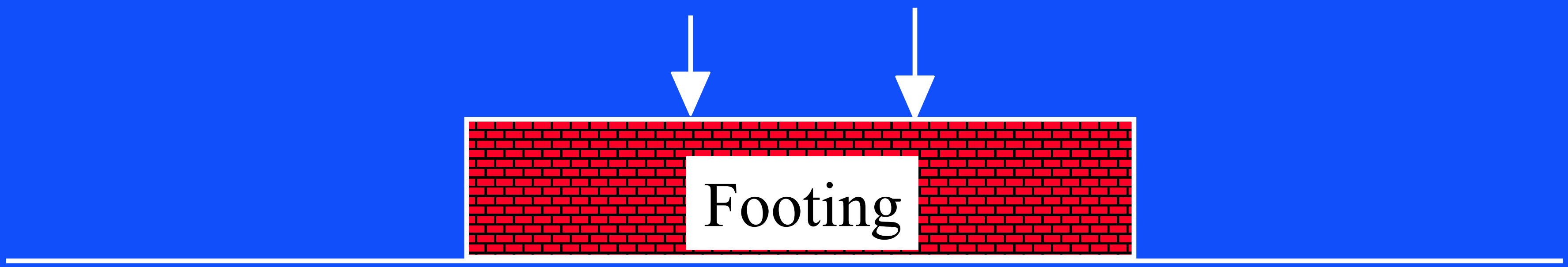
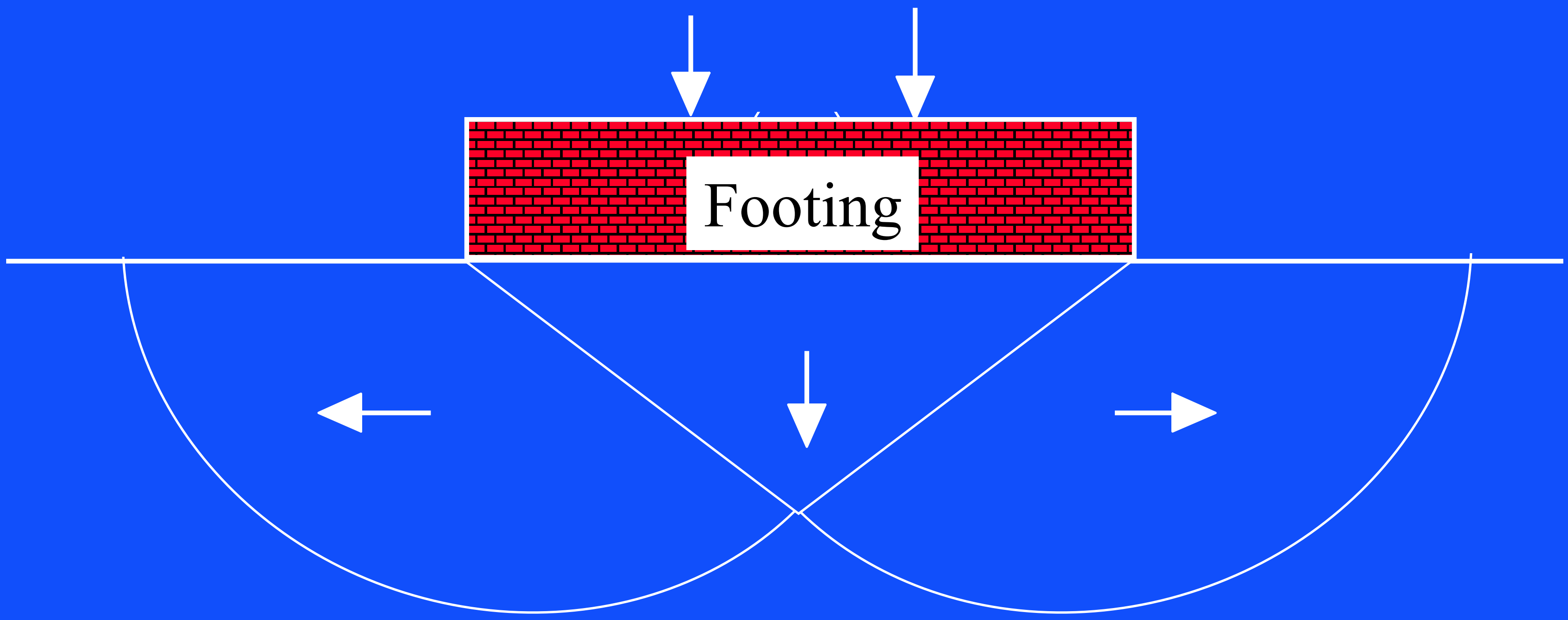
Bearing Capacity

