ATTACHMENT 4
RFP NO. RAM-7-77539

NWTC SOILS REPORT

CTC-GEOTEK

ENGINEERING TESTING INSPECTION

SOIL AND FOUNDATION INVESTIGATION

Expansion - Phase I
National Wind Technology Center
SE of Colorado Highways 93 & 128
Jefferson County, Colorado

PREPARED FOR:

National Renewable Energy Laboratory
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Attention: Mr. Eric Telesmanich

Project 942009 February 17, 1994

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SUMMARY

(1) Our borings encountered somewhat variable, generally granular, overburden soils consisting mostly of silty, clayey, sand and gravel with cobbles and perhaps boulders. Groundwater levels are at depths of approximately 3-1/2 to 8 feet.

(2) In our opinion, the on-site soils are suitable for supporting the proposed structures. A maximum allowable soil bearing pressure of 4,000 psf, should be used in design. Other design parameters are provided in the text of this report.

(3) The foundations will be at some risk of heave caused by wetting and subsequent swelling of the clay portion of the underlying soils.

(4) Potential construction difficulties are excavation of the dense, cobble and boulder, soils; fill compaction of rock containing materials; and groundwater at the deep turbine foundation at site 3.2.

(5) A representative of our office should observe the construction operations discussed in this report.

SCOPE OF STUDY

This report presents the results of a geotechnical investigation for the proposed Phase I expansion at the National Wind Technology Center approximately 1/2 mile southeast of Colorado Highways 93 and 128; Jefferson County, Colorado.

The purpose of this study was to explore the subsurface conditions, obtain some data of the pertinent engineering characteristics of the underlying strata, determine appropriate foundation systems, develop specific foundation design criteria, and address other geotechnical factors in the proposed development.

It should be understood that economic and practical constraints limit our sampling and laboratory testing to only a miniscule fraction of the total mass of soil and/or bedrock which lie within the zone of influence of the proposed structures.

Our analyses, conclusions and recommendations are based upon the assumption that the samples of subsurface strata, which we observed and tested, are representative of the entire soil mass.

PROPOSED CONSTRUCTION

As we understand, the proposed construction is to consist of work at two 80-meter tower sites (M-2, west and M-3 east) and six turbine sites (1.1, 1.2, 1.3, 1.4, 3.2 and 3.3). At each site, foundations will be necessary for turbines and/or meteorological towers and various other features such as guy cable anchors, control/data sheds, transformers, winches, etc.

No significant changes in surface grades are expected. Foundation levels are generally to range from the ground surface to a depth on the order of 12 feet. However, at site 3.2 the turbine foundation is expected to extend to a depth on the order of 20 feet.

In most cases, compressive loads are expected to be relatively light with the foundations themselves making up much of the dead-load. Generally, the foundations will be sized based on lateral loads and/or the mass necessary to resist uplift loads.

FIELD INVESTIGATION

Eight (8) exploratory test borings were drilled at the site, at the locations presented in Table 1. One boring was drilled at each of the eight Phase I sites. The borings were drilled with a truck-mounted AP-1000 drill rig. That is a percussion hammer drill rig which advances a dual-wall drill string (see Appendix).

At regular intervals, disturbed soil samples were obtained from the return up the inner casing of the drill string. The outer casing of the drill string was driven into the various subsoil strata with blows of the pile-driving hammer.

The number of hammer blows required to drive the casing one foot constitutes the penetration test with this drilling method. This field test is similar to the standard penetration test described by ASTM Method D-l586. Penetration resistance values, when properly evaluated, are an index to the soil strength and density. The depths at which the samples were taken and the penetration resistance values at those same depths are shown on the Logs of Exploratory Borings, Plates 1 and 2.

LABORATORY TESTING

All samples were carefully inspected and classified in the laboratory by the project engineer. Natural water contents, atterberg limits, and full and partial (percents passing the U.S. No. 200 sieve) gradations were obtained from disturbed bag samples of typical materials encountered (see Plates 4 and 5 and Table 1).

Swell-consolidation tests were performed on two remolded specimens of potentially swelling materials (see Plate 6). This is to indicate the behavior of these materials upon loading and wetting. It should be noted that the swell tests were performed on clay specimens which are not representative of most of the soils encountered. Generally, the subsurface soils are more granular and possess significantly lower swell potentials or are non-expansive.

SUBSURFACE CONDITIONS

Generally our borings encountered natural soils consisting of silty, clayey, sand and gravel with cobbles and perhaps some boulders of 12 to 24 inch size. These soils are medium moist to moist and dense to very dense. The swell potential of these mostly granular soils would be none to low. However, some lenses and layers of clay are occasionally present. These relatively thin, erratically located clay concentrations possess moderate to high swell potentials.

Strata of less coarse, less granular, silty clay and sand mixtures with gravels and cobbles were encountered in Borings 2-3.2 from 23 to 35 feet and in Boring 8-M2 from zero to 9-1/2 feet. Those soils are moist, medium dense to dense, and generally would possess low swell potentials. However, layers of concentrated clay have higher potentials for expansion.

Groundwater was noted in Boring 2-3.2 at a depth of 17 feet when checked 4 days after drilling. Water was not noted in the other borings. It should be noted that the water table can vary with changes in precipitation, irrigation and land use.

