ATLAS SYSTEMS, INC.

Manufacturer / Developer of Rapid Foundation Support Products and Equipment

STRUCTURAL LOAD, FACTOR OF SAFETY, GEOTECHNICAL INVESTIGATION

AND

PRODUCT SELECTION GUIDELINES

FOR ATLAS FOUNDATION SUPPORT PRODUCTS

(2000 Edition 1.4)

ATLAS SYSTEMS, INC. ®
Developer/Manufacturer of Foundation Support Products and Equipment
800 325-9375 • 800 241-1950

INDEX OF SYMBOLS USED IN THIS CHAPTER

ORDER OF APPEARANCE IN TEXT

GWT	--	Ground Water Table	A2
SPT	--	Standard Penetration Testing	A4
N	--	Standard Penetration Blow Count Per Foot	A4
c	--	Soil Cohesion (lb/ft^2)	A5
ϕ	--	Soil Friction Angle	A5
RQD	--	Rock Quality Designation	A5
LL	--	Liquid Limit	A5
PL	--	Plastic Limit	A5
PI	--	Plastic Index	A5
USCS	--	Unified Soil Classification System (See Table 2, Pg. A10.)	A6
q_U	--	Unconfined Compression Strength	A6
pcf	--	Pounds per Cubic Foot	A8
psf	--	Pounds per Square Foot	A8

INTRODUCTION

The use of manufactured steel foundation products generally requires a prior geotechnical investigation of the subsurface condition of the foundation soils at the site of the proposed project. In addition to the geotechnical investigation, it is necessary to define the structural load requirements and required Factor of Safety for use in the overall design approach. Atlas Systems, Inc. manufactures or supplies three main lines of steel foundation products:

- Resistance Piers for underpinning and repair of residential and commercial buildings, retaining structures and slabs.
- Helical Foundation Piers for new construction and repair of residential and commercial buildings; helical tiebacks used in excavation shoring systems, retaining walls and slope stabilization; and helical anchors used for communication towers, signs, light standards and commercial buildings subjected to wind and earthquake load.
- Rock Anchors for use in providing tension capacity where foundation stratum is competent rock and use of the helical type of anchor/tieback is not feasible. Rock anchors require grouting in place.

STRUCTURAL LOAD REQUIREMENTS AND FACTOR OF SAFETY

I. DESIGN OR WORKING LOADS

These loads are sometimes referred to as <u>UNFACTORED LOADS</u> and DO NOT INCORPORATE ANY FACTOR OF SAFETY. They may arise from Dead Loads, Live Loads, Snow Loads, and/or Earthquake Loads for bearing (compression) loading conditions; from Dead Loads, Live Loads, Snow Loads and/or Wind Loads for anchor loading conditions, and Earth Pressure, Water Pressure and/or Surcharge Loads (from buildings, etc.) for tieback holding conditions or;

II. ULTIMATE LOADS

Ultimate Loads (sometimes referred to as <u>FULLY FACTORED LOADS</u>) already fully incorporate Factors of Safety for the typical loading conditions described above. Atlas Systems, Inc. recommends to customers and designers that they use a minimum Factor of Safety of 2.0 for permanent loading conditions and 1.5 for any temporary loading condition. This Factor of Safety is applied to the design or working loads as defined above to achieve the ultimate load requirement.

GEOTECHNICAL INVESTIGATION REQUIREMENTS

I. PURPOSE

The primary purpose of the geotechnical investigation is to assist in identifying the key soil strength parameters for design of the steel foundation elements. In addition to the above, such studies are useful for the following reasons:

Resistance Piers:

- To locate the depth of firm bearing stratum for end bearing support of the underpinning pier.
- To establish the location of any weak soil zones in which column stability of the pier shaft must be considered.
-

parameters used in designing manufactured steel foundation products is given in the following sections.

II. RECONNAISSANCE AND PLANNING

Reconnaissance and planning includes: (1) reviewing the structural load requirements and size of the structure and whether the project is new construction or structure repair, (2) a review of the general soil and geologic conditions in the proximity of the site, (3) a site visit to observe topography and drainage conditions, rock outcrops if present, placement of borings, evidence of soil fill, including rubble and debris and evidence of landslide conditions. The planning portion includes making a preliminary determination of the number and depth of each boring as well as determining the frequency of soil sampling for laboratory testing and the requesting of marking of all utilities in the zone in which borings will be conducted. Indicated below are guidelines for determining the number of borings and the depth to which the boring should be taken based on the project type.