Shallow Foundations

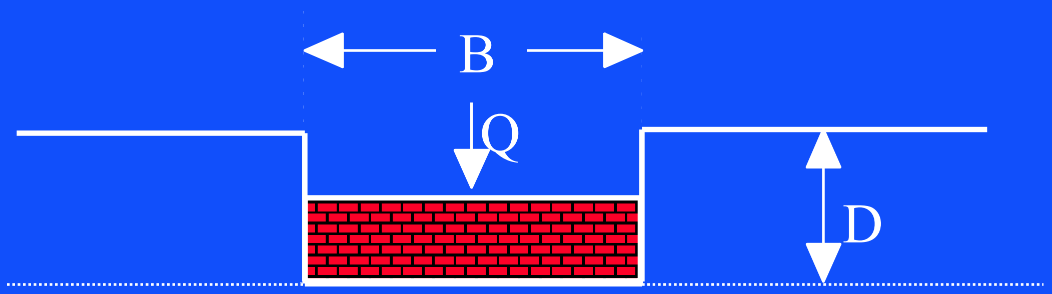


Shallow Foundations



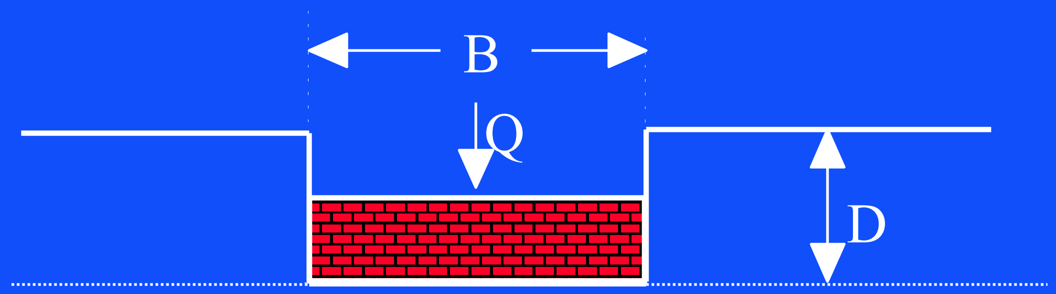
Shallow Foundations

Typical
Buried
Footing

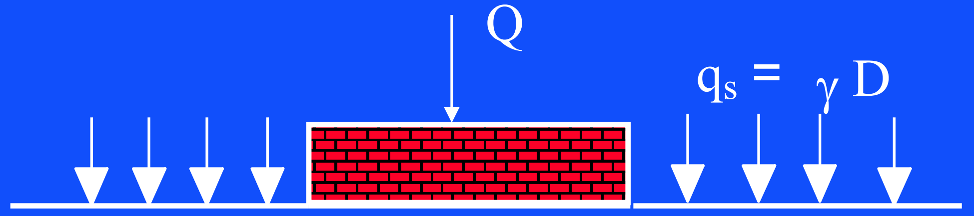


Shallow Foundations

Typical
Buried
Footing

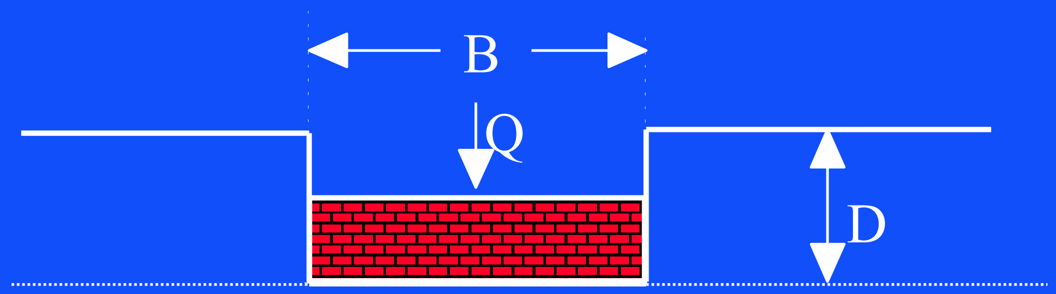


Equivalent
Surface
Footing



Shallow Foundations

Typical
Buried
Footing



Equivalent
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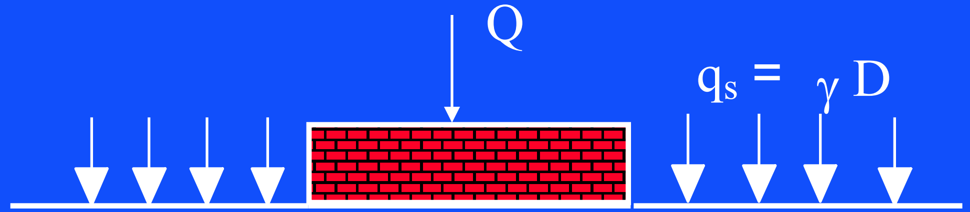
Footing