FOUNDATIONS

The overburden soils at the site are generally granular soils which exhibit good support characteristics. The present swell potential of the soils is generally none to low. Thus, the use of foundations placed on the on-site soils is suitable.

The structures at the site could be supported on footings, or in some cases on drilled shafts (piers), placed on the natural soils and/or structural fill. With proper design and construction, potential movements would be on the order of no more than 1 inch settlement and generally no more than 1 inch of heave due to swelling of subsoils. However, random, isolated locations could experience heaves of up to 4 inches. Footing settlements would occur almost immediately upon application of load. Heave due to swelling would occur only with wetting of underlying clayey soils.

Foundations should not bear directly on concentrated clay layers. If clay soil is exposed in the bottom of an excavation, it should be overexcavated and the foundation can either be placed deeper or new structural fill can be used to replace the removed clay. The depth of any concentrated clay layer is not expected to exceed 2 feet.

The foundations would be designed using a maximum allowable soil bearing pressure of 4,000 psf. An overload of up to 33 percent would be acceptable for wind and other temporary, short term loads.

Lateral footing resistance would be based on ultimate passive equivalent fluid density of 460 pcf and ultimate coefficient of friction of 0.50. For lateral pier design a horizontal modulus of subgrade reaction of 4 tcf per foot of depth is suitable for use in design. Thus, for example the modulus would be 8 tcf at 2 feet and 40 tcf at 10 feet.

Design frost depth at the site is 3 feet. Pads may be placed shallow without regard to frost depth if movement of the particular feature is not critical.

Other design parameters are a soil unit weight of 120 pcf, an angle of internal friction of 36 degrees and for mat or slab foundations a modulus of subgrade reaction of 200 pci.

STRUCTURAL FILL

Structural fill can consist of the on-site soils. However, use of the most clayey material should be minimized. Any imported material should be approved prior to its use.

Structural fill should be compacted to at least 95 percent of the maximum Standard Proctor density (per ASTM D-698) at a moisture content near the optimum. It should be noted that fills placed as backfill adjacent to foundations are considered to be structural.

Topsoil stripping on the site can be limited to the surface vegetation and the upper 2 inches of soil. These materials should not be reused in any structural area.

The structural fill lift thicknesses may be as deep as desired, provided adequate compaction is achieved for the full-depth of the lift. It should be noted that for most light to moderate duty compaction equipment lift thickness of 6 to 9 inches are appropriate. Oversize (greater than approximately 2/3's of the lift thickness) cobbles and boulders may need to be removed from fill materials in order to achieve adequate compaction.

DESIGN AND CONSTRUCTION DETAILS

PIERS:

(1) It should be noted that the soils at the site may "cave" during drilling. Thus, the use of temporary casing should be expected. The contractor should be prepared to place concrete into each pier shortly after it's completion. Water may still enter some piers. If significant water is present, greater than a depth of 2 inches, pumping would be necessary.

(2) The pier drilling contractor should also be aware of the presence of cobbles and some boulders in the soils at the site.

SHALLOW FOUNDATIONS:

(1) Foundations should be well reinforced. This is to give them sufficient strength to resist slight differential movements which may occur in the bearing strata below foundation levels.

(2) Care should be taken in excavating for the foundations so as to avoid disturbing the subsoils. Any soils disturbed during footing excavation or preparation should be removed or recompacted prior to placing concrete.

GENERAL:

(1) Backfill around the foundations should be moistened and well compacted. The grades adjacent to the foundations should be sloped away from them. A minimum slope of 6 inches in the first 10 feet is recommended.

(2) Significant concentrations of water soluble sulfates were not noted in the soils. However, we recommend that as a precautionary measure, Type II cement be used in all concrete exposed to the earth.

DEWATERING:

(1) Construction dewatering is not generally expected to be required for the planned 12 foot and shallower excavations.

(2) Deeper construction, such as to $20^{\pm}$ feet for the turbine foundation at site 3.2, could necessitate construction dewatering measures. Pumping from a sump dug at the side of the excavation, outside the actual foundation area, would probably be sufficient.

EXCAVATIONS:

(1) Caving of the soils at the site could occur during excavation. Shoring, trench boxes, and/or sloping trench walls will be necessary.

2) The presence of cobbles and some boulders in the soils at the site will present some excavation difficulties. The contractor should expect to need appropriate heavy-duty excavation equipment.

LATERAL EARTH PRESSURES

TEMPORARY EXCAVATION BRACING: No temporary bracing is necessary for excavated areas if a 1.5 (horizontal) to 1 (vertical) slope is maintained. It should be noted that even relatively shallow vertical excavations in the types of materials present on the site could present problems during even short-term construction time periods. Should bracing be necessary at some critical area or desirable for personnel safety or other reasons, we recommend that an 'active' earth pressure of 35 x Z-100 psf be used, where Z= depth of excavation, (for example, if a 12 foot excavation is planned, the temporary bracing should be designed for a lateral earth pressure of 35 x 12 - 100 = 320 psf per linear foot).

RESISTANCE: Lateral pressures may be resisted by an ultimate passive equivalent fluid density of 460 pcf. An ultimate coefficient of friction of 0.5 may also be used in the design. In all cases, a minimum factor of safety of 2 is suggested to obtain allowable values.

MISCELLANEOUS

In any subsurface investigation it is necessary to assume that foundation conditions do not change greatly from those indicated by our exploratory borings within the limits of the investigation. These borings are spaced in such a manner as to decrease the possibility of anomalies.

