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7. Abstract Applied Research Associates, Inc. (ARA), under contract to Argonne National Laboratory to perform work for Westinghouse Hanford Company (WHC), conducted nine Piezo Cone Penetration Tests (CPT) as part of an investigation of the fine-grained soils at the McGee Ranch Site. The cone penetration tests were conducted next to conventional boring to develop comparisons between the CPT and conventional drilling techniques. The CPT compared favorably to the boring logs and identified the same stratigraphy as present in the boring logs for each location. In addition, production rates and costs between the two methods were compared. The CPT was able to conduct ten 25-foot tests per day at a cost of \$17.50 per foot. These costs represent upper bounds and in a production type mode the production rate can be expected to increase, reducing the cost.		
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1.0 INTRODUCTION AND BACKGROUND

Applied Research Associates, Inc. (ARA), under contract to Argonne National Laboratory to perform work for Westinghouse Hanford Company (WHC), conducted Piezo Cone Penetration (P-CPT) Tests as part of an investigation of the fine-textured soils at the McGee Ranch site. The purpose of the investigation was to characterize a potential borrow area for fine-textured soil materials that would be used to construct multi-layer closure covers on the Hanford Site. As part of the investigation, WHC conducted nine auger-drill borings on the site during September 1992. ARA's objective was to characterize the soils at the McGee Ranch site using the cone penetrometer and compare the findings with the lithologic characterization obtained from geologic boring logs. This report documents ARA's site investigation efforts, test techniques, and analysis of the data for field work conducted April 14 and 15, 1993.

1.1 TEST LOCATION

The McGee Ranch site is located on the Hanford Site, about 1/2 mi northwest of the Yakima Barricade, west of State Highway 240, and north of State Highway 24. The area of interest for the P-CPT is a 400 ft² section denoted in Figure 1 (Skelly 1992). Nine P-CPT were conducted as part of the investigation. The P-CPT were conducted on a 3 x 3 grid spaced 200 ft on centers. All P-CPT were conducted to refusal, which was typically at a depth of 25 to 27 ft. At some locations the refusal can be seen in the tip stress profiles as a rapid increase in tip stress. At other locations the refusal was due to excessive rod friction and the tip stress does not increase at the bottom of the profile. Each of the nine P-CPT soundings (Table 1) is located within 5 ft of a nonradioactive dangerous waste landfill auger-drilled hole.

1.2 REPORT ORGANIZATION

The report is organized into four sections and an appendix. Section 2.0 contains a description of the P-CPT method, which documents the field techniques, calibration methods, and data acquisition system. Section 3.0 documents the methods used to derive properties and stratigraphy from the P-CPT data. Analysis of the data, cross sections, and P-CPT overlay plots of tip and sleeve stress are also presented in this section. Summary and conclusions of the P-CPT are presented in Section 4.0.

2.0 TESTING EQUIPMENT AND PROCEDURES

2.1 INTRODUCTION

The cone penetrometer was originally developed for use in soft soil. Over the years, cone and push system designs have evolved to the point that they can now be used in strong cemented soils and even soft rock. ARA's cone penetrometer consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck with the weight of the

truck providing the necessary reaction mass. The probe has a conical tip and a friction sleeve that independently measure vertical resistance beneath the tip as well as frictional resistance on the side of the probe as functions of depth. A schematic view of the cone penetrometer probe is shown in Figure 2. A pressure transducer in the cone penetrometer is used to measure the pore water pressure as the probe is pushed into the ground. The probe also includes three seismic transducers that are monitored while performing downhole seismic surveys.

2.2 THE CONE PENETROMETER TEST

The P-CPT is conducted using the ARA penetrometer truck. The penetrometer equipment is mounted inside a van body attached to a 10-wheel truck chassis with a diesel engine. Ballast in the form of metal weights and a water tank are added to the truck to achieve an overall push capability of 60,000 lbs. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame.

Standard dimensions of the cone penetrometer probe are 1.405-in-diameter, 60° conical tip, and a 1.405-in-diameter by 5.27-in-long friction sleeve. The shoulder between the base of the tip and the porous filter is 0.08 in. long. A 1.5-in-diameter expander, located 5.25 in. behind the top of the friction sleeve (Figure 2), pushes the penetration hole open and reduces the frictional drag on the push tubes behind the probe. The cone penetrometer is normally advanced vertically into the soil at a constant rate of 48 in/min. This rate must be reduced when hard layers are encountered. The P-CPT is conducted in accordance with ASTM D3441.

Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross section inside the probe, which is instrumented with four strain gages in a full-bridge circuit. Forces are sensed by the load cells and the data are transmitted from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the cone penetrometer truck. A set of data is normally recorded each second, for a minimum resolution of about one data point every 0.8 in. of cone penetrometer advance. The depth of penetration is measured using a string potentiometer mounted on the push frame.

Electronic data acquisition equipment for the P-CPT consists of a computer with a graphics monitor and a rack of eight signal conditioners. Analog signals are transmitted from the probe to the signal conditioners where the P-CPT data are amplified and filtered at 1 Hz. Seismic signals are amplified as required and filtered at 1,000 Hz. Once amplified, the analog signals are transmitted to a high speed analog-to-digital converter board where the signals are digitized; usually at the rate of one sample per second for the penetration data and 10,000 samples per second for the seismic data. The digital data are then read into memory and written to the internal hard disk for future processing. Upon completion of the P-CPT, the penetration, dissipation, and seismic data are plotted. Floppy disks containing the data are brought to ARA's New England Division in South Royalton, Vermont, for analysis and preparation of report plots.

2.2.1 Saturation of the Piezo-Cone Penetrometer

Penetration pore pressures are measured with a pressure transducer located behind the tip in the lower end of the probe. Water pressures in the soil are sensed through a 250 μ m porous polyethylene filter that is 0.25 in. high and 0.202 in. thick. The pressure transducer is connected to the porous filter through a pressure port (Figure 2). The pressure port and the filter are filled with a high viscosity silicone oil.

