Chapter 7. Foundations

Purpose : To prevent strength failure of soil and large deformation

Types : Shallow / Deep

Shallow Foundations : includes all those types which are designed to spread the building loads over a sufficient area of soil near ground surface to secure adequate bearing capacity & small deformation.

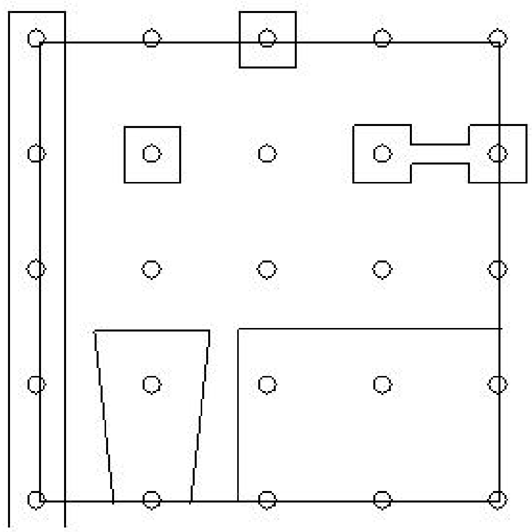
- Spread footing

  i) Independent(single) footing

  ii) Continuous(wall) footing

  iii) Combined footing

- Raft(mat) foundation



Deep foundations : used in case where the soils near the ground surface are incapable of supporting mat or single footings.

- Piles : installed by driving, vibrating as well as by excavation or drilling

- Piers (Drilled) : always installed by excavation or drilling

- Caissons : may be defined as a large watertight box that is used to exclude water and semi-fluid material during the excavation of foundations & ultimately becomes an integral part of the substructure

  ○ Pneumatic / Open / Box

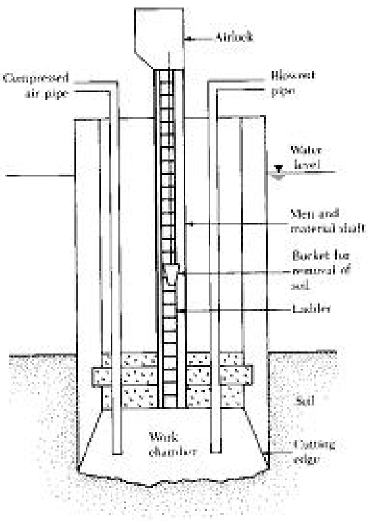


Figure 9.18 Pneumatic caisson

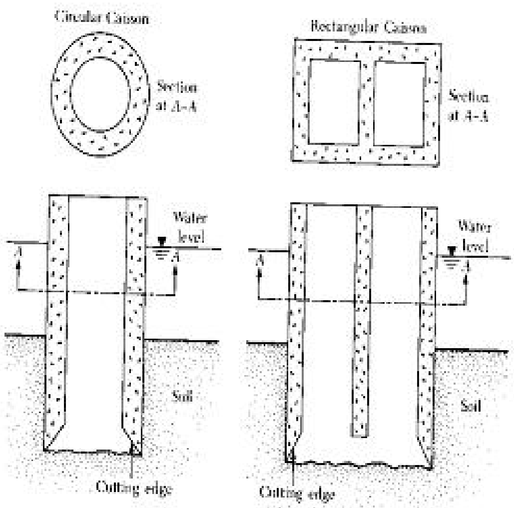


Figure 9.16 Open caisson

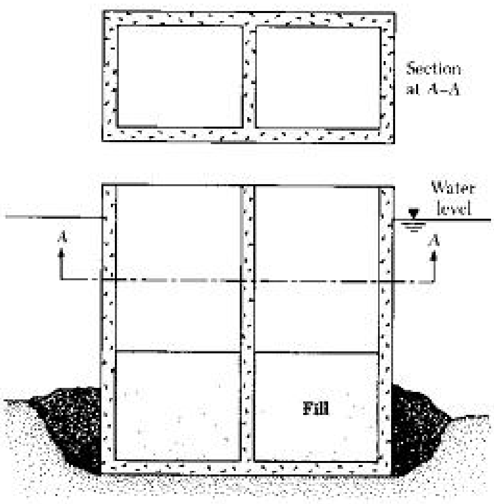


Figure 9.17 Box caisson

Requirements of Satisfactory Foundations

① must be properly located w.r.t. any future influence which could adversely affect its performance