However our experience has shown that anomalies do sometimes become apparent during construction. For this reason, we recommend that a representative of our firm who is familiar with the subsurface conditions observe the construction operations discussed in this report.

Respectfully submitted,

CTC-GEOTEK, INC.

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BORING LOCATIONS

Boring Number	Location
1 - M3	At M-3 (East Met Tower)
2 - 3.2	Center of Site 3.2
3 - 3.3	Center of Site 3.3
4 - 1.1	Center of Site 1.1
5 - 1.2	Center of Site 1.2
6 - 1.3	Center of Site 1.3
7 - 1.4	Center of Site 1.4
8 - M2	At M-2 (West Met Tower)

Towers and Sites are from the NREL Drawing Number C-PV-000-27, "National Wind Technology Center Turbine Siting Plan", dated November 8, 1993

Table 1

Clay and sand mixtures with gravels and cobbles, silty, medium dense to dense, moist

Sand & gravel with cobbles and perhaps boulders, silty, clayey, dense to very dense medium moist to moist, occasional clay lenses and layers

Water level, time after drilling

NOTES:

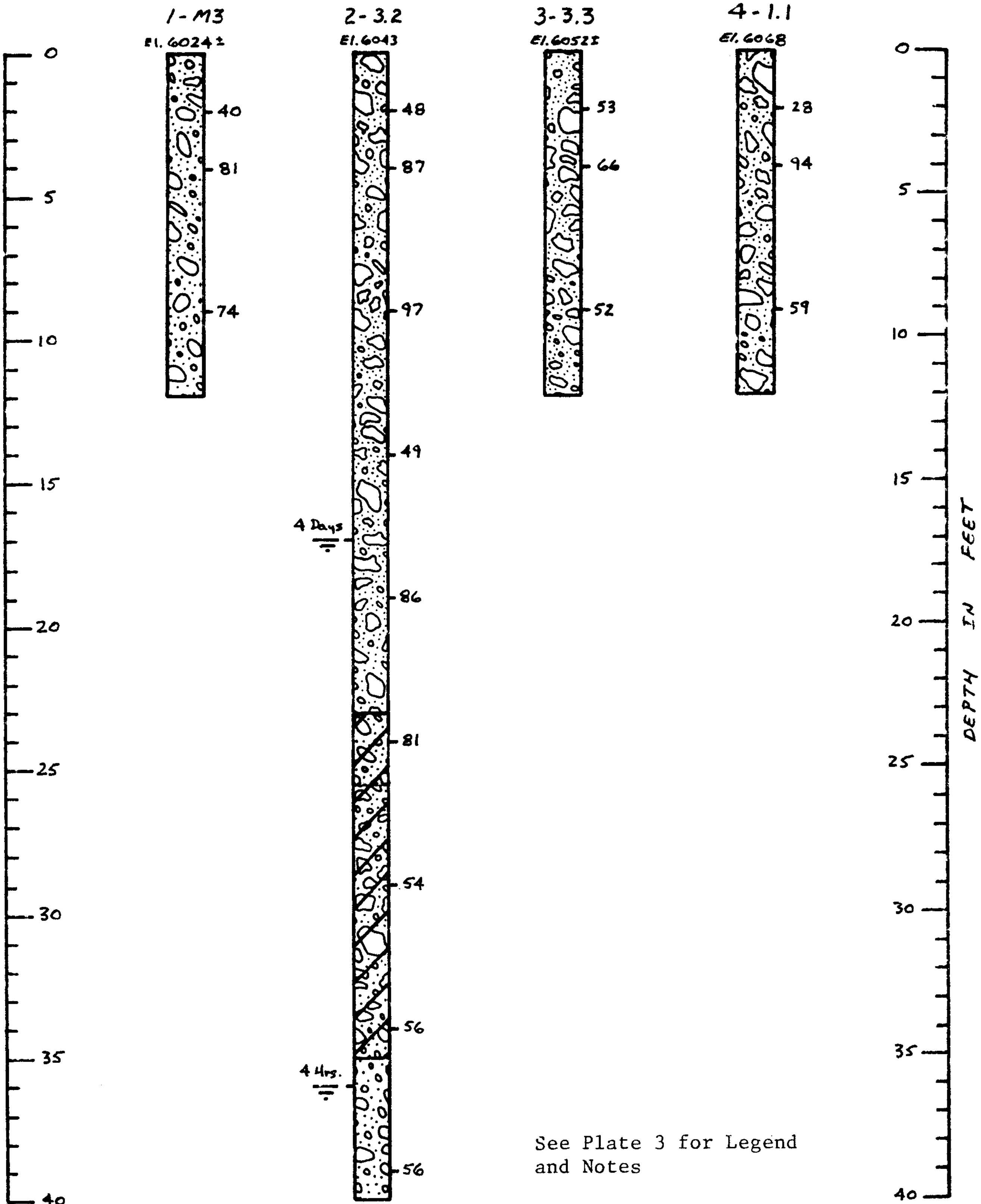
(1) The borings were drilled on February 10, 1994 with an AP-1000 Percussion Hammer Drill rig with a 9 inch outer drive casing and a 6 inch inner casing.

(2) 40 indicates that 40 blows of the pile-driving percussion hammer were required to drive the outer casing 12 inches. Conventional standard penetration test (SPT) blow counts are approximately 20 percent greater.

