ENGINEERING FIELD MANUAL
Supplement to Chapter 4

FOUNDATION ANALYSIS FOR STRUCTURES USED IN RESOURCE MANAGEMENT SYSTEMS

GENERAL

This supplement discusses the factors involved in determining soil bearing capacity and provides simplified methods for estimating soil bearing capacity.

The great increase in the installation of commercial structures for animal waste storage in recent years has increased our need to understand soil foundations and their capacity to support structures. This supplement provides an understanding of bearing capacity and the factors involved in its determination. Simplified computational methods for soil bearing capacity and settlement and an example of their use are included.

July, 1987

TABLE OF CONTENTS

Definitions....................................4-37

Soil Bearing Capacity and Settlement....................................4-39

Bearing Capacity Equation....................................4-40

Settlement....................................4-43

Appendix....................................4-47

A Shallow Bearing Capacity Equation....................................4-48
B Maximum Allowable Settlement....................................4-50
C Estimated Shear Strengths....................................4-51
D Settlement on Sand....................................4-52
E Settlement on Clay....................................4-54
F Example....................................4-56

Figures

4-1S Water Table Correction Factors....................................4-42
4-2S Depth of Significant Consolidation....................................4-46
4-3S Bearing Capacity Factors....................................4-49

Definitions

Parentheses ( ) will be used to group terms.

A dot "." will be used to indicate multiplication.

B	Footing width.
Bearing capacity	The maximum footing pressure that can be permitted on a soil, giving consideration to all pertinent factors.
c	Total unit cohesion, psf.
$\bar{c}$,bar c	Effective unit cohesion, psf (sometimes written c').
Cc	Compression index.
Cr	Recompression index.
Consolidation	Reduction in the volume of a soil due to increased loading.
e	Void ratio, volume of voids divided by the volume of solids.
g	Footing shape factor for the shallow bearing capacity equation.
Gs	Specific gravity of the soil grains.
γ,gamma	Unit weight of soil, pcf.
k	Footing shape factor for the shallow bearing capacity equation.
N	Blow count. The number of blows with a 140 lb hammer dropped 30 in required to drive a standard sampler 1 ft.
Nc,Nq,$N\gamma$	Bearing capacity factors from figure 4-3S.
po	The before construction soil load at the center of a strata or increment.
Δ p	The increase in load on a soil at the center of a strata or increment.

ϕ, phi	Total angle of internal friction of a soil.
$\bar{\phi}$, bar phi	Effective angle of internal friction of soil (Sometimes written ϕ').
q	The overburden pressure at the base of a footing.
qa	Allowable bearing capacity, usually qult/3.
qult	Ultimate bearing capacity. (Computed bearing capacity with no factor of safety).
R/C	Reinforced concrete.
Settlement, S	Downward movement of a structure due to soil consolidation.

Settlement, allowable- The maximum settlement or maximum differential settlement that will not cause structure malfunction.

Settlement, differential- The difference between the settlement at two points on a structure.

Settlement, total- The sum of the immediate and long term settlements at a given point on a structure foundation.

Settlement, uniform- The same total settlement at all points on a structure foundation.

Shallow Footing- A footing whose depth below the ground surface is less than or equal to its width.

W, W'	Water table elevation correction factors for use in the shallow bearing capacity equation.

Soil Bearing Capacity and Settlement

When designing animal waste storage and other conservation structures, a foundation's bearing capacity must be determined. Standard structure drawings will often call for a minimum soil bearing capacity, such as, 2,000 pounds per square foot. However, referring to a soil bearing capacity is a gross oversimplification. Structures must be designed so the loadings will not cause the soil beneath the footing to fail by shear, and settlements will not distress the structure. Foundation design is more often controlled by settlement than by soil shear strength.

Bearing capacity is determined by three soil factors;

Shear strength

Compressibility

Water table elevation

And three structure characteristics;

Foundation size and shape

Foundation depth

The structures' ability to settle without distress

Bearing Capacity Equation

Bearing capacity equations have been developed for both sand and clay soils based on theoretical analyses and model tests. The equation described below applies to shallow footings. Foundations for structures used in resource management systems will usually fit the definition for shallow footings. A shallow footing's depth below the ground surface is equal to or less than the footing's width. Footings that do not meet this criteria because their depth is greater than their width may still be conservatively designed by assuming the footing depth equal to the width.

For Class V or smaller structures the shallow bearing capacity equation is recommended when sizing footings for failure against shear. The equation is given below and in the appendix, Part A. Part A includes a sketch and definitions of the terms.

$$q_{ult} = (g \cdot c \cdot N_c) + (q \cdot N_q) + (k \cdot \gamma \cdot B \cdot N_\gamma)$$

qult = Ultimate Bearing Capacity. (The maximum unit loading a soil can support without failing in shear.)

Nc, Nq, and N_γ are bearing capacity factors. They are given in Appendix A, Table 4-3S. They depend on the $\bar{\phi}$ or ϕ soil strength parameter.

The first term in the equation is (g • c • Nc). For continuous linear footings, such as for walls, g = 1.0 and for square and round footings, such as for columns, g = 1.3. the c is the cohesion ($\overline{c}$ or c) soils strength parameter. This term accounts for the cohesive strength of the soil.

The second term is (q • Nq). q is the load per unit area (lb per sq. ft) on a horizontal plane beside the footing at the footing bottom elevation. This term accounts for the effect of overburden confining the soil beneath the footing. In some cases this term accounts for a major portion of the computed ultimate bearing capacity. Even small, 1 to 2-foot, backfill depths can be significant with noncohesive soils. In the case of eccentric loadings caused by a backfilled wall with an empty tank or a loaded tank with little backfill, both empty tank and full tank conditions may need to be checked to find the most critical case.

The third term is ($k \cdot \gamma \cdot B \cdot N\gamma$). k is dependent on the footing shape. γ is the unit weight of soil below the footing. Use moist soil weights. B is the footing width. Notice the value of the third term is directly proportional to the footing width. This term represents the frictional shearing strength of the soil beneath the footing.

Footing size for the soil bearing equation is measured on each structurally independent unit. The "B" for precast retaining wall units used as structure walls with a poured concrete floor is the B of each unit. Units set in line to form a continuous wall should be treated as a continuous footing rather than separate rectangular footings. However, when estimating settlement, the total loaded area must be considered because part of the load from one unit is spread to the soil beneath adjacent units and contributes to their settlement.