- frost action : 3/4 of the max. frost penetration, or thaw line
- soil volume change : expansive soil *
- adjacent structures, etc.
- scour & undermining by river currents & wave action
- ground water level
- underground defects such as faults, caves, mines

② safe against bearing capacity failure

③ not settle enough to damage the structure

* **TABLE 2.23 RELATION OF SOIL INDEX PROPERTIES AND PROBABLE VOLUME CHANGES FOR HIGHLY PLASTIC SOILS.**
(USBR, Earth Manual, 1973.)

Data from Index Tests[a]			Estimation of Probable Expansion[b]	
Colloid Content (Percent minus 0.001 mm)	*Plasticity Index*	*Shrinkage Limit, Percent*	*Percent Total Volume Change (Dry to Saturated Condition)*	*Degree of Expansion*
>28	>35	<11	>30	Very high
20–31	25–41	7–12	20–30	High
13–23	15–28	10–16	10–20	Medium
<15	<18	>15	<10	Low

[a] All three index tests should be considered in estimating expansive properties.
[b] Based on a vertical loading of 1.0 p.s.i. as for concrete canal lining. For higher loadings the amount of expansion is reduced, depending on the load and on the clay characteristics.

Safety Factor (Table 7.2, 7.3, p. 201)

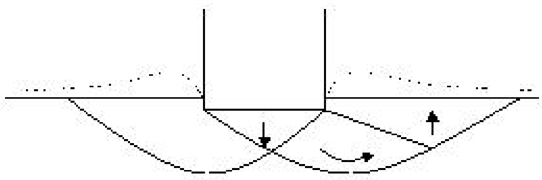
- partial / total safety factors

ex. $q_a = \frac{q_u}{F}$, F : Factor of safety

Shallow Foundations

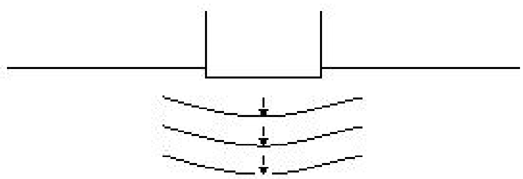
Modes of failures (Fig. 7.2, p. 194) : General shear, local shear, punching shear failures

- General shear failure



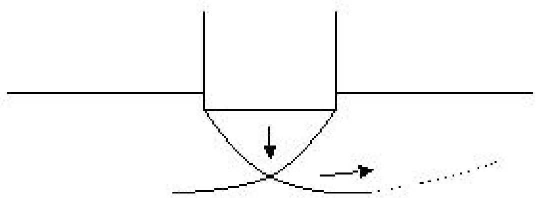
dense / stiff soil
D_R = 90~100% / OC clay

