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Bearing Capacity of Safety Related Buildings at CCNPP Unit 3

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Bearing Capacity of Safety Related Buildings at CCNPP Unit 3

Purpose

To calculate the bearing capacity of the Nuclear Island Common Mat (NI), Nuclear Auxiliary Building (NAB), ESWB and the EPGB at the CCNPP Unit 3 Site. The analysis is performed using closed form solutions. Factors of safety are obtained for different soil profile cases and compared with standard practice allowable values.

Background

The site geology at CCNPP is comprised of deep coastal plain sediments underlain by bedrock at approximately 2,500 ft below the ground surface. The soils consist of marine and fluvial deposits. The upper 400 ft of these soils are the subject of the CCNPP subsurface investigation. These soils are divided into the following principal strata:

- Stratum I: Terrace Sand
- Stratum IIa: Chesapeake Clay/Silt
- Stratum IIb: Chesapeake Cemented Sand
- Stratum IIc: Chesapeake Clay/Silt
- Stratum III: Nanjemoy Sand

Stratum IIb is further divided in three sublayers as a result of localized zones of cemented sand and poorly cemented sand.

References

1) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F9. “Soil Strata – Thicknesses and Termination Elevations”, August 2009.

2) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F16. “Triaxial Compression and Direct Shear Testing Calvert Cliffs Unit 3”, August 2009.

3) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F13. “Unit Weights Calvert Cliffs Unit 3”, August 2009.

4) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F20. “Construction loads, areas and elevations of CCNPP Unit 3 Buildings”, August 2009.

5) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F2. "EPGB and ESWB Best Estimate of Velocity Profile", August 2009.

6) J.E. Bowles, Foundation Analysis and Design, Fifth Edition, 1996.

7) US Army Corps of Engineers (USACE), Technical Engineering and Design Guides, No. 7: "Bearing Capacity of Soils", ASCE, 1993.

8) Calvert Cliffs Nuclear Power Plant Unit 3 (CCNPP3) FSAR Revision 5, Sections 2.4 and 2.5, Combined License Application, June 30, 2009.

9) International Building Code (IBC), International Code Council, Inc., Table 1804.2, 2006.

10) Paul C. Rizzo Associates, Inc., Calculation No. 09-4179.01-F17. "Undrained Shear Strength Calvert Cliffs Unit 3", August 2009.

Methodology

1. The soil profile of CCNPP Unit 3 is used in the analysis in order to determine the layer thickness and material properties. Stratum thicknesses and elevations are presented in Table 1.

2. Average values for effective cohesion (c'), friction angle (ϕ'), stratum thickness and material's unit weight (γ) are considered for each stratum. These parameters correspond to Unit 3 and CLA-1 areas. A weighted average, based on the relative thickness of each stratum, is obtained for each building in order to use the close form solutions (See Tables 2 through 8).

3. Calculate the ultimate static bearing capacity of the soil subsurface for all buildings using the model proposed by Vesic (1973, 1975) for footings supported on homogeneous soils (Ref. 5). Three different cases are considered in the analysis:

    a) Soil subsurface including all strata: For this case, weighted average values of c', ϕ' and γ' are used based on relative thickness of each stratum in the zone between the bottom of the footing and a depth B below this point, where B is the least lateral dimension of the building. For this case, effective soil parameters are used (drained conditions). Values are presented in Table 7.

    b) Soil subsurface considering only stratum IIb Chesapeake Cemented Sand. Soil parameters of this layer are used for the entire depth. For this case, effective soil parameters are used (drained conditions). Values are presented in Table 7.

    c) Soil subsurface considering only stratum IIc Chesapeake Clay/Silt. Soil parameters of this layer are used for the entire depth. For this case, total soil parameters are used (undrained conditions) where $c = s_u$ and $\phi = 0$. Values are presented in Table 7.

4. Calculate the ultimate static bearing capacity of the soil subsurface for all buildings using the close form solution proposed by Meyerhof (1980, 1974) for footings supported on a dense sand stratum over a soft clay stratum. In this solution a punching shear failure using a circular slip path is assumed (Ref. 6). For this case, effective soil parameters are used (drained conditions). Values are presented in Table 8.

5. All buildings are considered to have equivalent rectangular foundations. For the NI Common Mat, an average uniform load is considered in the analysis. The vertical load imposed by other buildings is conservatively not considered in this analysis, only the surcharge imposed by the backfill is considered.

6. Calculate the ultimate bearing capacity for dynamic loading. The static allowable bearing capacity is typically increased by one third for dynamic or transient loading conditions (IBC 2006; Ref. 9).

7. Calculate the factors of safety of all cases comparing the bearing capacity of the soil subsurface with the corresponding bearing pressures of each building (See Tables 9 and 10).

Design Inputs

1. The bearing pressures for all buildings are obtained from Ref. 4. For the Nuclear Island Common mat an average uniform load of 11.8 ksf is considered in the analysis. The post-construction water table elevation will average approximately 69 ft msl (grade elevation) at the areas close to the NI Common mat (Ref. 8). However, for this analysis the water table is conservatively considered at elevation 83 ft msl (grade elevation). Therefore, an effective unit weight is considered for the backfill around the NI.

2. Soil strength parameters (c', ϕ', s_u) and unit weights are obtained from Ref. 2, Ref. 3 and Ref. 10. Average values are considered in the analysis. Average unit weights are calculated using data from the Unit 3 area; limited number of samples were available for strength parameters in the Unit 3 area, therefore data from the CLA area are included in the calculation of the average values. Sand layers present a relatively low cohesion due to the presence of fine particles, based on laboratory tests results (Ref. 2). However, for this analysis the cohesion for sand layers is conservatively not considered ($c' = 0$).

3. A factor of safety of 3.0 for static loads (dead plus live loads) and 2.0 for dynamic loading are considered to be acceptable, based on Ref. 8.

Results

The bearing capacity factors of safety of all buildings are above the minimum requirements (FS = 3). The lowest calculated factor of safety (FS = 6) corresponds to the NI Common Mat, and the highest corresponds to the EPGB (FS = 30). Cases a (all strata within 1B) and b (only sand stratum) give similar factors of safety. For all structures, the lowest factors of safety correspond to Case c as a result of considering only the clay layer in undrained conditions; this Case represents a lower bound in the analysis. For the ESWB and the EPGB Case c is not considered, the location of the clay stratum is relatively deep, outside the failure

zone. Therefore, the failure pattern beneath the foundation is mostly determined by the upper strata. Results are sensitive to the strength parameters, particularly to the friction angle.

The Meyerhof model represents a more realistic approach to calculate the bearing capacity of the soil subsurface at CCNPP 3, by considering a dense sand layer underlying a softer clay layer. This model considers a punching shear failure mechanism between both layers.

Ultimate, allowable and recommended factors of safety for static loading in all buildings are presented in Table 9. Allowable bearing capacities for dynamic loading of all buildings are presented in Table 10.

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TABLE 1
STRATUM THICKNESS AND SOIL PROPERTIES FOR BEARING CAPACITY ANALYSIS
CCNPP UNIT 3

Stratum	Elevation (ft) (1)		Thickness (2) (ft)	Average unit weight γ (3) (pcf)	Effective avg. unit weight γ ' (pcf)
	top	bottom			
Backfill	83.0	41.5	41.50	145	82.6
Stratum IIb-1 Chesapeake Cemented Sand	41.5	15.5	26.00	122	59.6
Stratum IIb-2 Chesapeake Cemented Sand	15.5	-7.5	23.00	123	60.6
Stratum IIb-3 Chesapeake Cemented Sand	-7.5	-23.5	16.00	123	60.6
Stratum IIc Chesapeake Clay/Silt	-23.5	-213.5	190.00	104	41.6
Stratum III Nanjemoy Sand (4)	-213.5	-317.0	103.50	127	64.6

(1) Backfill top elevation is an average value for the Unit 3 area (Ref. 8); the bottom elevation corresponds to the NI Common mat foundation elevation (Ref. 8).
Elevations for the other stratum are calculated based on thickness.
(2) Layer thicknesses correspond to average values for Unit 3 (Ref. 1).
(3) Unit weights correspond to average values for Unit 3 (Ref. 3).
(4) Thickness of Stratum III is based on Geophysical data (Ref. 5).

TABLE 2
LAYER THICKNESS WEIGHT FACTORS
FOR THE NI COMMON MAT

Stratum	Weight factors (1)		
	Case a (2)	Case b (3)	Case c (4)
Backfill	-	-	-
Stratum IIb-1 Chesapeake Cemented Sand	0.096	0.400	-
Stratum IIb-2 Chesapeake Cemented Sand	0.085	0.354	-
Stratum IIb-3 Chesapeake Cemented Sand	0.059	0.246	-
Stratum IIc Chesapeake Clay/Silt	0.704	-	1.000
Stratum III Nanjemoy Sand	0.056	-	-

(1) Weight factors based on layer thickness used in the analysis to obtain average values of the parameters within a depth of 1 B
(2) All stratum are included
(3) Only sand layer IIb is included (with three sublayers).
(4) Only clay layer (IIc) is included

NI Common Mat equivalent rectangle dimensions

Elevation = 41.5 ft (Table 3.3; Ref. 4)

From the original cruciform footprint:

A =	80210	ft^2	Figure 1 of Ref. 4
I_B =	6.11E+08	ft^4	Figure 1 of Ref. 4
I_L =	5.09E+08	ft^4	Figure 1 of Ref. 4

For an equivalent rectangle:

B =	270	ft	NI Common mat least lateral dimension
L =	300	ft	
			approx. difference
A' =	81000.0	ft^2	1%
I_B' =	6.08E+08	ft^4	-1%
I_L' =	4.92E+08	ft^4	-3%

Total depth of the model = 358.5 ft

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Loads, areas and centroids for the NI Common mat buildings (Ref. 4):

Building	P (kips)	A (ft2)	w (ksf)	xc (ft)	yc (ft)
Reactor Building	313477	26268	11.9	91.7	182.1
Fuel Building	216806	14545	14.9	88.8	294.2
Safeguard 1	108064	9198	11.7	224.6	182.3
Safeguard 2&3	200814	20952	9.6	94.8	56.2
Safeguard 4	104079	9247	11.3	-41.5	182.6

Location of the resultant force:

xc,NI = 92.2 ft
yc,NI = 181.1 ft

From the Reactor building center:

xc,NI = 0.5 ft
yc,NI = -1.0 ft

Resulting moments due to vertical loads:

M_B = -9.02E+05 k-ft
M_L = 5.10E+05 k-ft
P_t = 943240 kips

Centroids for all NI Common Mat buildings (based on footprint of Ref. 4):

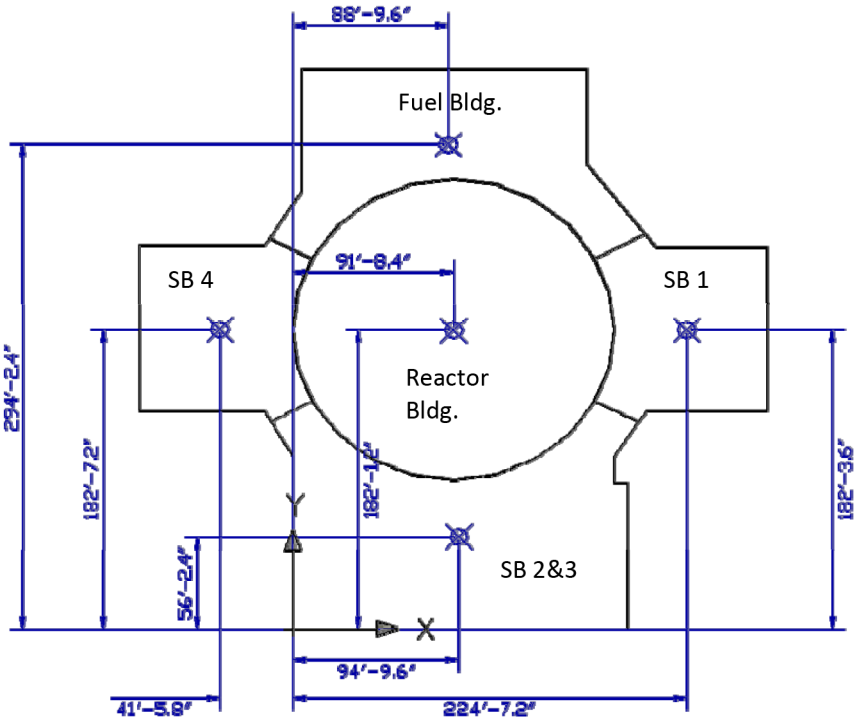

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TABLE 3
LAYER THICKNESS WEIGHT FACTORS
FOR THE NAB

Stratum	Weight factors (1)		
	Case a (2)	Case b (3)	Case c (4)
Backfill	0.062	0.091	-
Stratum IIb-1 Chesapeake Cemented Sand	0.248	0.364	-
Stratum IIb-2 Chesapeake Cemented Sand	0.219	0.322	-
Stratum IIb-3 Chesapeake Cemented Sand	0.152	0.224	-
Stratum IIc Chesapeake Clay/Silt	0.319	-	1.000
Stratum III Nanjemoy Sand	0.000	-	-

(1) Weight factors based on layer thickness used in the analysis to obtain average values of the parameters within a depth of 1 B
(2) All stratum are included
(3) Only sand layer IIb is included (with three sublayers).
(4) Only clay layer (IIc) is included

NAB dimensions (considered as a rectangle)

Elevation = 48 ft (Table 3.3; Ref. 4)

From the original building footprint:

A =	12559	ft^2	Figure 1 of Ref. 4
I_B =	1.51E+07	ft^4	Figure 1 of Ref. 4
I_L =	1.13E+07	ft^4	Figure 1 of Ref. 4

For an equivalent rectangle:

B =	105	ft	
L =	120	ft	
			approx. difference
A' =	12600.0	ft^2	0%
I_B' =	1.51E+07	ft^4	0%
I_L' =	1.16E+07	ft^4	3%

The load for this building is considered constant across the entire area; therefore there are no eccentricities

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TABLE 4
LAYER THICKNESS WEIGHT FACTORS
FOR THE ESWB

Stratum	Weight factors (1)		
	Case a (2)	Case b (3)	Case c (4)
Backfill	0.186	0.231	-
Stratum IIb-1 Chesapeake Cemented Sand	0.248	0.308	-
Stratum IIb-2 Chesapeake Cemented Sand	0.219	0.272	-
Stratum IIb-3 Chesapeake Cemented Sand	0.152	0.189	-
Stratum IIc Chesapeake Clay/Silt	0.195	-	1.000
Stratum III Nanjemoy Sand	0.000	-	-

(1) Weight factors based on layer thickness used in the analysis to obtain average values of the parameters within a depth of 1 B
(2) All stratum are included
(3) Only sand layer IIb is included (with three sublayers).
(4) Only clay layer (IIc) is included

ESWB dimensions (considered as a rectangle)

Elevation = 61 ft (Table 3.3; Ref. 4)

From the original building footprint:

A =	16284	ft^2	Figure 1 of Ref. 4
I_B =	3.30E+07	ft^4	Figure 1 of Ref. 4
I_L =	1.45E+07	ft^4	Figure 1 of Ref. 4

For an equivalent rectangle:

B =	105	ft	
L =	155	ft	
			approx. difference
A' =	16275.0	ft^2	0%
I_B' =	3.26E+07	ft^4	-1%
I_L' =	1.50E+07	ft^4	3%

The load for this building is considered constant across the entire area; therefore there are no eccentricities

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TABLE 5
LAYER THICKNESS WEIGHT FACTORS
FOR THE EPGB

Stratum	Weight factors (1)		
	Case a (2)	Case b (3)	Case c (4)
Backfill	0.411	0.347	-
Stratum IIb-1 Chesapeake Cemented Sand	0.310	0.261	-
Stratum IIb-2 Chesapeake Cemented Sand	0.274	0.231	-
Stratum IIb-3 Chesapeake Cemented Sand	0.006	0.161	-
Stratum IIc Chesapeake Clay/Silt	0.000	-	1.000
Stratum III Nanjemoy Sand	0.000	-	-

(1) Weight factors based on layer thickness used in the analysis to obtain average values of the parameters within a depth of 1 B
(2) All stratum are included
(3) Only sand layer IIb is included (with three sublayers).
(4) Only clay layer (IIc) is included

EPGB dimensions (considered as a rectangle)

Elevation = 76 ft (Table 3.3; Ref. 4)

From the original building footprint:

A =	12611	ft^2	Figure 1 of Ref. 4
I_B =	2.39E+07	ft^4	Figure 1 of Ref. 4
I_L =	7.39E+06	ft^4	Figure 1 of Ref. 4

For an equivalent rectangle:

B =	84	ft	
L =	150	ft	
			approx. difference
A' =	12600.0	ft^2	0%
I_B' =	2.36E+07	ft^4	-1%
I_L' =	7.41E+06	ft^4	0%

The load for this building is considered constant across the entire area; therefore there are no eccentricities

TABLE 6

SOIL STRENGTH PARAMETERS FOR BEARING CAPACITY ANALYSIS (1)

CCNPP UNIT 3

Stratum	Case a		Case b		Case c	
	C ' (ksf)	ϕ ' (deg)	C ' (ksf)	ϕ ' (deg)	C = Su (ksf)	ϕ (deg)
Backfill (2)	0.0	40.0	0.0	40.0	-	-
Stratum IIb-1 Chesapeake Cemented Sand	0.0	33.5	0.0	33.5	-	-
Stratum IIb-2 Chesapeake Cemented Sand	0.0	31.2	0.0	31.2	-	-
Stratum IIb-3 Chesapeake Cemented Sand (3)	0.0	31.7	0.0	31.7	-	-
Stratum IIc Chesapeake Clay/Silt	2.3	26.1	-	-	5.5	0.0
Stratum III Nanjemoy Sand (4)	0.0	40.0	-	-	-	-

(1) Strength parameters correspond to average values of Unit 3 and CLA areas (Ref. 2 and Ref. 10).
Cohesion for sand layers is not considered in the analysis.

(2) Friction angle corresponds to standard practice recommended value for compacted backfill

(3) For sublayer IIb-3 values from entire site are considerd, no data is available for Unit 3 and CLA areas.

(4) For layer III the effective friction angle was obtained from Ref. 8, there is no available data for this stratum in Ref. 2.

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TABLE 7
WEIGHTED AVERAGE SOIL PARAMETERS
BEARING CAPACITY USING VESIĆ SOLUTION

1) NI Common Mat

Case (1)	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Case a	110	1.6	28.4	-
Case b	123	0.0	32.2	-
Case c	104	-	0.0	5.5

(1) Using weight factors of Table 2.

2) NAB

Case (1)	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Case a	118	0.7	30.8	-
Case b	125	0.0	32.9	-
Case c	104	-	0.0	5.5

(1) Using weight factors of Table 3.

3) ESWB

Case (1)	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Case a	123	0.4	32.5	-
Case b	128	0.0	34.0	-
Case c	104	-	0.0	5.5

(1) Using weight factors of Table 4.

4) EPGB

Case (1)	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Case a	132	0.0	35.5	-
Case b	130	0.0	34.9	-
Case c	104	-	0.0	5.5

(1) Using weight factors of Table 5.

TABLE 8
WEIGHTED AVERAGE SOIL PARAMETERS
BEARING CAPACITY USING MEYERHOF SOLUTION

1) NI Common Mat

Stratum	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Stratum IIb Chesapeake Cemented Sand (1)	123	0	32.2	-
Stratum IIc Chesapeake Clay/Silt	104	-	0	5.5

(1) Average values of stratum IIb sublayers.

2) NAB

Stratum	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Stratum IIb Chesapeake Cemented Sand (1)	125	0	32.9	-
Stratum IIc Chesapeake Clay/Silt	104	-	0	5.5

(1) Average values of stratum IIb sublayers.

3) ESWB

Stratum	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Stratum IIb Chesapeake Cemented Sand (1)	128	0	34.0	-
Stratum IIc Chesapeake Clay/Silt	104	-	0	5.5

(1) Average values of stratum IIb sublayers.

4) EPGB

Stratum	γ (pcf)	C ' (ksf)	ϕ ' (deg)	Su (ksf)
Stratum IIb Chesapeake Cemented Sand (1)	130	0	34.9	-
Stratum IIc Chesapeake Clay/Silt	104	-	0	5.5

(1) Average values of stratum IIb sublayers.

