0
	Strawn (MW)	Shales with sandstone and limestone beds	434.0	388.1	26.0	2202.0
Deep Site Profile[2]	Atoka[12]	Sands and shales interbedded	2636.0	-1814.0	417.0	1995.0
	Smithwick	Shale	4631.0	-3809.0	34.0	123.0
	Big Saline[12]	Conglomerate and sandstones	4754.0	-3932.0	122.0	41.0
	Marble Falls	Limestone	4795.0	-3973.0	37.0	223.0
	Barnett	Shale	5018.0	-4196.0	145.0	247.0
	Ellenburger	Limestone	5265.0	-4443.0	73.0	>3000

Table 4. Dynamic properties of subsurface rock materials. Sheet 2 of 4: shear- (V_s) and pressure-wave (V_p) velocity and Poisson's ratio (cont.).

		Depth from YG[3] (ft)	Mean Vs (ft/sec)	+Variability[4] (ft/sec)	-Variability[4] (ft/sec)	Mean Vp (ft/sec)	+Variability[4] (ft/sec)	-Variability[4] (ft/sec)	Poisson's Ratio[8]
	Fill Concrete	N/A	6800.0	7300.0	6300.0	-	-	-	0.20
	Compacted Fill	0.0	650.0	975.0	325.0	-	-	-	0.35
		3.0	800.0	1200.0	400.0	-	-	-	0.35
		20.0	1000.0	1500.0	500.0	-	-	-	0.35
	Fill/Residuum	-	-	-	-	-	-	-	-
Shallow Site Profile[1]	A	-	3548.0	4435.0	2661.0	8788.0	10985.0	6591.0	0.40
	B1	24.0	2609.0	3261.3	1956.8	6736.0	8420.0	5052.0	0.41
	B2	32.0	2716.0	3395.0	2037.0	7640.0	9550.0	5730.0	0.43
	C	**40.0**	**5685.0**	7106.3	4263.8	**11324.0**	14155.0	8493.0	**0.33**
	D	105.0	3019.0	3773.8	2264.3	8312.0	10390.0	6234.0	0.42
	E1	108.0	4943.0	6178.8	3707.3	10486.0	13107.5	7864.5	0.36
	E2	132.0	6880.0	8600.0	5160.0	13164.0	16455.0	9873.0	0.31
	E3	166.0	4042.0	5052.5	3031.5	9255.0	11568.8	6941.3	0.38
	F	200.0	3061.0	3826.3	2295.8	7927.0	9908.8	5945.3	0.41
	G	229.0	3290.0	4112.5	2467.5	7593.0	9491.3	5694.8	0.38
	H	309.0	3429.0	4286.3	2571.8	8188.0	10235.0	6141.0	0.39
	I	371.0	3092.0	3865.0	2319.0	7686.0	9607.5	5764.5	0.40
	Strawn (MW)	434.0	5546.0	6932.5	4159.5	10627.0	13283.8	7970.3	0.32
Deep Site Profile[2]	Atoka[12]	2636.0	7642.0	10011.0	5273.0	13921.0	18236.5	9605.5	0.28
	Smithwick	4631.0	5557.0	7279.7	3834.3	10894.0	14271.1	7516.9	0.32
	Big Saline[12]	4754.0	10247.0	13423.6	7070.4	18004.0	23585.2	12422.8	0.26
	Marble Falls	4795.0	10520.0	13781.2	7258.8	19740.0	25859.4	13620.6	0.30
	Barnett	5018.0	7783.0	10195.7	5370.3	12858.0	16844.0	8872.0	0.21
	Ellenburger	5265.0	10906.0	14286.9	7525.1	20382.0	26700.4	14063.6	0.30

Table 4. Dynamic properties of subsurface rock materials. Sheet 3 of 4: Additional dynamic properties.

	Unit	Unit Weight[9]		Shear Modulus[10] Mean (ksi)	Minimum C_v for Shear Modulus		G_{max} variation LB	G_{max} variation UB	Damping		
		Wet (pcf)	Dry (pc)		LB	UB	$[G_{max}/(1+C_v)]$ (ksi)	$[G_{max}x(1+C_v)]$ (ksi)	Low Strain D_s Damping[11] (%)	Variation with Strain Relation	Low Strain D_c Damping[13] (%)
	Fill Concrete	150.0	140.0	1495.9	-	-	-	-	-	N/A	-
	Compacted Fill	125.0	--	11.4	-	-	-	-	1.5	Curve 1[16]	0.8
		125.0	-	17.3	-	-	-	-	1.5	Curve 1[16]	0.8
		125.0	-	27.0	-	-	-	-	1.1	Curve 2[16]	0.6
	Fill/Residuum	-	-		-	-	-	-	-	-	-
Shallow Site Profile[1]	A	145.0	135.0	393.7	0.8	0.6	218.7	629.9	1.8	Curve 3[15]	0.9
	B1	135.0	117.0	198.2	0.8	0.6	110.1	317.1	2.0	Curve 4[15]	1.0
	B2	135.0	117.0	214.8	0.8	0.6	119.3	343.7	2.0	Curve 4[15]	1.0
	C	155.0	148.0	1080.4	0.8	0.6	600.2	1728.6	1.8	Curve 3[15]	0.9
	D	135.0	117.0	265.4	0.8	0.6	147.4	424.6	2.0	Curve 4[15]	1.0
	E1	155.0	149.0	816.8	0.8	0.6	453.8	1306.9	1.8	Curve 3[15]	0.9
	E2	155.0	149.0	1582.3	0.8	0.6	879.1	2531.7	1.8	Curve 3[15]	0.9
	E3	150.0	142.0	528.5	0.8	0.6	293.6	845.6	1.8	Curve 3[15]	0.9
	F	130.0	112.0	262.7	0.8	0.6	145.9	420.3	2.0	Curve 4[15]	1.0
	G	135.0	120.0	315.1	0.8	0.6	175.1	504.2	2.0	Curve 5[15]	1.0
	H	140.0	130.0	355.0	0.8	0.6	197.2	568.0	2.0	Curve 4[15]	1.0
	I	145.0	132.0	299.0	0.8	0.6	166.1	478.4	2.0	Curve 5[15]	1.0
	Strawn (MW)	150.0	-	995.0	0.8	0.6	552.8	1592.0	1.8	Curve 2[15]	0.9
Deep Site Profile[2]	Atoka[12]	150.0	-	1890.0	1.0	1.0	945.0	3780.0	1.0	Curve 2[15]	0.5
	Smithwick	150.0	-	1000.0	1.0	1.0	500.0	2000.0	1.0	Curve 2[15]	0.5
	Big Saline[12]	150.0	-	3400.0	1.0	1.0	1700.0	6800.0	1.0	Curve 2[15]	0.5
	Marble Falls	150.0	-	3580.0	1.0	1.0	1790.0	7160.0	0.8	Curve 1[15]	0.4
	Barnett	150.0	-	1960.0	1.0	1.0	980.0	3920.0	1.0	Curve 2[15]	0.5
	Ellenburger	150.0	-	3850.0	1.0	1.0	1925.0	7700.0	0.8	Curve 1[15]	0.4

Table 4. Dynamic properties of subsurface rock materials. Sheet 4 of 4: Notes to Sheets 1–3.

