BEARING CAPACITY OF SHALLOW FOUNDATION

2.1 (Ultimate) Bearing Capacity (q_{ult})

It is the least pressure which would cause shear failure of the supporting soil immediately below and adjacent to a foundation.

What are the different shear failure modes of supporting soil?

2.2 MODES OF SHEAR FALUIRE

There are three modes of shear failures i.e. General, Local, and Punching shear failures depending upon the compressibility of soil and depth of footing with respect to its breath (i.e. D/B ratio).

2.2.1 General Shear Failure (figure 2.1a)

- Characterized by well defined failure pattern, consisting of a wedge and slip surface and bulging (heaving) of soil surface adjacent to the footing.
- Sudden collapse occurs, accompanied by tilting of the footing
- Occurs in dense or stiff soil.
- Failure load is well defined.

2.2.2 Local Shear Failure (figure 2.1 b)

- Failure pattern consist of wedge and slip surface but is well defined only under the footing. Slight bulging of soil surface occurs. Tilting of footing is not expected.
- Large settlement occurs.
- Ultimate load is not well defined.
- Occurs in soil of high compressibility.

2.2.3 Punching Shear Failure (figure 2.1c)

- Failure pattern is not well defined.
- No bulging of ground surface, no tilting of footing.
- Failure take place immediately below footing and surrounding soil remains relatively unaffected.
- Large settlements-ultimate load is not well defined.
- Occurs in soil of very high compressibility.
- It also occurs in the soil of very high compressibility, if the foundation is located at considerable depth (figure 2.2).

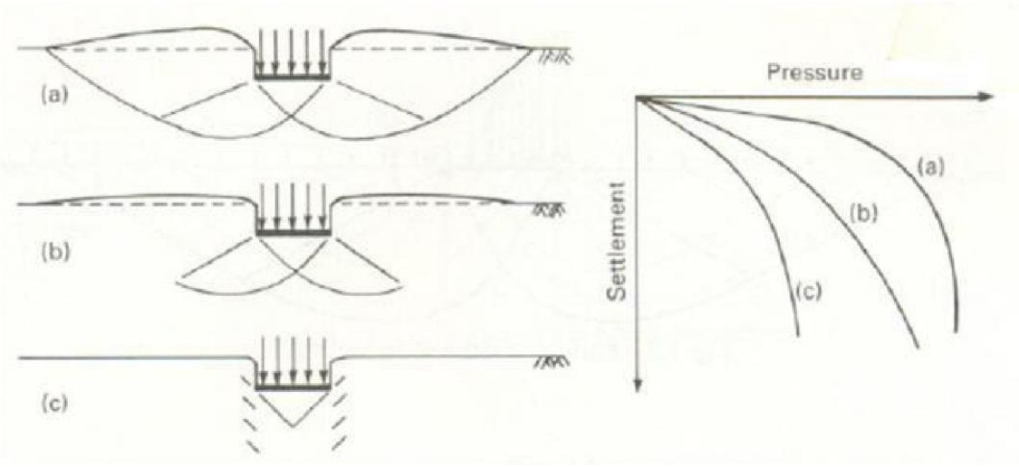


Figure 2-1 Modes of Failures (a) general shear (b) local shear (c) punching shear

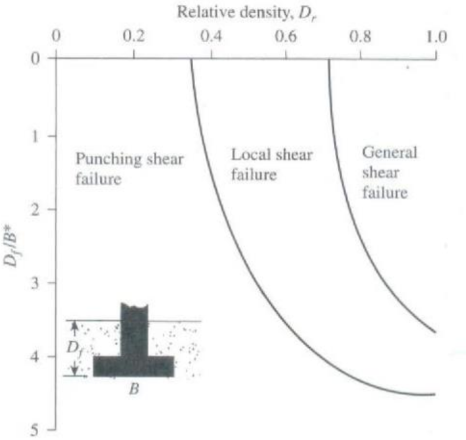


Figure 2-2 Effect of D/B and Dr on mode of failure

The applied load (stress) causing shear failure of supporting soil can be in terms of gross or net pressure intensity.

2.3 Gross Pressure Intensity (q_{gross}):-

It is the total pressure at base of the footing due to the weight of superstructure and earth fill if any (figure 2.3)

W_{ss} = Load from superstructure.