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1. Bearing capacity of the NI Common Mat

A) Vesić model

$$q_{ult} = CN_c s_c d_c i_c g_c b_c + 0.5\gamma' B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma r_\gamma + qN_q s_q d_q i_q g_q b_q$$

where: q = effective surcharge pressure at the foundation depth
γ' = effective unit weight of the foundation media
B' = effective width
Nq, Nc and Nγ = Bearing capacity factors
s_c and s_γ = Foundation shape correction factors (Table 4-5a,b of Ref. 6)
d, i, g and b = shape, depth and inclination factors (Table 4-5a,b of Ref. 6)

Bearing Capacity Factors (Table 4-1 Ref. 6):

$$N_\gamma = 2(N_q + 1)\tan\phi \qquad N_q = e^{\pi \tan\phi} \tan^2(45 + \phi/2)$$

$$N_c = (N_q - 1)\cot\phi$$

A.1) Case a - all strata within 1B

C' =	1.6	ksf
φ' =	28.4	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	1.6	ksf		B =	270.0	ft
footing base	φ =	28.35	degrees		L =	300.0	ft
	φ =	0.495	radians	Base depth,	H =	41.50	ft
	γ_{moist} =	0.110	kcf				
	$\gamma_{buoyant}$ =	0.047	kcf	Water table depth,	D_w =	0	ft

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Static forces applied to NI Common Mat buildings

Vertical force Fz =	9.432E+05	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	5.103E+05	kip-ft
M_L =	-9.018E+05	kip-ft

Effective width and length calculations

e_B –	0.54	ft,	B - $2e_B$ –	268.9	ft,	B' –	268.9	ft		L/B' –	1.116
e_L =	0.96	ft,	L - $2e_L$ =	298.1	ft,	L' =	298.1	ft		H/B =	0.15

Bearing capacity factors:

N_c =	26.50
N_γ =	17.59
N_q =	15.30

Shape factors:

s_c =	1.52
s_γ =	0.64
s_q =	1.49

Depth factors:

k =	0.15
d_c =	1.06
d_γ =	1.00
d_q =	1.05

Inclination factors:

i_c =	1.0
i_γ =	1.0
i_q =	1.0

Base on slope factors:

g_c =	1.0
g_γ =	1.0
g_q =	1.0

Tilted base factors:

b_c =	1.0
b_γ =	1.0
b_q =	1.0

Effective surcharge: q = 3.428 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.59

Ultimate Bearing Capacity

q_{ult} =	from c =	69.2	ksf
	from γ =	42.1	ksf
	from q =	81.5	ksf
	total q_{ult} =	**192.7**	**ksf**

Ultimate toe stress: (on effective area B' L')

P_u =	1.54E+07	kips
$P_a = P_u / FS$ =	1.54E+07	kips
σ_u =	**196.7**	**ksf**

For: FS = 1

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For static loading:

FS =	**3.0**	
q a =	**64.2**	**ksf**

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**11.8**	**ksf**
FS =	**16.4**	

A.2) Case b - cemented sand layer

C' =	0.0	ksf
ϕ' =	32.2	degrees

Soil parameters

soil above	water γ =	0.0624	kcf					
footing base	γ_{moist} =	0.145	kcf					
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf		Eq. Rectangular footing dimensions:			
soil below	c =	0.0	ksf			B =	270.0	ft
footing base	ϕ =	32.24	degrees			L =	300.0	ft
	ϕ =	0.563	radians		Base depth,	H =	41.50	ft
	γ_{moist} =	0.123	kcf					
	$\gamma_{buoyant}$ =	0.060	kcf		Water table depth,	D_w =	0	ft

Static forces applied to NI Common Mat buildings

Vertical force Fz =	9.432E+05	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	5.103E+05	kip-ft
M_L =	-9.018E+05	kip-ft

Effective width and length calculations

e_B =	0.54	ft,	$B - 2e_B$ =	268.9	ft,	B' =	268.9	ft		L/B' =	1.116
e_L =	0.96	ft,	$L - 2e_L$ =	298.1	ft,	L' =	298.1	ft		H/B =	0.15

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	36.22	s_c =	1.59	k =	0.15
N_γ =	31.35	s_γ =	0.64	d_c =	1.06
N_q =	23.85	s_q =	1.57	d_γ =	1.00
				d_q =	1.04

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

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Effective surcharge: q = 3.428 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.59

Ultimate Bearing Capacity

q_{ult} =	from c =	0.0	ksf	Ultimate toe stress:	(on effective area B' L')		
	from γ =	95.3	ksf		P_u =	1.83E+07	kips
	from q =	133.6	ksf		$P_a = P_u / FS$ =	1.83E+07	kips
	total q_{ult} =	**228.9**	**ksf**		**σ_u =**	**233.5**	**ksf**
					with FS = 1.0		
For static loading:							
					FS = 1		
	FS =	**3.0**					
	q a =	**76.3**	**ksf**				

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**11.8**	**ksf**
FS =	**19.5**	

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A.3) Case c - clay layer

$C' = S_u =$	5.5	ksf
$\phi' =$	0.0	degrees

Soil parameters

soil above	water $\gamma =$	0.0624	kcf				
footing base	$\gamma_{moist} =$	0.145	kcf				
(backfill)	$\gamma_{buoyant} =$	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	$c =$	5.5	ksf		$B =$	270.0	ft
footing base	$\phi =$	0.00	degrees		$L =$	300.0	ft
	$\phi =$	0.000	radians	Base depth,	$H =$	41.50	ft
	$\gamma_{moist} =$	0.104	kcf				
	$\gamma_{buoyant} =$	0.042	kcf	Water table depth,	$D_w =$	0	ft

Static forces applied to NI Common Mat buildings

Vertical force Fz =	9.432E+05	kips
Horizontal force Vx,y =	0.000E+00	kips
$M_B =$	5.103E+05	kip-ft
$M_L =$	-9.018E+05	kip-ft

Effective width and length calculations

$e_B =$	0.54	ft,	$B - 2e_B =$	268.9	ft,	$B' =$	268.9	ft		$L/B' =$	1.116
$e_L =$	0.96	ft,	$L - 2e_L =$	298.1	ft,	$L' =$	298.1	ft		$H/B =$	0.15

Bearing capacity factors:		Shape factors:		Depth factors:	
$N_c =$	5.14	$s_c =$	1.175	$k =$	0.15
$N_\gamma =$	0.00	$s_\gamma =$	0.640	$d_c =$	1.06
$N_q =$	1.00	$s_q =$	1.000	$d_\gamma =$	1.00
				$d_q =$	1.00

Inclination factors:		Base on slope factors:		Tilted base factors:	
$i_c =$	1.0	$g_c =$	1.0	$b_c =$	1.0
$i_\gamma =$	1.0	$g_\gamma =$	1.0	$b_\gamma =$	1.0
$i_q =$	1.0	$g_q =$	1.0	$b_q =$	1.0

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Effective surcharge: q = 3.428 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.59

Ultimate Bearing Capacity

q_{ult} =	from c =	35.2	ksf	Ultimate toe stress:	(on effective area B' L')		
	from γ =	0.0	ksf		P_u =	3.10E+06	kips
	from q =	3.4	ksf		$P_a = P_u / FS$ =	3.10E+06	kips
	total q_{ult} =	**38.6**	**ksf**		**σ_u =**	**39.4**	**ksf**
					with FS = 1.0		
For static loading:							
					FS = 1		
	FS =	**3.0**					
	q a =	**12.9**	**ksf**				

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**11.8**	**ksf**
FS =	**3.3**	

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B) Meyerhof model

$$q_{ult} = q_{u,b} + \frac{2\gamma_1 H_t^2}{B}\left(1 + \frac{2D}{H_t}\right)K_{ps}\tan\phi_1 - \gamma_1 H_t \le q_{ut}$$

where:
$q_{u,b}$ = ultimate bearing capacity on a very thick bed of the bottom soft clay layer, ksf

$$q_{u,b} = C_2 N_{c2}\varsigma_{c2} + 0.5\gamma_2' B' N_{\gamma 2}\varsigma_{\gamma 2} r_\gamma + \gamma_1'(H_t + D)N_{q2}\varsigma_{q2}$$

q_{ut} = ultimate bearing capacity of upper dense sand, ksf

$$q_{ut} = C_1 N_{c1}\varsigma_{c1} + 0.5\gamma_1' B' N_{\gamma 1}\varsigma_{\gamma 1} r_\gamma + \gamma_b' D N_{q1}\varsigma_{q1}$$

γ'_1= effective unit weight of the upper sand layer, kcf
γ'_2= effective unit weight of the lower clay layer, kcf
γ'_b= effective unit weight of backfill, kcf
ϕ_1 = friction angle of upper sand layer, degrees
ϕ_2 = friction angle of lower clay layer, degrees
C_1 = cohesion of upper sand layer, ksf
C_2 = cohesion of lower clay layer, ksf
Nq, Nc and Nγ = Bearing capacity factors
Ht = depth below footing base to soft clay, ft
D =depth of footing base below ground surface, ft
K_{ps} = punching shear coefficient, Figures 4-2a, 4-2b and 4-2c of Ref. 7
B' = least effective width of footing, ft
ζq, ζc and ζγ = geometry factors

Bearing capacity factors are:

$$N_\gamma = (N_q - 1)\tan 1.4\phi$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_q = e^{\pi\tan\phi}\tan^2(45 + \phi/2)$$

	Dense sand Layer IIb	clay Layer IIc
C' (ksf) =	0.0	5.5
ϕ' (deg) =	32.2	0.0
γ (kcf) =	0.123	0.104

Soil parameters

backfill: γ_{moist} = 0.145 kip/ft^3
$\gamma_{buoyant}$ = 0.083 kip/ft^3

dense sand layer: c = 0.0 kip/ft^2

	ϕ =	32.2	degrees
	ϕ =	0.563	radians
	γ_{moist} =	0.123	kip/ft^3
	$\gamma_{buoyant}$ =	0.060	kip/ft^3
clay layer:	c =	5.5	kip/ft^2
	ϕ =	0.0	degrees
	ϕ =	0.000	radians
	γ_{moist} =	0.104	kip/ft^3
	$\gamma_{buoyant}$ =	0.042	kip/ft^3
	water γ =	0.0624	kip/ft^3

Eq. Rectangular footing dimensions:

least lateral dim :	B =	270.0	ft	
greatest lateral dim :	L =	300.0	ft	
Base depth :	D =	41.50	ft	
sand layer thickness :	H =	65.00	ft	
Water table depth :	D_w =	0	ft	
Bearing capacity ratio :	R_{bc} =	0.94		Figure 4-2d, Ref. 7
Punching shear parameter :	C_{ps} =	0.95		Figure 4-2d, Ref. 7
Punching shear coeff. :	K_{ps} =	11.5		Figure 4-2c, Ref. 7