Notes

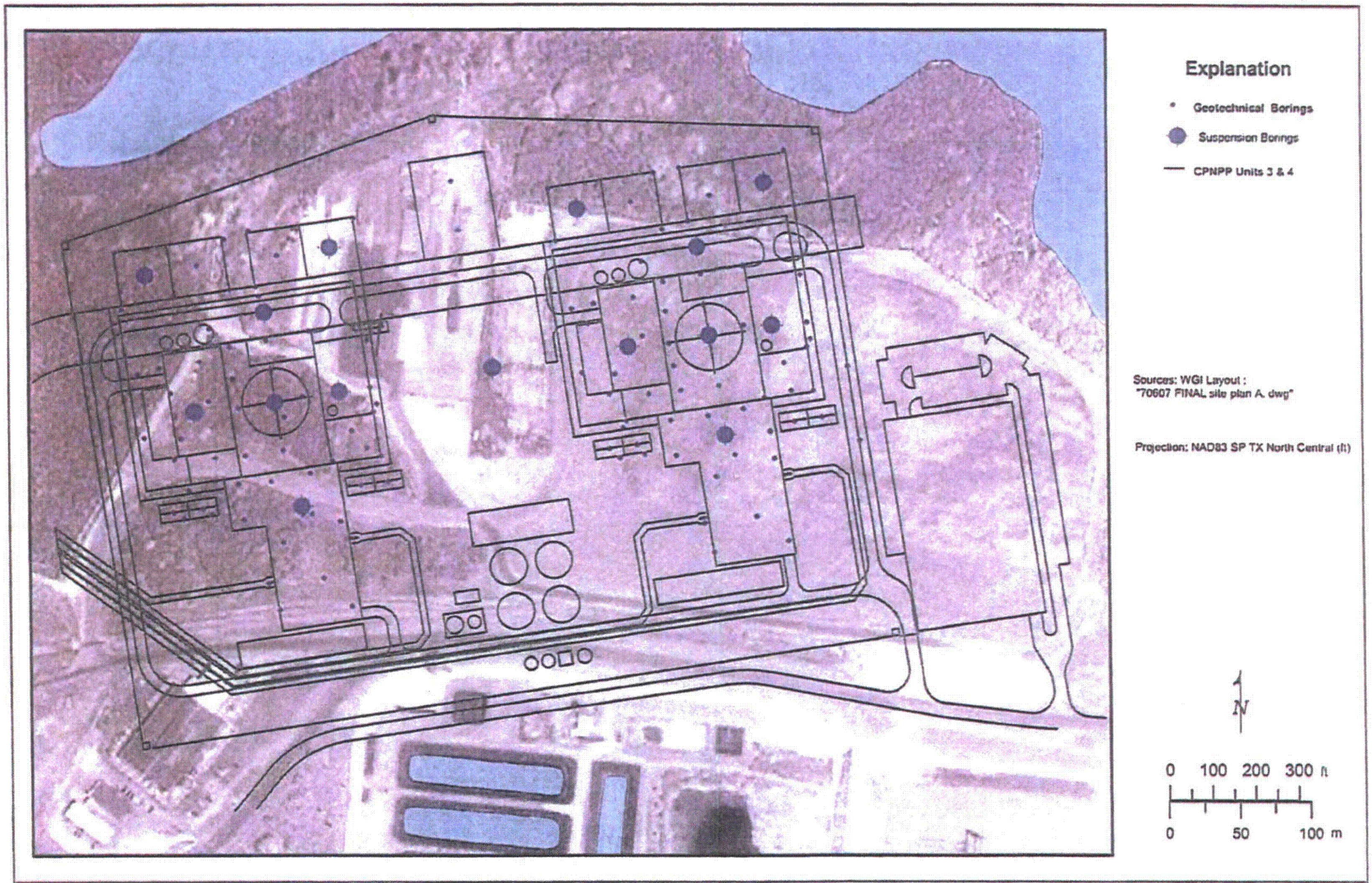
1.0 Shallow Site Profile derived from site specific data (Ref TXUT-001-FSAR-2.5-CALC-003 andTXUT-001- FSAR-2.5 CALC-004)
2.0 Deep Velocity Profile derived from regional wells as described in the preceeding text
3.0 Depth calculated from the difference between Yard Grade (822 ft MSL (Mean Sea Level)) and the average elevation
4.0 The selected Variability for Velocity is +/- 25% for shallow profile; +/- 50for the compacted fill) ; +/- 31% for deep profile; and +/-500 fps for fill concrete
5.0 Yard Grade is the elevation to which the site will be cut = 822 ft MSL
6.0 Foundation Unit is the top of Layer C on which all critical structures will be founded (either directly or backfilled with concrete)
7.0 Max and Min elevation tops not available for deep site profile, which yielded only one estimate for the top each horizon
8.0 Poisson's Ratio for Shallow Site Profile calculated from Vs and Vp suspension measurements (Ref TXUT-001-FSAR-2.5-CALC-003 and TXUT-001-FSAR-2.5-CALC-004). Deep Site Profile values estimated from deep regional well Vp data as described in the preceeding text
9.0 Unit weight values for Layers A through G estimated based on results of the laboratory tests. Values for Layers H, I, and Strawn (MW) estimated from FSAR Table 2.5.4-5G and based on lithology.
10.0 G_{max} calculated based on suspension Vs or estimated Vs for Deep Site Profile Materials
11.0 Low Strain Damping Ratio in Shear estimated from lithology for Shallow Site Profile through discussion with Dr. Ken Stokoe (Figure A2-2). Deep Site Profile values based on comparison of Vs and lithology of shallow site layers
12.0 Standard deviation in elevation of the top of Big Saline and top Atoka estimated from average standard deviation for other layer elevations
13.0 Damping Ratio in unconstrained compression, D_c should be taken as $0.5D_s$ with a maximum value of 5%.
14.0 Recommended minimum C_v (shear modulus variation factor) values are based on +/- 25% variation in V_s or Min values recommended by DCD (0.5 if test data is available or 1.0 if test data is not available), whichever is higher.
15.0 Curves are assigned from Figure A2-2 in Appendix 2 of this report and were used for the non-linear sensitivity study
16.0 EPRI Curves shown on Figure A2-4b were used for non-linear response of the compacted fill layers

Subnotes (changes based on meeting with WGI and MHI 1-7-08 in Princeton)

A Increase COV for compacted backfill to 50%
B Evaluate increase of compacted backfill Vs as appropriate
C Lower damping % in deep profile to 1.0 for all units except limestone to be kept at 0.8
D Lower damping % to no greater than 2.0 (this is to increase the spectra in the high freq range to lessen the dip of the spectra)
E COV for the shallow profile Vs increased to 25%
F Yard grade changed from 830 to 822

Table 5. Unit weight values.

	Unit Weights		
	Wet Unit Weight (pcf)		
	Avg	Min	Max
Shale	141.6	128.8	161
Limestone	155.3	129.8	164.5
Limestone/Shale	136.7	136.7	136.7
Sandstone	132.7	124.4	140
Soil			
Unit A	151.1	130.2	162.4
Unit B	143.3	128.8	162.9
Unit C	155.1	129.8	164.5
Unit D	143.4	133.1	157.8
Unit E	152.1	135	161.2
Unit F	129.6	124.4	132.5
Unit G	135.8	131	140
Unit H	0	142	142
Unit I	0	0	0



Sources: WGI Layout : "70607 FINAL site plan A. dwg"

Projection: NAD83 SP TX North Central (ft)

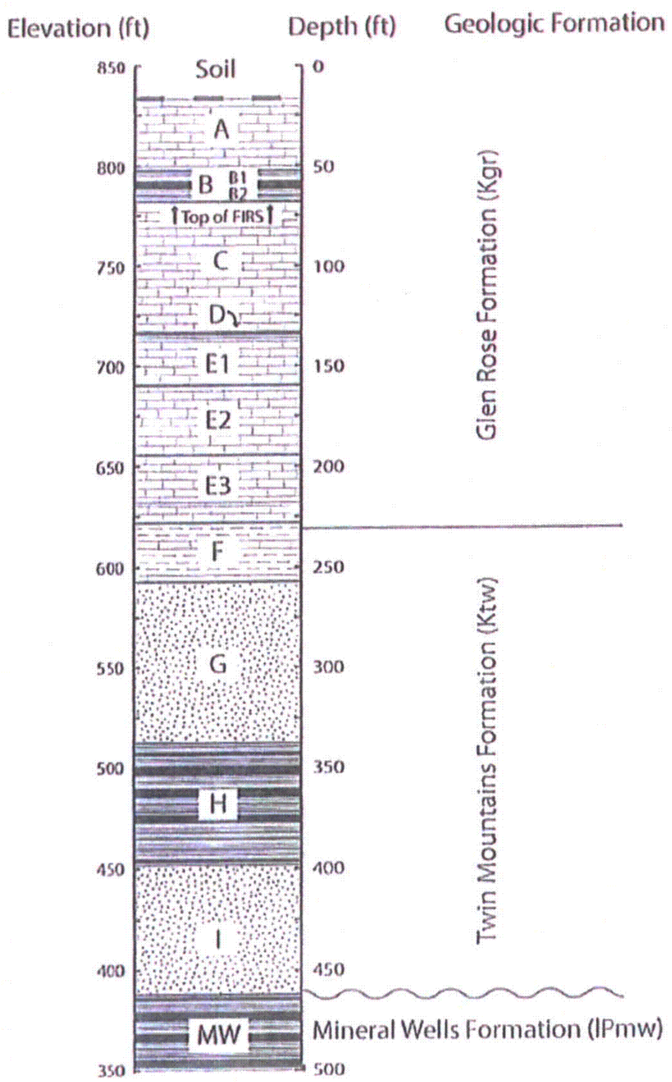
WLA

TXU COMANCHE PEAK

Boring Location Plan Units 3 & 4

Figure 1

Shallow Stratigraphic Profile



Engineering Unit

A - Limestone with a thicker shale bed at the top and thinner shale beds at the base

B1 - Bed of shale with thin interbed of limestone

B2 - Bed of limestone at top dominated with shale at base

C - Massive limestone

D - Two beds of shale with interbed of limestone

E - Massive limestone with subunits E1, E2, and E3 distinguished by changes in resistivity