For the pressure transducer to respond rapidly and correctly to changing pore pressures upon penetration, the filter and pressure port must be saturated with oil upon assembly of the probe. A vacuum pump is used to de-air the silicone oil before use and to saturate the porous filters with oil. The probe is assembled with the pressure transducer facing upwards and the cavity above the pressure transducer is filled with de-aired oil. A previously saturated filter is then placed on a tip and oil is poured over the threads. When the cone tip is screwed into place, excess oil is ejected through the pressure port and filter, thereby forcing out any trapped air.

Saturation of the P-CPT is verified with field calibrations before and after each P-CPT. The high viscosity of the silicone oil coupled with the small pore space in the filter prevents the loss of saturation as the cone penetrometer is pushed through dry soils. Saturation of the cone penetrometer can be verified with a calibration check at the completion of the penetration. Extensive field experience has proven the reliability of this technique.

2.2.2 Field Calibrations

Many factors can effectively change the calibration factors used to convert the raw instrument readouts, measured in volts, to units of force or pressure. As a quality control measure, as well as a check for instrument damage, the load cells and the pressure transducer are routinely calibrated in the field. Calibrations are completed with the probe ready to insert into the ground so that factors affecting any component of the instrumentation system will be included and detected during the calibration.

The tip and sleeve load cells are calibrated with the conical tip and friction sleeve in place on the probe. For each calibration, the probe is placed in the push frame and loaded onto a precision reference load cell. The reference load cell is periodically calibrated against instruments traceable to National Institute of Standards and Technology (NIST). To calibrate the pore pressure transducer, the saturated probe is inserted into a pressure chamber with air pressure supplied by the compressor on the truck. The reference transducer in the pressure chamber is also periodically calibrated against an NIST traceable instrument. Additionally, the string potentiometer used to measure the depth of penetration is periodically checked against a tape measure.

Each instrument is calibrated using a specially developed computer code that displays the output from the reference device and the probe instrument in graphical form. During the calibration procedure, the operator checks for linearity and repeatability in the instrument output. At the completion of each calibration, this code computes the needed calibration factors using a linear regression algorithm. As a minimum, each probe instrument is

calibrated at the beginning of each field test. Furthermore, the pressure transducer is recalibrated each time the porous filter is changed and the cone penetrometer resaturated. If damage is suspected, calibrations are conducted on the instruments to confirm operability.

Friction sleeve measurements are difficult to obtain and prone to error, so additional operating procedures were used to ensure quality data. The three primary sources of error in the sleeve measurements are: (1) wear, (2) soil in the sleeve, and (3) heating. Wear occurs as a result of diameter variations along the length of the sleeve. When one of these occur, the sleeve may not experience the true lateral earth pressures. Soil jamming occurs when native soils become lodged between the sleeve and cone penetrometer. A mud block is in place to prevent this, however, penetration through dense layers and extensive cycling often results in loss or destructions of the mud block. The third source of error is caused by heating of the friction sleeve load cell. This may occur as the probe penetrates through extremely dense soils with high frictional properties or when cycling. The heat generation creates elevated local temperatures that causes the strain gage bridge to exhibit a thermal induced drift. Pausing or cycling will allow the probe to return to normal temperatures.

2.2.3 Penetration Data Format

The penetration pore pressure, which is measured as the probe is advanced, is plotted in Figure 3. As shown in Figure 2, the piezo-cone penetrometer probe senses the pore pressure immediately behind the tip. Currently, there is no accepted standard for the location of the sensing element. ARA chose to locate the sensing element behind the tip since the filter is protected from the direct thrust of the cone penetrometer and the measured pore pressure can be used to correct the tip resistance data (Section 2.2.4) (Robertson and Campanella, 1988). The magnitude of the penetration pore pressure is a function of the soil compressibility and, most importantly, permeability. In freely draining soil layers, the measured pore pressures will be very close to the hydrostatic pressure computed from the elevation of the water table. When low permeability soil layers are encountered, excess pore pressures generated by the penetration process cannot dissipate rapidly, which results in measured pore pressures that are significantly higher than the hydrostatic pressures. When the cone penetrometer is stopped to add another section of push tube, or when a pore pressure dissipation test is run, the excess pore pressure may begin to dissipate. When the penetration is resumed, the pore pressure quickly rises to the level measured before the penetrometer was stopped. This process causes some of the spikes that appear in the penetration pore pressure data.

2.2.4 Pore Pressure Correction of Tip Stress

Cone penetrometers must have a joint between the tip and sleeve. Pore pressure behind the tip decreases the total tip resistance that would be measured if the cone penetrometer was without joints. The influence of pore pressure in these joints is compensated for by using the net area concept

(Robertson and Campanella, 1988). The corrected tip resistance is given by:

$$q_T = q_c + u \left(1 - \frac{A_n}{A_T} \right) \quad (1)$$

where:

- q_T = corrected tip resistance (psi)
- q_c = measured tip resistance (psi)
- u = penetration pore pressure measured behind the tip (psi)
- A_n = net area behind the tip not subjected to the pore pressure (1.257 in²)
- A_T = projected area of the tip (1.550 in²).

Hence, the tip resistance is corrected for the ARA cone design as:

$$q_T = q_c + u(.1890) \quad (2)$$

Laboratory calibrations have verified Equation 2 for ARA's piezo-cone penetrometer design.

Another joint is behind the top of the sleeve (Figure 2). However, since the sleeve is designed to have the same cross-sectional area on both ends, the pore pressures acting on the sleeve cancel out. Laboratory tests verified that the sleeve is not subjected to unequal end area effects. Thus, no correction for pore pressure is needed for the sleeve friction data.

The net effect of applying the pore pressure correction is to increase the tip resistance. Generally, this correction is only significant when the measured tip resistance is very low.