Static forces applied to NI Common Mat buildings

Vertical force Fz =	9.432E+05	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	5.103E+05	kip-ft
M_L =	-9.018E+05	kip-ft

Effective width and length calculations

e_B =	0.54	ft,	B - $2e_B$ =	268.9	ft,	B' =	268.9	ft		L/B' =	1.116
e_L =	0.96	ft,	L - $2e_L$ =	298.1	ft,	L' =	298.1	ft		H/B =	0.15

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Dense sand layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	36.22	s_c =	1.59	d_c =	1.06
N_γ =	22.96	s_γ =	1.30	d_γ =	1.03
N_q =	23.85	s_q =	1.30	d_q =	1.03

Inclination factors:

i_q =	1.0
i_c =	1.0
i_γ =	1.0

Clay layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	5.14	s_c =	1.180	d_c =	1.08
N_γ =	0.00	s_γ =	1.000	d_γ =	1.00
N_q =	1.00	s_q =	1.000	d_q =	1.00

Inclination factors:

i_c =	1.0
i_γ =	0.0
i_q =	1.0

Effective surcharge: q = 3.428 kip/ft^2 from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma B'N\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.59

Sand layer ultimate bearing capacity

q_{ut} =	from c =	0.0	kip/ft^2
	from γ =	145.3	kip/ft^2
	from q =	109.0	kip/ft^2
	total q_{ult} =	**254.3**	**kip/ft^2**

Clay layer ultimate bearing capacity

$q_{u,b}$ =	from c =	35.9	kip/ft^2
	from γ =	0.0	kip/ft^2
	from q =	7.3	kip/ft^2
	total q_{ult} =	**43.3**	**kip/ft^2**

The ultimate bearing capacity of a sand layer underlain by a clay layer is:

q_u = 70.5 ksf

For static loading:

FS = 3.0
q a = 23.5 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 11.8 ksf
FS = 6.0

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2. Bearing capacity of the Nuclear Auxiliary Building (NAB)

A) Vesić model

$$q_{ult} = CN_c s_c d_c i_c g_c b_c + 0.5\gamma' B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma r_\gamma + qN_q s_q d_q i_q g_q b_q$$

where: q = effective surcharge pressure at the foundation depth
γ' = effective unit weight of the foundation media
B' = effective width
Nq, Nc and Nγ = Bearing capacity factors
s_c and s_γ = Foundation shape correction factors (Table 4-5a,b of Ref. 6)
d, i, g and b = shape, depth and inclination factors (Table 4-5a,b of Ref. 6)

Bearing Capacity Factors (Table 4-1 Ref. 6):

$$N_\gamma = 2(N_q + 1)\tan\phi \qquad N_q = e^{\pi \tan\phi} \tan^2(45 + \phi/2)$$

$$N_c = (N_q - 1)\cot\phi$$

A.1) Case a - all strata within 1B

C' =	0.7	ksf
φ' =	30.8	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.7	ksf		B =	105.0	ft
footing base	φ =	30.76	degrees		L =	120.0	ft
	φ =	0.537	radians	Base depth,	H =	35.00	ft
	γ_{moist} =	0.118	kcf				
	$\gamma_{buoyant}$ =	0.056	kcf	Water table depth,	D_w =	0	ft

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Static forces applied to the NAB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B –	0.00	ft,	B - $2e_B$ –	105.0	ft,	B' –	105.0	ft		L/B' –	1.143
e_L =	0.00	ft,	L - $2e_L$ =	120.0	ft,	L' =	120.0	ft		H/B =	0.33

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	32.05	s_c =	1.55	k =	0.33
N_γ =	25.09	s_γ =	0.65	d_c =	1.13
N_q =	20.08	s_q =	1.52	d_γ =	1.00
				d_q =	1.09

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

Effective surcharge: q = 2.891 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Ultimate Bearing Capacity

q_{ult} =	from c =	41.3	ksf
	from γ =	32.8	ksf
	from q =	96.6	ksf
	total q_{ult} =	**170.7**	**ksf**

Ultimate toe stress: (on effective area B' L')

P_u =	2.15E+06	kips
$P_a = P_u / FS$ =	2.15E+06	kips
σ_u =	**170.7**	**ksf**

For : FS = 1

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For static loading:

FS = 3.0
q a = 56.9 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 9.7 ksf
FS = 17.6

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A.2) Case b - cemented sand layer

C' =	0.0	ksf
ϕ' =	32.9	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.0	ksf		B =	105.0	ft
footing base	ϕ =	32.95	degrees		L =	120.0	ft
	ϕ =	0.575	radians	Base depth,	H =	35.00	ft
	γ_{moist} =	0.125	kcf				
	$\gamma_{buoyant}$ =	0.062	kcf	Water table depth,	D_w =	0	ft

Static forces applied to the NAB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	$B - 2e_B$ =	105.0	ft,	B' =	105.0	ft		L/B' =	1.143
e_L =	0.00	ft,	$L - 2e_L$ =	120.0	ft,	L' =	120.0	ft		H/B =	0.33

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	38.47	s_c =	1.59	k =	0.33
N_γ =	34.91	s_γ =	0.65	d_c =	1.13
N_q =	25.93	s_q =	1.57	d_γ =	1.00
				d_q =	1.09

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

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Effective surcharge: q = 2.891 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Ultimate Bearing Capacity

q_{ult} =	from c =	0.0	ksf	Ultimate toe stress:	(on effective area B' L')		
	from γ =	51.1	ksf		P_u =	2.26E+06	kips
	from q =	128.0	ksf		$P_a = P_u / FS$ =	2.26E+06	kips
	total q_{ult} =	**179.1**	**ksf**		**σ_u =**	**179.1**	**ksf**
					with FS = 1.0		
For static loading:							
					FS = 1		
	FS =	**3.0**					
	q a =	**59.7**	**ksf**				

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**9.7**	**ksf**
FS =	**18.4**	

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A.3) Case c - clay layer

$C' = S_u =$	5.5	ksf
$\phi' =$	0.0	degrees

Soil parameters

soil above	water $\gamma =$	0.0624	kcf				
footing base	$\gamma_{moist} =$	0.145	kcf				
(backfill)	$\gamma_{buoyant} =$	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	$c =$	5.5	ksf		$B =$	105.0	ft
footing base	$\phi =$	0.00	degrees		$L =$	120.0	ft
	$\phi =$	0.000	radians	Base depth,	$H =$	35.00	ft
	$\gamma_{moist} =$	0.104	kcf				
	$\gamma_{buoyant} =$	0.042	kcf	Water table depth,	$D_w =$	0	ft

Static forces applied to the NAB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
$M_B =$	0.000E+00	kip-ft
$M_L =$	0.000E+00	kip-ft

Effective width and length calculations

$e_B =$	0.00	ft,	$B - 2e_B =$	105.0	ft,	$B' =$	105.0	ft		$L/B' =$	1.143
$e_L =$	0.00	ft,	$L - 2e_L =$	120.0	ft,	$L' =$	120.0	ft		$H/B =$	0.33

Bearing capacity factors:		Shape factors:		Depth factors:	
$N_c =$	5.14	$s_c =$	1.170	$k =$	0.33
$N_\gamma =$	0.00	$s_\gamma =$	0.650	$d_c =$	1.13
$N_q =$	1.00	$s_q =$	1.000	$d_\gamma =$	1.00
				$d_q =$	1.00

Inclination factors:		Base on slope factors:		Tilted base factors:	
$i_c =$	1.0	$g_c =$	1.0	$b_c =$	1.0
$i_\gamma =$	1.0	$g_\gamma =$	1.0	$b_\gamma =$	1.0
$i_q =$	1.0	$g_q =$	1.0	$b_q =$	1.0

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Effective surcharge: q = 2.891 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Ultimate Bearing Capacity

q_{ult} =	from c =	37.4	ksf	
	from γ =	0.0	ksf	
	from q =	2.9	ksf	
	total q_{ult} =	**40.3**	**ksf**	

Ultimate toe stress: (on effective area B' L')

P_u =	5.08E+05	kips
$P_a = P_u / FS$ =	5.08E+05	kips
σ_u =	**40.3**	**ksf**

with FS = 1.0

For static loading:

FS = 1

FS =	**3.0**	
q a =	**13.4**	**ksf**

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**9.7**	**ksf**
FS =	**4.2**	

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B) Meyerhof model

$$q_{ult} = q_{u,b} + \frac{2\gamma_1 H_t^2}{B}\left(1 + \frac{2D}{H_t}\right)K_{ps}\tan\phi_1 - \gamma_1 H_t \le q_{ut}$$

where:
$q_{u,b}$ = ultimate bearing capacity on a very thick bed of the bottom soft clay layer, ksf

$$q_{u,b} = C_2 N_{c2}\varsigma_{c2} + 0.5\gamma_2' B' N_{\gamma 2}\varsigma_{\gamma 2} r_\gamma + \gamma_1'(H_t + D)N_{q2}\varsigma_{q2}$$

q_{ut} = ultimate bearing capacity of upper dense sand, ksf

$$q_{ut} = C_1 N_{c1}\varsigma_{c1} + 0.5\gamma_1' B' N_{\gamma 1}\varsigma_{\gamma 1} r_\gamma + \gamma_b' D N_{q1}\varsigma_{q1}$$

γ'_1= effective unit weight of the upper sand layer, kcf
γ'_2= effective unit weight of the lower clay layer, kcf
γ'_b= effective unit weight of backfill, kcf
ϕ_1 = friction angle of upper sand layer, degrees
ϕ_2 = friction angle of lower clay layer, degrees
C_1 = cohesion of upper sand layer, ksf
C_2 = cohesion of lower clay layer, ksf
Nq, Nc and Nγ = Bearing capacity factors
Ht = depth below footing base to soft clay, ft
D =depth of footing base below ground surface, ft
K_{ps} = punching shear coefficient, Figures 4-2a, 4-2b and 4-2c of Ref. 7
B' = least effective width of footing, ft
ζq, ζc and ζγ = geometry factors

Bearing capacity factors are:

$$N_\gamma = (N_q - 1)\tan 1.4\phi$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_q = e^{\pi\tan\phi}\tan^2(45 + \phi/2)$$

	Dense sand Layer IIb	clay Layer IIc
C' (ksf) =	0.0	5.5
ϕ' (deg) =	32.9	0.0
γ (kcf) =	0.125	0.104