F - Gradational zone: sandstone, shale, and limestone beds

G - Massive sandstone with interbeds of shale

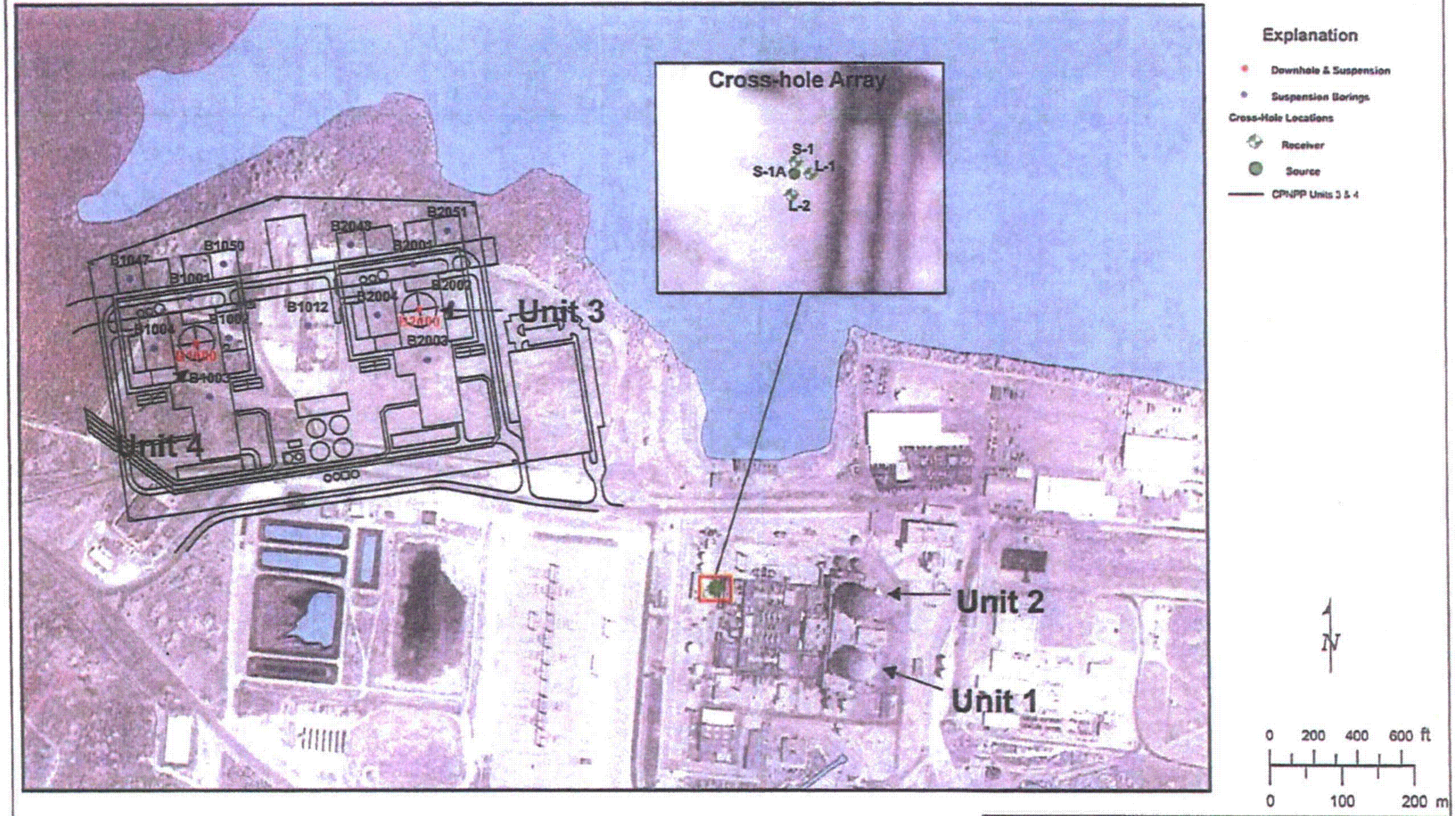
H - Shale with thin bed of limestone at top and a bed of sandstone at base

I - Massive sandstone with basal conglomerate

MW - Mineral Wells Formation - Shale

▦ Limestone
▬ Shale
▒ Sandstone
– – Elevation (830 ft) and Depth (20 ft) of Yard Grade
A Engineering Unit Symbol

Figure 2



Sources: Building Footprint from WGI DWG file 7/6/07
Aerial photograph - USGS DOQQ false color composite, 1994 - 1997

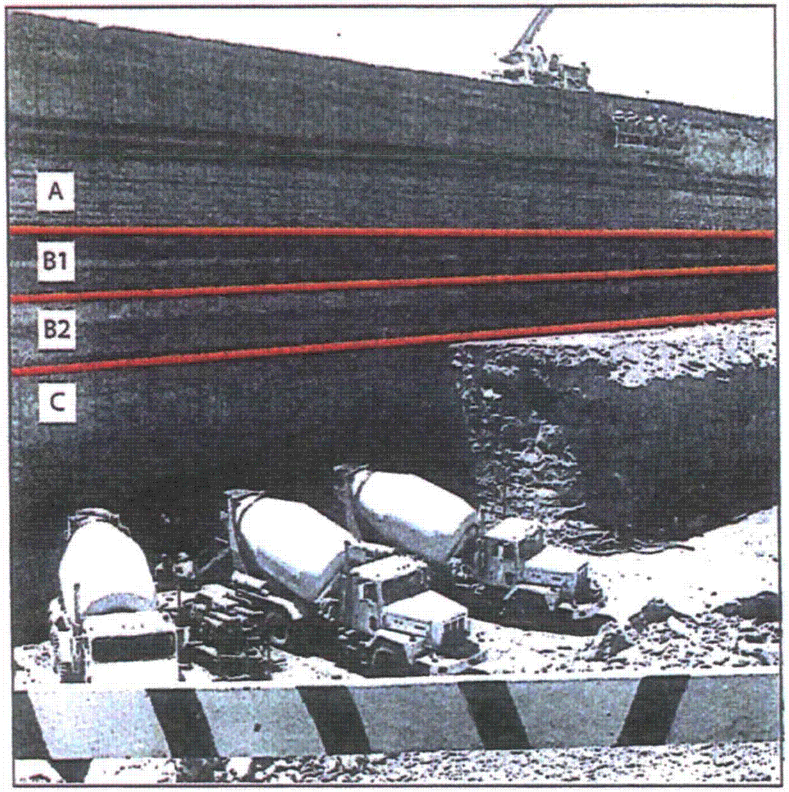
Projection: NAD83 Texas North Central State Plane Feet

TXU Comanche Peak

Velocity Data for Units 3 & 4 with Cross-hole Locations from Units 1 & 2

WLA William Lettis & Associates, Inc.

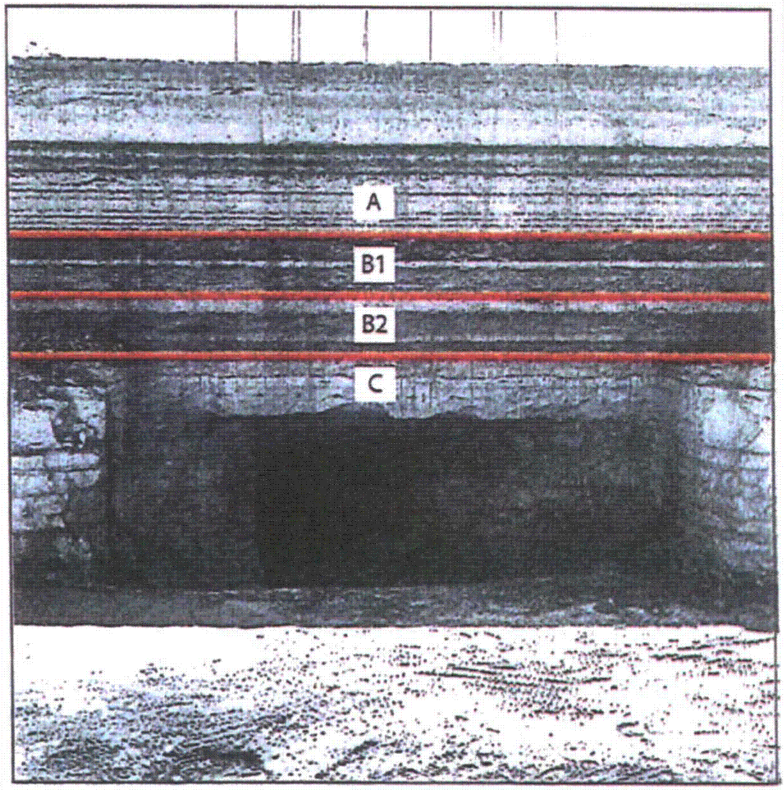
Figure 3



NUMBER 87
AUGUST 8, 1975

TEXAS UTILITIES SERVICES, INC.
COMANCHE PEAK STEAM ELECTRIC STATION
1980-82 2300 MW INSTALLATION

TURBINE GENERATOR AREA. BOTTOM—PUMPING CONCRETE INTO UNIT 1 CIRCULATING WATER DISCHARGE TUNNEL; TOP—SCALING SOUTH EXCAVATION WALL. VIEW TO SOUTHWEST