If the water table is at a distance of more than "B" below the footing bottom, then it does not affect bearing capacity. If the water table is between the bottom and depth B below the footing, the $(k \cdot \gamma \cdot B \cdot N\gamma)$ factor must be modified by adding a water table correction factor W'. The third term is then $(W' \cdot k \cdot \gamma \cdot B \cdot N\gamma)$. If the water table is above the bottom of the footing, then the term $(q \cdot Nq)$ must also be corrected by adding W. The second term is then $(W \cdot q \cdot Nq)$ W' and W can be read from figure 4-1S.

WATER TABLE CORRECTION FACTORS

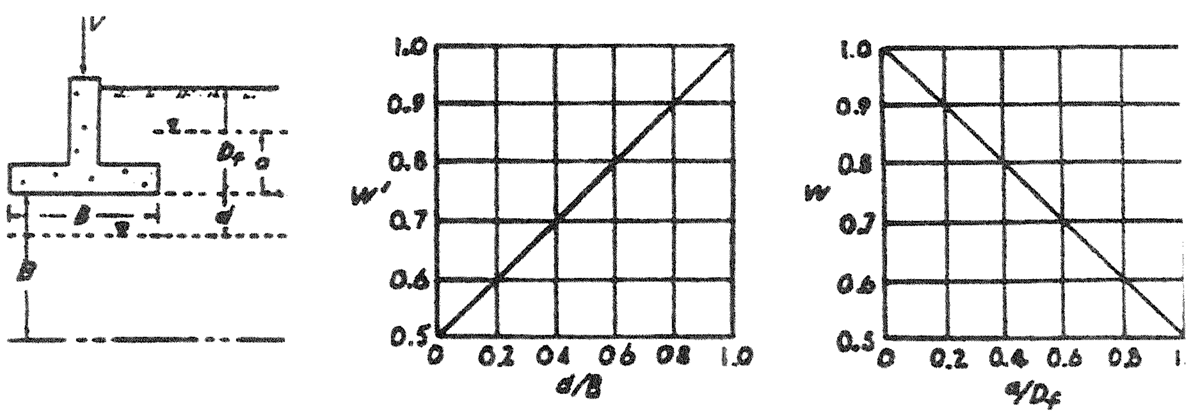


FIGURE 4-1S

Settlement

Two settlement conditions must be considered. They are uniform settlement and differential settlement.

Total settlement is the sum of immediate and long-term settlements at a given point on the structure foundation. If all points in the foundation have the same total settlement, the structure settles uniformly. Since settlement is uniform, uneven stresses are not created in the structure.

Most structures can withstand fairly large uniform settlement, especially if the potential settlement is anticipated and provisions are made for it in design. Uniform settlement can cause problems such as: shearing or malfunction of loading and unloading conduits and fixtures and disruption of surface and subsurface drainage.

Even very small differential settlements can cause structural damage such as cracking of concrete, opening of joints, and bending and dimpling of steel structures. Part B of the Appendix contains a chart of allowable settlements for various structure types.

Any loading of the soil causes settlement due to (a) relocation and consolidation of the soil particles, and (b) movement of water and/or air from the void spaces. Conversely, any excavation or structure removal unloads the underlying soil so that new loads will cause only small settlements until the reloading exceeds the previous load. Soils that have not been previously loaded greater than at present are called "normally consolidated." Soils previously subjected to greater loadings than present are called "overconsolidated" or "preconsolidated".

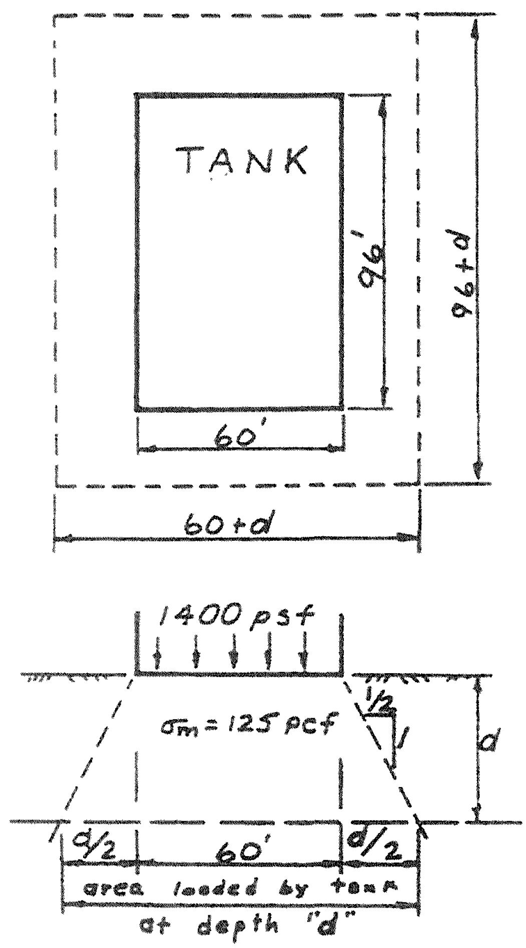
Loads on certain compressible soils can cause significant consolidation to a depth where the weight of the imposed load is 10% of the existing overburden pressure. This can be quite deep. Figure 4-25 page 4-46 gives an example of the computation of this depth. Settlements will be large in soft fine grained soils and in low density sands. Rock, dense tills, gravels, and highly overconsolidated fine grained soils will have few or no settlement problems.

Extensive geologic investigation, sampling, and testing are required to reliably estimate settlement. However, depending on the soil and the characteristics of the structure, settlement may be reasonably estimated using the methods and guidelines described in the Appendix. These methods should not be applied to high hazard structures or where soil characteristics outlined in the Appendix can not be reasonably estimated. Rationale for determining the significance of the settlement and estimated values should be documented in the design file.

Differential settlements occur when foundation soils are not uniform and/or when loadings are nonuniform and under large flexible foundations and floors on compressible foundations. Relatively small differential settlements (1 to 2 inches) will cause distress in many structures especially concrete structures. When total settlement is large, a high potential for large differential settlement usually exists. It is important to select uniform foundation soil conditions and to keep loading uniform. For example, it would be poor practice to place a structure partially on rock and partially on a compressible soil. Also, a foundation should not be constructed partially on a dense till and partially on a compressible alluvium. Where compressible soils occur in a foundation, an investigation must be adequate to assure the compressible material is of uniform depth. In some situations sampling and testing may be required. Examples of loadings and resultant settlements are given in the Appendix.

Depth of Significant Consolidation

A 60 ft by 96 ft rectangular animal waste storage tank sets on the ground surface. When loaded, it exerts 1400 pounds per square foot (psf) on the foundation soil. The foundation soil weighs 125 pcf. It is deep to the water table. Assume the load spreads at a slope of 1/2:1. At what depth is the load imposed by the loaded tank less than 10% of the existing overburden pressure?