2.2.5 Numerical Editing of the Penetration Data

When the CPT is stopped or pulled back during a test, misleading data can result; i.e., when the probe is stopped to add the next push tube section or when a pore pressure dissipation test is run, the excess pore pressures dissipate towards the hydrostatic pore pressure. When the penetration is resumed, the pore pressure generally rises very quickly to the pressures experienced prior to the pause in the P-CPT. Additionally, the probe is sometimes pulled back and cycled up and down at intervals in deep holes to reduce soil friction on the push tubes. This results in erroneous tip stress data when the cone penetrometer is advanced in the previously penetrated hole.

To eliminate this misleading data from the penetration profile, the data is numerically edited before it is plotted or used in further analysis. Each time the cone penetrometer stops or backs up (as apparent from the depth data) the penetration data is not plotted. Plotting of successive data is resumed only after the tip is fully re-engaged in the soil by one tip length (1.22 in). This algorithm also eliminates any data acquired at the ground surface before the tip has been completely inserted into the ground. The sleeve data is similarly treated and this results in the first data point not occurring at the ground surface, as can be seen in the tip and sleeve profiles

of Figure 3. These procedures ensure the penetration data that is plotted and used for analysis was acquired with the probe advancing fully into undisturbed soil.

3.0 DATA ANALYSIS

3.1 SOIL CLASSIFICATION

The tip and sleeve resistance and pore pressure values from CPT profiles (Figure 3) can be used to determine soil classification versus depth. Both methods of soil classification use the empirical chart proposed by Robertson (1990) as shown in Figure 4. The soil classification is determined from the charts by using the corrected tip stress (q_T) in bars and pore pressure ratio (B_q or normalized friction ratio of f_{SN}). The pore pressure ratio is defined as:

$$B_q = \frac{u_{meas} - u_0}{q_T - \sigma_{v0}} \quad (3)$$

where:

- u_{meas} = measured penetration pore pressure
- u_0 = static pore pressure, determined from the water elevation
- q_T = corrected tip resistance
- σ_{v0} = total overburden stress.

and the normalized friction ratio is defined as:

$$f_{SN} = \frac{f_s}{q_T - \sigma_{v0}} \times 100\% \quad (4)$$

The intersection point of the q_T and B_q or f_{SN} values normally falls in a classification zone. The classification zone number corresponds to a soil type as shown in Figure 3. The classification zone number is plotted versus elevation. At some depths, the P-CPT data will fall outside the range of the classification chart. When this occurs, no data is plotted and a break is seen in the classification profile. Soil classifications for this work were determined using only the friction ratio chart in Figure 4.

3.2 TYPICAL SUBSURFACE CONDITIONS AT THE MCGEE RANCH SITE

The subsurface conditions of the McGee Ranch test site can generally be classified as a uniform silty sand. There are two apparent zones in the northern parts of the site and three in the southeast parts of the site; however, the differences in these zones are very slight. In the southeast the upper 3 ft classifies as a sand to silty sand. There is a transition to stiff sand to clayey sand, which is consistent to a depth of approximately 10 to 12 ft. Below the 10-ft material to the refusal depth, alternating fine sand and cemented silty sand materials are present. In the northern locations the stiff sand to clayey sand is found at the surface to the approximately

10 to 12 ft. The alternating pattern of fine sands and cemented silty sands is encountered again below 10 ft to the refusal depth.

3.3 COMPARISON OF P-CPT DATA TO BORING LOGS

Direct comparisons between the cone penetrometer penetration profiles and the boring logs are presented in this section. These comparisons were made to show how P-CPT based soil classifications relate to the visual classifications made by the site geologist.

3.3.1 Location P-II-1

The P-CPT profile for this location (Figure 5) indicates four separate layers of material. The first layer is a very fine sand to sandy silt material that extends from the ground surface to an elevation of 812 ft. This interpretation agrees with the geologist log (Figure 6) of a silty loam material from the ground surface to an elevation of 815 ft.

The first layer is followed by a very similar material from elevation 812 to 806 ft. This material is a silt material (friction ratio of approximately 2) with fewer fines than the upper material. This layer also contains more interbedding (i.e., a high variability in the friction ratio profile) than the upper material. The geologist's log of this layer describes the material as alternating silt loam and very fine sandy loams. The geologist's log notes that this layer represents the upper portion of the Touchet Beds, which contains less fine material than the lower portion of the Touchet Beds.

For the lower portion of the Touchet Beds, the geologist's logs indicate that the material is alternating silt loams, silty sand and sand loams. The P-CPT profile for this location presents this material as two slightly different sections, which are both clayey silts and appear to contain more fines than the layer immediately above. The first section extends from elevation 806 to 798 ft. This material is highly interbedded with silty clay seams, silt seams, and very fine sand seams. The lower section extends from elevation 798 to 794.5 ft and has the same general material, except the material is more uniform and not nearly as interbedded. The P-CPT profile was concluded in a gravelly or dense sand material at an elevation of 793.5 ft.

Two other aspects of this particular profile should be noted. First, the data between elevation 804 and 804.5 ft appears to be bad due to an operator error during some cycling that occurred during penetration. The second aspect is the missing data from elevation 799.5 to 798 ft. At an elevation of 799.5 ft, the P-CPT was stopped and the rods were pulled out to add rods with expanders to reduce rod friction and increase penetration. After the rod shift was made, the operator accidentally penetrated to 798 ft before turning on the data acquisition system.

3.3.2 Location P-II-2

The cone penetration profile for location P-II-2 (Figure 7) presents five layers of materials. The first layer is the very fine sand or silt material that represents the topsoil material at the McGee Ranch site. This material extends from the ground surface down to an elevation of 808 ft. Below this material is the upper portion of the Touchet Beds. This material is characterized by a friction ratio of approximately 4 and only minor interbedding. The pore pressure profile indicates that this material may be moist. The upper two materials are very similar to the geologist's log (Figure 8), which presents a silt loam material from the ground surface to elevation 807.1 ft and silt loam to very fine sandy loam material below that to an elevation of 798.1 ft. The geologist's log notes that the second material represents the upper portion of the Touchet Beds.