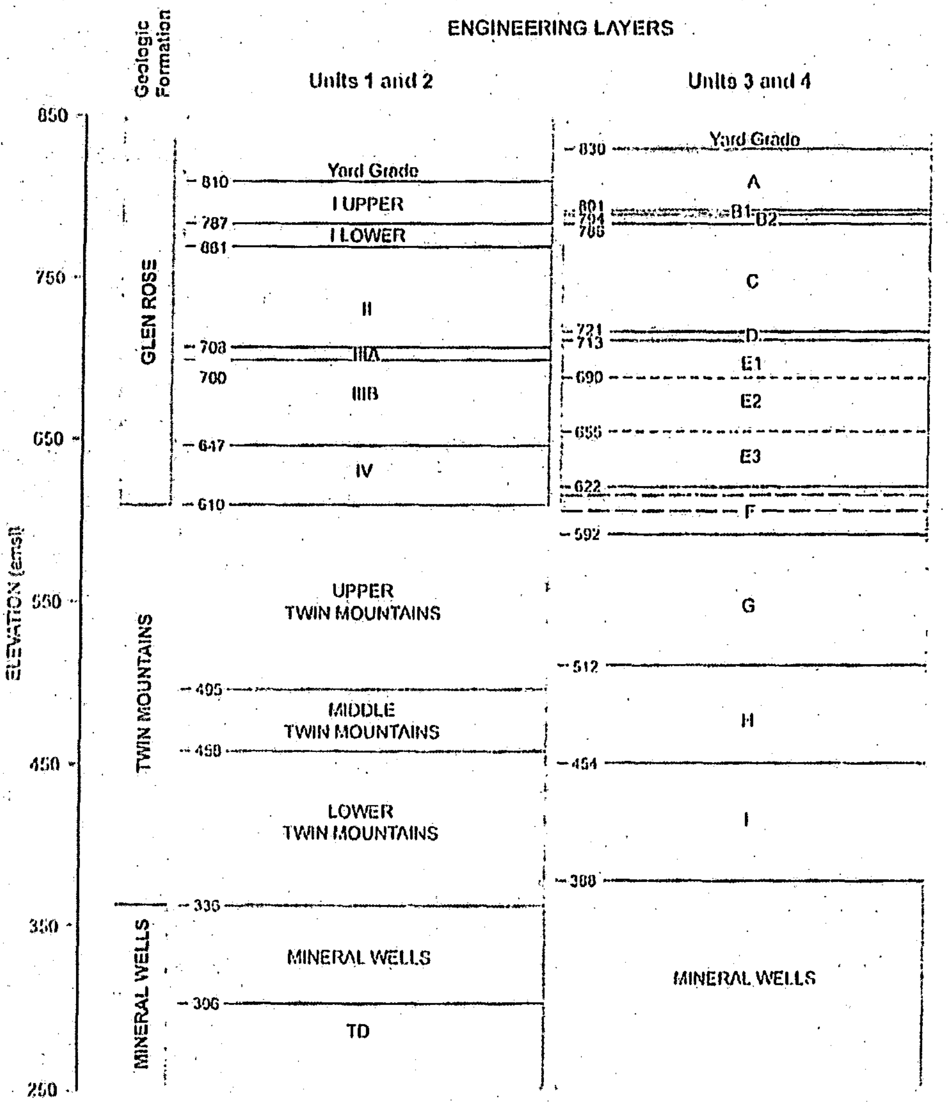


NUMBER 101
SEPTEMBER 22, 1975

TEXAS UTILITIES SERVICES, INC.
COMANCHE PEAK STEAM ELECTRIC STATION
1980-82 2300 MW INSTALLATION

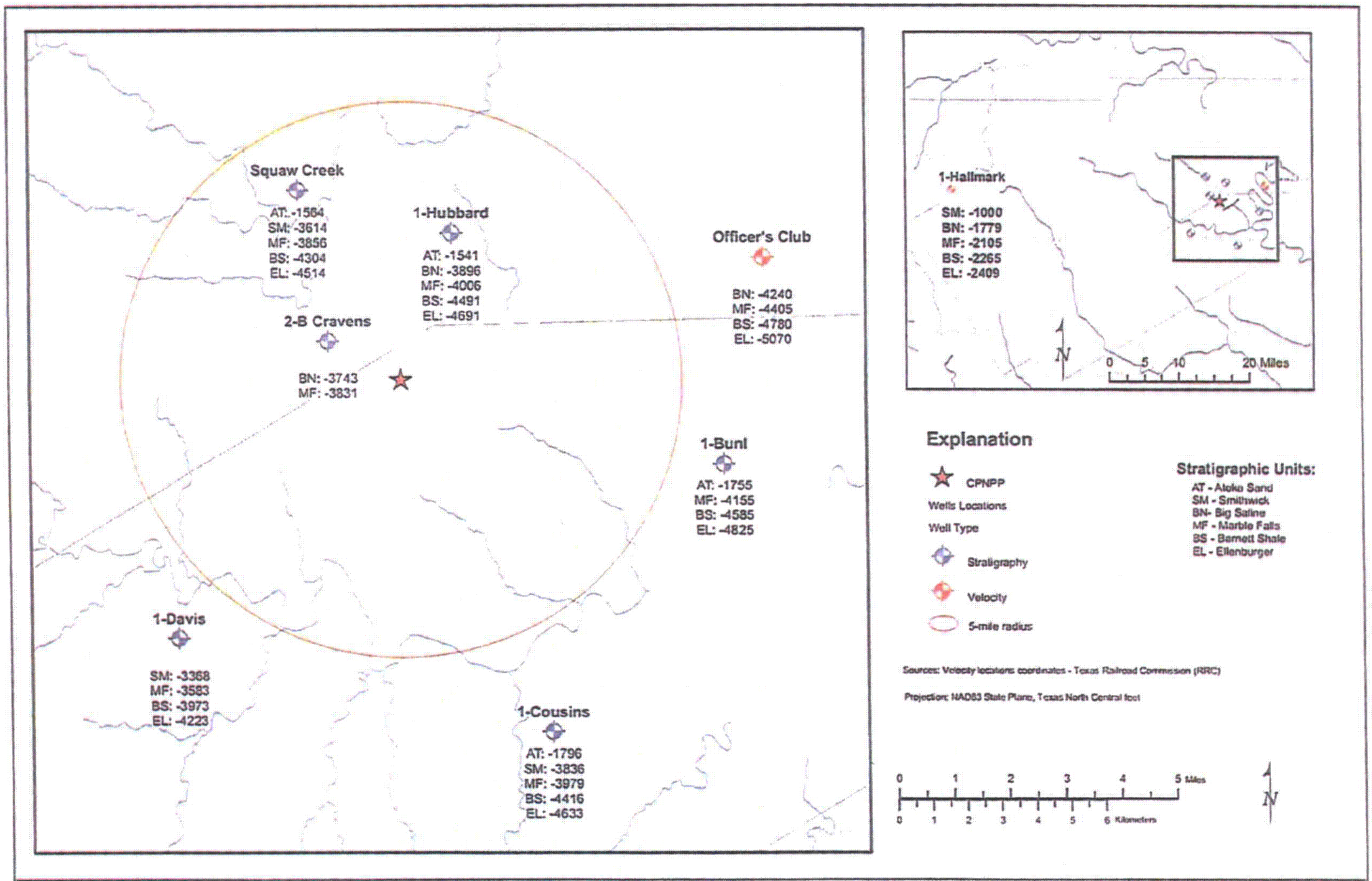
UNIT 1 TURBINE DISCHARGE WATERBOX OVERHANG EXCAVATION. VIEW TO SOUTH

Figure 4 CP Units 1 & 2 excavation photos with interpreted Units 3 & 4 Engineering Stratigraphy (see Fig. 2)



Comparison of Engineering Stratigraphy

Figure 5



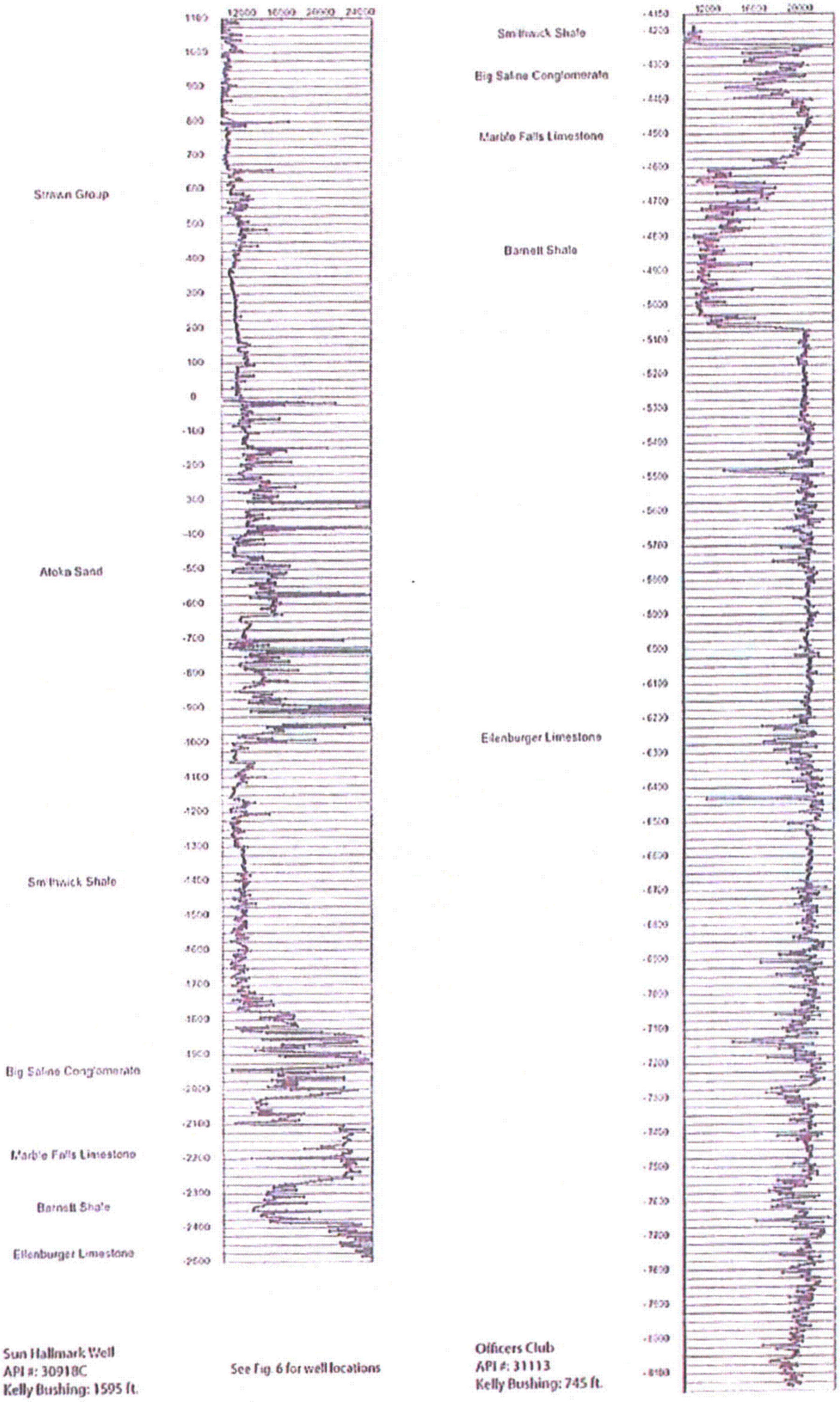
WLA

Map of Well Data Used for Deep Stratigraphy Velocity Profile

TXU COMANCHE PEAK

Figure 6

Well Vp Data



Sun Hallmark Well
API #: 30918C
Kelly Bushing: 1595 ft.