Soil parameters

backfill: γ_{moist} = 0.145 kip/ft^3
$\gamma_{buoyant}$ = 0.083 kip/ft^3

dense sand layer: c = 0.0 kip/ft^2

	ϕ =	32.9	degrees
	ϕ =	0.575	radians
	γ_{moist} =	0.125	kip/ft^3
	$\gamma_{buoyant}$ =	0.062	kip/ft^3
clay layer:	c =	5.5	kip/ft^2
	ϕ =	0.0	degrees
	ϕ =	0.000	radians
	γ_{moist} =	0.104	kip/ft^3
	$\gamma_{buoyant}$ =	0.042	kip/ft^3
	water γ =	0.0624	kip/ft^3

Eq. Rectangular footing dimensions:

least lateral dim :	B =	105.0	ft	
greatest lateral dim :	L =	120.0	ft	
Base depth :	D =	35.00	ft	
sand layer thickness :	H =	71.50	ft	
Water table depth :	D_w =	0	ft	
Bearing capacity ratio :	R_{bc} =	0.40		Figure 4-2d, Ref. 7
Punching shear parameter :	C_{ps} =	0.65		Figure 4-2d, Ref. 7
Punching shear coeff. :	K_{ps} =	8.1		Figure 4-2c, Ref. 7

Static forces applied to the NAB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	B - $2e_B$ =	105.0	ft,	B' =	105.0	ft		L/B' =	1.143
e_L =	0.00	ft,	L - $2e_L$ =	120.0	ft,	L' =	120.0	ft		H/B =	0.33

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Dense sand layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	38.47	s_c =	1.59	d_c =	1.12
N_γ =	25.93	s_γ =	1.30	d_γ =	1.06
N_q =	25.93	s_q =	1.30	d_q =	1.06

Inclination factors:

i_q =	1.0
i_c =	1.0
i_γ =	1.0

Clay layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	5.14	s_c =	1.175	d_c =	1.20
N_γ =	0.00	s_γ =	1.000	d_γ =	1.00
N_q =	1.00	s_q =	1.000	d_q =	1.00

Inclination factors:

i_c =	1.0
i_γ =	0.0
i_q =	1.0

Effective surcharge: q = 2.891 kip/ft^2 from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Sand layer ultimate bearing capacity

q_{ut} =	from c =	0.0	kip/ft^2
	from γ =	80.3	kip/ft^2
	from q =	103.1	kip/ft^2
	total q_{ult} =	**183.5**	**kip/ft^2**

Clay layer ultimate bearing capacity

$q_{u,b}$ =	from c =	39.9	kip/ft^2
	from γ =	0.0	kip/ft^2
	from q =	7.3	kip/ft^2
	total q_{ult} =	**47.2**	**kip/ft^2**

The ultimate bearing capacity of a sand layer underlain by a clay layer is:

q_u = 105.8 ksf

For static loading:

FS = 3.0
q a = 35.3 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 9.7 ksf
FS = 10.9

TRUE COPY - NOT ORIGINAL

3. Bearing capacity of the Emergency Power Generating Building (EPGB)

A) Vesić model

$$q_{ult} = CN_c s_c d_c i_c g_c b_c + 0.5\gamma' B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma r_\gamma + qN_q s_q d_q i_q g_q b_q$$

where: q = effective surcharge pressure at the foundation depth
γ' = effective unit weight of the foundation media
B' = effective width
Nq, Nc and Nγ = Bearing capacity factors
s_c and s_γ = Foundation shape correction factors (Table 4-5a,b of Ref. 6)
d, i, g and b = shape, depth and inclination factors (Table 4-5a,b of Ref. 6)

Bearing Capacity Factors (Table 4-1 Ref. 6):

$$N_\gamma = 2(N_q + 1)\tan\phi \qquad N_q = e^{\pi \tan\phi} \tan^2(45 + \phi/2)$$

$$N_c = (N_q - 1)\cot\phi$$

A.1) Case a - all strata within 1B

C' =	0.0	ksf
φ' =	35.5	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.0	ksf		B =	84.0	ft
footing base	φ =	35.53	degrees		L =	150.0	ft
	φ =	0.620	radians	Base depth,	H =	7.00	ft
	γ_{moist} =	0.132	kcf				
	$\gamma_{buoyant}$ =	0.069	kcf	Water table depth,	D_w =	0	ft

TRUE COPY - NOT ORIGINAL

Static forces applied to the EPGB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	$B - 2e_B$ =	84.0	ft,	B' =	84.0	ft		L/B' =	1.786
e_L =	0.00	ft,	$L - 2e_L$ =	150.0	ft,	L' =	150.0	ft		H/B =	0.08

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	48.42	s_c =	1.41	k =	0.08
N_γ =	52.23	s_γ =	0.78	d_c =	1.03
N_q =	35.57	s_q =	1.40	d_γ =	1.00
				d_q =	1.02

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

Effective surcharge: q = 0.578 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.71

Ultimate Bearing Capacity

q_{ult} =	from c =	0.0	ksf	Ultimate toe stress:	(on effective area B' L')
	from γ =	84.2	ksf	P_u =	1.43E+06 kips
	from q =	29.4	ksf	$P_a = P_u / FS$ =	1.43E+06 kips
	total q_{ult} =	**113.6**	**ksf**	**σ_u =**	**113.6 ksf**
				FS = 1	

TRUE COPY - NOT ORIGINAL

For static loading:

FS = 3.0

q a = 37.9 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 3.2 ksf

FS = 35.6

TRUE COPY - NOT ORIGINAL

A.2) Case b - cemented sand layer

C' =	0.0	ksf
ϕ' =	34.9	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.0	ksf		B =	84.0	ft
footing base	ϕ =	34.93	degrees		L =	150.0	ft
	ϕ =	0.610	radians	Base depth,	H =	7.00	ft
	γ_{moist} =	0.130	kcf				
	$\gamma_{buoyant}$ =	0.068	kcf	Water table depth,	D_w =	0	ft

Static forces applied to the EPGB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	B - $2e_B$ =	84.0	ft,	B' =	84.0	ft		L/B' =	1.786
e_L =	0.00	ft,	L - $2e_L$ =	150.0	ft,	L' =	150.0	ft		H/B =	0.08

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	45.84	s_c =	1.40	k =	0.08
N_γ =	47.52	s_γ =	0.78	d_c =	1.03
N_q =	33.02	s_q =	1.39	d_γ =	1.00
				d_q =	1.02

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

TRUE COPY - NOT ORIGINAL

Effective surcharge: q = 0.578 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.71

Ultimate Bearing Capacity

q_{ult} =	from c =	0.0	ksf	Ultimate toe stress:	(on effective area B' L')		
	from γ =	75.1	ksf		P_u =	1.29E+06	kips
	from q =	27.1	ksf		$P_a = P_u / FS$ =	1.29E+06	kips
	total q_{ult} =	**102.2**	**ksf**		**σ_u =**	**102.2**	**ksf**
					with FS = 1.0		
For static loading:							
					FS = 1		
	FS =	**3.0**					
	q a =	**34.1**	**ksf**				

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**3.2**	**ksf**
FS =	**32.1**	

Case c is not calculated for this building. The depth of the failure zone, estimated with H=0.5*B*tan(45+phi/2), results in approximately 81 ft. The depth to the clay layer IIc is approximately 100 ft; therefore, this layer has a relatively small influence in the failure mechanism. The case including a soft layer (clay) underlying a dense layer (sand) is analyzed using the Meyerhof model.

B) Meyerhof model

$$q_{ult} = q_{u,b} + \frac{2\gamma_1 H_t^2}{B}\left(1 + \frac{2D}{H_t}\right)K_{ps}\tan\phi_1 - \gamma_1 H_t \le q_{ut}$$

where:

$q_{u,b}$ = ultimate bearing capacity on a very thick bed of the bottom soft clay layer, ksf

$$q_{u,b} = C_2 N_{c2}\varsigma_{c2} + 0.5\gamma_2' B' N_{\gamma 2}\varsigma_{\gamma 2} r_\gamma + \gamma_1'(H_t + D)N_{q2}\varsigma_{q2}$$

q_{ut} = ultimate bearing capacity of upper dense sand, ksf

$$q_{ut} = C_1 N_{c1}\varsigma_{c1} + 0.5\gamma_1' B' N_{\gamma 1}\varsigma_{\gamma 1} r_\gamma + \gamma_b' D N_{q1}\varsigma_{q1}$$

γ'_1 = effective unit weight of the upper sand layer, kcf
γ'_2 = effective unit weight of the lower clay layer, kcf
γ'_b = effective unit weight of backfill, kcf
ϕ_1 = friction angle of upper sand layer, degrees
ϕ_2 = friction angle of lower clay layer, degrees
C_1 = cohesion of upper sand layer, ksf
C_2 = cohesion of lower clay layer, ksf
Nq, Nc and Nγ = Bearing capacity factors
Ht = depth below footing base to soft clay, ft
D =depth of footing base below ground surface, ft
K_{ps} = punching shear coefficient, Figures 4-2a, 4-2b and 4-2c of Ref. 7
B' = least effective width of footing, ft
ζq, ζc and ζγ = geometry factors

	Dense sand Layer IIb	clay Layer IIc
C' (ksf) =	0.0	5.5
ϕ' (deg) =	34.9	0.0
γ (kcf) =	0.130	0.104

Soil parameters

backfill: γ_{moist} = 0.145 kip/ft^3
$\gamma_{buoyant}$ = 0.083 kip/ft^3

dense sand layer: c = 0.0 kip/ft^2

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	ϕ =	34.9	degrees
	ϕ =	0.610	radians
	γ_{moist} =	0.130	kip/ft^3
	$\gamma_{buoyant}$ =	0.068	kip/ft^3
clay layer:	c =	5.5	kip/ft^2
	ϕ =	0.0	degrees
	ϕ =	0.000	radians
	γ_{moist} =	0.104	kip/ft^3
	$\gamma_{buoyant}$ =	0.042	kip/ft^3
	water γ =	0.0624	kip/ft^3

Eq. Rectangular footing dimensions:

least lateral dim :	B =	84.0	ft	
greatest lateral dim :	L =	150.0	ft	
Base depth :	D =	7.00	ft	
sand layer thickness :	H =	99.50	ft	
Water table depth :	D_w =	0	ft	
Bearing capacity ratio :	R_{bc} =	0.42		Figure 4-2d, Ref. 7
Punching shear parameter :	C_{ps} =	0.65		Figure 4-2d, Ref. 7
Punching shear coeff. :	K_{ps} =	8.1		Figure 4-2c, Ref. 7