The third material is the lower portion of the Touchet Beds. This material has a friction ratio of approximately 2, indicating coarser grained materials than the upper portions of the Touchet Beds. This material extends from elevation 799 to 794 ft and is followed by another layer of material that is very similar to the upper portions of the Touchet Beds. This material has an average friction ratio of approximately 3.5 and is slightly interbedded. Two sand seams are evident in both the sleeve stress and friction ratio profiles at elevations of 792.5 and 791 ft. The penetration ended at an elevation of 788 ft in a sand and cemented basalt pebble material, which was the cause of refusal in a majority of the profiles.

The geologist's log presents a silt loam, silty sand, and sandy loam from elevation 798.1 to 787.3 ft. This agrees with the P-CPT profile from elevation 799 to 794 ft, but does not present the shift to a fine grained material, which the P-CPT identifies from elevation 794 to 789.5 ft. The geologist's log and the P-CPT identify a change to a sandy or pebble type material at an elevation of 788 ft.

3.3.3 Location P-II-3

The P-CPT P-II-3 was one of the shallower penetrations made during the McGee Ranch demonstration. Three layers of material were identified as presented in Figure 9. The first material extends from the ground surface to an elevation of 804.5 ft. This material is a uniform silty clay as evident from an average ratio friction ratio of 3.5. The material appears to be moist and gradually becomes denser with depth. From elevation 804.5 to 800.5 ft the material becomes highly interbedded with numerous thin silt and very fine sand seams interbedded with the silty clay. The geologist's log (Figure 10) indicates a silt loam from elevation 815.8 to 811.8 ft and layers of alternating silt loam and very fine sandy loam from 811.8 ft to 801.6 ft.

From elevation 800.5 ft to the end of the profile at elevation 796 ft, a silty sand or very fine sand material is present as evident by the reduction in friction ratio to approximately 1. This material is also highly interbedded with both fine sand and silt materials. This material agrees with the geologist's log of alternating silty loam, sandy loam, and silty sand. The geologist's logs state that this material is the lower portion of the Touchet Beds, and is predominantly sandy, compared to the upper Touchet Beds, which is predominantly silty. The P-CPT profile agrees with these findings.

3.3.4 Location P-II-4

The P-CPT data at this location reveals typical conditions as shown in Figure 11. The upper 3 ft shows increasing tip and sleeve stresses and classifies as a sand to silty sand near the surface and transitions to stiff sand to clayey sand near elevation 808 ft. The geologist's logs (Figure 12) classify the upper 3.9 ft of this material as a silt loam, reflecting a mixture of sand and silt sized particles.

The zone between elevation 808 and 798 ft is uniform, as revealed in the consistent tip and sleeve stress values of 3,000 psi and 80 psi, respectively. Small zones of variable sleeve stress are encountered as the soils types change between clayey sand and silty sand. Two clear silty sand seams can be seen at elevation 804 and 800.5 ft. In general, this zone compares well with the geologist's description of the 3.9 to 10 ft depth interval, described as silt loam and sandy loam. The geologist notes the location of the Touchet Beds that would cause the apparent detection of cementation. Alignment in a parallel orientation of platy fine-grained particles may be the source of the apparent cementation.

Below elevation 796 ft until refusal at 784 ft, the cone penetrometer encountered alternating sand and cemented silty sand zones. This alternation is exhibited in the friction ratio profile of approximately 2 and soil classification profile of 6 (sands - clean sand to silty sand). The geologist described the zone between 10 and 26 ft depth as alternating silt loam, silty sand, and sandy loam typical of the lower portion of the Touchet Beds. Overall, the P-CPT soil stratigraphy and the geologist descriptions are in agreement and indicate mixed soils containing sand and silt size particles.

3.3.5 Location P-II-5

Uniform subsurface conditions are also observed at this P-CPT location. The classification profile (Figure 13) reveals a very stiff sand to clayey sand extending from elevation 819 to 805 ft. The tip stress and sleeve stress values confirm this classification of 3,000 psi and above, and 80 psi and above, respectively. The geologist's log (Figure 14) reveals a sand loam from the surface to a depth of 5 ft. This material is fairly uniform with only an occasional fine sand seam (i.e., elevation 811.5, 807.5, and 806 ft).

At elevation 805 ft down to refusal at elevation 792 ft, clean sands to silty sands are encountered that alternate with the cemented silty sand layers. This is also observed on the P-CPT profile. The sleeve stresses tend to fluctuate rapidly in this material indication interbedding. A general decreasing trend in the tip resistance is also present. The friction ratio is generally decreased from 2.5 to 1.7 throughout this material. The geologist describes alternating silt loam with very fine sandy loams from 5 ft deep to 29 ft, agreeing with the P-CPT results.

3.3.6 Location P-II-6

From elevation 825 to 817 ft a stiff fine grained sand material is encountered (Figure 15). This classification corresponds to the geologists description of a silt loam from the surface to a depth of 5 ft (Figure 16).

Tip stress remains fairly constant at 2,000 psi to 3,000 psi and sleeve stresses of 100 psi are typical in this material. These values correspond to a friction ratio of 3.5 to 4.0. This material is highly uniform with one sand seam at elevation 818 ft.

From elevation 817 to 812 ft a zone of highly interbedded materials is detected as represented by the friction ratio profile of approximately 1. This material is typical of the upper portions of the Touchet Beds and is predominantly fine grained silts or clays. The geologist's description compares with the P-CPT results and is consistent with the other locations. The alternating silt loam and very fine sandy loam is reported from 5 to 26 ft deep. The lower portion of the Touchet Beds begins at elevation 812 and extends to 801 ft. Again, this portion of the Touchet Beds is predominantly sandy as represented by the lower friction ratio (approximately 1) than in the upper Touchet Beds (friction ratio greater than 3). Overall, the geologist's log and the P-CPT profiles agree.