See Fig. 6 for well locations

Officers Club
API #: 31113
Kelly Bushing: 745 ft.

Figure 7

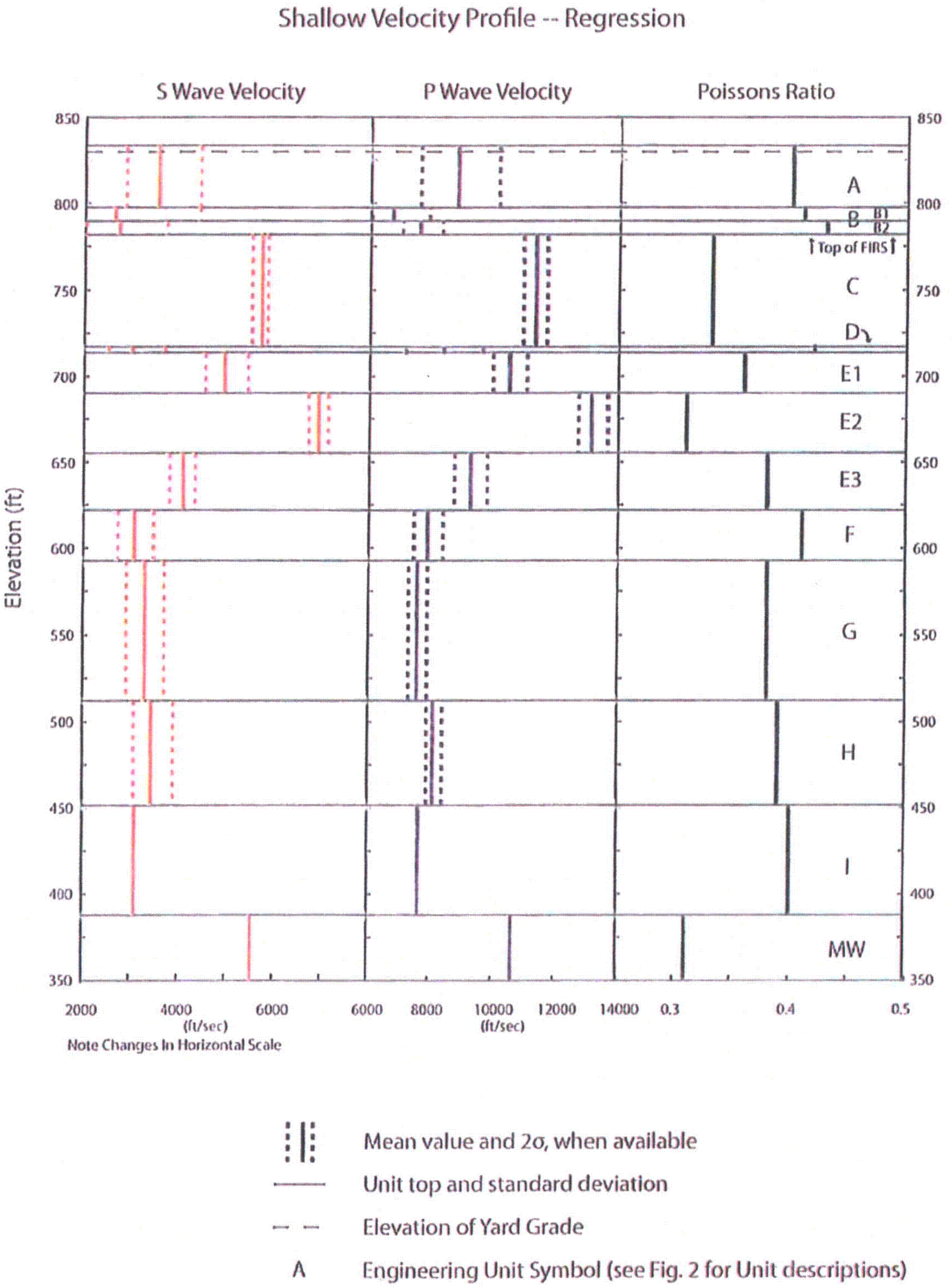
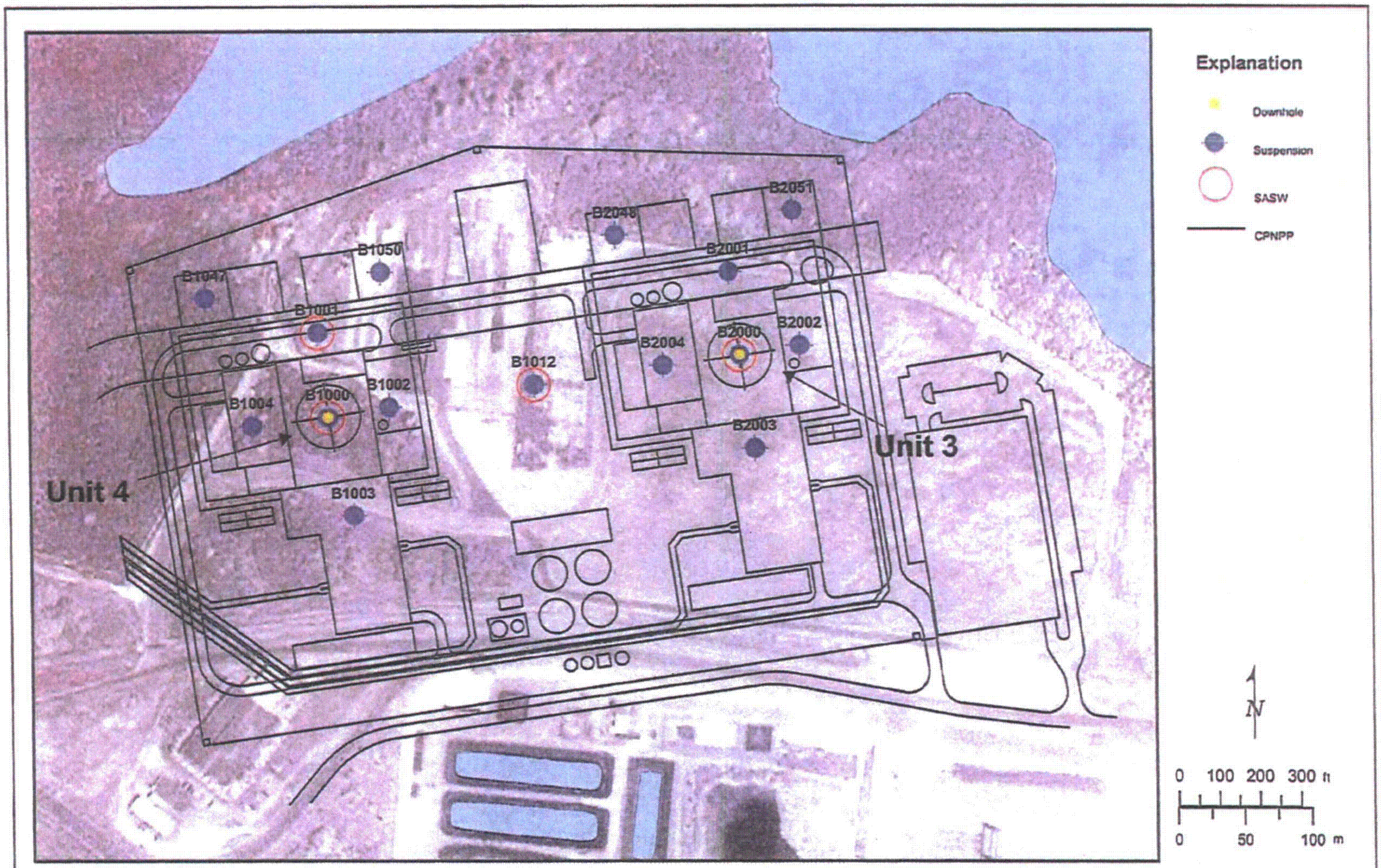

Shallow Velocity Profile -- Regression
S Wave Velocity
P Wave Velocity
Poissons Ratio
Elevation (ft)
850
800
750
700
650
600
550
500
450
400
350
A
B
B1
B2
Top of FIRS
C
D
E1
E2
E3
F
G
H
I
MW
2000
4000
6000
(ft/sec)
Note Changes In Horizontal Scale
6000
8000
10000
12000
14000
(ft/sec)
0.3
0.4
0.5
Mean value and 2σ, when available
Unit top and standard deviation
Elevation of Yard Grade
A
Engineering Unit Symbol (see Fig. 2 for Unit descriptions)