- Punching shear failure



loose / soft soil
D_R = 10~20%

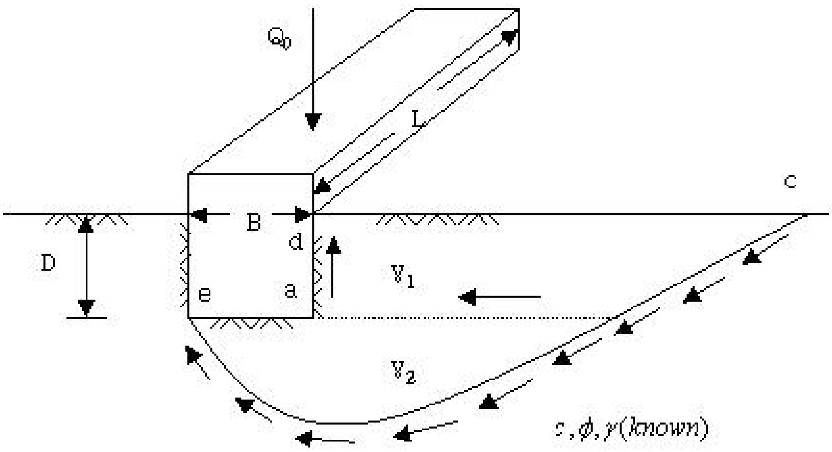
- Local shear failure



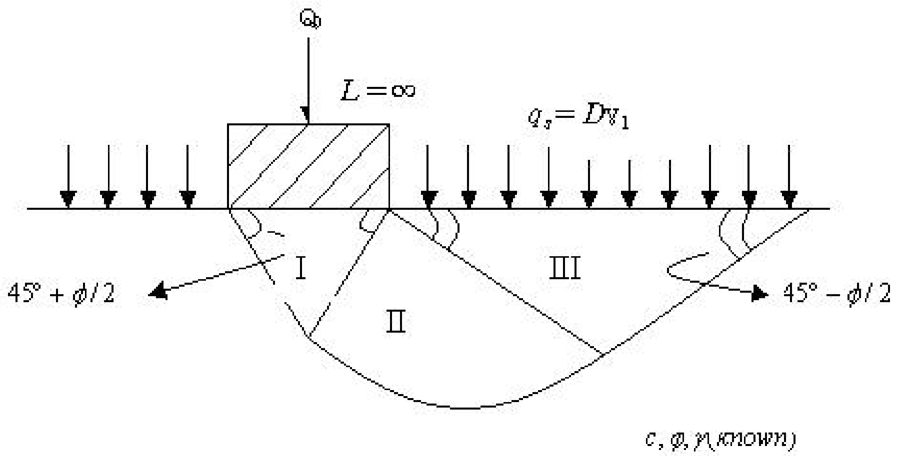
medium soil
D_R = 50%

◎ Computation of ultimate load

Real situation



Idealized situation



Ⅰ : Active Rankine
Ⅱ : Radial Prandtl
Ⅲ : Passive Rankine

zone

* To be determined is the maximum unit load $q_0 = \frac{Q_0}{BL}$ which this foundation can support.

Assumptions & Simplifications

1. The soil mass is of semi-infinite and homogeneous.

2. Shear strength defined by c & ϕ

3. Rigid-plastic stress-strain relationship.

4. Plane strain condition.

5. The overburden soil replaced by a uniformly distributed surcharge, $q_s = D\gamma$

6. Shallow foundation ($D \leq B$)

Analytical solutions

Case 1 : $\gamma = 0$

$$q_0 = cN_c + qN_q$$

Case 2 : $c = 0$, $q_s = 0$

$$q_0 = \frac{1}{2}\gamma BN_\gamma$$

N_c , N_q , N_γ : Bearing capacity factor (Dimensionless, $f(\phi)$)

Case 3 : $c \neq 0$, $q_s \neq 0$, $\gamma \neq 0$

$$q_0 = cN_c + q_sN_q + \frac{1}{2}\gamma BN_\gamma$$

Bearing-capacity equations by the several authors indicated

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

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

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

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

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

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

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

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

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

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

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

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

when $\phi = 0$

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

$N_q =$ 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 $i_i < 1$.

Bearing-capacity factors for the Meyerhof, Hansen, and Vesić bearing-capacity equations

Note that N_c and N_q are the same for all three methods; subscripts identify author for N_γ

ϕ	N_c	N_q	$N_{\gamma(H)}$	$N_{\gamma(M)}$	$N_{\gamma(V)}$	N_q/N_c	$2\tan\phi(1-\sin\phi)^2$
0	5.14*	1.0	0.0	0.0	0.0	0.195	0.000
5	6.49	1.6	0.1	0.1	0.4	0.242	0.146
10	8.34	2.5	0.4	0.4	1.2	0.296	0.241
15	10.97	3.9	1.2	1.1	2.6	0.359	0.294
20	14.83	6.4	2.9	2.9	5.4	0.431	0.315
25	20.71	10.7	6.8	6.8	10.9	0.514	0.311
26	22.25	11.8	7.9	8.0	12.5	0.533	0.308
28	25.79	14.7	10.9	11.2	16.7	0.570	0.299
30	30.13	18.4	15.1	15.7	22.4	0.610	0.289
32	35.47	23.2	20.8	22.0	30.2	0.653	0.276
34	42.14	29.4	28.7	31.1	41.0	0.698	0.262
36	50.55	37.7	40.0	44.4	56.2	0.746	0.247
38	61.31	48.9	56.1	64.0	77.9	0.797	0.231
40	75.25	64.1	79.4	93.6	109.3	0.852	0.214
45	133.73	134.7	200.5	262.3	271.3	1.007	0.172
50	266.50	318.5	567.4	871.7	761.3	1.195	0.131

* = $\pi + 2$ as limit when $\phi \rightarrow 0°$.