3.3.7 Location P-II-7

The penetration profile at P-II-7 is slightly different from the other profiles because the material is fairly uniform and interbedding appears to be reduced. The entire profile (Figure 17) has friction ratio of approximately 4 from elevation 824 ft to the end of the penetration. This friction ratio indicates a silty clay material. Overall, this material is not highly interbedded, although there is some bedding present in the profiles. Four particular layers stand out. The first two are thin clay seams at elevation 815 and 814 ft. These two layers are present in the friction ratio profile as values of 6. The other two layers are thin sand seams (i.e., reduced friction ratios of 2) at elevation 809 and 806 ft.

The geologist's log (Figure 18) for the neighboring boring indicates a silt loam at the surface that extends to an elevation of 824.5 ft. Below this, the geologist notes that alternating silt loam and very fine sandy loams exist to an elevation of 800.5 ft. The log also notes that at this location there is no significant difference in grain size or sand content between the upper and lower part of the Touchet Beds. The consistent friction ratio profile of 4 or greater (which is sensitive to grain size) also shows no grain size variances between the upper and lower portions of the Touchet Beds.

3.3.8 Location P-II-8

The penetration profile for location P-II-8 (Figure 19) presents three material types. From the ground surface to an elevation of 817 ft a silty or very fine sand material is present. The fine content of this material increases with depth. From elevation 817 to 806 ft a fairly uniform silty clay material is present. This material is identified by a friction ratio value of approximately 4, which is fairly consistent. Penetration pore pressures of 2 psi indicate this material may be moist and is fairly uniform. Below elevation 817 to the end of the penetration at elevation 798 ft, the friction ratio decreases to approximately 2.5 and becomes much more sporadic. This material is a silty material that is highly interbedded. This material is typical of the lower Touchet Beds, in that the lower portion contains fewer fine grained materials than the upper portion.

The geologist's logs (Figure 20) tend to agree with the P-CPT results for the upper two materials, but do not present clear identification of the lower Touchet Beds. The logs identify two layers. The first layer extends from the ground surface to elevation 818 ft and is a silty loam. The second layer extends to an elevation of 797.4 ft, which is below the P-CPT penetration profile, and consists of alternating silt loam and very fine sandy loam. The geologist's logs clearly indicate no significant grain size difference exists between the upper and lower portions of the Touchet Beds, although the P-CPT profile clearly indicates an upper and lower portion showing the same trends seen at other locations.

3.3.9 Location P-II-9

The final penetration profile conducted at McGee Ranch site was at location P-II-9. This P-CPT profile is presented in Figure 21 and identifies two separate layers. The first layer extends from the ground surface to an elevation of 817.5 ft. This material is a silty clay with a friction ratio of approximately 4. In addition, this material is fairly uniform. From elevation 817.5 to the end of the penetration profile, a stiff silty clay material is present as indicated by the soil classification profile. This material is highly interbedded and contains slightly more fine grained material than either the upper material or other material at this site as presented in the friction ratio profile. Two thin sand seams are identified (friction ratio decreases to approximately 2) in the profile at elevations of 808.5 and 802.5 ft.

The geologist's logs for this location (Figure 22) indicate a silty loam material from the ground surface to an elevation of 821 ft. Below this, alternating layers of silt loam and very fine sandy loam are present. At this location the geologist's logs indicate there is more significant grain size or sand content differences between the upper and lower portions of the Touchet Beds, agreeing with the P-CPT results.

The end of the P-CPT profile, as with many of the other locations, occurs in a material consisting of sand and basalt pebbles with extensive carbonate cementation.

3.4 DISCUSSION OF PORE PRESSURE RESPONSE

Examination of the P-CPT penetration pressure data generally indicates positive pore pressures throughout the profile. The water table at these locations is below the P-CPT refusal depth. Positive penetration pore pressures can be observed in the vadose zone if the soils are nearly saturated and have a low permeability. Positive penetration pore pressures can also be measured in a perched water table (which is not believed to occur at this site). The P-CPT penetration pore pressure response is interpreted to indicate that these soils are nearly saturated, have a low permeability, and a significant fine grained soil content. Variations in the penetration pore pressure response with depth is principally a function of the fine grained soil content. Zones with few fines will have very low (or zero) pore pressures, while zones with high pore pressures contain more fine grained soils. An example can be seen at location P-II-6 (Figure 15). To elevation 821 ft the pore pressures are positive but low, indicating some fine grained

material. At elevation 821 ft the pore pressure increases indicating an increase in fines content to elevation 814 ft where the pressure begins to decrease. From elevation 814 to 810 ft the pore pressure decreases indicating reduced fine grain content. To refusal at elevation 803 ft, the pore pressure is relatively constant indicating little variation in the fines content. The P-CPT indicates a variation in the fines content at this location with the Touchet Beds having the greatest fines content at elevation 814 ft.

3.5 SITE CONSISTENCY

The subsurface conditions described are generally consistent throughout the McGee Ranch site. To show this consistency, two overlay plots and four cross-section plots have been produced. On these overlay plots, the tip stress, sleeve stress and ratio profiles from several plots are overlaid on one plot. Figure 23 has the curves from locations P-II-4, P-II-5, and P-II-6 overlaid on it, representing a cross section along the west boundary for the test matrix. Figure 23 shows that the material at the different locations is consistent in terms of layering. Figure 24 has the curves from locations P-II-4, P-II-6, P-II-8 and P-II-2 (the four corners), along with P-II-9, the center location. In both these figures the tip stresses are highly consistent and vary by no more than approximately 1,000 psi. The sleeve stresses show additional scatter, but sleeve measurements are much more sensitive and difficult to measure as presented in Section 2.0. In addition, the sleeve stress and friction ratio profile varies dramatically due to various changes in the fine grained soil content, to which the friction sleeve is sensitive. Overall, the comparisons are favorable and indicate uniform site characteristics.