Figure 8



WLA

Suspension, Downhole, & SASW Log Locations Units 3 & 4

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Figure 9

Comparison of Shallow Velocity Measurements

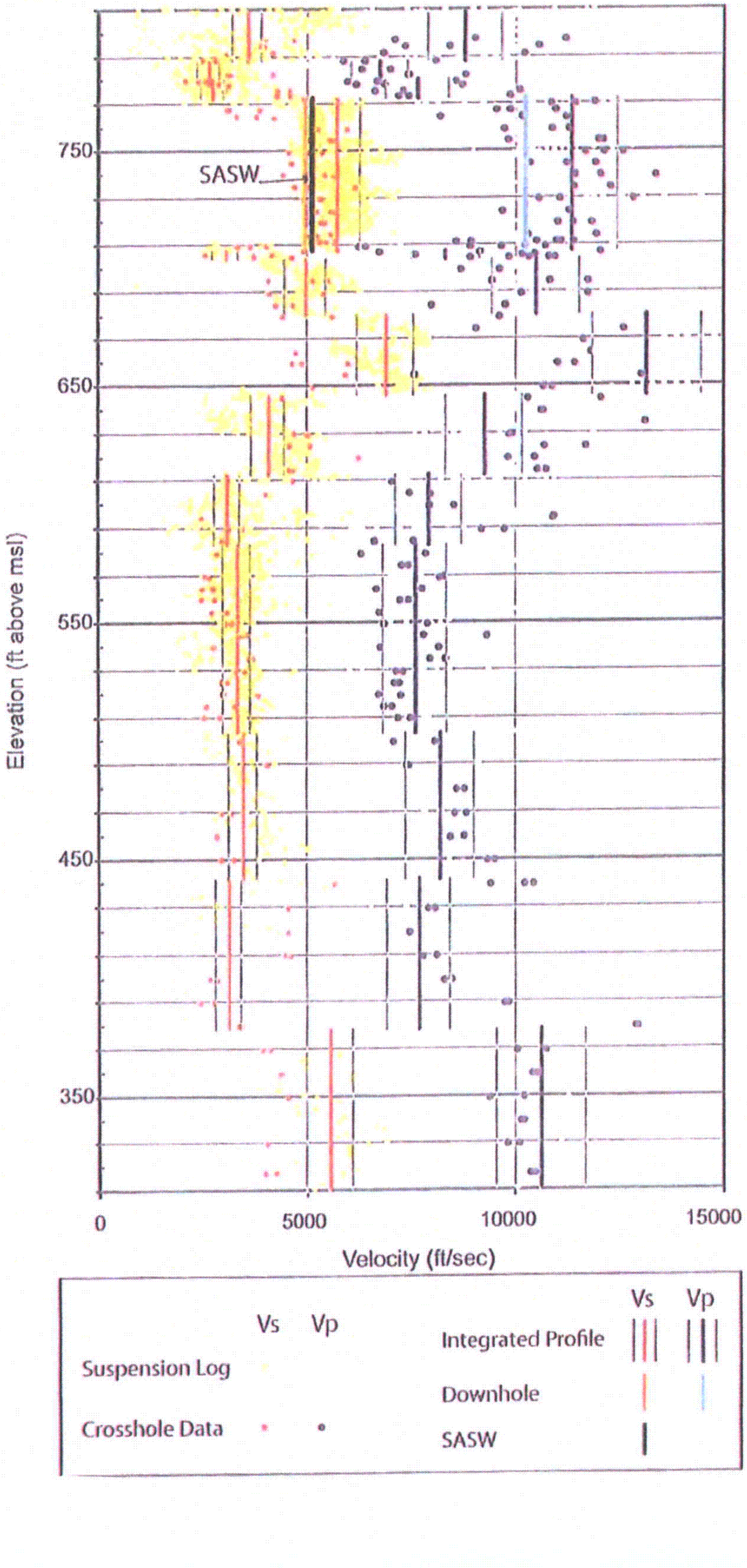


Figure 10

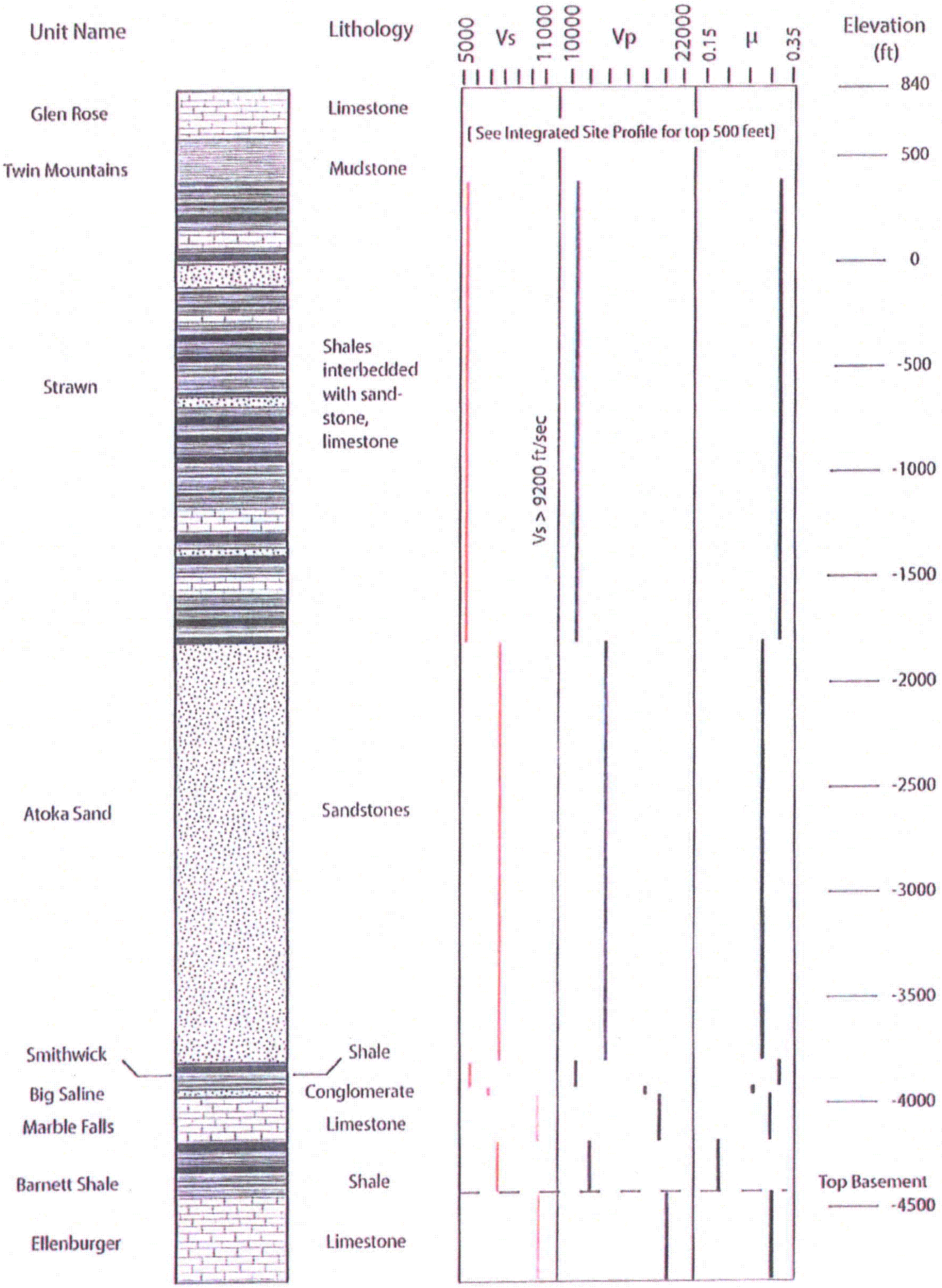
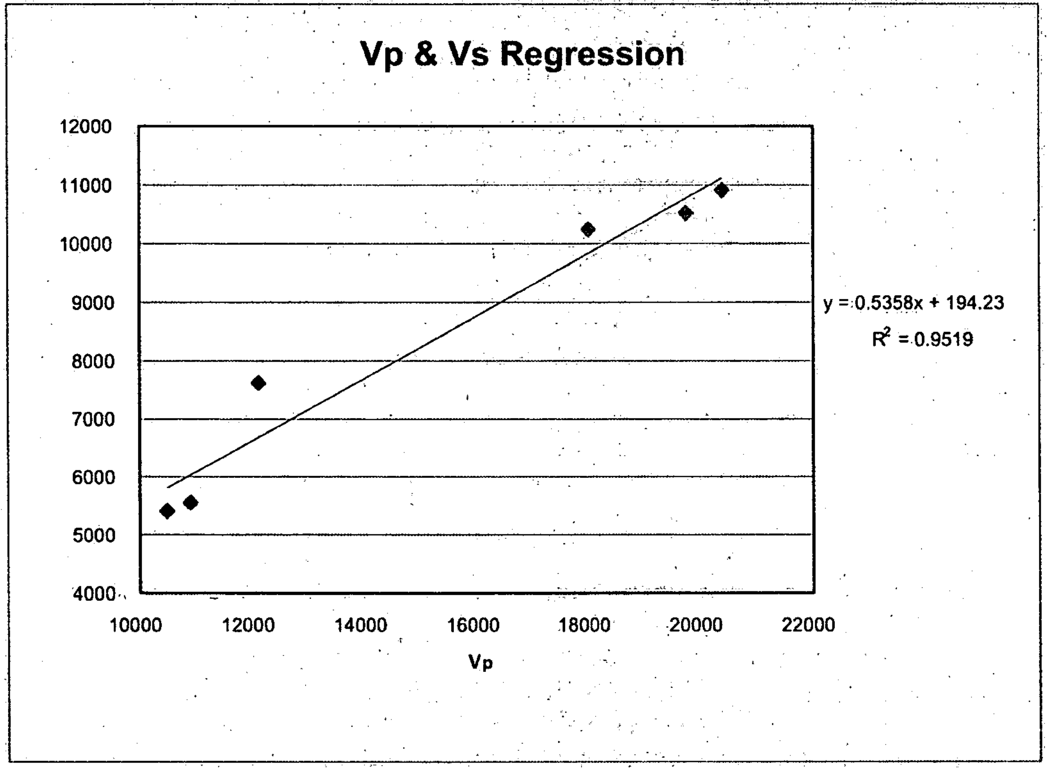