Static forces applied to the EPGB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	B - $2e_B$ =	84.0	ft,	B' =	84.0	ft		L/B' =	1.786
e_L =	0.00	ft,	L - $2e_L$ =	150.0	ft,	L' =	150.0	ft		H/B =	0.08

Dense sand layer:

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Bearing capacity factors:

N_c = 45.84
N_γ = 36.71
N_q = 33.02

Shape factors:

s_c = 1.41
s_γ = 1.21
s_q = 1.21

Depth factors:

d_c = 1.03
d_γ = 1.02
d_q = 1.02

Inclination factors:

i_q = 1.0
i_c – 1.0
i_γ = 1.0

Clay layer:

Bearing capacity factors:

N_c = 5.14
N_γ = 0.00
N_q = 1.00

Shape factors:

s_c = 1.112
s_γ = 1.000
s_q = 1.000

Depth factors:

d_c = 1.25
d_γ = 1.00
d_q = 1.00

Inclination factors:

i_c = 1.0
i_γ = 0.0
i_q = 1.0

Effective surcharge: q = 0.578 kip/ft^2 from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.71

Sand layer ultimate bearing capacity

q_{ut} =	from c =	0.0	kip/ft^2
	from γ =	91.6	kip/ft^2
	from q =	23.4	kip/ft^2
	total q_{ult} =	**115.0**	**kip/ft^2**

TRUE COPY - NOT ORIGINAL

Clay layer ultimate bearing capacity

$q_{u,b}$ =	from c =	39.3	kip/ft^2
	from γ =	0.0	kip/ft^2
	from q =	7.3	kip/ft^2
	total q_{ult} =	**46.7**	**kip/ft^2**

The ultimate bearing capacity of a sand layer underlain by a clay layer is:

q_u = 115.0 ksf

For static loading:

FS = 3.0
q a = 38.3 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 3.2 ksf
FS = 36.1

TRUE COPY - NOT ORIGINAL

4. Bearing capacity of the Emergency Service Water Building (ESWB)

A) Vesić model

$$q_{ult} = CN_c s_c d_c i_c g_c b_c + 0.5\gamma' B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma r_\gamma + qN_q s_q d_q i_q g_q b_q$$

where: q = effective surcharge pressure at the foundation depth
γ' = effective unit weight of the foundation media
B' = effective width
Nq, Nc and Nγ = Bearing capacity factors
s_c and s_γ = Foundation shape correction factors (Table 4-5a,b of Ref. 6)
d, i, g and b = shape, depth and inclination factors (Table 4-5a,b of Ref. 6)

Bearing Capacity Factors (Table 4-1 Ref. 6):

$$N_\gamma = 2(N_q + 1)\tan\phi \qquad N_q = e^{\pi \tan\phi} \tan^2(45 + \phi/2)$$

$$N_c = (N_q - 1)\cot\phi$$

A.1) Case a - all strata within 1B

C' =	0.4	ksf
φ' =	32.5	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.4	ksf		B =	105.0	ft
footing base	φ =	32.48	degrees		L =	155.0	ft
	φ =	0.567	radians	Base depth,	H =	22.00	ft
	γ_{moist} =	0.123	kcf				
	$\gamma_{buoyant}$ =	0.061	kcf	Water table depth,	D_w =	0	ft

TRUE COPY - NOT ORIGINAL

Static forces applied to the ESWB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	$B - 2e_B$ =	105.0	ft,	B' =	105.0	ft		L/B' =	1.476
e_L =	0.00	ft,	$L - 2e_L$ =	155.0	ft,	L' =	155.0	ft		H/B =	0.21

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	36.97	s_c =	1.45	k =	0.21
N_γ =	32.52	s_γ =	0.73	d_c =	1.08
N_q =	24.54	s_q =	1.43	d_γ =	1.00
				d_q =	1.06

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

Effective surcharge: q = 1.817 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Ultimate Bearing Capacity

q_{ult} =	from c =	26.1	ksf	Ultimate toe stress:	(on effective area B' L')
	from γ =	52.1	ksf	P_u =	2.37E+06 kips
	from q =	67.5	ksf	$P_a = P_u / FS$ =	2.37E+06 kips
	total q_{ult} =	**145.7**	**ksf**	**σ_u =**	**145.7 ksf**
				FS = 1	

TRUE COPY - NOT ORIGINAL

For static loading:

FS = 3.0

q a = 48.6 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 5.4 ksf

FS = 26.7

TRUE COPY - NOT ORIGINAL

A.2) Case b - cemented sand layer

C' =	0.0	ksf
ϕ' =	34.0	degrees

Soil parameters

soil above	water γ =	0.0624	kcf				
footing base	γ_{moist} =	0.145	kcf				
(backfill)	$\gamma_{buoyant}$ =	0.083	kcf	Eq. Rectangular footing dimensions:			
soil below	c =	0.0	ksf		B =	105.0	ft
footing base	ϕ =	34.03	degrees		L =	155.0	ft
	ϕ =	0.594	radians	Base depth,	H =	22.00	ft
	γ_{moist} =	0.128	kcf				
	$\gamma_{buoyant}$ =	0.065	kcf	Water table depth,	D_w =	0	ft

Static forces applied to the ESWB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	B - $2e_B$ =	105.0	ft,	B' =	105.0	ft		L/B' =	1.476
e_L =	0.00	ft,	L - $2e_L$ =	155.0	ft,	L' =	155.0	ft		H/B =	0.21

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	42.29	s_c =	1.47	k =	0.21
N_γ =	41.28	s_γ =	0.73	d_c =	1.08
N_q =	29.56	s_q =	1.46	d_γ =	1.00
				d_q =	1.05

Inclination factors:		Base on slope factors:		Tilted base factors:	
i_c =	1.0	g_c =	1.0	b_c =	1.0
i_γ =	1.0	g_γ =	1.0	b_γ =	1.0
i_q =	1.0	g_q =	1.0	b_q =	1.0

TRUE COPY - NOT ORIGINAL

Effective surcharge: q = 1.817 ksf from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Ultimate Bearing Capacity

q_{ult} =	from c =	0.0	ksf	Ultimate toe stress:	(on effective area B' L')		
	from γ =	71.2	ksf		P_u =	2.50E+06	kips
	from q =	82.6	ksf		$P_a = P_u / FS$ =	2.50E+06	kips
	total q_{ult} =	**153.8**	**ksf**		**σ_u =**	**153.8**	**ksf**
					with FS = 1.0		
For static loading:							
					FS = 1		
	FS =	**3.0**					
	q a =	**51.3**	**ksf**				

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q =	**5.4**	**ksf**
FS =	**28.2**	

Case c is not calculated for this building. The depth of the failure zone, estimated with H=0.5*B*tan(45+phi/2), results in approximately 99 ft. The depth to the clay layer IIc is approximately 85 ft; therefore, this layer has a relatively small influence in the failure mechanism. The case including a soft layer (clay) underlying a dense layer (sand) is analyzed using the Meyerhof model.

TRUE COPY - NOT ORIGINAL

B) Meyerhof model

$$q_{ult} = q_{u,b} + \frac{2\gamma_1 H_t^2}{B}\left(1 + \frac{2D}{H_t}\right)K_{ps}\tan\phi_1 - \gamma_1 H_t \le q_{ut}$$

where:
$q_{u,b}$ = ultimate bearing capacity on a very thick bed of the bottom soft clay layer, ksf

$$q_{u,b} = C_2 N_{c2}\varsigma_{c2} + 0.5\gamma_2' B' N_{\gamma 2}\varsigma_{\gamma 2} r_\gamma + \gamma_1'(H_t + D)N_{q2}\varsigma_{q2}$$

q_{ut} = ultimate bearing capacity of upper dense sand, ksf

$$q_{ut} = C_1 N_{c1}\varsigma_{c1} + 0.5\gamma_1' B' N_{\gamma 1}\varsigma_{\gamma 1} r_\gamma + \gamma_b' D N_{q1}\varsigma_{q1}$$

γ'_1= effective unit weight of the upper sand layer, kcf
γ'_2= effective unit weight of the lower clay layer, kcf
γ'_b= effective unit weight of backfill, kcf
ϕ_1 = friction angle of upper sand layer, degrees
ϕ_2 = friction angle of lower clay layer, degrees
C_1 = cohesion of upper sand layer, ksf
C_2 = cohesion of lower clay layer, ksf
Nq, Nc and Nγ = Bearing capacity factors
Ht = depth below footing base to soft clay, ft
D =depth of footing base below ground surface, ft
K_{ps} = punching shear coefficient, Figures 4-2a, 4-2b and 4-2c of Ref. 7
B' = least effective width of footing, ft
ζq, ζc and ζγ = geometry factors

	Dense sand Layer IIb	clay Layer IIc
C' (ksf) =	0.0	5.5
ϕ' (deg) =	34.0	0.0
γ (kcf) =	0.128	0.104

Soil parameters

backfill: γ_{moist} = 0.145 kip/ft^3
$\gamma_{buoyant}$ = 0.083 kip/ft^3

dense sand layer: c = 0.0 kip/ft^2

TRUE COPY - NOT ORIGINAL

	ϕ =	34.0	degrees
	ϕ =	0.594	radians
	γ_{moist} =	0.128	kip/ft^3
	$\gamma_{buoyant}$ =	0.065	kip/ft^3
clay layer:	c =	5.5	kip/ft^2
	ϕ =	0.0	degrees
	ϕ =	0.000	radians
	γ_{moist} =	0.104	kip/ft^3
	$\gamma_{buoyant}$ =	0.042	kip/ft^3
	water γ =	0.0624	kip/ft^3

Eq. Rectangular footing dimensions:

least lateral dim :	B =	105.0	ft	
greatest lateral dim :	L =	155.0	ft	
Base depth :	D =	22.00	ft	
sand layer thickness :	H =	84.50	ft	
Water table depth :	D_w =	0	ft	
Bearing capacity ratio :	R_{bc} =	0.46		Figure 4-2d, Ref. 7
Punching shear parameter :	C_{ps} =	0.68		Figure 4-2d, Ref. 7
Punching shear coeff. :	K_{ps} =	8.5		Figure 4-2c, Ref. 7

Static forces applied to the ESWB

Vertical force Fz =	0.000E+00	kips
Horizontal force Vx,y =	0.000E+00	kips
M_B =	0.000E+00	kip-ft
M_L =	0.000E+00	kip-ft