The cross-section plots in Figures 25 through 28 are along the diagonals across the test matrix. Figure 25 and 26 present the tip stress variations, and Figures 27 and 28 present the friction ratio profiles. These plots again show the consistency of the layering and the three major layers of material. The first layer is a fairly uniform very fine sand to silty material that extends to a depth of approximately 4 to 6 ft in all profiles. Below this material are highly interbedded sequences of silts and fine sands. Below the topsoil material is the Touchet Beds materials. This material is a highly interbedded silty clay to sandy silt material. In the majority of profiles, this material can be broken into an upper and lower portion of the Touchet Beds. The upper part is generally finer grained and not quite as interbedded as the sandier lower portion. In the four cross sections presented, the break between the upper and lower portion can be identified at each of the four corners, but can only be estimated in the center profile P-II-9. This uncertainty is presented in the figures as a dashed line. The third major material presented in the cross sections is a cemented sand and basalt pebbles. All penetration profiles were terminated either near the surface of this layer or just into this material. In summary, these cross sections of P-CPT profiles present a consistent uniform layering sequence across the test area.

4.0 SUMMARY AND CONCLUSIONS

A time study of P-CPT operations was performed to determine the production rate during the McGee Ranch investigation. Using a production time value, which includes only the time the P-CPT truck was at each hole (the average production rate for the 280 lineal feet of sounding conducted) is 403 ft/day. If set-up time, move time, and calibration time are included in the production time the actual realized production rate for the McGee Ranch site was 247 ft/day or approximately 10 25-ft holes/day. These production rates are based on a 10-hr work day and in general are typical of P-CPT operations.

To produce a cost breakdown of the work performed, the rate of \$3,000.00/day was used. The work at McGee Ranch site required one half day of setup and approximately 11 hr of testing. Using these times and rate, the cost for the nine locations was approximately \$17.50/ft or \$450.00 per 25-ft hole. This cost represents an upper bound: in a production mode the production rate can be expected to increase.

The results of the tests from the nine locations at the McGee Ranch site have shown the P-CPT method to be a cost effective and time efficient means of characterizing this site. The high resolution of the cone penetrometer has produced a detailed and accurate description of the subsurface conditions. The type of results produced allow for a quantitative comparison of different site locations by means of the overlay plots. This type of comparison is an excellent method for determining the consistency of the materials located at the site, which is an important aspect of the investigation at the McGee Ranch site. Additional analysis of the digital P-CPT data can be conducted to develop statistical measures of the site variability, to include developing contour maps of soil type and variability in three dimensions.

5.0 REFERENCES

- American Society for Testing and Materials, "Standard Method for Deep Quasi-static, Cone and Friction-Cone Penetration Tests of Soil," ASTM Designation: D3441, 1986.
- Robertson, P. K., and R. G. Campanella, "Guidelines for Using the CPT CPTU and Marchetti DMT for Geotechnical Design," Volume II, University of British Columbia, Vancouver, BC, Canada, March 1988.
- Robertson, P. K., "Soil Classification Using the Cone Penetration Test," Canadian Geotechnical Journal, Volume 27, No. 1, February 1990.
- Skelly, W. A., 1992, *Characterization Plan for Fine-Textured Soils in the McGee Ranch Site Vicinity*, WHC-SD-EN-AP-051, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Table 1. Summary of P-CPT Test Locations.

CPT LOCATION	DATE	NORTHING (FEET)	EASTING (FEET)	DEPTH (FEET)	ELEVATION (FEET)
CPT-P11-1	14-Apr-93	457217	457110	19.0	818.4
CPT-P11-2	14-Apr-93	457018	457102	25.0	812.6
CPT-P11-3	14-Apr-93	457018	457110	20.0	818.4
CPT-P11-4	14-Apr-93	457014	456706	26.6	809.9
CPT-P11-5A	15-Apr-93	457215	456720	27.5	819.3
CPT-P11-6	15-Apr-93	457413	456719	23.0	825.6
CPT-P11-7	15-Apr-93	457416	456917	28.2	828.8
CPT-P11-8A	15-Apr-93	457419	457119	24.2	822.2
CPT-P11-9	15-Apr-93	457218	456911	30.0	825.1

WAS\122892-L

Figure 1. Site Map of the McGee Ranch Showing Locations of the Nine P-CPT.

Figure 2. Schematic of ARA's Cone Penetrometer Probe.

CPT-P11-7

APPLIED RESEARCH ASSOCIATES, INC.

04/15/93

North 457416.908

East 456917.157

Elevation 828.8

Figure 3. Typical Penetration Profile from the McGee Ranch Site.

Figure 4. Soil Classification using the P-CPT (Robertson 1990).

Figure 5. P-CPT Data from Location P-II-1 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Soil Classification Numbers

- 1 - Sensitive Fine Grained
- 2 - Organic Soils - Peat
- 3 - Clays - Clay to Silty Clay
- 4 - Silt Mixtures - Clayey Silt to Silty Clay
- 5 - Sand Mixtures - Silty Sand to Sandy Silt
- 6 - Sands - Clean Sand to Silty Sand
- 7 - Gravelly Sand to Sand
- 8 - Very Stiff Sand to Clayey Sand*
- 9 - Very Stiff, Fine Grained*

*Cemented or Overconsolidated

**Figure 5. P-CPT Data from Location P-II-1 at the McGee Ranch
 Showing Soil Classification Information. (sheet 2 of 2)**

Borehole P-II-1 (Position 3,2)

<u>Elevation (ft)</u>	<u>Description</u>
818.4 - 815.4	Silt loam: dark gray brown (2.5 Y 4/2) in upper 0.7' (root zone), light yellow brown (2.5 Y 6/3) below; massive to blocky structure; eolian origin. Vigorous reaction to HCl below root zone; limonite staining associated with zones of heaviest carbonate accumulation.
815.4 - 805.4	Alternating silt loam and very fine sandy loam: light yellow brown (2.5 Y 6/3) to light gray (2.5 Y 7/2); consisting of laminated and thin-bedded sand and silt units; some sand-silt pairs represent individual upward-fining sequences. This interval corresponds to the upper part of the Touchet Beds. At this location, the Touchet Beds can be divided into an upper part, which appears to be predominantly silty, and a lower part, which appears to be predominantly sandy. Reaction to HCl is vigorous throughout (strongest in silts).
805.4 - 792.4	Alternating silt loam, silty sand and sandy loam: colors and structures as above. This interval corresponds to the lower part of the Touchet Beds.
792.4 - 784.4	Sand, silty sand, and gravelly sand, with extensive carbonate (caliche) cementation: pinkish gray color. Gravels are pebble-sized basalt clasts. This interval is interpreted to be the top of the Ringold Formation, which exhibits a well-developed paleosol.