Compute the total Wt. of the tank and contents.

Wt = Area · Wt/unit area

= (60'·96')·1400 pcf

Wt = <u>8,064,000</u> lb

Compare the imposed load and existing overburden pressure at depth "d".

try d = 45 ft

Compute imposed load

$\Delta\sigma$ = Wt/area

$\Delta\sigma$ = 8064,000/(60+d)·(96+d)

$\Delta\sigma$ = <u>545 psf</u>

Compute overburden pressure at "d"

σ_o = 125 pcf · 45 ft

σ_o = <u>5625 psf</u>

Compare $\Delta\sigma$ with σ_o

$(\Delta\sigma/\sigma_o)\cdot 100 = (545/5625)\cdot 100$

$(\Delta\sigma/\sigma_o)\cdot 100$ = <u>9.7% < 10%</u>

<u>At 45 ft depth the imposed load becomes less than 10% of the overburden</u>

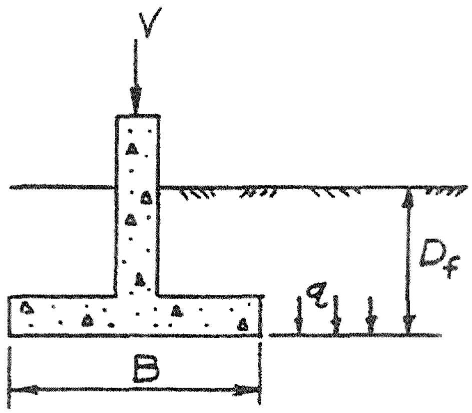
Figure 4-2S

APPENDIX

PART	SUBJECT
A	The Shallow Bearing Capacity Equation...............4-48
B	Maximum Allowable Settlement for Structures Used in Resource Management systems......................4-50
C	Guide for Estimating Soil Strengths.................4-51
D	Settlement on Sand..................................4-52
E	Settlement on Clay..................................4-54
F	Example...4-56

PART A

THE SHALLOW BEARING CAPACITY EQUATION



Df<B

qult = $(g \cdot c \cdot N_c) + (W \cdot q \cdot Nq) + (W' \cdot k \cdot \gamma \cdot B \cdot N_\gamma)$

qult = Ultimate Soil Bearing Capacity

qa = qult/3 = Allowable Bearing Capacity

$\bar{c}$ or c = Soil Cohesion Parameter

$\bar{\phi}$ or ϕ = Soil Friction Parameter

g & k   Footing Shape Factors

Continous Footing	g = 1.0, k = 0.5
Square Footing	g = 1.3, k = 0.4
Round Footing	g = 1.3, k = 0.3

Df= Depth of Footing

γ = Soil Unit Weight

q = Df$\cdot\gamma$, Effective Vertical Soil Pressure

B = Footing Width

Nc, Nq, Nγ = Bearing Capicity Factors

W, W' = Watertable Correction Factors

BEARING CAPACITY FACTORS

ϕ	Nc	Nq	$N\gamma$
0	5.7	1.0	0.0
5	6.7	1.4	0.2
10	8.0	1.9	0.5
15	9.7	2.7	0.9
20	11.8	3.9	1.7
25	14.8	5.6	3.2
30	22.6	11.1	8.5
35	48.0	32.8	35.2
40	95.7	81.3	100.4

Figure 4-3S

This chart lists local shear factors for $\phi < 28°$, general shear factors for $\phi > 38°$, and interpolates between local and general factors between $\phi = 28°$ & $\phi = 38°$.

PART B

MAXIMUM ALLOWABLE SETTLEMENT
for
STRUCTURES USED IN RESOURCE MANAGEMENT SYSTEMS
(Maximum Settlement In Inches) 1/

STRUCTURE	WIDTH OR DIAMETER FEET				
TYPE	20	40	60	80	100
1	0.5	1.0	1.5	2.0	2.5
2	0.7	1.5	2.0	3.0	3.5
3	1.2	2.5	3.5	5.0	6.0
4	2.5	5.0	7.0	10.0	12.0

1 (a) Masonry walls.
  (b) R/C walls, no cracking permitted.

2 (a) R/C walls, minor cracking may occur.
  (b) Precast R/C units that must remain watertight.
  (c) Steel tanks.

3 (a) Simple wood or steel framed structure.
  (b) Precast R/C units, leakage permitted.

4 Impervious earth lined structures.

1/
If the foundation soils are shown to be uniform through the depth of significant settlement the allowable settlements from the chart may be doubled. *

Estimated allowable settlements are taken from observations and studies on buildings and structures. The maximum allowable settlements in the table are based on the assumption differential settlements may equal total settlement and occur at opposite sides of the structure. This assumption may not be conservative in that maximum and minimum settlement may be at intermediate points. If the foundation is uniform then differential settlements will be less than total settlement and the allowable settlement may be increased.

* Appurtenances (pipes, ramps, etc) must be articulated at their contact with the structure to allow settlement without damage.

Part C

ESTIMATING SHEAR STRENGTHS

The following guide may be used to estimate shear strength when test data are not available

Strength of Sands and Sands with Gravel Based on Estimated Density

c = 0

Soil Density	N Blows/ft	$\bar{\phi}$ Deg
Very Loose	2	27
Loose	7	30
Medium	20	35
Dense	40	37
Very Dense	>50	40

Strength of Silts and Sandy Silts with Little or No Plasticity

c = 0

Soil Density	$\bar{\phi}$ Deg
Loose	27
Dense	30

Strength of Clays and Silty Clays Based On Consistency

phi = 0

Soil consistency	Cohesion psf	Blowcount N	
Very soft	*	<2	Thumb will penetrate >1"
Soft	250	2-4	Thumb will penetrate about 1"
Firm	500	4-15	Thumb will penetrate about 1/4 "
Hard	2000	15-30	Readly indented with thumbnail
Very hard	4000	>30	Thumbnail will not indent

* Requires special evaluation of shear strength

PART D

SETTLEMENT ON SAND

Settlement of structures on sand may be estimated from the results of standand penetration tests with the equation

$$qa = 720 \cdot (N-3) \cdot ((B+1)/2B)^2 \cdot W' \cdot Kd$$

qa= Net increase in soil pressure in psf producing 1 inch of settlement.

N= Blow count from the standard penetration test.

B= Width of footing.

W'= Water reduction factor as defined in Part A.

Kd= 1+Df/B But no greater than 2.