W_F=Weight of foundation.

W_{bs}=Weight of the back fill soil.

$q_{gross} = (W_{ss} + W_F + W_{bs})/A$

A=Area of the footing

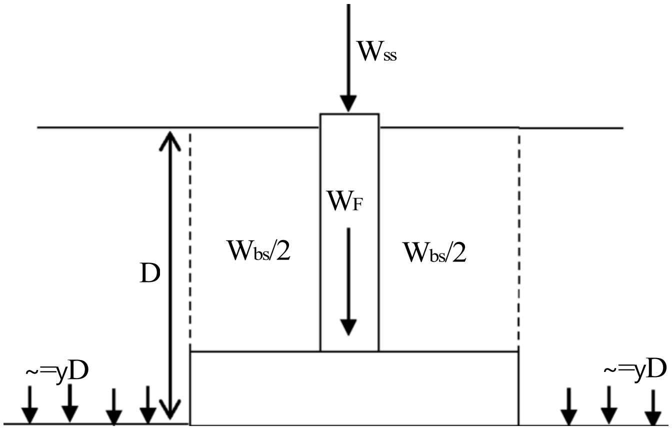


Figure 2-3 Gross and Net pressure demonstration

2.3.1 Net Pressure Intensity (q_{net})

It is the increase in pressure at foundation level, being the total weight less the weight of the soil permanently removed.

(1) Before removal of soil, stress at foundation level is

$= y \times D$

(2) After removal

$q_{net} = q_{gross} - \gamma D$

If $q_{gross} = \gamma D$

$q_{net} = 0$ (it means that the weight of the soil excavated is equal to the weight of the structure)

Settlement of foundation (theoretically) = 0

Putting the relation for q_{gross}

$q_{net} = (W_{ss} + W_F + W_{bs})/A - \gamma D$

$q_{net} = (W_{ss})/A + (W_F + W_{bs})/A - \gamma D$

if W_F is taken roughly equal to W_{bs} then

$(W_F+W_{bs})/A = \gamma D$

This leads to $q_{net} = Wss/A$

2.4 Safe bearing capacity (q_{safe})

The safe bearing capacity (gross) to avoid shear failure is obtained by reducing (or dividing) the ultimate bearing capacity by a safety factor.

$q_{safe} = q_{ult}$/FOS

FOS = 2.5-*3 (Generally)

It is not only the strength criteria that should put a limit on the applied stress, but the serviceability criteria (settlement of foundation) should also be considered.

$q_{safe(net)}$ in terms of net pressure is be in terns = qult (net) / FOS = (qult - γD)/FOS

2.5 Allowable Bearing Capacity (qa)

It is the maximum pressure which may be applied to the soil such that the two fundamental requirements are satisfied.

a) Limiting the settlement to a tolerable amount
b) Shear failure of supporting soil is prevented.

So the allowable pressure is the minimum of

- qsafe
- Stress required to cause a specified amount of settlement

2.6 Methods of bearing capacity determination

1) Analytic method i.e. through bearing capacity equations like using Terzaghi equation, Meyerhof equation, Hansen equation etc.
2) Correlation with field test data e.g. Standard Penetration Test (SPT), Cone Penetration Test (CPT) etc.
3) On-site determination of bearing capacity e.g. plate load test (PLT), pile load test.
4) Presumptive bearing capacity (recommended bearing capacity in various codes)