A. Minimum Number Of Borings

Whether the project involves underpinning/repair of an existing structure or new construction, boring(s) should be made at each location where a pier or series of piers are to be placed. The recommended <u>minimum</u> number of borings necessary to establish a foundation soil profile is given below:

- Residential Home - One (1) boring.
- Commercial Building - One (1) boring for every 50 to 100 lineal feet for multistory-story structures, and every 100 to 150 lineal feet for other commercial buildings, warehouses and manufacturing buildings.
- Communication Towers - One (1) boring for each location of a pier anchor cap and One (1) boring at the tower center foundation footing.
- Sheet Pile/Earth Stabilization for Earth Cuts - One (1) boring for every 200 to 400 feet of project length.

B. Depth Of Boring(s)

The depth of each boring will vary depending on the project type, magnitude of foundation loads and area extent of the project structure. Some general guidelines for use in estimating required boring depth is given below:

- Residential Home - At least 15 feet into good bearing stratum, generally N > 8 to 10 (See Section III-A, Page A4 for a description of Standard Penetration Test and "N" values.)
- Commercial Building - At least 20 feet into good bearing stratum (generally N> 15)
- Communication Towers - Minimum of 35 feet for towers over 100 feet tall and at least 20 feet into a suitable bearing stratum (typically medium dense to dense for sands and stiff to very stiff for clays) for anchor piers. The suitable bearing

III. TEST BORING AND SAMPLING PROGRAM

A. Method Of Boring And Frequency Of Sampling

The most common method used in soil exploration is the use of truck mounted continuous flight auger systems together with the use of Standard Penetration Test (SPT) equipment. The continuous flight augers can be either hollow stem or solid stem. The equipment and procedure used are in conformance to ASTM D 1586. *Figure 1* shows a typical drill truck with a hollow stem auger being used to continuously sample the soil. The advantage of use of the hollow stem auger is to permit the sampler rod for the SPT to be inserted through the auger rather than have to remove the auger stems each time an SPT is conducted. As the auger rotates, the soil moves to the surface and based on visual observation is classified as to type and condition and recorded on a log sheet at the depth of the auger stem. The result of this auger advance process is to establish the vertical sequence of the soil substrata. Generally a sample is recovered and visually classified at each 5-ft. interval of depth or at a change in soil type. This classification continues to the bottom of the boring. During the advance of the auger in the borehole, the driller also records the depth to any observed ground water table (GWT). The presence of a GWT will influence the unit weight and strength characteristics of the soil.

Figure 1. Rotary Auger Boring

B. Standard Penetration Test And Sampling

The Standard Penetration Test (SPT) consists of driving the sampler with a 140-pound hammer and counting the number of blows (drops of the 140-pound hammer) applied in each of three 6" increments of penetration. The SPT, "N" value is then determined by adding together the total number of blows for the last 12" of penetration. The split spoon sampler consists of a 2" OD hollow (split spoon) sampler tube mounted on the bottom of a steel rod. *Figure 2* shows the SPT being conducted and *Figure 3* shows the split spoon sampler opened showing the soil sample

Figure 2. Standard Penetration Test (SPT)

contained in the sampler. These blow counts are shown on the field-boring log at the depth the SPT was conducted. If the sampler is driven less than 18", such as would occur in highly resistant material, the blows for each complete 6" and for each partial increment is shown on the boring log. Portions of the recovered samples from each SPT are placed in sealed bags for the purpose of conducting laboratory tests.

The STP results are the most widely used soil parameter to guide the selection of soil strength for the design of helical foundation piers. The N values also can assist in determining the depth of installation requirements for resistance piers. Values of soil friction angle (ϕ) and cohesion (c) can be selected through correlation with the SPT, "N" values. References are provided on page A12 at the end of this section to guide the user in selecting correlated values.