Df= Footing depth below ground surface.

When B becomes very large then $((B+1)/2B)^2$ approaches 0.25

When the footing depth (D) is very shallow in relation to the footing width, then Kd approaches 1.

When $d/B > 1$, $W' = 1$

Assuming a load on the foundation soil that is wide and at a shallow depth such as a manure tank set at the soil surface and a deep water table we can compute soil loadings that will produce 1 inch of settlement.

Sand Density	N Blows/ft	Load psf
Very Loose	2	1/
Loose	7	700
Medium	20	3000
Dense	40	6000
Very Dense	50	8000

1/ <u>Even very light loads will produce settlements in excess of 1 inch.</u>

Total settlement for any foundation load can be estimated by relating it to the load producing 1 inch of settlement. For example, on a sand of medium density, a 2000 lb load will produce 2/3 the settlement of a 3000 lb load or 2/3 of an inch. If the footing is large and flexible, the loading of the soil under the edge will be about 1/2 the loading under the center and settlements will be about 1/2 as much. On a large structure, a 5 inch thick reinforced concrete floor will act like a flexible floor.

To compute settlement for any load;

Settlement (in) = (actual load psf)/(load producing 1 in of settlement)

PART E

SETTLEMENT ON CLAY

The settlement of a structure on a clay soil foundation is estimated using consolidation theory. The void ratio and compression index (Cc) for the soil is needed in order to make the settlement computations.

If the soil has been loaded in the past with a greater load than it now has, it is said to be preconsolidated, overconsolidated or preloaded. Compacted fill has been preloaded by the compaction equipment. In the case of preconsolidated soil the, recompression index (Cr) is used in place of Cc in the computations. Cc and Cr are determined by consolidation testing of undisturbed samples from the foundation. Cc can be estimated from the liquid limit with the formula;

$$Cc = 0.009 \cdot (LL-10)$$

Or from the liquid limit and the void ratio with the formula

$$Cc = (0.0035 \cdot LL \cdot (eo-0.4))^{1/2}$$

Cr is usually 15 to 25% Of Cc.

Void ratio can be computed from the dry density and specific gravity of the soil with the formula;

$$e = (Gs \cdot \gamma w/\gamma d)-1$$

e= void ratio

γd= dry density of the soil in pcf

Gs= the specific gravity of the soil grains Usually between 2.65 and 2.75

γw= 62.4 pcf

The formula for settlement is;

$$S = ((Cc \cdot H)/(1+eo)) \cdot \log10\ ((po+\Delta p)/po)$$

S= total settlement

Cc= compression index

H= depth of compressible strata. Thick strata should be divided into 4 to 10 foot thick increments.

po= The existing vertical soil pressure at the center of the strata or increment.

eo= The void ratio of the compressable strata before loading.

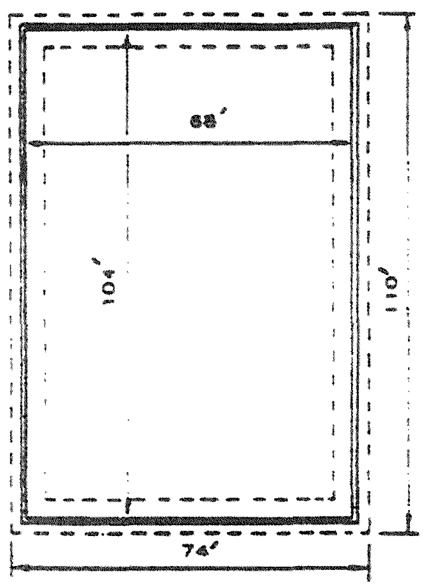
Δp= The added load at the center of the strata or increment.

log10= The logarithm of this number to the base 10.

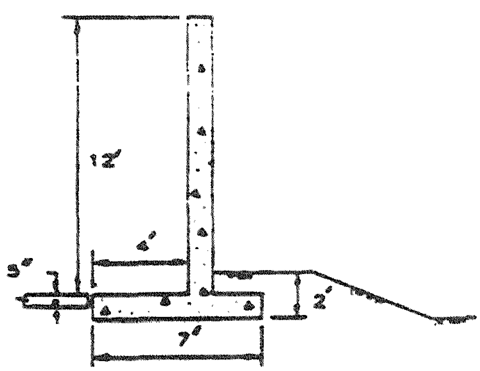
EXAMPLE

An animal waste storage structure with inside dimensions of 68 ft by 104 ft by 12 ft is to be constructed of precast R/C units. The units are 7 ft wide, 12 ft long and produce a 12 ft high wall. They weigh 2800 lb per ft of length. A 5 in thick R/C floor will be cast and all the joints will be sealed to produce a water tight structure. The units will be placed on a smoothed ground surface and backfilled on the outside to a depth of 2 ft. The foundation consists of 40 ft of firm silty clay with a liquid limit of 40. The dry unit weight is 90 pcf and the wet unit weight is 118 pcf. The unit weight of the animal waste is 65 pcf. The water table is 10 ft below the ground surface.

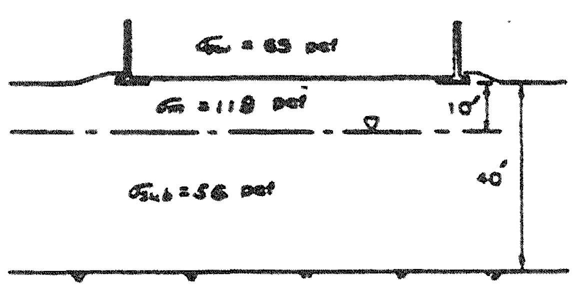
Assess the adequacy of the foundation soil to support this structure when it is full.