Effective width and length calculations

e_B =	0.00	ft,	B - $2e_B$ =	105.0	ft,	B' =	105.0	ft		L/B' =	1.476
e_L =	0.00	ft,	L - $2e_L$ =	155.0	ft,	L' =	155.0	ft		H/B =	0.21

TRUE COPY - NOT ORIGINAL

Dense sand layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	42.29	s_c =	1.48	d_c =	1.08
N_γ =	31.33	s_γ =	1.24	d_γ =	1.04
N_q =	29.56	s_q =	1.24	d_q =	1.04

Inclination factors:

i_q =	1.0
i_c =	1.0
i_γ =	1.0

Clay layer:

Bearing capacity factors:		Shape factors:		Depth factors:	
N_c =	5.14	s_c =	1.135	d_c =	1.20
N_γ =	0.00	s_γ =	1.000	d_γ =	1.00
N_q =	1.00	s_q =	1.000	d_q =	1.00

Inclination factors:

i_c =	1.0
i_γ =	0.0
i_q =	1.0

Effective surcharge: q = 1.817 kip/ft^2 from backfill (considering water table at el. 83 ft)

Size reduction factor for: $0.5\gamma' B' N\gamma\ s_\gamma\ d_\gamma$ (Ref. 6)

$r_\gamma = 1 - 0.25 \log (B/k)$ where k = 6 r_γ = 0.69

Sand layer ultimate bearing capacity

q_{ut} =	from c =	0.0	kip/ft^2
	from γ =	95.5	kip/ft^2
	from q =	69.2	kip/ft^2
	total q_{ult} =	**164.7**	**kip/ft^2**

Clay layer ultimate bearing capacity

$q_{u,b}$ =	from c =	38.6	kip/ft^2
	from γ =	0.0	kip/ft^2
	from q =	7.3	kip/ft^2
	total q_{ult} =	**45.9**	**kip/ft^2**

The ultimate bearing capacity of a sand layer underlain by a clay layer is:

q_u = 118.0 ksf

For static loading:

FS = 3.0
q a = 39.3 ksf

The ultimate bearing capacity q_{ult} is compared with the average bearing pressure to calculate the corresponding factor of safety for static loading.

q = 5.4 ksf
FS = 21.7

TABLE 9

STATIC BEARING CAPACITY AND FACTORS OF SAFETY FOR ALL SAFETY RELATED BUILDINGS

CCNPP UNIT 3

Building	Ultimate Bearing Capacity, q_{ult} (ksf)				Allowable Bearing Capacity, q_a (ksf) (1)				Foundation pressure, q_s (ksf) (3)
	VESIĆ			MEYERHOF	VESIĆ			MEYERHOF	
	Case a	Case b	Case c	Dense sand over soft clay	Case a	Case b	Case c	Dense sand over soft clay	
NI Common Mat	192.7	228.9	38.6	70.5	64.2	76.3	12.9	23.5	11.8
Nuclear Auxiliary Building	170.7	179.1	40.3	105.8	56.9	59.7	13.4	35.3	9.7
EPGB (4)	113.6	102.2	NA	115.0	37.9	34.1	NA	38.3	3.2
ESWB	145.7	153.8	NA	118.0	48.6	51.3	NA	39.3	5.4

Building	Factor of Safety (2)				Recommended Factor of Safety
	VESIĆ			MEYERHOF	
	Case a	Case b	Case c	Dense sand over soft clay	
NI Common Mat	16	19	3	6	6
Nuclear Auxiliary Building	18	18	4	11	10
EPGB (4)	36	32	NA	36	30
ESWB	27	28	NA	22	20

(1) The allowable bearing capacity is calculated using a factor of safety FS = 3.0 : $q_a = q_u/FS$

(2) Factors of safety are calculated using the estimated design foundation pressures (q_s) : $FS = q_{ult} / q_s$

(3) Foundation pressures are obtained from Ref. 4.

(4) For the EPGB and ESWB, Case c is not calculated. The location of the clay stratum is relatively deep compared to the building's lateral dimensions.

TABLE 10

DYNAMIC ALLOWABLE BEARING CAPACITY FOR ALL SAFETY RELATED BUILDINGS

CCNPP UNIT 3

Building	Allowable Bearing Capacity, q_a (ksf) (1)			
	VESIĆ			MEYERHOF
	Case a	Case b	Case c	Dense sand over soft clay
NI Common Mat	85.7	101.7	17.2	31.3
Nuclear Auxiliary Building	75.9	79.6	17.9	47.0
EPGB	50.5	45.4	NA	51.1
ESWB	64.7	68.3	NA	52.4

(1) Allowable bearing capacity for static loading is increased by one third for the dynamic loading (Ref. 9)

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The Terzaghi Bearing-Capacity Equation

One of the early sets of bearing-capacity equations was proposed by Terzaghi (1943) as shown in Table 4-1. These equations are similar to Eq. (*k*) derived in the previous section, but Terzaghi used shape factors noted when the limitations of the equation were discussed. Terzaghi's equations were produced from a slightly modified bearing-capacity theory devel-

TABLE 4-1
Bearing-capacity equations by the several authors indicated

Terzaghi (1943). See Table 4-2 for typical values and for $K_{p\gamma}$ values.

$$q_{ult} = cN_c s_c + \bar{q}N_q + 0.5\gamma B N_\gamma s_\gamma \qquad N_q = \frac{a^2}{a\cos^2(45 + \phi/2)}$$

$$a = e^{(0.75\pi - \phi/2)\tan\phi}$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_\gamma = \frac{\tan\phi}{2}\left(\frac{K_{p\gamma}}{\cos^2\phi} - 1\right)$$

For:	strip	round	square
$s_c =$	1.0	1.3	1.3
$s_\gamma =$	1.0	0.6	0.8

Meyerhof (1963).* See Table 4-3 for shape, depth, and inclination factors.

Vertical load: $q_{ult} = cN_c s_c d_c + \bar{q}N_q s_q d_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma$

Inclined load: $q_{ult} = cN_c d_c i_c + \bar{q}N_q d_q i_q + 0.5\gamma B' N_\gamma d_\gamma i_\gamma$

$$N_q = e^{\pi\tan\phi}\tan^2\left(45 + \frac{\phi}{2}\right)$$

$$N_c = (N_q - 1)\cot\phi$$

$$N_\gamma = (N_q - 1)\tan(1.4\phi)$$

Hansen (1970).* See Table 4-5 for shape, depth, and other factors.

General:† $q_{ult} = cN_c s_c d_c i_c g_c b_c + \bar{q}N_q s_q d_q i_q g_q b_q + 0.5\gamma B' N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$

when $\phi = 0$

use $q_{ult} = 5.14 s_u(1 + s'_c + d'_c - i'_c - b'_c - g'_c) + \bar{q}$

N_q = same as Meyerhof above

N_c = same as Meyerhof above

$N_\gamma = 1.5(N_q - 1)\tan\phi$

Vesić (1973, 1975).* See Table 4-5 for shape, depth, and other factors. Use Hansen's equations above.

N_q = same as Meyerhof above

N_c = same as Meyerhof above

$N_\gamma = 2(N_q + 1)\tan\phi$

*These methods require a trial process to obtain design base dimensions since width B and length L are needed to compute shape, depth, and influence factors.

†See Sec. 4-6 when $i_i < 1$.

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TABLE 4-5*a*

Shape and depth factors for use in either the Hansen (1970) or Vesić (1973, 1975*b*) bearing-capacity equations of Table 4-1. Use s'_c, d'_c when $\phi = 0$ only for Hansen equations. Subscripts H, V for Hansen, Vesić, respectively.

Shape factors	Depth factors
$s'_{c(H)} = 0.2\dfrac{B'}{L'}$ $(\phi = 0°)$	$d'_c = 0.4k$ $(\phi = 0°)$
$s_{c(H)} = 1.0 + \dfrac{N_q}{N_c} \cdot \dfrac{B'}{L'}$	$d_c = 1.0 + 0.4k$
$s_{c(V)} = 1.0 + \dfrac{N_q}{N_c} \cdot \dfrac{B}{L}$	$k = D/B$ for $D/B \le 1$
$s_c = 1.0$ for strip	$k = \tan^{-1}(D/B)$ for $D/B > 1$
	k in radians
$s_{q(H)} = 1.0 + \dfrac{B'}{L'}\sin\phi$	$d_q = 1 + 2\tan\phi(1 - \sin\phi)^2 k$
$s_{q(V)} = 1.0 + \dfrac{B}{L}\tan\phi$	k defined above
for all ϕ	
$s_{\gamma(H)} = 1.0 - 0.4\dfrac{B'}{L'}$ ≥ 0.6	$d_\gamma = 1.00$ for all ϕ
$s_{\gamma(V)} = 1.0 - 0.4\dfrac{B}{L}$ ≥ 0.6	

Notes:

1. Note use of "effective" base dimensions B', L' by Hansen but not by Vesić.
2. The values above are consistent with either a vertical load or a vertical load accompanied by a horizontal load H_B.
3. With a vertical load and a load H_L (and either $H_B = 0$ or $H_B > 0$) you may have to compute two sets of shape s_i and d_i as $s_{i,B}$, $s_{i,L}$ and $d_{i,B}$, $d_{i,L}$. For i, L subscripts of Eq. (4-2), presented in Sec. 4-6, use ratio L'/B' or D/L'.

TABLE 4-5*b*

Table of inclination, ground, and base factors for the Hansen (1970) equations. See Table 4-5*c* for equivalent Vesić equations.

Inclination factors	Ground factors (base on slope)
$i'_c = 0.5 - \sqrt{1 - \dfrac{H_i}{A_f C_a}}$	$g'_c = \dfrac{\beta°}{147°}$
$i_c = i_q - \dfrac{1 - i_q}{N_q - 1}$	$g_c = 1.0 - \dfrac{\beta°}{147°}$
$i_q = \left[1 - \dfrac{0.5H_i}{V + A_f c_a \cot\phi}\right]^{\alpha_1}$	$g_q = g_\gamma = (1 - 0.5\tan\beta)^5$
$2 \le \alpha_1 \le 5$	
	Base factors (tilted base)
$i_\gamma = \left[1 - \dfrac{0.7H_i}{V + A_f c_a \cot\phi}\right]^{\alpha_2}$	$b'_c = \dfrac{\eta°}{147°}$ $(\phi = 0)$
$i_\gamma = \left[1 - \dfrac{(0.7 - \eta°/450°)H_i}{V + A_f c_a \cot\phi}\right]^{\alpha_2}$	$b_c = 1 - \dfrac{\eta°}{147°}$ $(\phi > 0)$
$2 \le \alpha_2 \le 5$	$b_q = \exp(-2\eta\tan\phi)$
	$b_\gamma = \exp(-2.7\eta\tan\phi)$
	η in radians

Notes:

1. Use H_i as either H_B or H_L, or both if $H_L > 0$.
2. Hansen (1970) did not give an i_c for $\phi > 0$. The value above is from Hansen (1961) and also used by Vesić.
3. Variable c_a = base adhesion, on the order of 0.6 to 1.0 × base cohesion.
4. Refer to sketch for identification of angles η and β, footing depth D, location of H_i (parallel and at top of base slab; usually also produces eccentricity). Especially note V = force *normal* to base and is not the resultant R from combining V and H_i.