(3) The stratification lines represent the approximate boundary between soil types and the transition may be gradual.

(4) The boring logs show subsurface conditions at the dates and locations indicated, and it is not warranted that they are representative of subsurface conditions at other locations and times.

LEGEND AND NOTES	CTC-GEOTEK ENGINEERING TESTING INSPECTION 155 S. Navajo ● Denver, CO 80223 ● 303-698-1050
National Wind Technology Center SE of Colorado Highways 93 & 128 Jefferson County, Colorado	DRAWN BY: CHECKED BY: DATE: 2/17/94 SCALE: Vertical Horizontal N/A JOB NO. 942009 PLATE 3



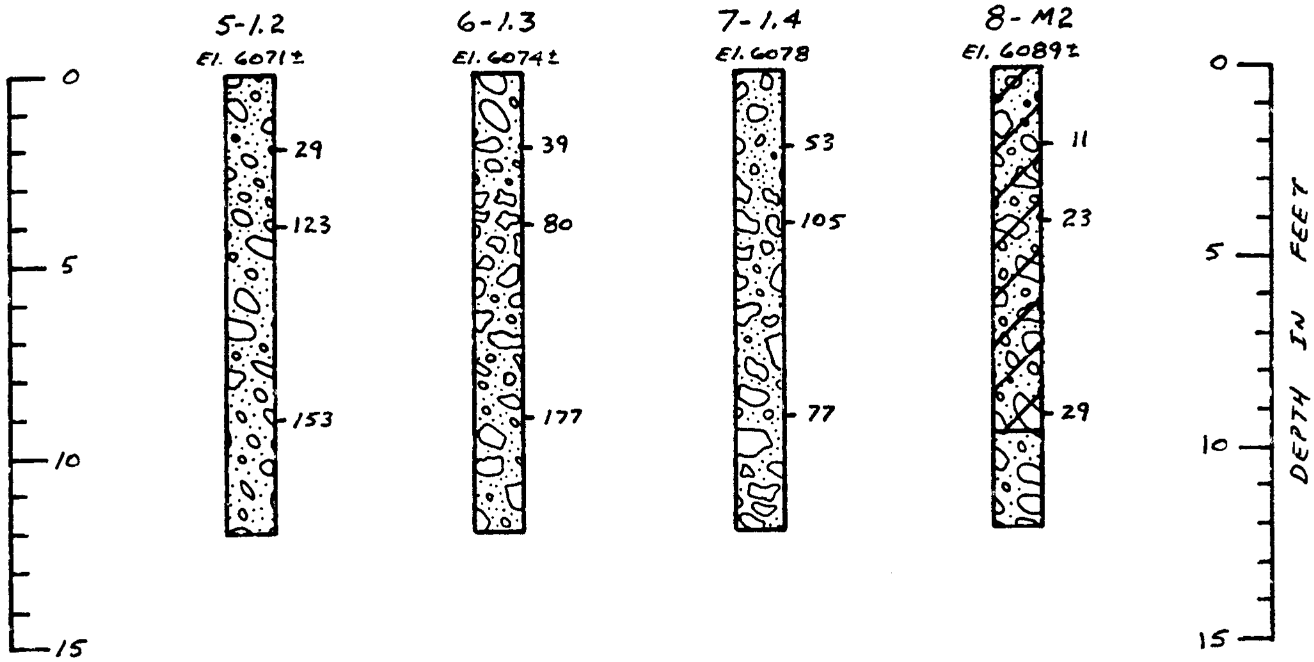
See Plate 3 for Legend and Notes

LOGS OF EXPLORATORY BORINGS

CTC-GEOTEK
ENGINEERING TESTING INSPECTION
155 S. Navajo ● Denver, CO 80223 ● 303-698-1050

National Wind Technology Center
SE of Colorado Highways 93 & 128
Jefferson County, Colorado

DRAWN BY: MTB	SCALE: Vertical 1"=5'	
CHECKED BY:	Horizontal	
DATE: 2/17/94	JOB NO. 942009	PLATE 1