We will discuss only Analytical Methods at this stage

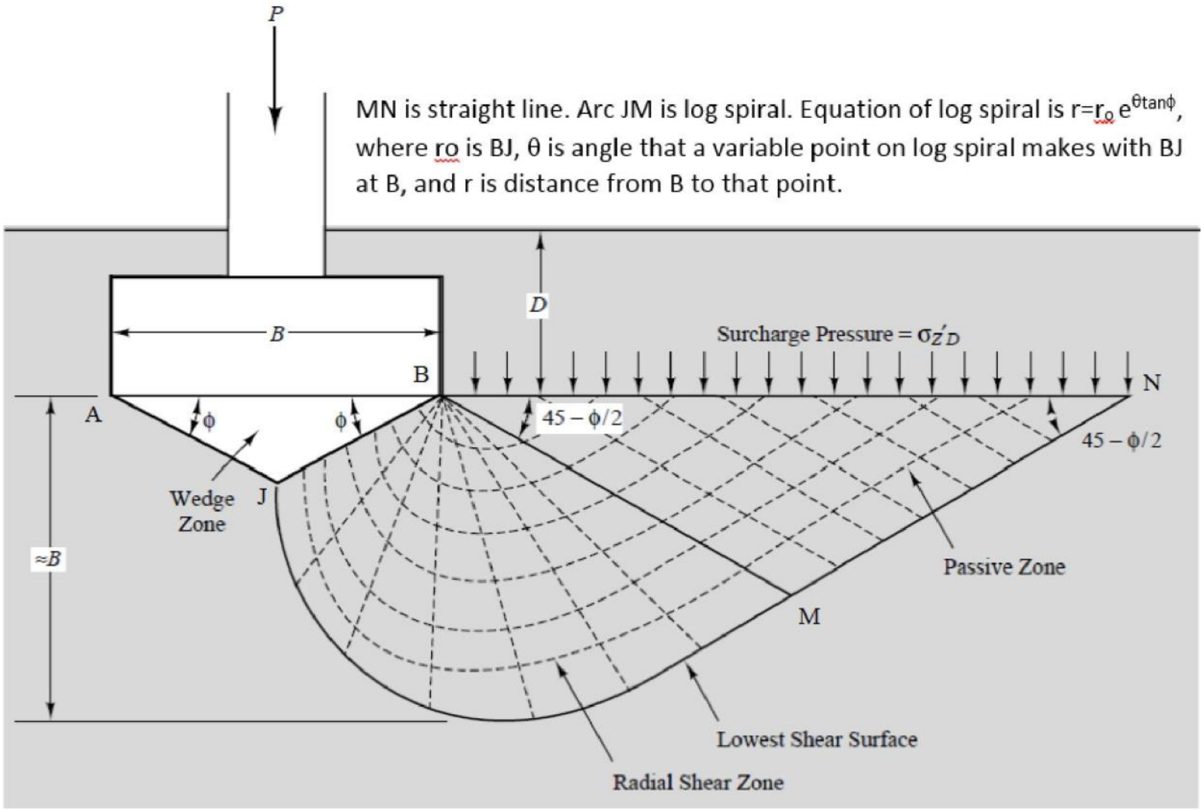
Terzaghi's Bearing Capacity Equation (1943)

Terzaghi developed a general formula for ultimate bearing capacity of spread footing foundations using the Limit Equilibrium method. He made the following assumptions:

- The depth of the footing is less than or equal to its width (D, B).
- The foundation is rigid and has a rough bottom.
- The soil beneath the footing is a homogeneous semi-infinite mass.
- Strip foundation with a horizontal base and level ground surface under vertical loads.
- The general shear mode of failure governs and no consolidation of the soil occurs (settlement is due only to shearing and lateral movement of the soil).
- The shear strength of the soil is described by $s = c + \sigma \tan \varphi$

The collapse mechanism assumed by Terzaghi is given in figure 2-6. Terzaghi considered three zones in the soil, as shown in Figure 6.5. Immediately beneath the foundation is a (Elastic) wedge zone that remains intact and moves downward with the foundation. The movement of the wedge forces the soil aside and produces radial shear zone and linear shear zone. The radial shear zone extends from each side of the wedge, where he took the shape of the shear planes to be logarithmic spirals. The outer portion is the linear shear or Passive zone in which the soil shears along planar surfaces. Since Terzaghi neglected the shear strength of soils between the ground surface and a depth D, the shear surface stops at this depth and the overlying soil has been replaced with the surcharge pressure $q = \gamma D \cdot$ This approach is conservative, and is part of the reason for limiting the method to relatively shallow foundations (D ~B).

Terzaghi developed his theory for continuous foundations (i.e., those with a very large L/B ratio). This is the simplest case because it is a two-dimensional problem. He then extended it to square and round foundations by adding empirical coefficients (shape factors) obtained from model tests.



MN is straight line. Arc JM is log spiral. Equation of log spiral is $r=r_o\, e^{\theta\tan\phi}$, where ro is BJ, θ is angle that a variable point on log spiral makes with BJ at B, and r is distance from B to that point.