PLAN



WALL CROSS SECTION



PROFILE

NENTC PROJECT Example

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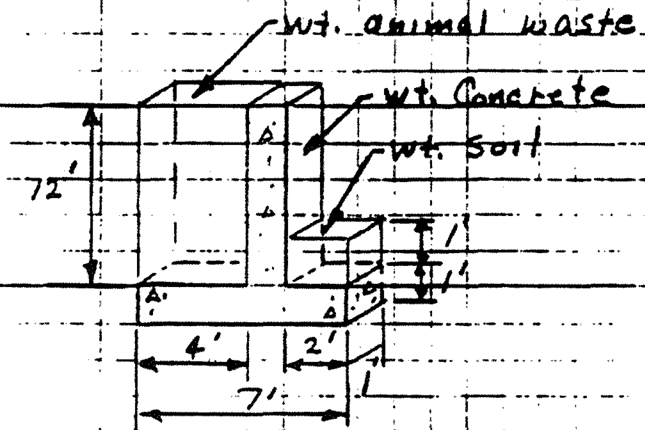
SUBJECT Foundation Analysis SHEET OF 1/8

Compute the Actual Load on the Soil Under the Precast Units With 12ft of Waste in the tank.



$$\frac{\text{Load}}{\text{Area}} = \frac{\text{wt. Concrete} + \text{wt. animal waste} + \text{wt. soil}}{1' \cdot 7'}$$

$$= \frac{2800^{lb} + (65 pcf \cdot 1' \cdot 4' \cdot 12') + (118 pcf \cdot 1' \cdot 1' \cdot 2')}{7 \, ft^{SF}}$$

$$= \frac{2800 + 3120 + 236}{7} = \frac{6156}{7}$$

= 880 psf

Compute Allowable Bearing Capacity

From part A

$q_{ult} = (q \cdot c \cdot N_c) + (W \cdot q \cdot N_q) + (W' \cdot K \cdot \gamma_m \cdot B \cdot N_\gamma)$

From Part C

Silty clay - firm gives, $\phi = 0$ and $c = 500$ psf

From Part A, Table 1, @ $\phi = 0$ gives

$N_c = 5.7$, $N_q = 1.0$, $N_\gamma = 0.0$

$q = (2^{ft})(118\ pcf)$

$= 236$ psf Effective Vertical Pressure

Assume the precast units act like a Continous footing with $B = 7^{ft}$

$q = 1.0$, $K = 0.5$, $\gamma_m = 118$ pcf

From Page 4-42, d=10' which is greater tha B=7'

Therefore $W' = 1.0$

$q_{ult} = (1.0 \cdot 500 \cdot 5.7) + (1 \cdot 236 \cdot 1.0) + (1 \cdot 0.5 \cdot 118 \cdot 7 \cdot 0.0)$

$= 2850 + 236 + 0 = 3086$ psf

$q_a = q_{ult}/3$ (allowable bearing capacity)

$q_a = \frac{3086}{3} = 1028$ psf

$1028^{psf} < 880^{psf}$

Allowable bearing capacity exceeds actual

Therefore Bearing Capacity is O.K.

Estimate Actual Settlement

Compute total wt. on foundation

wt. walls	= 2800 #/ft · 2 · (69 + 105) =	974,400
wt. Floor	= 150 pcf · 5/12' · (60 · 96) =	360,000
wt. waste	= 65 pcf · 68 · 104 · 12	= 5,516,160
wt. soil	= 118 pcf · 1' · 2' · (2(72 + 108)) =	84,960
	Total	6935,520 lbs

Compute the increased loading (Δp) from the loaded tank at the surface and at 5, 15, 25 and 35 foot depths. Assume the load spreads at a ½:1 slope.

$$\text{Loading, } \Delta p = \frac{\text{Total Load}}{\text{Area}}$$

$$\text{Surface} = \frac{6935,520}{74' \cdot 110'} = 852 \text{ psf}$$

$$5' \text{ depth} = \frac{6935,520}{79' \cdot 115'} = 763 \text{ psf}$$

$$15' \text{ depth} = \frac{6935,520}{89' \cdot 125'} = 623 \text{ psf}$$

$$25' \text{ depth} = \frac{6935,520}{99' \cdot 135'} = 519 \text{ psf}$$

$$35' \text{ depth} = \frac{6935,520}{109' \cdot 145'} = 439 \text{ psf}$$

Compute the existing vertical soil pressures (p_o) at 5, 15, 25 and 35 foot depth.

$p_o\ (5^{ft}) = (5')(118\ pcf) = 590\ psf$

$p_o\ (15^{ft}) = (10')(118\ pcf) + (5')(56^{1/}\ pcf) = 1460\ psf$

$p_o\ (25^{ft}) = (10')(118\ pcf) + (15')(56^{1/}\ pcf) = 2020\ psf$

$p_o\ (35^{ft}) = (10')(118\ pcf) + (25')(56^{1/}\ pcf) = 2580\ psf$

Estimate the void ratio

$$e = \frac{G_s \gamma_\omega}{\gamma_d} - 1$$

$\gamma_d = 90\ pcf$

G_s (estimated) $= 2.65$

$$e = \frac{2.65 \cdot 62.4}{90} - 1$$

$e = \underline{\underline{0.84}}$

Estimate the compression index

From part E

$C_c = [0.0035 \cdot LL \cdot (e_o - 0.4)]^{1/2}$

$C_c = [0.0035 \cdot 40 \cdot (0.84 - 0.4)]^{1/2}$

$C_c = \underline{\underline{0.25}}$

1/ Bouyant weight of soil below the water table
$118^{pcf} - 62.4^{pcf} \approx 56^{pcf}$

Compute settlement by 10 foot thick foundation strata

From part E

$$S = \frac{C_c \cdot H}{1+e_o} \log 10 \frac{P_o + \Delta P}{P_o}$$

$$= \frac{0.25 \cdot 10}{1+0.84} \log 10 \frac{P_o + \Delta P}{P_o}$$

$$= 1.36 \log 10 \frac{P_o + \Delta P}{P_o}$$

Representative from (ft)	Strata to (ft)	P_o psf	ΔP psf	S feet
0	10	590	763	0.49
10	20	1460	623	0.21
20	30	2020	519	0.14
30	40	2580	439	0.09

Total Estimated Actual Settlement 0.93 ft

or $0.93^{ft} \cdot 12^{in}/ft$ = 11.1 inches

Determine allowable settlement and compare with estimated settlement

From part B

Structure type 2, width 74', use 80'

Maximum Allowable Settlement = 3.0 inches

11.1 inches is much greater than 3.0 inches

Foundation is not adequate

Assume the silty clay is overconsolidated with a dry density of 105 pcf. Estimate the settlement.

From part E

The recompression index, C_r is usually 15 to 25% of C_c, use 20%

From page 4-60, $C_c = 0.25$

$C_r = 0.2 \cdot 0.25 = 0.05$

$$e = \frac{G_s \gamma_w}{\gamma_d} - 1 = \frac{2.65 \cdot 62.4}{105} - 1$$

$= 0.57$

$$S = \frac{0.050 \cdot 10}{1+0.57} \log_{10} \frac{P_o + \Delta P}{P_o}$$

$$= 0.32 \log_{10} \frac{P_o + \Delta P}{P_o}$$

Representative from (ft)	Strata to (ft)	P_o psf	ΔP psf	S feet
0	10	625	763	0.11
10	20	1570	623	0.05
20	30	2220	519	0.03
30	40	2860	439	0.02
			Total	0.21 feet

or $0.21 \text{ ft} \cdot 12 \text{ in/ft} = 2.5$ inches

2.5 < 3.0 settlement O.K.