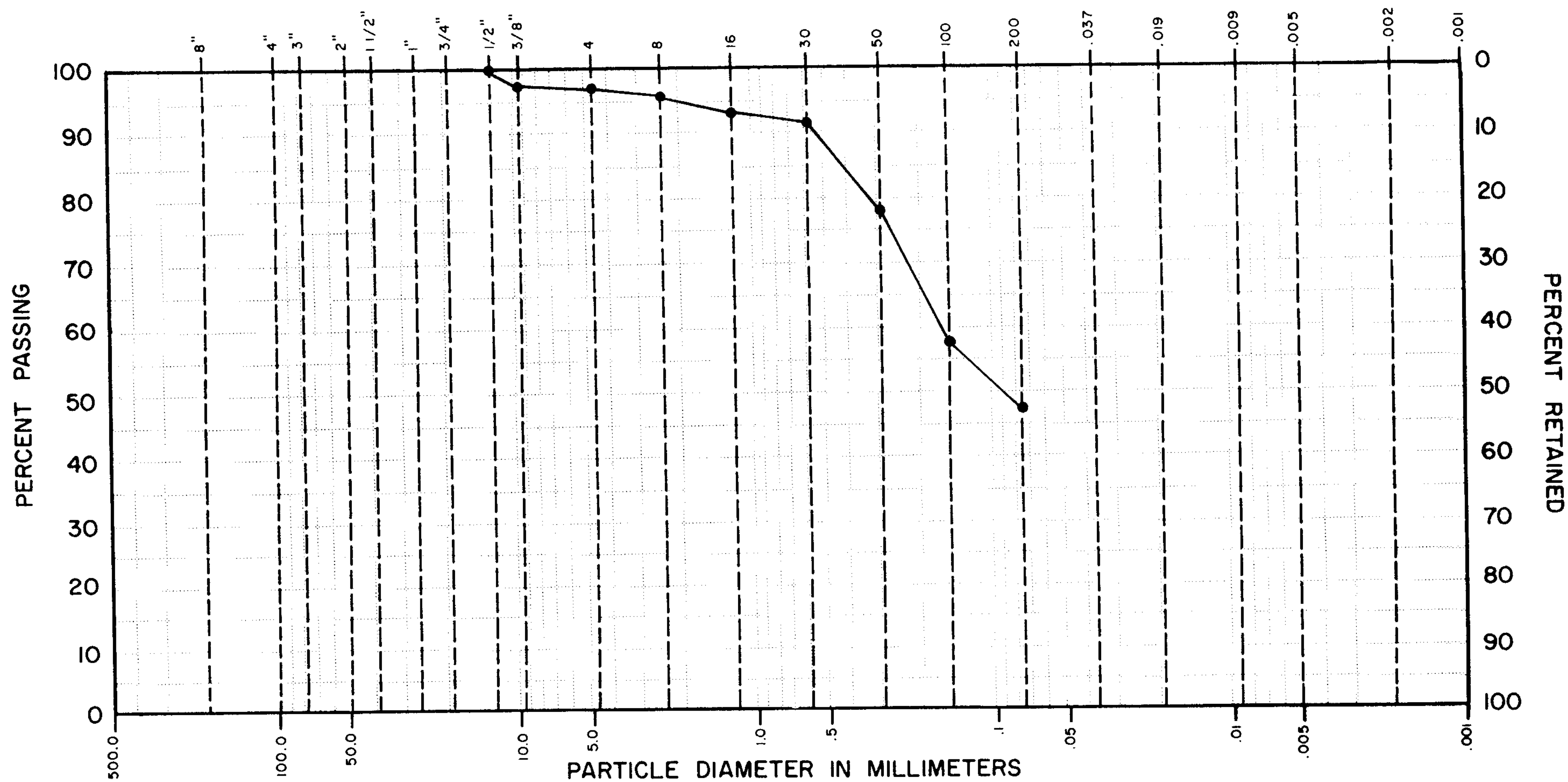
See Plate 3 for Legend and Notes

LOGS OF EXPLORATORY BORINGS

CTC-GEOTEK
ENGINEERING TESTING INSPECTION
155 S. Navajo ● Denver, CO 80223 ● 303-698-1050

National Wind Technology Center
SE of Colorado Highways 93 & 128
Jefferson County, Colorado

DRAWN BY: MTB	SCALE: Vertical 1"=5' Horizontal
CHECKED BY:	
DATE: 2/17/94	JOB NO. 942009 / PLATE 2



COBBLES TO BOULDERS	GRAVEL		SAND			CLAY (Plastic) TO SILT (Non-Plastic)
	Coarse	Fine	Coarse	Medium	Fine	

BORING NO.	SAMPLE NO.	DEPTH IN FEET	PL	LL	PI	NAT. WC	SOIL DESCRIPTION
8-M2		9 - 10	14	42	28	14.4	Sand, and silty clay, trace gravel