Figure 3. Recovered Sample from Split Spoon Sampler (SPT)

C. Rock Coring And Quality Of Rock Measurement

When bedrock is encountered, and rock anchors are a design consideration, a continuous rock core must be recovered to the depth or length specified. Typical rock anchors may be seated 20 ft. or 30 ft. into the rock formation. The same type of truck drill rig is used for the rock coring operation, however, hardened steel or a diamond coring bit is used at the end of the core barrel to assist in cutting through the rock to recover the sample. Water under pressure is forced down the barrel and into the bit to carry the rock dust out of the hole as the water is circulated.

In addition to conducting compressive tests on the recovered rock core samples (See *Table 1*, below.); the rock core is examined and measured to determine the rock competency (soundness or quality). The rock quality designation (RQD) is the most commonly used measure of rock quality and is defined as:

$$\mathbf{RQD} = \frac{\Sigma\ \text{Length of intact pieces of core (>100 mm.)}}{\text{Length of core advance}}$$

The values of RQD range between 0 and 1.0 where an RQD of 0.90 or higher is considered excellent quality rock.

IV. LABORATORY TESTING OF RECOVERED SOIL SAMPLES

Every recovered sample from the field boring and sampling program is inspected visually and given a visual description as to its color, condition and type. (See *Table 2*.) In addition to this visual classification, a representative number of samples are selected to conduct the following tests:

- Water Content – measures the amount of moisture in the soil.
- Particle Size Analysis -- measures the distribution of particle sizes within the soil sample.
- Liquid Limit (LL), Plastic Limit (PL) and Plastic Index (PI) – applies to cohesive types of soil and is a measure of the relative stiffness of the soil and potential for expansion.

- Strength Characteristics – in some instances undisturbed soil samples are recovered in the field using a thin wall (Shelby) tube. These recovered samples are tested either in triaxial or direct shear tests to determine directly the friction angle (ϕ) and the cohesion (c) of the soil. For cohesive (clay) soil samples, an unconfined compression (q_u) is often conducted. The cohesion of the clay sample is then taken to be one-half of q_u.

The results of the above tests are used to classify the soil as to type and condition. The most widely used classification system is the Unified Soil Classification System (USCS). This classification system divides soils between cohesionless (sands, gravels, silty sands, etc.) and cohesive (clays, silty or sandy clays, etc.) types. This classification is an important consideration in choosing the number and sizes of the helical plates since the strength mechanism for cohesionless and cohesive soils are quite different. The classification system also recognizes that soils occur in a mixed condition where the soil may exhibit both cohesionless and cohesive characteristics. *Table 2*, page A10 gives an introduction to USCS classification and the references at the end of this section provides a full description of the USCS.

TABLE 1. MECHANICAL PROPERTIES OF VARIOUS ROCKS

Rock	**Young's Modulus at Zero Load** (10^5 kg/cm^2)	**Bulk Density** (g/cm^3)	**Porosity** (percent)	**Compressive Strength** (kg/cm^2)	**Tensile Strength** (kg/cm^2)
Granite	2 - 6	2.6-2.7	0.5-1.5	1,000-2,500	70-250
Microgranite	3 - 8				
Syenite	6 - 8				
Diorite	7-10			1,800-3,000	150-300
Dolerite	8-11	3.0-3.05	0.1-0.5	2,000-3,500	150-350
Gabbro	7-11	3.0-3.1	0.1-0.2	1,000-3,000	150-300
Basalt	6-10	2.8-2.9	0.1-1.0	1,500-3,00	100-300
Sandstone	0.5-8	2.0-2.6	5 - 25	200-1,700	40-250
Shale	1-3.5	2.0-2.4	10 - 30	100-1,000	20-100
Mudstone	2 - 5				
Limestone	1 - 8	2.2-2.6	5 - 20	300-3,500	50-250
Dolomite	4-8.4	2.5-2.6	1 - 5	800-2,500	150-250
Coal	1 - 2			50-500	20-50
Quartzite		2.65	0.1-0.5	1,500-3,000	100-300
Gneiss		2.9-3.0	0.5-1.5	500-2,000	50-200
Marble		2.6-2.7	0.5-2	1,000-2,500	70-200
Slate		2.6-2.7	0.1-0.5	1,000-2,000	70-200

Note:
1. For the igneous rocks listed above Poisson's ratio is approximately 0.25.
2. For a certain rock type, the strength normally increases with increase in density and increase in Young's modulus. (After Farmer, 1968)
3. Taken from *"Foundation Engineering Handbook"* by Winterkorn and Fong, Van Nostrand Reinhold, pg. 72.