Notes: $\beta + \eta$ 90° (Both β and η have signs (+) shown.)
β ϕ

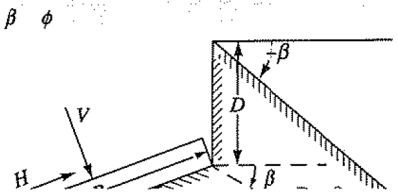

TABLE 4-5*c*

Table of inclination, ground, and base factors for the Vesić (1973, 1975*b*) bearing-capacity equations. See notes below and refer to sketch for identification of terms.

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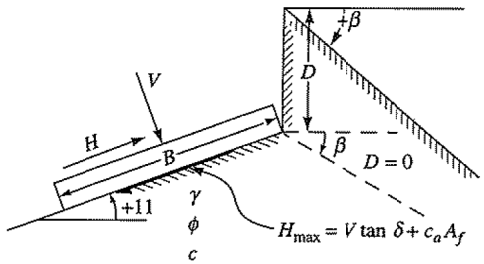
Notes: $\beta + \eta$ 90° (Both β and η have signs (+) shown.)

β ϕ



For: $L/B \le 2$ use ϕ_{tr}

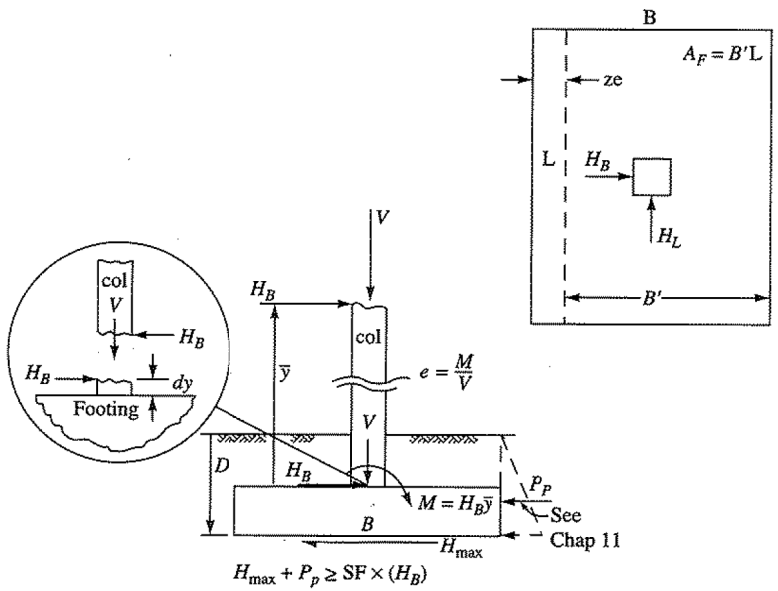
$L/B > 2$ use $\phi_{ps} = 1.5\,\phi_{tr} - 17°$

$\phi_{tr} \le 34°$ use $\phi_{tr} = \phi_{ps}$

δ = friction angle between base and soil ($.5\phi \le \delta \le \phi$)

$A_f = B'L'$ (effective area)

c_a = base adhesion (0.6 to 1.0c)



$H_{max} + P_p \ge SF \times (H_B)$

TABLE 4-5*c*

Table of inclination, ground, and base factors for the Vesić (1973, 1975*b*) bearing-capacity equations. See notes below and refer to sketch for identification of terms.

Inclination factors	Ground factors (base on slope)
$i'_c = 1 - \dfrac{mH_i}{A_f c_a N_c}$ $(\phi = 0)$	$g'_c = \dfrac{\beta}{5.14}$ β in radians
$i_c = i_q - \dfrac{1 - i_q}{N_q - 1}$ $(\phi > 0)$	$g_c = i_q - \dfrac{1 - i_q}{5.14 \tan\phi}$ $\phi > 0$
i_q, and m defined below	i_q defined with i_c
$i_q = \left[1.0 - \dfrac{H_i}{V + A_f c_a \cot\phi}\right]^m$	$g_q = g_\gamma = (1.0 - \tan\beta)^2$
	Base factors (tilted base)
$i_\gamma = \left[1.0 - \dfrac{H_i}{V + A_f c_a \cot\phi}\right]^{m+1}$	$b'_c = g'_c$ $(\phi = 0)$
$m = m_B = \dfrac{2 + B/L}{1 + B/L}$	$b_c = 1 - \dfrac{2\beta}{5.14 \tan\phi}$
$m = m_L = \dfrac{2 + L/B}{1 + L/B}$	$b_q = b_\gamma = (1.0 - \eta \tan\phi)^2$

Notes:

1. When $\phi = 0$ (and $\beta \ne 0$) use $N_\gamma = -2\sin(\pm\beta)$ in N_γ term.
2. Compute $m = m_B$ when $H_i = H_B$ (H parallel to B) and $m = m_L$ when $H_i = H_L$ (H parallel to L). If you have both H_B and H_L use $m = \sqrt{m_B^2 + m_L^2}$. Note use of B and L, not B', L'.
3. Refer to Table sketch and Tables 4-5*a*,*b* for term identification.
4. Terms N_c, N_q, and N_γ are identified in Table 4-1.
5. Vesić always uses the bearing-capacity equation given in Table 4-1 (uses B' in the N_γ term even when $H_i = H_L$).
6. H_i term $\le$ 1.0 for computing i_q, i_γ (always).

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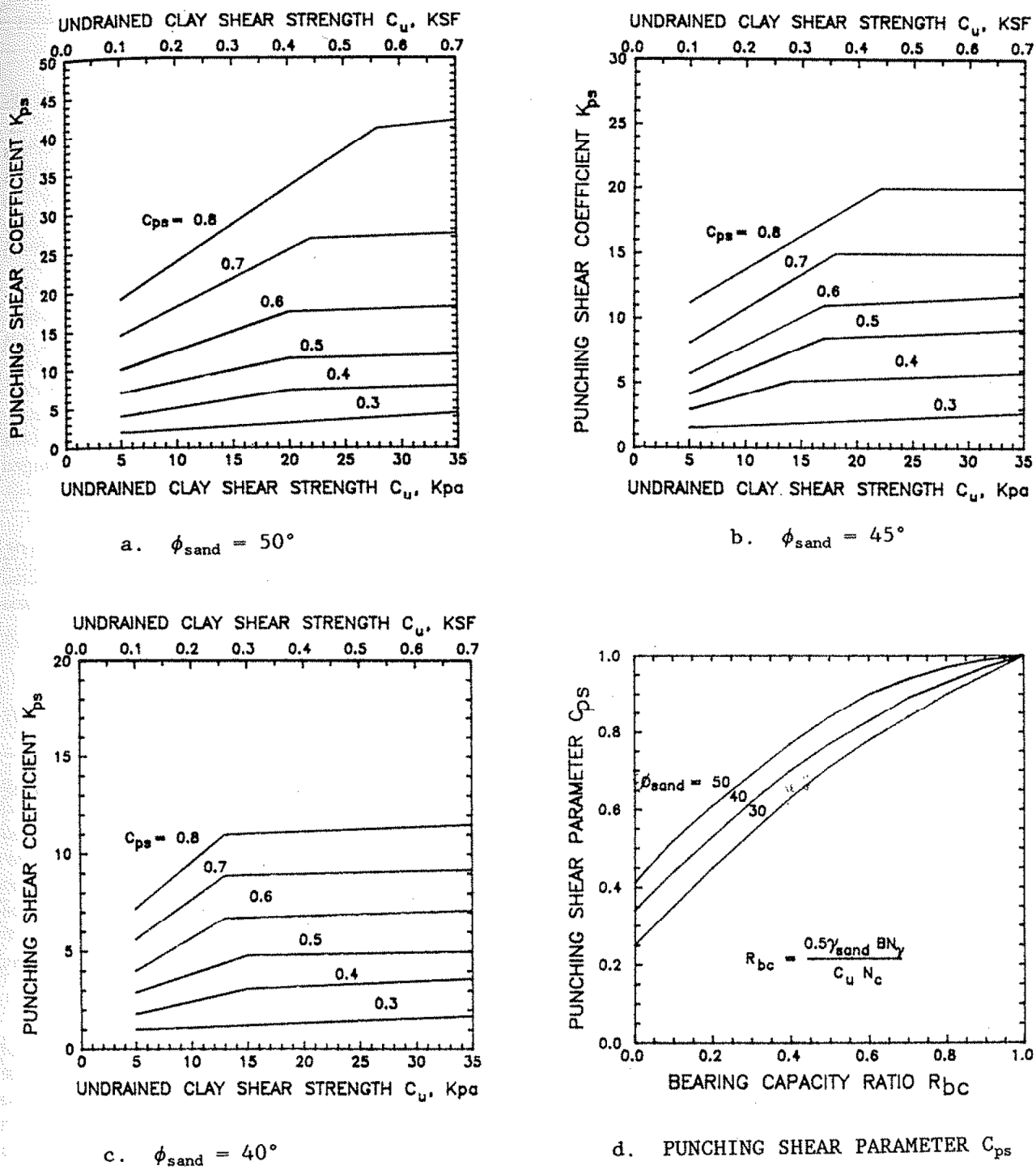

Figure 4-2. Charts for calculation of ultimate bearing capacity of dense sand over soft clay (Data from Hanna and Meyerhof 1980)

term $0.5 \cdot B'\gamma'_H N_\gamma \zeta_\gamma$ by a reduction factor (Bowles 1988)

$$r_\gamma = 1 - 0.25\log_{10}\frac{B}{6} \qquad (4\text{-}13)$$

where $B > 6$ ft.

I. PRESUMPTIVE BEARING CAPACITY.

Refer to Table or typical presumptive allowable bearing pressures q_{na}. Presumptive allowable pressures should