Figure 2-6 Collapse Mechanism assumed by Terzaghi (Only right side of the slip lines/failure mechanism is shown in the figure. Failure mechanism is symmetrical

The free body diagram of elastic wedge is shown in figure 2-7.

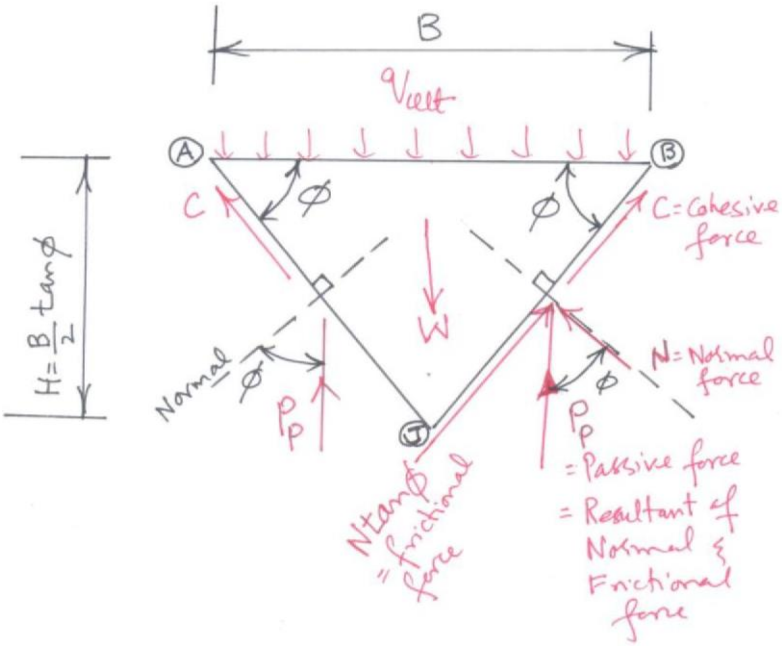
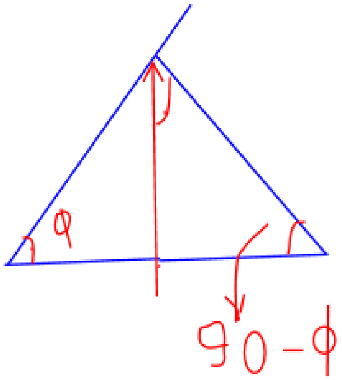


Figure 2-7



$$\sum F_y = 0$$

$$q_{\_} \times B = -W + 2C Sin\phi + 2Pp$$

$$C = c \times JB \qquad \text{[c=cohesion of soil]}$$

$$C = c \times \frac{B}{2\cos\phi}$$

$$W = \gamma \times \frac{B \times H}{2} = \frac{\gamma B}{2}\left(\frac{B}{2}\tan\phi\right)$$

$$W = \frac{\gamma B^{2}}{4}\tan\phi$$

Contribution to Pp is due to the self weight of the soil y, soil cohesion c, and surcharge q=yD. Therefore Pp is divided respectively into Pp'y, Ppc, and Ppq.

However finding all three components of Pp simultaneously is an indeterminate problem. To remedy this difficulty, we split the problem into three pieces.

The three separate problems are defined as follows:

Problem 1: Evaluate Ppc by assuming the soil has cohesion and friction but is weightless and has no surcharge.

Problem 2: Evaluate Ppq by assuming the soil has surcharge and friction but has no cohesion and is weightless.

Problem 3: Evaluate Pp'y by assuming the soil has weight and friction but no cohesion and no surcharge.

This method of superposition is introduces errors but the simplification is conservative and does not seem to introduce major error.

After evaluating these components of Pp (not done here), and putting their values in the above equation of equilibrium, the Terzaghi bearing capacity equation is obtained.

$$q_{ult}=cN_c + qN_q+0.5\ \gamma BN\gamma$$

N_c, N_q and N_r are bearing capacity factors or coefficients due to cohesion, surcharge and soil weight respectively. They depends on the value of the value of ~ and on the shape of the failure zone as assumed by the different researchers.

Terzaghi used shape factors to make the formula applicable to other shapes of foundations using the shape factors s_c and s_7.

$$q_{ult}=cN_cS_c + qN_q+0.5\ 'yBN\gamma s$$

The first term in the BC equation is the contribution to BC due to cohesion of soil, the 2nd term corresponds to the overburden pressure or depth of the footing, the 3rd term is due to the self- weight of the soil.