Assume the structure is to be placed on a loose sand foundation with $\gamma_m = 125\ lb/ft^3$. Compute allowable bearing capacity.

From part C

Loose sand, $N = 7$, $\bar{\phi} = 30$, $c = 0$

From part A, table I

$N_c = 22.6$, $N_q = 11.1$, $N_\gamma = 8.5$

$$q_{ult} = (q \cdot c \cdot N_c) + (W \cdot q \cdot N_q) \pm (W' \cdot K \cdot \gamma \cdot B \cdot N_\gamma)$$

$$q_{ult} = (1.0 \cdot 0 \cdot 22.6) + (1 \cdot 250 \cdot 11.1) + (1.5 \cdot 125 \cdot 7.85)$$

$$= 0 + 2780 + 3720$$

$$q_{ult} = 6500$$

$$q_a = q_{ult}/3 = 2170\ psf \text{ (allowable bearing)}$$

$$2170\ psf > 880\ psf$$

Bearing Capacity is Adequate

Notice that 43% of the computed bearing capacity comes from the second term in the equation and is dependent on the two feet of backfill.

Estimate Actual Settlement

From part D

$qa = 720 \cdot (N-3) \cdot ((B+1)/2B)^2 \cdot W' \cdot Kd$

$N = 7, B = 74,$

$K_d = 1 + D/B = 1 + 2/74$

$= 1.0$

W' from page 4-42, $d/B = 10/74 = 0.14$

$W' = 0.57$

$qa = 720 \cdot (7-3) \cdot ((74+1)/(2 \cdot 74))^2 \cdot 0.57 \cdot 1.0$

= 420 psf produces 1 inch of Settlement

s = Actual ground pressure / qa

$s = \frac{860}{420} = 2.0$ inches

2.0 inches < 3.0 inches allowable

Foundation soil is adequate

LOG SHEET

Project: ______________________ **Location:** ______________________ **Date:** __________

Investigator: ______________________ **Title:** ______________ **Equipment:** ______________________

SIZE DISTRIBUTION

<---by weight--><--by volume-->

Interval (feet)	% Fines	% Sand	% Gravel	% Cobbles	% Boulders	Angularity (coarse frac.)	Color (when moist)	Moisture content	Consistency of fines	Density (coarse fraction)	Structure	Plasticity of fines	Dilatancy	Group name	Unified symbol	Geologic origin	Sample No.
0 -																	

Notes:

Test Hole No.: ________ Station: ________ Elevation: ________ Water Table Elevation: ______ after ____ hours. Sheet ____ of ____

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

TABLE 2 Criteria for Describing Particle Shape

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with width/thickness > 3
Elongated	Particles with length/width > 3
Flat and elongated	Particles meet criteria for both flat and elongated

TABLE 3 Criteria for Describing Moisture Condition

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

TABLE 4 Criteria for Describing the Reaction With HCl

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

TABLE 5 Criteria for Describing Consistency

Description	Criteria for Fine-grained Saturated Soils	Penetrometer tons/ft², or kg/cm²	Std. Penetration Test (ASTM D-1586) blows/ft
Very Soft	Thumb will penetrate soil more than 1 inch	< 0.10	< 2
Soft	Thumb will penetrate soil about 1 inch	0.10 - 0.25	2 - 4
Firm	Thumb will indent soil about ¼ inch	0.25 - 1.00	4 - 15
Hard	Thumb will not indent soil but readily indented with thumbnail	1.00 - 2.00	15 - 30
Very Hard	Thumbnail will not indent soil	> 2.00	> 30

TABLE 6 Criteria for Describing Cementation

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick; note thickness
Laminated	Alternating layers of varying material or color with the layers less than 6 mm thick; note thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thickness
Homogeneous	Same color and appearance throughout

TABLE 8 Criteria for Describing Dry Strength

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface
Very high	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9 Criteria for Describing Dilatancy

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing

TABLE 10 Criteria for Describing Toughness

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 11 Criteria for Describing Plasticity

Description	Criteria
Nonplastic	A ⅛-in. (3-mm) thread cannot be rolled at any water content
Low	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit
Medium	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit

CHECKLIST - DESCRIPTION OF COARSE-GRAINED SOILS - ASTM D-2488

1. Typical Name: Boulders Cobbles Gravel Sand
   Add descriptive adjectives for minor constituents.
2. Gradation: Well-graded Poorly-graded (Uniformly graded or gap-graded)
3. Size Distribution: Percent gravel, sand, and fines in fraction finer than 3-inch (76 mm), to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   - Trace: < 5 %
   - Few: 5 - 10 %
   - Little: 15 - 25 % ---> Or, e.g., with gravel
   - Some: 30 - 45 % ---> Or, e.g., gravelly
   - Mostly: 50 - 100 %
4. Percent Cobbles and Boulders: By volume.
5. Particle Size Range: Gravel -- fine, coarse
   Sand -- fine, medium, coarse
6. Angularity of Coarse Material: Angular Subangular Subrounded Rounded
7. Particle Shape (if appropriate): Flat Elongated Flat and Elongated
8. Plasticity of Fines: Nonplastic Low Medium High
9. Mineralogy: Rock type for gravel, predominant minerals in sand. Note presence of mica flakes, shaley particles, and organic materials.
10. Color: Use common terms or Munsell notation. Based on moist or wet condition.
11. Odor (for dark-colored or unusual soils only): None Earthy Organic
12. Moisture Content: Dry Moist Wet

--for intact samples--

13. Natural Density: Loose Dense
14. Structure: Stratified Lensed Nonstratified
15. Cementation: Weak Moderate Strong
16: Reaction (dilute HCl): None Weak Strong (or pH)
17. Geologic Origin: Examples - Alluvium, Residuum, Colluvium, Glacial till, Outwash, Dune sand, Alluvial fan, Talus, etc.
18. Unified Soil Classification Symbol: Estimate. (See Field Identification of Coarse-grained Soils below.)

Note: Refer to Tables 1-11 for criteria for describing many of the above factors.