V. GEOTECHNICAL REPORT

The geotechnical report provides a summary of the findings of the three phases detailed above and also contains recommendations on options for a foundation together with the recommended soil related design values. Included in this report are the results of the laboratory testing of the soil samples and borings logs providing a visual summary of the vertical profile of foundation soils at the project site. *Figure 4* gives the boring log generated from the field exploration program as shown in *Figures 1* through *3*. A review of this boring log indicates the following:

- The total depth of the boring was 74.3 ft. Except for the upper one-half foot, the soil layers were all lean or lean to fat clay with some variations in color and stiffness down to the depth of 64 ft. At 64 ft., a shale stratum was encountered which was in a highly weathered condition. Shale is a rock but in a weathered condition such as noted on the boring log, it is probable that the helical plates of a pier could be set 1 ft. to 3 ft. into the shale stratum.
- Standard Penetration Tests (SPT) were conducted at each 5-ft. interval of depth down to the bottom of the boring. From the SPT, N column on the boring log, it is noted that the stiffness (or strength) of the lean clay is fairly consistent from depth 30 ft. to 64 ft. (N ranged from 9 to 14). The upper part of this stratum (around 35 ft. to 40 ft. is where the helical plates would be seated).
- Moisture contents were taken on the recovered split spoon samples from the SPT. Again, below about 25 ft., the moisture content of the soil was fairly consistent (ranging between 23-1/2 to 26-1/2 percent). This low variation in moisture content is consistent with the consistent range of N values.
- Liquid Limit and Plastic Limit tests were also conducted on the recovered split spoon samples. The average LL = 45; the average PL = 20, resulting in a PI = 25. These results indicate that the in-situ moisture content of the lean clay ($\cong$ 25%) from 30 ft. to 60 ft. is just above the Plastic Limit (20%). As the in-situ moisture content approaches the Plastic Limit, the clay soil will become stiffer (higher cohesion).
- The boring log also shows a column for unconfined compression strength for the clay type soil. The values indicated in this column were determined in the field using a hand held penetrometer device inserted into the split spoon sampler at the end of the exposed soil sample. This is not recognized as an accurate type of strength test for clay type soil but does provide a general order of magnitude of strength and also allows a comparison of strengths between various depths in the boring log. At a depth of 35 ft., the unconfined compression strength, q_U = 5000 psf. The cohesion of the soil, c, is taken to be 1/2 of qu or c = 2500 psf. This is generally a higher value than would be determined through correlation of the cohesion through the N value. From standard correlation charts, the cohesion, c, would likely be between 1500 and 1800 psf.
- In the bottom left hand corner of the boring log of *Figure 4*, it is indicated that no ground water table (GWT) was identified at the site.
- The fourth column in *Figure* 4 shows the soil classification symbols to help describe the soils. *Table 2*, Page A10 gives an abbreviated listing of the Unified Soil Classification system.