Shape factor	Strip footing	Round	Square	Rectangular
S_c	1	1.3	1.3	
$S_,$	1	0.6	0.8	

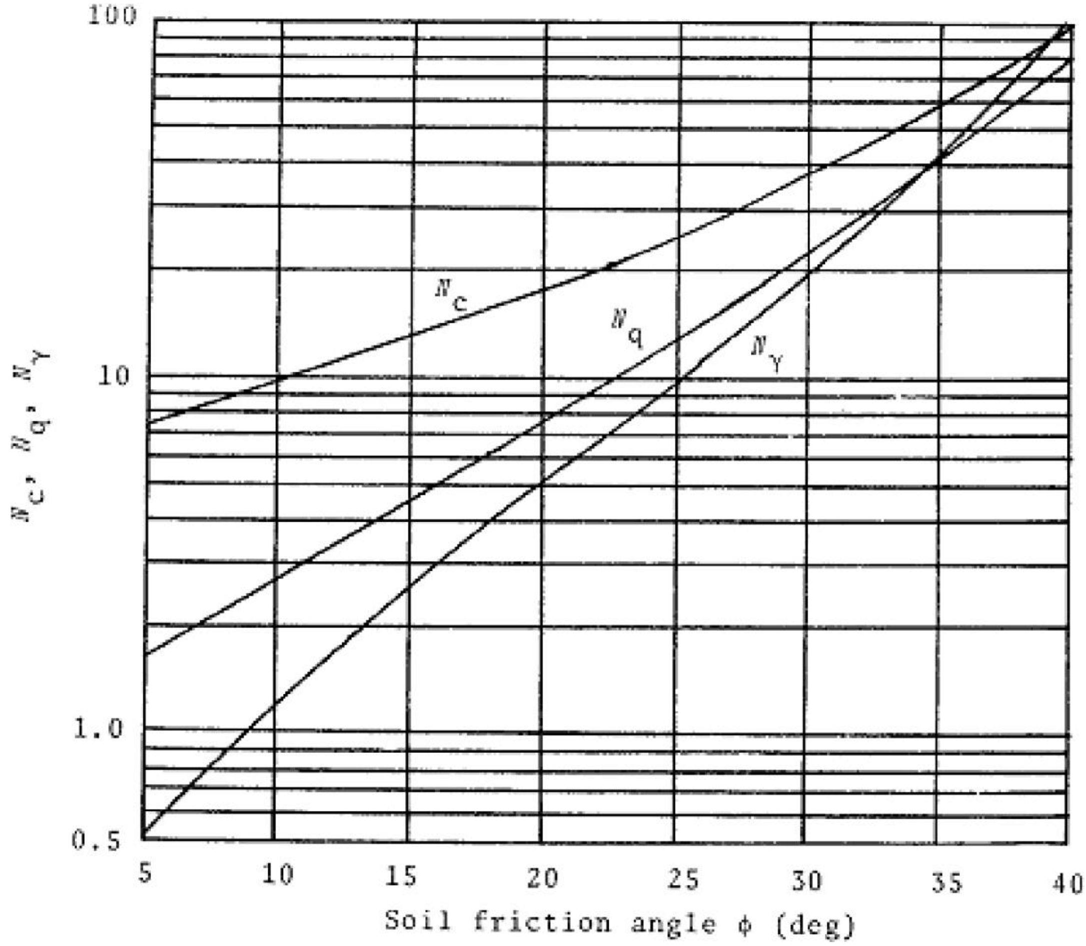


Figure 2-8 Terzaghi's Bearing Capacity factors (Nc, Nq, Ny)

Bearing-capacity factors for the Terzaghi equations

ϕ, deg	N_c	N_q	N_γ
0	5.7*	1.0	0.0
5	7.3	1.6	0.5
10	9.6	2.7	1.2
15	12.9	4.4	2.5
20	17.7	7.4	5.0
25	25.1	12.7	9.7
30	37.2	22.5	19.7
34	52.6	36.5	36.0
35	57.8	41.4	42.4
40	95.7	81.3	100.4
45	172.3	173.3	297.5
48	258.3	287.9	780.1
50	347.5	415.1	1153.2