==

FIELD IDENTIFICATION - COARSE-GRAINED SOILS

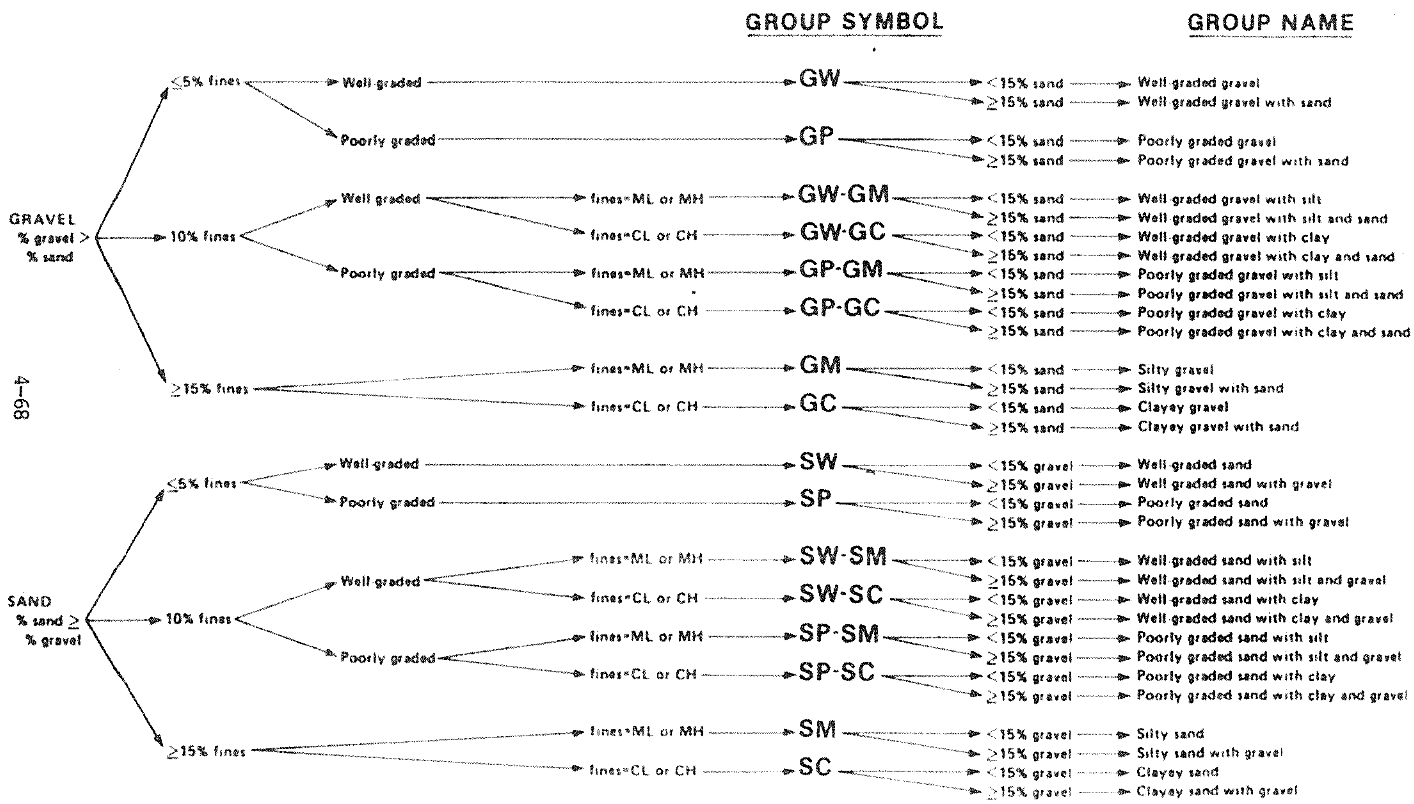
COARSE PARTICLE GRADE SIZES

Grade Name	Grade Size	Sieve No.	Comparative Size
Boulders	12" +	-	Basketball or larger
Large Cobbles	6" - 12"	-	Cantaloupe to Basketball
Small Cobbles	3" - 6"	-	Orange to Cantaloupe
(Exclude fraction larger than 3" for Unified Classification)			
Coarse Gravel	3/4" - 3"	-	Cherry to Orange
Fine Gravel	1/4" - 3/4"	4 - 3/4"	Pea to Cherry
Coarse Sand	2.0 - 4.76 mm	10 - 4	Wheat Grain to Pea
Medium Sand	0.42 - 2.0 mm	40 - 10	Sugar to Wheat Grain
Fine Sand	0.074 - 0.42 mm	200 - 40	Flour to Sugar

COARSE-GRAINED SOILS[1]	GRAVEL AND GRAVELLY SOILS[2]	More than half of coarse fraction (by weight) is larger than ¼-inch.	CLEAN GRAVELS Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate sizes.	GW
				Mostly one size or a range of sizes with some intermediate sizes missing.	GP
			DIRTY GRAVELS Will leave a dirt stain on a wet palm.	Low to nonplastic fines (for identification of fines see Field Identification of Fine-grained Soils for ML soils).	GM
				Plastic fines (for identification of fines see Field Identification of Fine-grained Soils for CL soils).	GC
	SAND AND SANDY SOILS[2]	More than half of coarse fraction (by weight) is smaller than ¼-inch.	CLEAN SANDS Will not leave a dirt stain on a wet palm.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	SW
				Mostly one size or a range of sizes with some intermediate sizes missing.	SP
			DIRTY SANDS Will leave a dirt stain on a wet palm.	Low to nonplastic fines (for identification of fines see Field Identification of Fine-grained Soils for ML soils).	SM
				Plastic fines (for identification of fines see Field Identification of Fine-grained Soils for CL soils).	SC

1/ To classify as Coarse-grained, more than half of the material (by weight) must consist of individual grains visible to the naked eye. Individual grains finer than no. 200 sieve cannot be seen with the naked eye nor felt by the fingers.

2/ For visual classification, ¼-inch size may be used as equivalent to no. 4 sieve.



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5%.