Figure 6. Geologist's Log for Borehole P-II-1.

Figure 7. P-CPT Data from Location P-II-2 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 7. P-CPT Data from Location P-II-2 at the McGee Ranch
 Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-2 (Position 3,3)

<u>Elevation (ft)</u>	<u>Description</u>
812.6 - 807.1	Silt loam: pale yellow (2.5 Y 7/3); massive to tabular structure; eolian origin. Strong reaction to HCl throughout; carbonate stringers infilling burrows and/or root casts.
807.4 - 798.1	Silt loam and very fine sandy loam: dull yellow (2.5 Y 6/3) to light yellow (2.5 Y 7/3); consisting of laminated and thin-bedded, alternating silt and sand units. Individual beds average 0.3 to 1.5 ft thick; lamination within beds are 3 to 4 mm thick. Several clastic dikes, infilled with fine sand, occur between 8 and 10 ft. At this location, the Touchet Beds can be divided into an upper part, which appears to be predominantly silty, and a lower part, which exhibits increased sand content. This interval corresponds to the upper part of the Touchet Beds.
798.1 - 787.3	Silt loam, silty sand and sandy loam: colors and stratifications as above. This interval corresponds to the lower part of the Touchet Beds. Sands are more numerous and coarser than above, ranging from very fine to medium grained.
787.3	Cemented sand and gravelly sand; heavy carbonate (caliche) cementation. Gravels are basalt clasts. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 8. Geologist's Log for Borehole P-II-2.

Figure 9. P-CPT Data from Location P-II-3 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 9. P-CPT Data from Location P-II-3 at the McGee Ranch
 Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-3 (Position 2,3)

<u>Elevation (ft)</u>	<u>Description</u>
815.8 - 811.8	Silt loam: pale yellow (2.5 Y 7/3); with root zone in uppermost 0.5 ft. Vigorous reaction to HCl throughout.
811.8 - 801.6	Alternating silt loam and very fine sandy loam, moist: light olive brown (2.5 Y 5/3) to olive gray (2.5 Y 4/3); interval consists of laminated and thin-bedded sands and silts; some sand-silt pairs represent individual upward-fining sequences. This interval corresponds to the upper part of the Touchet Beds. At this location, the Touchet Beds can be divided into an upper part, which appears to be predominantly silty, and a lower part, which appears to be predominantly sandy. Vigorous reaction to HCl throughout.
801.6 - 788.0	Alternating silt loam, sandy loam and silty sand: colors and structures as above. This interval corresponds to the lower part of the Touchet Beds.
788.0	Gravel with carbonate (caliche) cementation; this horizon is interpreted as the paleosol marking the top of the Ringold Foundation.

Figure 10. Geologist's Log for Borehole P-II-3.

Figure 11. P-CPT Data from Location P-II-4 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 11. P-CPT Data from Location P-II-4 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-4 (Position 1,3)

<u>Elevation (ft)</u>	<u>Description</u>
809.9 - 806.0	Silt loam: light yellow brown (2.5 Y 6/3), changing to pale yellow (2.5 Y 7.3) near the bottom; root zone and organic matter present in upper most 6 in.; eolian origin. Moderate to vigorous reaction to HCl throughout, increasing with depth.
806.0 - 799.9	Alternating silt loam and very fine sandy loam: pale yellow (2.5 Y 7/3) and light yellow brown (2.5 Y 6/3); made up of laminated and thin-bedded sands and silts. At this location the Touchet Beds are divisible into a silty upper part and a sandy lower part. This is the upper Touchet Beds interval. Vigorous reaction to HCl throughout.
799.9 - 783.4	Alternating silt loam, silty sand and sandy loam: colors and structures as above. Lowest 1.0 ft is a single bed of clean, very fine sand. This is the lower Touchet Beds interval. Moderate to strong reaction to HCl throughout.
783.4	Sand and gravelly sand, with heavy carbonate (caliche) cementation. This horizon is interpreted as the top of the Ringold Formation. Pinkish white or gray color (logged as 7.5 YR 8/2).

Figure 12. Geologist's Log for Borehole P-II-4.

Figure 13. P-CPT Data from Location P-II-5 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 13. P-CPT Data from Location P-II-5 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-5 (Position 1,2)

<u>Elevation (ft)</u>	<u>Description</u>
819.3 - 814.3	Silt loam: pale yellow (2.5 Y 7/3), with root zone in upper 0.5 ft; massive structure, lacking internal stratification; eolian origin. Vigorous reaction to HCl.
814.3 - 790.3	Alternating silt loam and very fine sandy loam: colors under moist conditions are light olive brown (2.5 Y 5/3) to olive gray (2.5 Y 4/3); consisting of laminated and thin-bedded sands and silts; some sand-silt pairs represent individual upward-fining sequences. This interval corresponds to the Touchet Beds. At this location, the lower part of the Touchet Beds is not notably sandier than the upper part. Strong reaction to HCl throughout.
790.3	Sand and gravelly sand, with extensive carbonate (caliche) cementation; gavel are pebble-sized basalt clasts. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 14. Geologist's Log for Borehole P-II-5.