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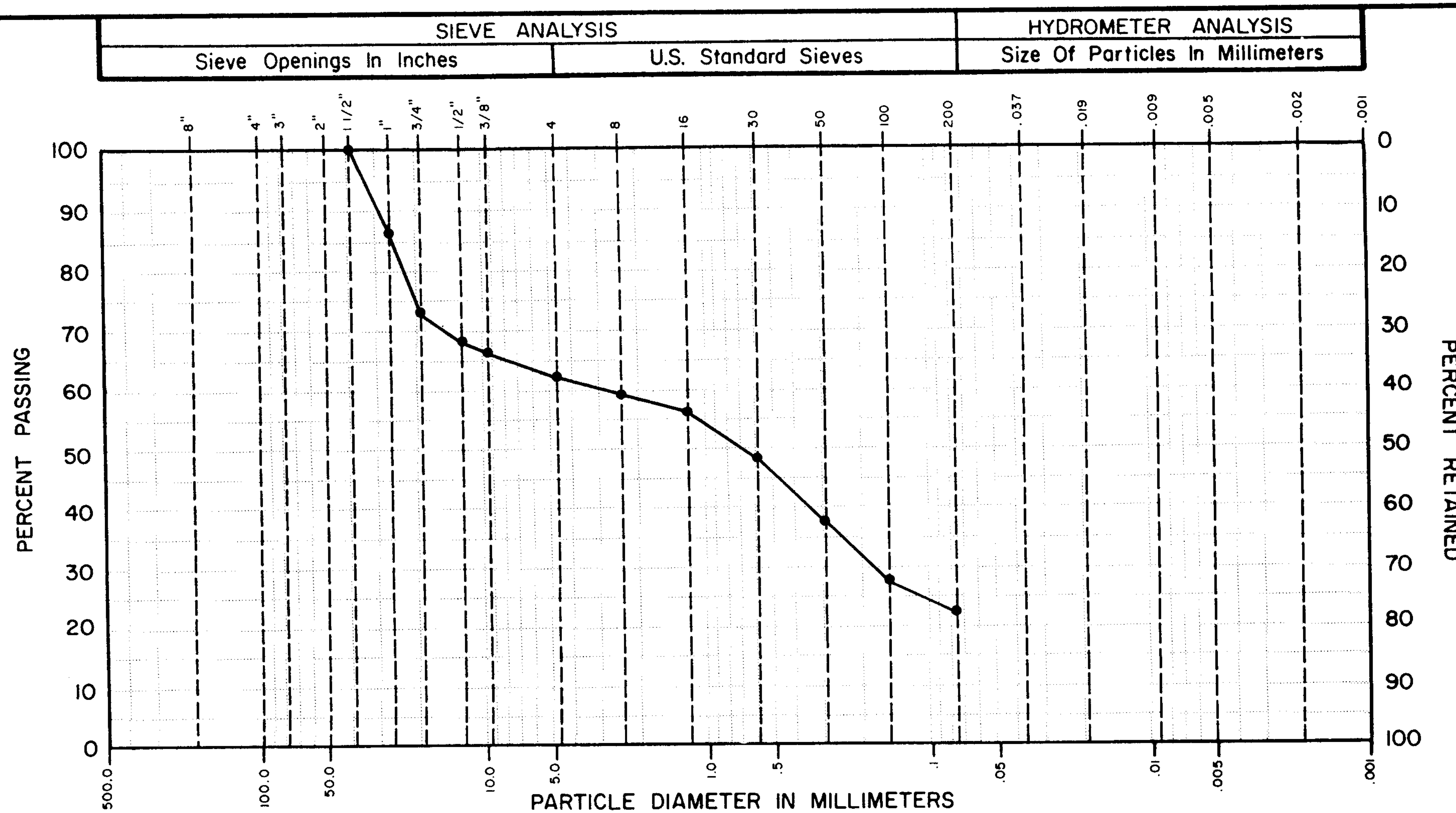
GRADATION ANALYSIS

DRAWN BY: BGP	JOB NO. 942009
DATE: 2/16/94	PLATE 4

L-7, 1/76



COBBLES TO BOULDERS	GRAVEL		SAND			CLAY (Plastic) TO SILT (Non-Plastic)
	Coarse	Fine	Coarse	Medium	Fine	

BORING NO.	SAMPLE NO.	DEPTH IN FEET	PL	LL	PI	NAT. WC	SOIL DESCRIPTION
2-3.2		24 - 25	12	37	25	11.9	Sand, and gravel, some silty clay