Unit Name
Lithology
5000
Vs
11000
10000
Vp
22000
0.15
μ
0.35
Elevation (ft)
840
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
Top Basement
-4500
Glen Rose
Limestone
[See Integrated Site Profile for top 500 feet]
Twin Mountains
Mudstone
Strawn
Shales interbedded with sandstone, limestone
Vs > 9200 ft/sec
Atoka Sand
Sandstones
Smithwick
Shale
Big Saline
Conglomerate
Marble Falls
Limestone
Barnett Shale
Shale
Ellenburger
Limestone

Figure 11

APPENDIX 1
Calculation of V_s for Atoka Unit

Unit	V_p	V_s
Mineral Wells	10485	5406
Smithwick	10894	5557
Big Saline	18004	10247
Marble Falls	19740	10520
Barnett	12118	7620
Ellenburger	20382	10906
Atoka	13921	7642



APPENDIX 2

Non-Linear Sensitivity Analysis

Non-linear Sensitivity Analysis

Overview

Site-specific and regional data indicate that the CPNPP site is underlain by a sequence of limestones, shales and sandstones with shear wave (Vs) velocities greater than about 5800 feet/sec. Because these velocities are about half of what would be measured for crystalline rock yet more than double than a typical soil site, the profile was tested for sensitivity to non-linear behavior.

Using shear wave velocity, rock lithology (limestone, shale and sandstone) and depth as discriminators, shear modulus (G/Gmax) and damping ratio (D) versus shear strain relationships were developed through consultation with Dr. Ken Stokoe, Professor University of Texas. These properties as summarized in Table 4 above and shown on Figures A2-1 and A2-2 were then used to generate a test case to compare the strains to a profile where the properties were assumed to behave linearly.

Estimation of Strain Dependent Properties

The profile was divided into lithologies within the upper 400 feet and those deeper than 400 feet to account for increasing confining stress and unit weight. The following relationships were determined with corresponding minimum damping ratio (D_{min}) defined:

Figure A2-1 and A2-2 Curve	Material and Properties	Shear Strain %	G/G_{max}	D %
1	Deep Limestone (Depth > 400 ft)	0.0001	1.000	0.800
		0.0010	1.000	0.800
		0.0030	0.990	0.900
		0.0100	0.980	1.100
		0.0300	0.940	1.600
2	Deep Shale & Sandstone (Depth >400 ft)	0.0001	1.000	1.800
		0.0002	1.000	1.800
		0.0005	1.000	1.800
		0.0010	0.990	1.900
		0.0020	0.985	2.000
		0.0050	0.980	2.200
		0.0100	0.960	2.400
		0.0200	0.910	3.000

3	Shallow Limestone (Depth <400 ft)	0.0001	1.000	1.800
		0.0002	1.000	1.800
		0.0005	1.000	1.800
		0.0010	0.990	1.900
		0.0020	0.985	2.000
		0.0050	0.980	2.200
		0.0100	0.960	2.400
		0.0200	0.910	3.000
4	Shallow Shale (Depth <400 ft)	0.0001	1.000	3.200
		0.0002	1.000	3.200
		0.0005	0.980	3.500
		0.0010	0.950	3.800
		0.0020	0.900	4.200
		0.0050	0.820	5.100
		0.0100	0.730	6.200
		0.0200	0.620	7.600
5	Shallow Sandstone (Depth <400 ft)	0.0001	1.000	2.500
		0.0002	1.000	2.500
		0.0005	0.990	2.600
		0.0010	0.980	2.700
		0.0020	0.950	2.900
		0.0050	0.910	3.200
		0.0100	0.850	4.000
		0.0200	0.770	5.000

Calculations

Site-response calculations were performed using an equivalent-linear formulation and,using as rock input the 10^{-4} broadband spectrum from the probabilistic seismic hazard analysis, and considering a profile that extends from bedrock to Elevation 782 feet (top of Glen Rose Limestone Layer C). Calculations were performed for two separate cases, as follows: (1) a linear analysis, using the low-strain damping ratios from Table 4; and (2) a non-linear analysis, using the strain-dependent damping and stiffness properties given in Figures A2-1 and A2-2 and tabulated above.

Results

Figures A2-3 compares the spectra at the top of the profile, for the two sets of calculations. The linear results are slightly higher than the non-linear results. This is which is attributed mainly to the conscious conservative choice of damping ratios for the linear analysis (see Table 4, subnotes C and D). An additional contributor is the increased damping that accompanies nonlinear deformation.

Appendix 2 References

Risk Engineering, Inc. (2007). *High frequency and low frequency horizontal rock spectra,* REI QA record 0737-ACR-026.

Risk Engineering, Inc. (2008). *Calculation of Site Response for Comanche Peak Units 2 and 3, Rev. 1.* REI QA record 0737-ACR-030.