FIG. 2 Flow Chart for Identifying Coarse-Grained Soils (less than 50 % fines)

CHECKLIST - DESCRIPTION OF FINE-GRAINED SOILS - ASTM D-2488

1. Typical Name: Silt   Elastic Silt   Lean Clay   Fat Clay
   Silty Clay   Organic Silt or Clay   Peat
2. Dry Strength: None   Low   Medium   High   Very High
3. Size Distribution: Percent gravel, sand, and fines in fraction finer than 3 inches (76 mm), to nearest 5 percent. If desired, the percentages may be stated in terms indicating a range of values, as follows:
   - Trace: < 5 %
   - Few: 5 - 10 %
   - Little: 15 - 25 % ---> Or, e.g., with sand
   - Some: 30 - 45 % ---> Or, e.g., sandy
   - Mostly: 50 - 100 %
4. Percent Cobbles and Boulders: By volume.
5. Dilatancy: None   Slow   Rapid
6. Toughness of Plastic Thread: Low   Medium   High
7. Plasticity of Fines: Nonplastic   Low   Medium   High
8. Color: Use common terms or Munsell notation. (In moist or wet condition)
9. Odor (for dark-colored or unusual soils only): None   Earthy   Organic
10. Moisture Content: Dry   Moist   Wet

--For intact samples--

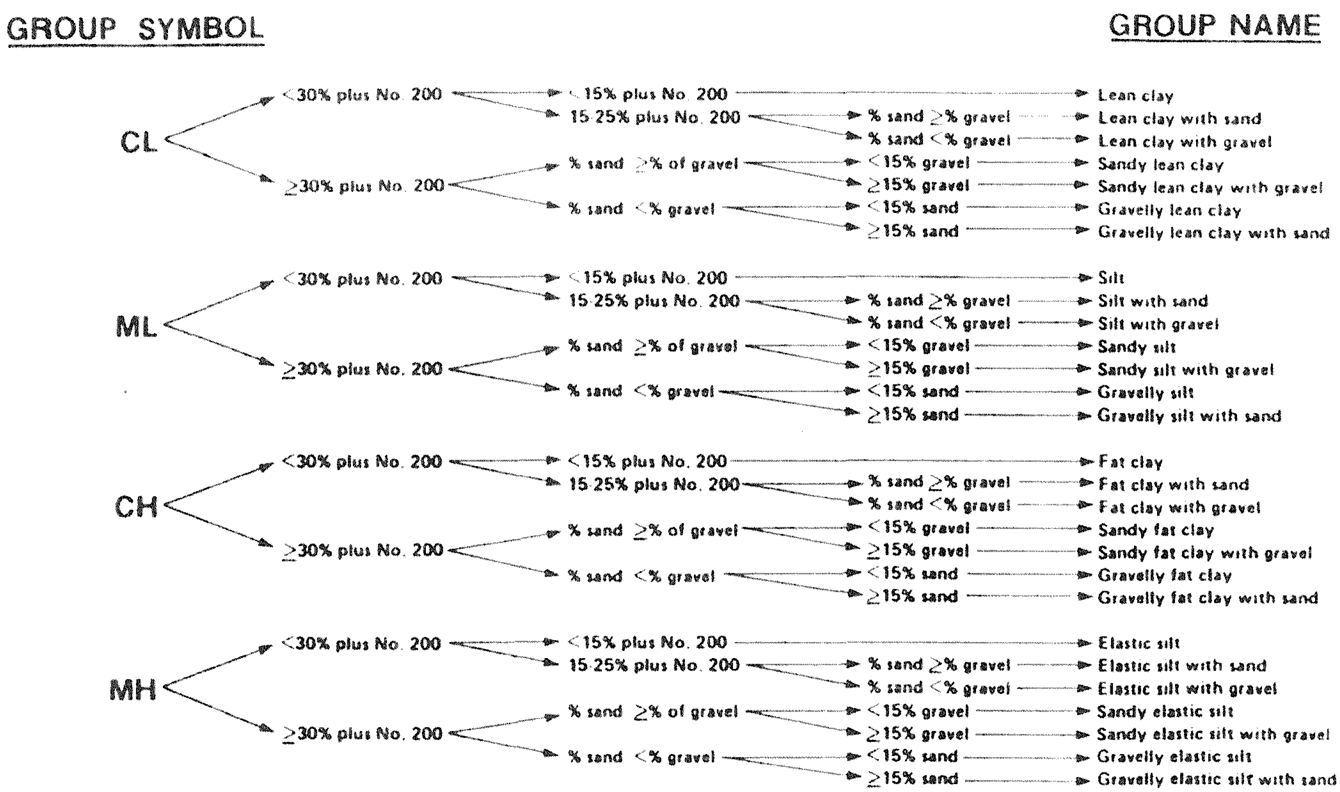
11. Consistency: Very Soft   Soft   Firm   Hard   Very Hard
12. Structure: Stratified   Laminated (varved)   Fissured   Slickensided
    Blocky   Lensed   Homogeneous
13. Cementation: Weak   Moderate   Strong
14. Reaction (dilute HCl): None   Weak   Strong   (or pH)
15. Geologic Origin: Examples - Alluvium, Residuum, Colluvium, Loess, Glacial Till, Lacustrine, etc.
16. Unified Soil Classification Symbol: Estimate. (See Field Identification of Consistency of Fine-grained Soils below, and Table 12: Identification of Inorganic Fine-grained Soils from Manual Tests.)

Note: Refer to Tables 1-11 for criteria for describing many of the above factors.

FIELD IDENTIFICATION - FINE-GRAINED SOILS[1]

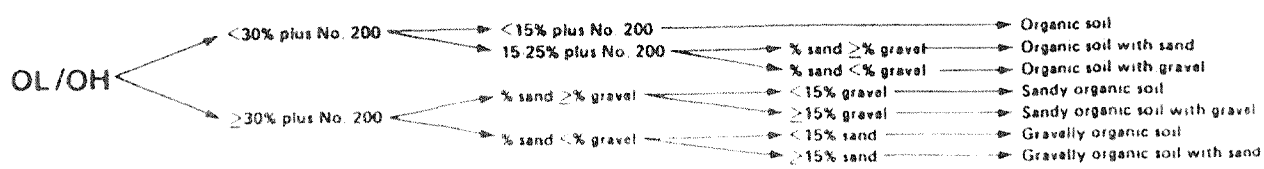
Dry Strength	Dilatancy	Toughness	Plasticity	Symbol
None to Low	Slow to Rapid	Low or No Thread	Nonplastic to Low	ML
Medium to High	Slow	Medium	Low to Medium	CL
Low to Medium	None to Slow	Low (Spongy)	None to Low	OL
Medium	None to Slow	Low to Medium	Low to Medium	MH
Very High	None	High	Medium to High	CH
Medium to High	None	Low to Med. (Spongy)	Medium to High	OH
HIGHLY ORGANIC SOILS	Primarily organic matter, dark in color, spongy feel, organic odor, and often fibrous texture.			PT

1/ To classify as Fine-grained, more than half of the material (by weight) must consist of fines (material finer than the no. 200 sieve).



NOTE—Percentages are based on estimating amounts of fines, sand, and gravel to the nearest 5 %.

FIG. 1a Flow Chart for Identifying Inorganic Fine-Grained Soil (50 % or more fines)



NOTE — Percentages are based on