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GRADATION ANALYSIS

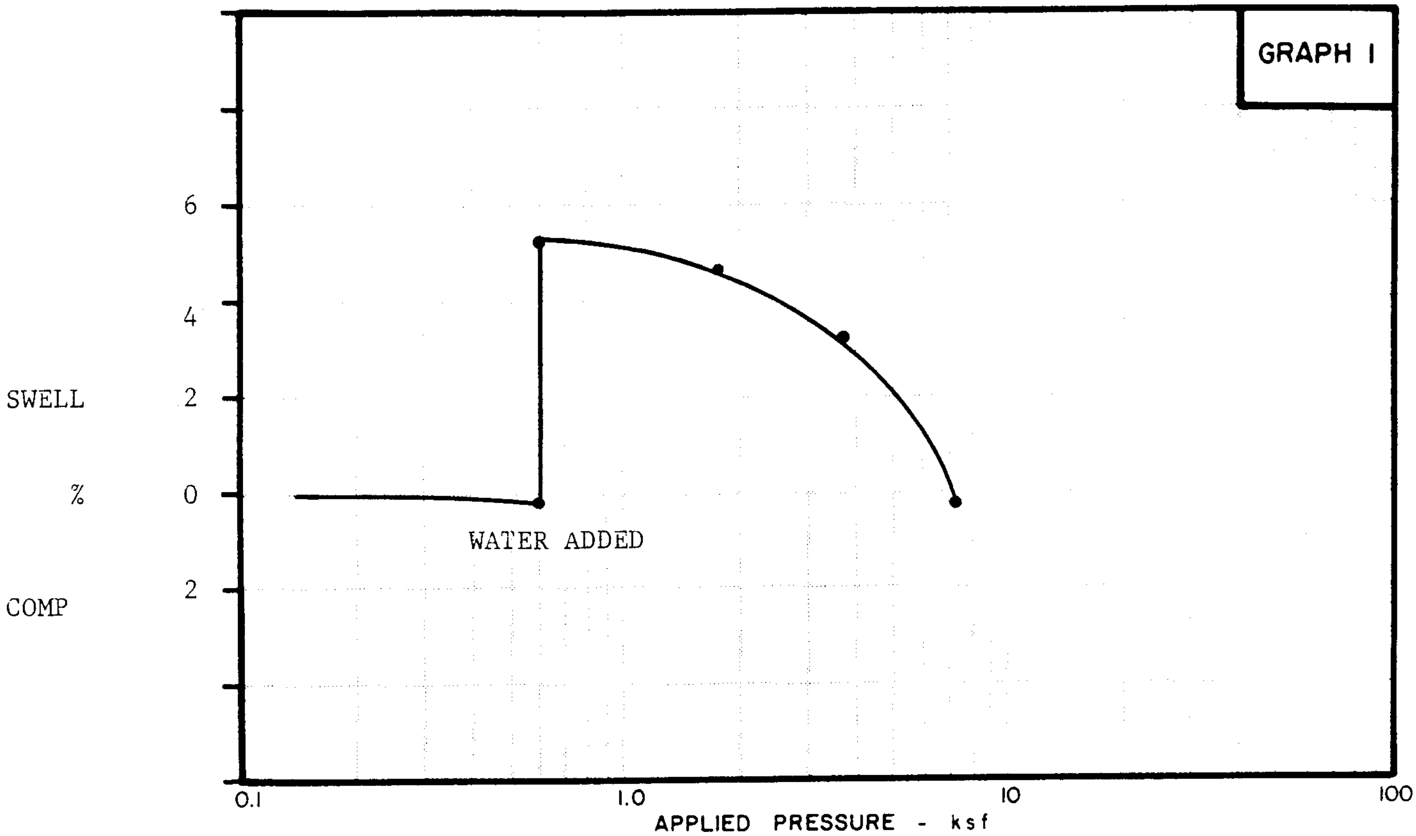
DRAWN BY: BGP

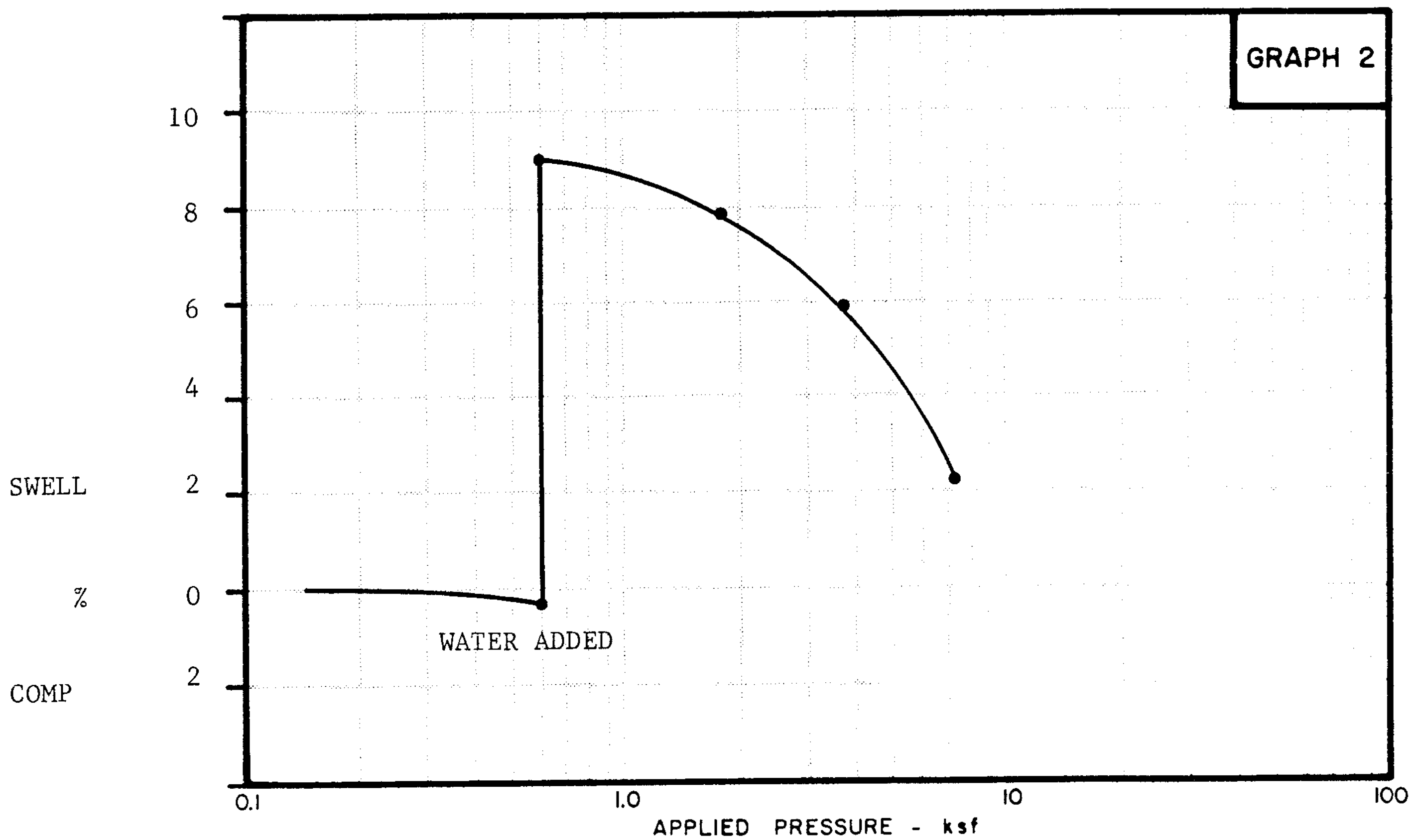
JOB NO. 942009

DATE: 2/16/94

PLATE 5

L-7, 1/76





GRAPH NO.	BORING NO.	SAMPLE NO.	DEPTH IN FEET	DRY DENSITY (PCF)	MOISTURE (%)	SOIL DESCRIPTION
1	5-1.2		2-3	94	26	Clay, little sand
2	8-M2		2-3	106	21	Clay, some sand