Figure A2-1: G/G_{max} vs. Strain for Rock Materials

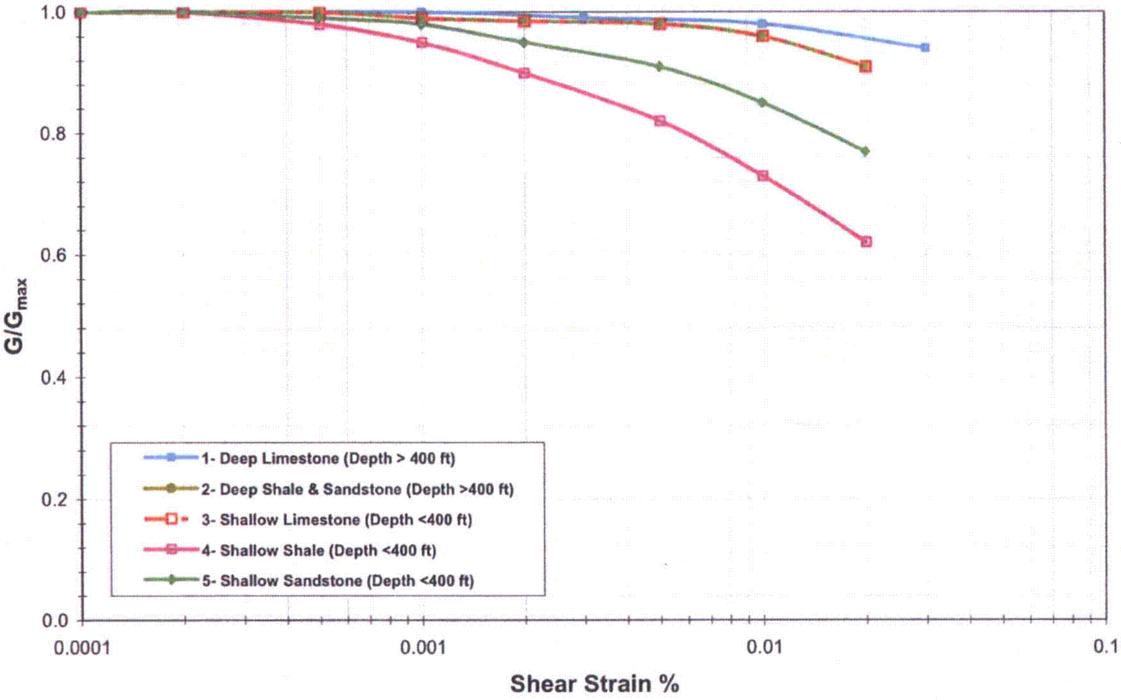


Figure A2-2: Damping in Shear vs. Strain for Rock Materials

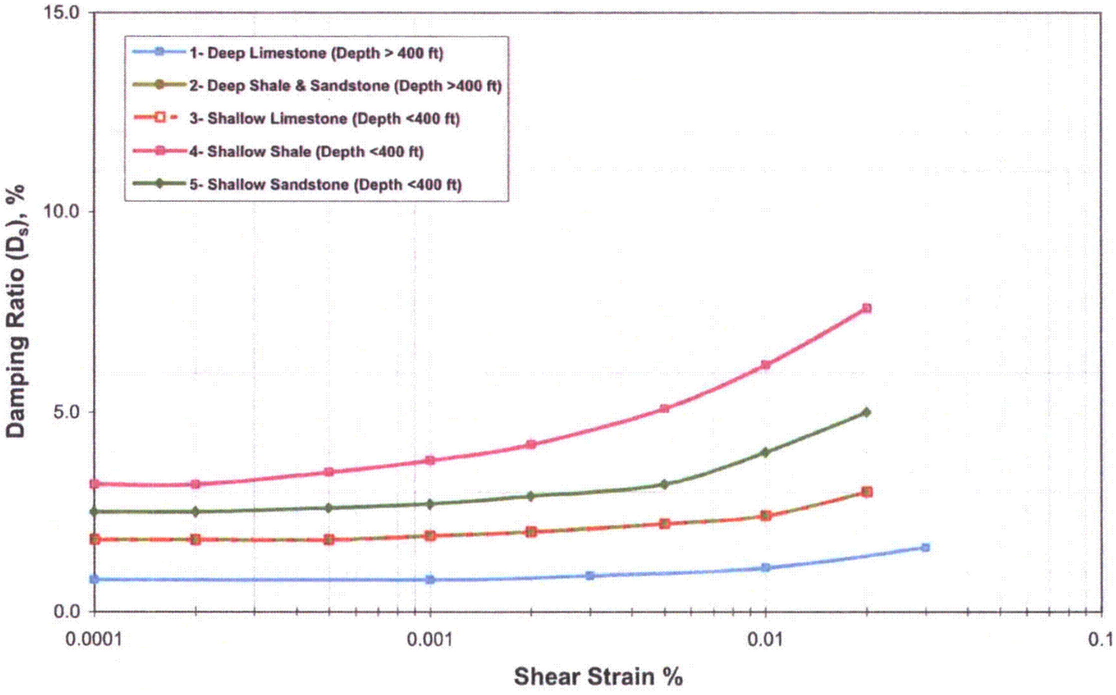


Figure A2-3: 1E-4 Broadband Linear vs. Nonlinear Median Soil Spectra

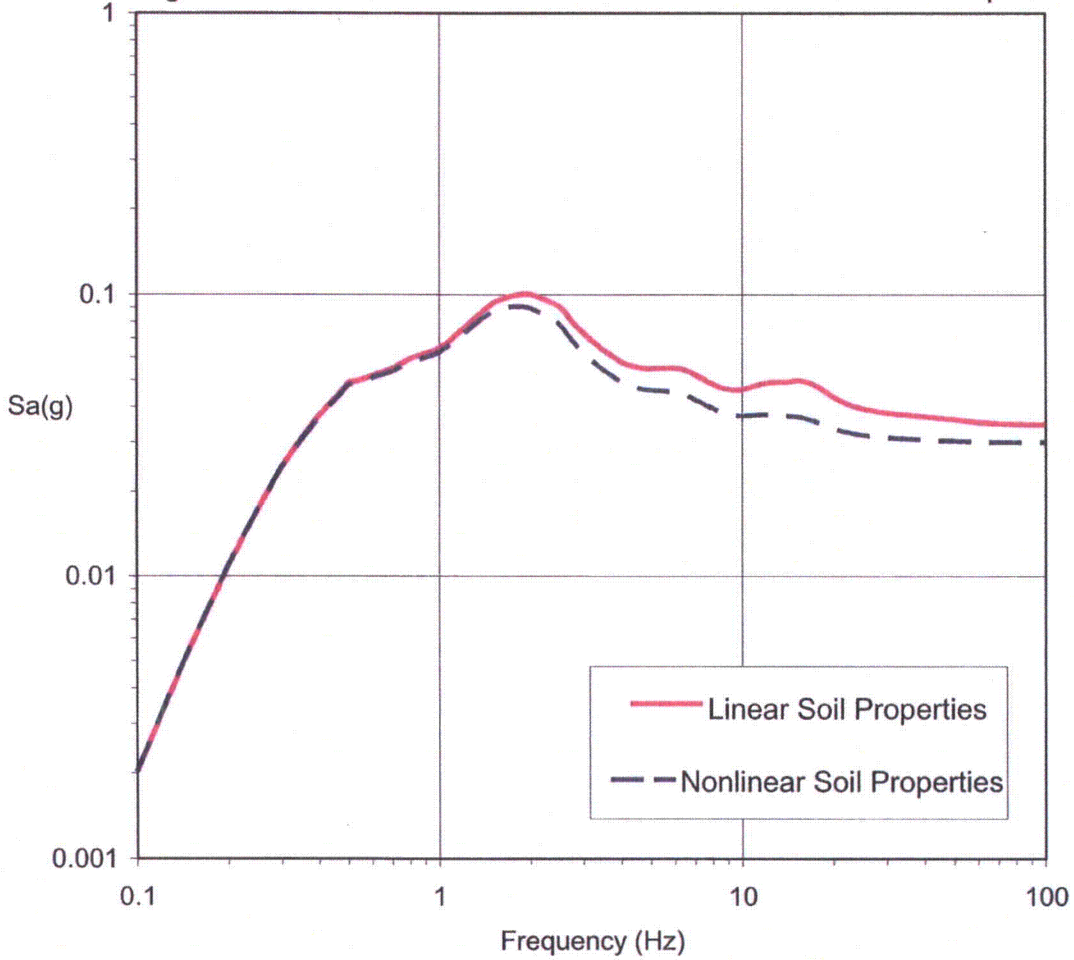


Figure A2-4a: G/G$_{max}$ vs. Strain (Sand Characteristic Behaviour, EPRI 1993)

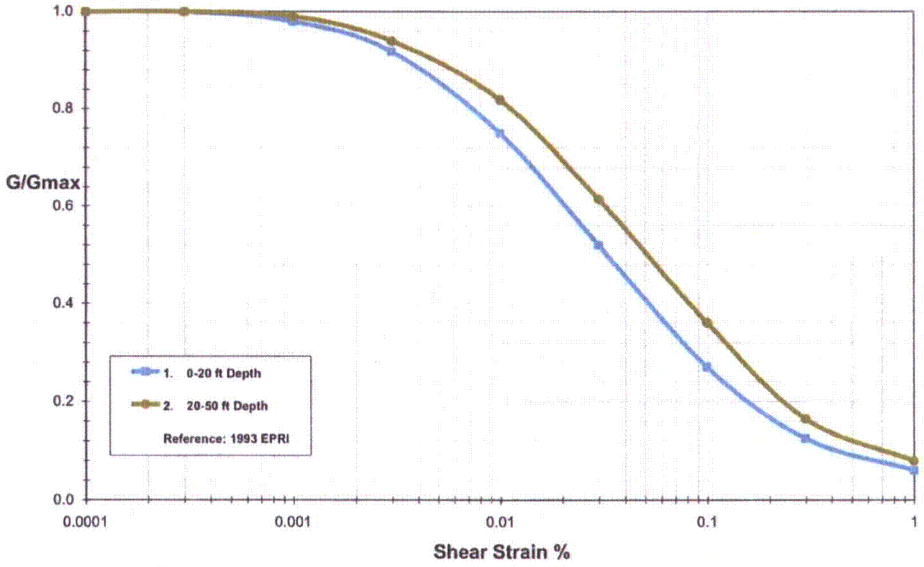
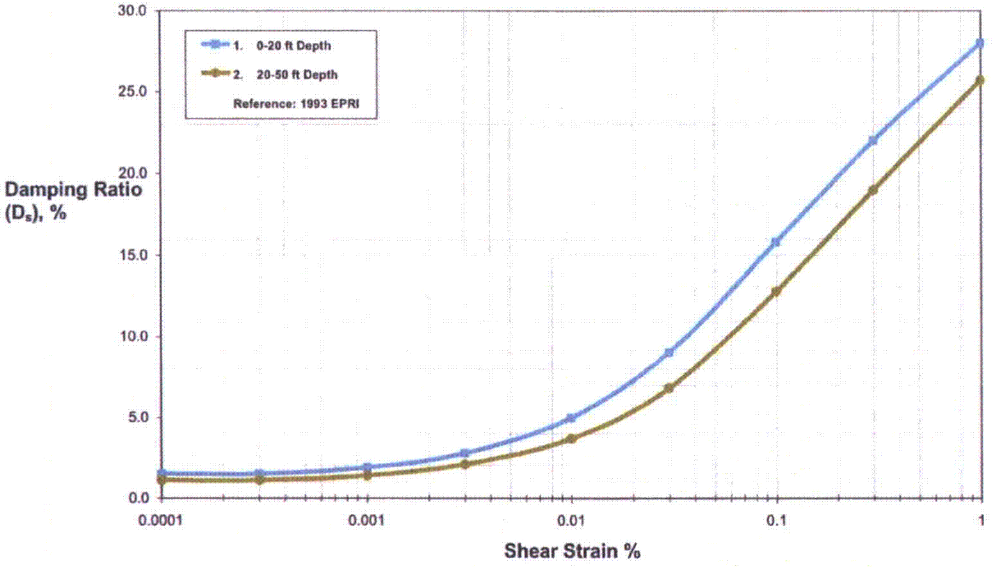


Figure A2-4b: Damping in Shear vs. Strain (Sand Characteristic Behaviour, EPRI 1993)



Attachment 3

SASSI Model of US-APWR Reactor Building, 4DS-CP34-20080048 Rev.1, Mitsubishi Heavy Industries, LTD, September 17, 2008

This calculation is proprietary and will be submitted by a separate letter.

Attachment 4

Site Specific SSI Analysis of US-APWR Reactor Building, SSI-12-05-100-003 Rev. C, URS, November 13, 2009.

This calculation is proprietary and will be submitted by a separate letter.