LOG OF BORING No. B-1

CLIENT: ATLAS SYSTEMS, INC. | **DATE:** 6-22-99 | #02995604 | **RIG:** CME 75

SITE: 1026B South Powell Road
Independence, Missouri

PROJECT: ATLAS LOAD TEST

GRAPHIC LOG	DESCRIPTION	DEPTH ft.	USCS SYMBOL	NUMBER	TYPE	RECOVERY in.	SPT – N BLOWS/ft	WATER CONTENT %	DRY UNIT WT. pcf	UNCONFINED STRENGTH q_U psf	ATTERBERG LIMITS LL, PL, PI
	6” GRAVEL LEAN CLAY, silty trace organics, gray brown, trace dark brown and red brown, medium (Possible Fill)				PA						
			CL	1	SS	14	7	34.1		2000*	45,21,34
	LEAN CLAY, calcareous, trace sand and limestone gravel dark brown, brown, very stiff (Possible Fill)	5			HS						
		10	CL	2	SS	6	5	18.6		7000*	45,23,22
					HS						
	LEAN CLAY, trace silt, gray brown, trace dark gray, red brown and dark brown, stiff to very stiff	15	CL	3	SS	24	9	24.1		5500*	
					HS						
		20	CL	4	SS	24	10	22.3		3500*	44,20,24
					HS						
	LEAN CLAY, silty, gray brown, trace dark brown, stiff to very stiff	25	CL	5	SS	24	5	27.6		2500*	
					HS						
		30	CL	6	SS	24	19	26.5		5000*	42,18,24
					HS						
	Trace limonites at 34.0’ LEAN TO FAT CLAY, gray brown, trace dark brown, very stiff	35	CL-CH	7	SS	24	14	23.5		5000*	
					HS						

Figure 4. Sample Boring Log

LOG OF BORING No. 1 (CONTINUED FROM PREVIOUS PAGE**)**

GRAPHIC LOG	DESCRIPTION	**DEPTH** ft.	**USCS SYMBOL**	**NUMBER**	**TYPE**	**RECOVERY** in.	**SPT – N** BLOWS/ft	**WATER CONTENT** %	**DRY UNIT WT.** pcf	**UNCONFINED STRENGTH** q_U psf	**ATTERBERG LIMITS** LL, PL, PI
	LEAN TO FAT CLAY, gray brown, trace dark brown, very stiff	**40**	CL-CH	8	SS HS	24	13	24.3		5000*	48,20,26
	LEAN CLAY, silty, gray brown, brown, trace dark brown, red brown and gray, medium to stiff Trace gravel at 49.0’	**45**	CL	9	SS HS	24	11	24.5		3000*	
		50	CL	10	SS HS	24	10	26.3		3000*	46,21,25
		55	CL	11	SS WB	24	13	24.7		3500*	
	Trace gravel at 59.0’	**60**	CL	12	SS WB	24	9	25.7		1500*	
	***SHALE, highly weathered, trace silty clay and gravel olive brown, gray trace brown	**65**		13	SS WB	16	55	21.1		9000*	
	***SHALE, highly weathered, trace clay and black coal, very dark gray, gray	**70**		14	SS WB	6	44/3”	37.6			
	***SHALE, highly weathered, calcareous, gray 74.3 BOTTOM OF BORING			15	SS		50/1”	13.1		3000*	
	WATER LEVEL OBSERVATIONS, ft. NONE – WD NONE - AB										

***** Calibrated Hand Penetrometer
** CME 140H SPT automatic hammer
*** Classification estimated from disturbed samples. Core samples and petrographic analysis may reveal other rock types.
The stratification lines represent the approximate boundary lines between soil and rock types: in-situ, the transition may be gradual.

Figure 4. (Continued) Sample boring log

TABLE 2. UNIFIED SOIL CLASSIFICATION

MAJOR DIVISIONS		SYMBOL	TYPICAL NAMES
GRAVELS (More than half of coarse fraction larger than #4 sieve size)	Clean gravel	**GW**	Well graded gravel, gravel-sand mixtures
		GP	Poorly graded gravel, gravel-sand mixtures
	Gravel with fines	**GM**	Silty gravels, gravel-sand-silt mixtures
		GC	Clayey gravels, gravel-sand clay mixtures
SANDS (More than half of coarse fraction smaller than #4 sieve size)	Clean Sands	**SW**	Well graded sands, gravelly sands
		SP	Poorly graded sands, gravelly sands
	Sands with fines	**SM**	Silty sands, sand-silt mixture
		SC	Clayey sands, sand-clay mixtures
		ML	Inorganic silt & very fine sands, clayey fine sands/silts with slight plasticity

REFERENCES

1. Soil Engineering, Merlin G. Spangler and Richard L. Handy, Intext Educational Publishers, New York.
2. Foundation Analysis and Design, Joseph E. Bowles, McGraw Hill Book Co., New York.
3. An Introduction to Geotechnical Engineering, Robert D. Holtz and William D. Kovacs, Prentice-Hall, New Jersey.