Figure 15. P-CPT Data from Location P-II-6 at the McGee Ranch
Showing Soil Classification Information. (sheet 1 of 2)

Figure 15. P-CPT Data from Location P-II-6 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-6 (Position 1,1)

<u>Elevation (ft)</u>	<u>Description</u>
825.6 - 820.6	Silt loam: light olive brown (2.5 Y 5/3), grading lower to pale yellow (2.5 Y 7/3), with root zone and accumulated organic matter in upper 0.7 ft; massive structure, lacking internal stratification; eolian origin. Vigorous reaction to HCl throughout.
820.6 - 799.6	Alternating silt loam and very fine sandy loam; dry colors are light yellow brown (2.5 Y 6/3) to pale yellow (2.5 Y 7/3), olive brown when wet; consisting of laminated and thin-bedded sands and silts; some sand-silt pairs represent individual upward fining sequences. This interval corresponds to the Touchet Beds. At this location, the lower part of the Touchet Beds is not notably sandier than the upper part. Strong reaction to HCl throughout.
799.6	Sand and basalt pebbles, with extensive carbonate (caliche) cementation: caliche is pinkish white. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 16. Geologist's Log for Borehole P-II-6.

Figure 17. P-CPT Data from Location P-II-7 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 17. P-CPT Data from Location P-II-7 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-7 (Position 2,1)

<u>Elevation (ft)</u>	<u>Description</u>
878.8 - 824.6	Silt loam: light olive brown (2.5 Y 5/3), grading lower to light gray (2.5 Y 7/2), with root zone and organic matter in upper 0.6 ft; massive structure, lacks internal stratification; eolian origin. Vigorous reaction to HCl throughout; interval contains numerous thin lenses with elevated carbonate content.
824.6 - 800.5	Alternating silt loam and very fine sandy loam: light olive brown (2.5 Y 5/3) to light yellow brown (2.5 Y 6/3) - moist; consisting of laminated and thin-bedded sands and silts; some sand-silt pairs represent individual upward-fining sequences; clastic dike between about 8 and 9.5 ft. This interval corresponds to the Touchet Beds. At this location, there is no significant difference in grain size or sand content between the upper and lower parts of the Touchet Beds interval. Strong reaction to HCl throughout.
800.5	Sand and basalt pebbles, with extensive carbonate (caliche) cementation. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 18. Geologist's Log for Borehole P-II-7.

Figure 19. P-CPT Data from Location P-II-8 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Soil Classification Numbers

- 1 - Sensitive Fine Grained
- 2 - Organic Soils - Peat
- 3 - Clays - Clay to Silty Clay
- 4 - Silt Mixtures - Clayey Silt to Silty Clay
- 5 - Sand Mixtures - Silty Sand to Sandy Silt
- 6 - Sands - Clean Sand to Silty Sand
- 7 - Gravelly Sand to Sand
- 8 - Very Stiff Sand to Clayey Sand*
- 9 - Very Stiff, Fine Grained*

*Cemented or Overconsolidated

**Figure 19. P-CPT Data from Location P-II-8 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)**

Borehole P-II-8 (Position 3,1)

<u>Elevation (ft)</u>	<u>Description</u>
822.2 - 818.2	Silt loam: pale yellow (2.5 Y 7/3); with root zone and organic matter in upper part; massive structure; eolian origin. Vigorous reaction to HCl throughout.
818.2 - 797.4	Alternating silt loam and very fine sandy loam: light olive brown (2.5 Y 5/3) to pale yellow (2.5 Y 7/3) - dry; consisting of laminated and thin-bedded sands and silts. This interval corresponds to the Touchet Beds. At this location, there is no significant difference in grain size or sand content between the upper and lower parts of the Touchet Beds interval. Strong reaction to HCl throughout.
797.4	Sand and basalt pebbles, with extensive carbonate (caliche) cementation. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 20. Geologist's Log for Borehole P-II-8.

Figure 21. P-CPT Data from Location P-II-9 at the McGee Ranch
 Showing Soil Classification Information. (sheet 1 of 2)

Figure 21. P-CPT Data from Location P-II-9 at the McGee Ranch
Showing Soil Classification Information. (sheet 2 of 2)

Borehole P-II-9 (Position 2,2)

<u>Elevation (ft)</u>	<u>Description</u>
825.1 - 821.1	Silt loam with small pebbles: pale yellow (2.5 Y 7/3); with root zone and organic matter in upper 0.6 ft; no apparent structure; predominantly eolian origin, possibly containing some colluvial material.
821.1 - 794.4	Alternating silt loam and very fine sandy loam: light olive brown (2.5 Y 5/3) to pale yellow (2.5 Y 7/3); consisting of laminated and thin-bedded sands and silts; clastic dikes occur between 14-16 ft and 19-21 ft. Isolated basalt pebbles occur at about 25.3 ft. This interval corresponds to the Touchet Beds. At this location, there is no significant difference in grain size or sand content between the upper and lower parts of the Touchet Beds interval. Strong reaction to HCl throughout.
794.4	Sand and basalt pebbles, with extensive carbonate (caliche) cementation. This horizon is interpreted as the paleosol at the top of the Ringold Formation.

Figure 22. Geologist's Log for Borehole P-II-9.

Figure 23. Comparison Plot of the Tip and Sleeve Stress Profiles from Locations P-II-4, P-II-5, and P-II-6 at McGee Ranch.

Figure 24. Comparison Plot of the Tip and Sleeve Stress Profiles from Locations P-II-4, P-II-6, P-II-8, P-II-2, and P-II-9 at McGee Ranch.

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Figure 25. Cross Section of Tip Stress Profiles along the Northeast Diagonal of the Test Matrix at McGee Ranch.

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Figure 26. Cross Section of Tip Stress Profiles along the Northwest Diagonal of the Test Matrix at McGee Ranch.

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Figure 27. Cross Section of Friction Ratio Profiles along the Northeast Diagonal of the Test Matrix at McGee Ranch.

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MCGEE RANCH, HANFORD

Figure 28. Cross Section of Friction Ratio Profiles along the Northwest Diagonal of the Test Matrix at McGee Ranch.

**DATE
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12 / 14 / 93

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