Slight differences in above table can be obtained using program BEARING.EXE on diskette depending on computer used and whether or not it has floating point.

Ultimate values of the settlement of foundations (according to ČSN 73 1001)

Type of building	The foundation soil consolidates			
	very quickly (for example, sands)		slowly (for example, clays)	
	difference of settlement	total settlement	difference of settlement	total settlement
	$\Delta s/L$	s [cm]	$\Delta s/L$	s [cm]
1. Buildings:				
panels[1])	0.0005 (0.002)	6 (7)	0.0007 (0.002)	8 (5)
bricks and blocks	0.0007	6	0.001	8
bricks, block reinforced with concrete strips	0.001	8	0.0013	10
reinforced concrete skeleton	0.0007	6	0.001	8
	$\Delta s/l$	s [cm]	$\Delta s/l$	s [cm]
2. Structures:				
statically determinate	0.003	10	0.003	10
statically indeterminate steel	0.0015	6	0.002	8
statically indeterminate reinforced concrete	0.001	4	0.0015	6
	$\Delta s/B$	s [cm]	$\Delta s/B$	s [cm]
rigid and massive massive foundation to a height of 20 m	0.005	20	0.005	20
higher than 20 m (chimneys)	0.002	10	0.002	10
	$\Delta s/l$	s [cm]	$\Delta s/l$	s [cm]
3. Crane tracks with bridge crane longitudinally and laterally	0.0015	—	0.0015	—

[1]) Values in brackets are according to Professor Šimek, mentioned in the Proposed Code for the Foundations of Panel Housing. Difference of settlement values are used when there is strong no connection between adjacent vertical structures.

Tolerable differential settlement of buildings, mm*

Recommended maximum values in parentheses

Criterion	Isolated foundations	Rafts
Angular distortion (cracking)	1/300	
Greatest differential settlement		
Clays	45 (35)	
Sands	32 (25)	
Maximum settlement		
Clays	75	75–125 (65–100)
Sands	50	50–75 (35–65)

*After MacDonald and Skempton (1955) but see also Wahls (1981).

Permissible differential building slopes by the USSR code on both unfrozen and frozen ground

All values to be multiplied by L = length between two adjacent points under consideration. H = height of wall above foundation.*

Structure	On sand or hard clay	On plastic clay	Average max. settlement, mm
Crane runway	0.003	0.003	
Steel and concrete frames	0.002	0.002	100
End rows of brick-clad frame	0.0007	0.001	150
Where strain does not occur	0.005	0.005	
Multistory brick wall			25 $L/H \geq 2.5$
L/H to 3	0.0003	0.0004	100 $L/H \leq 1.5$
Multistory brick wall			
L/H over 5	0.0005	0.0007	
One-story mill buildings	0.001	0.001	
Smokestacks, water towers, ring foundations	0.004	0.004	300
Structures on permafrost			
Reinforced concrete	0.002–0.0015		150 at 40 mm/year†
Masonry, precast concrete	0.003–0.002		200 at 60 mm/year
Steel frames	0.004–0.0025		250 at 80 mm/year
Timber	0.007–0.005		400 at 129 mm/year

*From Mikhejev et al. (1961) and Polshin and Tokar (1957).

†Not to exceed this rate per year.

Construction and/or material	Maximum δ/L
Masonry (center sag)	1/250–1/700
(edge sag)	1/500–1/1000
Masonry and steel	1/500
Steel with metal siding	1/250
Tall structures	< 1/300 (so tilt not noticeable)
Storage tanks (center-to-edge)	< 1/300