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SWELL - CONSOLIDATION TEST

DRAWN BY: mrB

JOB NO. 942009

DATE: 2/16/94

PLATE 6

L-13, 1/76

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SUMMARY OF LABORATORY TEST RESULTS

PROJECT NO. 942009

BORING NO.	SAMPLE NO.	DEPTH IN FEET	SAMPLE TYPE (NOTE 1)	NATURAL DRY DENSITY (PCF)	NATURAL MOISTURE (%)	ATTERBERG LIMITS			% FINES	WATER SOLUBLE SULFATES (%)	SHEAR STRENGTH (PSF) (NOTE 2)	ADDITIONAL TEST RESULTS ATTACHED (NOTE 3)		SOIL DESCRIPTION
						LL	PI	PL						
5-1.2		2-3	BS		26.1	78	52	26						Clay, little sand
5-1.2		2-3	RM	94	26.0								SW	Clay, little sand
8-M2		2-3	BS		20.1	69	48	21	62.5					Clay and sand, little gravel
8-M2		2-3	RM	106	21.0								SW	Clay, some sand
8-M2		9-10	BS		14.0	42	28	14	47.3				GA	Sand and silty clay, trace gravel
2-3.2		24-25	BS		11.9	37	25	12	22.4				GA	Sand and gravel, some silty clay
2-3.2		34-35	BS		18.3	47	34	13	53.5					Silty clay and sand, tr. gravel

RF-1, 1/76

NOTE 1 - SAMPLE TYPE

BS - Bag Sample
AS - Auger Sample
ST - Shelby Tube Sample
CA - California Sample
RM - Remolded Sample
HD - Hand Drive
AD - Air Dried

NOTE 2 - SHEAR STRENGTH TESTS

C_1 - Unconfined Compression
C_2 - Miniature Vane Shear
C_3 - Pocket Penetrometer
C_4 - Pocket Vane

NOTE 3 - ADDITIONAL TEST RESULTS ATTACHED

SW - Swell-Consolidation Test
TT - Triaxial Test
PT - Proctor
GA - Gradation Analysis
CT - Consolidation Test

TABLE 2

APPENDIX

Percussion Hammer Drilling Method

PERCUSSION HAMMER DRILLING METHOD

METHOD:

The AP-1000 Drill Rig is equipped with a single-cylinder diesel piledriving hammer. The hammer advances a dual-wall drill string (casing) equipped with an open face drill bit. As the casing is advanced, high pressure compressed air is injected down the annulus of the dual-wall drill string. The air returns the cuttings from the rear of the cutting shoe back to the surface through the center of the drill string. The cuttings are ejected through a vortex unit mounted on the side of the drill rig.

Five significant features serve to make the hammer method unique:

1. The piledriving percussion hammer provides a very fast and efficient method of advancing the casing.

2. The dual-wall construction of the casing which allows the flow of compressed air to act as a drilling fluid without significant penetration of the formation.

3. The large center opening (6") of the drill string which permits return of soil, rocks and cobbles without the need for conventional crushing or grinding.

4. The method allows the hole to be drilled and cased in one operation thus minimizing the potential cross contamination between zones.

5. The method permits penetration of sands, cobbles and boulders at speeds much greater than conventional methods. As an example, the hammer drill can normally outdrill a cable tool rig by a factor of 10, even in difficult formations. The average rate of drilling is on the order of sixty feet per hour.

GEOLOGICAL SAMPLING

The Percussion Hammer Method is ideally suited for overburden sampling. As an intrinsic part of the drilling process, the drill automatically provides a continuous, accurate sample of the penetrated formation. The drill, in effect, actually penetrates the formation by sampling it. The method provides the following advantages:

1. The large center opening allows almost all material to enter the casing unbroken. There is no triconing, grinding or crushing of the formation before it is returned to the surface.

2. Utilizing air as the drilling fluid and returning the sample to the inside of the drill string allows the sample to be unaltered and uncontaminated by materials previously penetrated.

3. The sample is continuous for the total depth of the hole.

GEOTECHNICAL SAMPLING

The AP-1000 Hammer Drill Rig is an extremely versatile rig with the capability to drill in virtually any formation. This offers a significant advantage when drilling on sites where there is limited knowledge of formation. This versatility combined with the rig's features, tools and techniques, allows the drill to provide a broader range of geotechnical information than any other single method.

The continuous cyclone sample obtained while drilling is disturbed, but otherwise unaltered and is representative of the formation being penetrated at any given time. The cyclone sample allows for identification of the soil, provides grain size determination in granular materials and is usually suitable for moisture determination in cohesive formations. The continuous sample also insures that critical formations (e.g.: soft seams, slickensides) are not overlooked.

The rapid progress of the drilling method often justifies the presence of a geologist or a soils engineer at the drill where information can be collected first hand. This direct control allows the engineer to evaluate this information immediately as it is produced, ensuring that the proper steps are being taken to maximize data generated by the drilling process.

SAMPLING METHODS

Continuous Blow Count:

As the hole is advanced, blow count on the advancement of the open casing (OC) provides continuous information on the density of the formation. The approximate correlation of the OC value and the SPT is expressed as: SPT = (1.2 X OC).