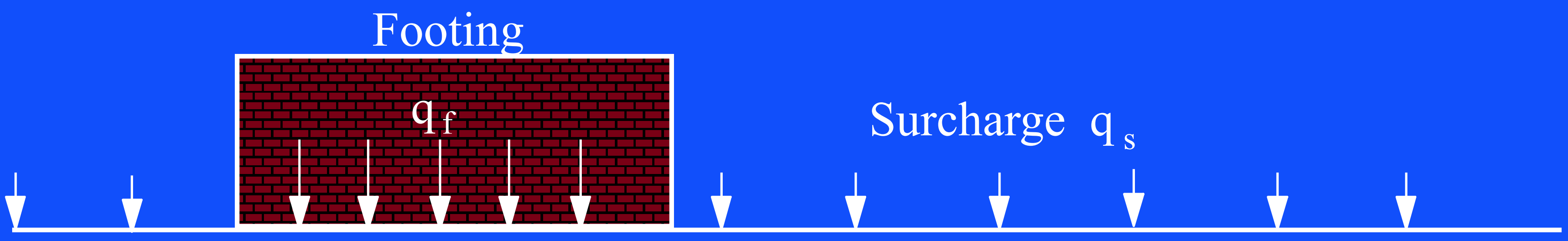
Shallow Foundations have D/B < 1

Shallow Foundations

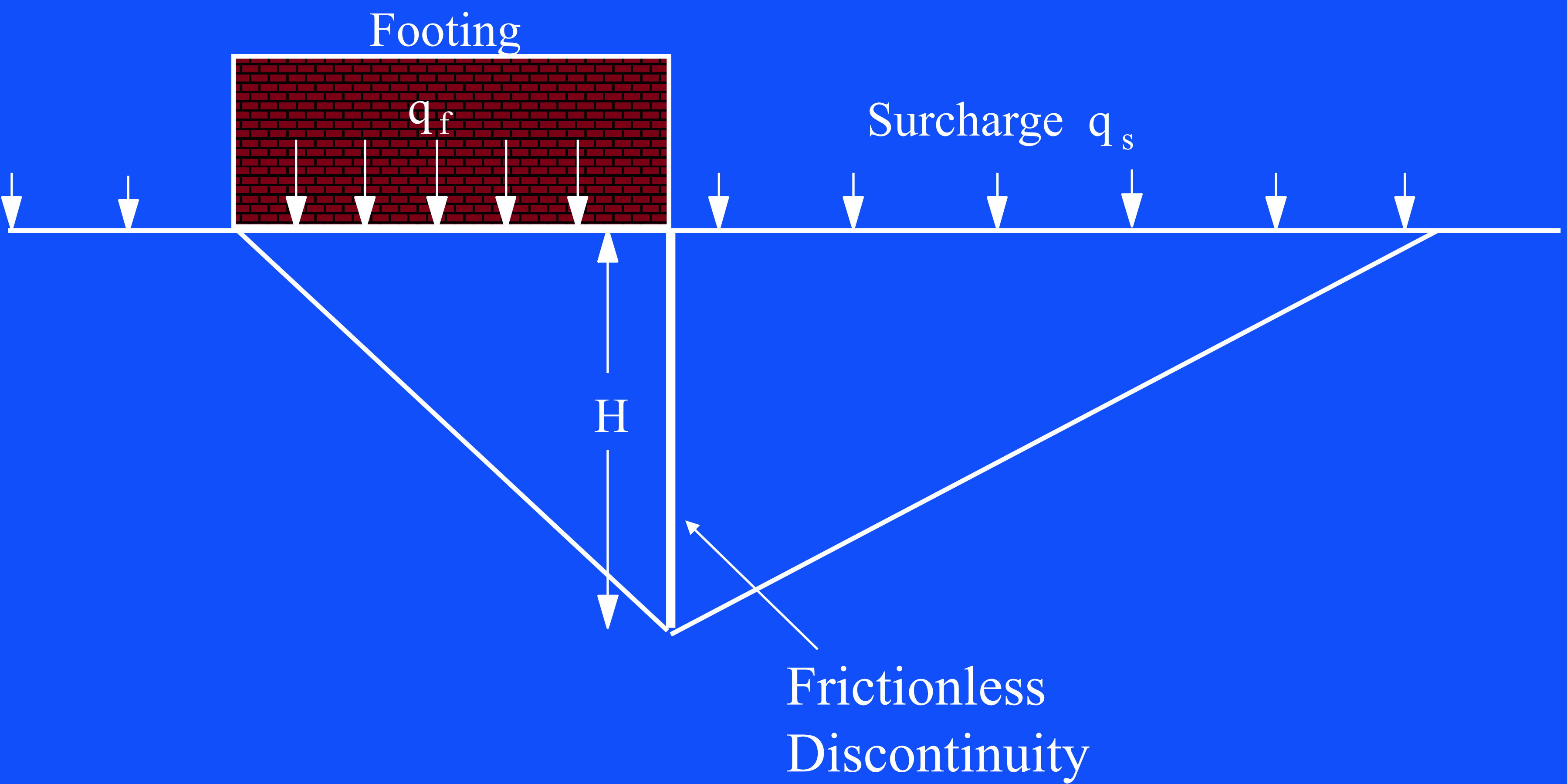
Methods of analysis

- Lower bound approach
  - failure stress state in equilibrium
  - failure load less than or equal to true collapse
- Upper bound approach
  - failure mechanism assumed
  - failure load greater than or equal to true collapse

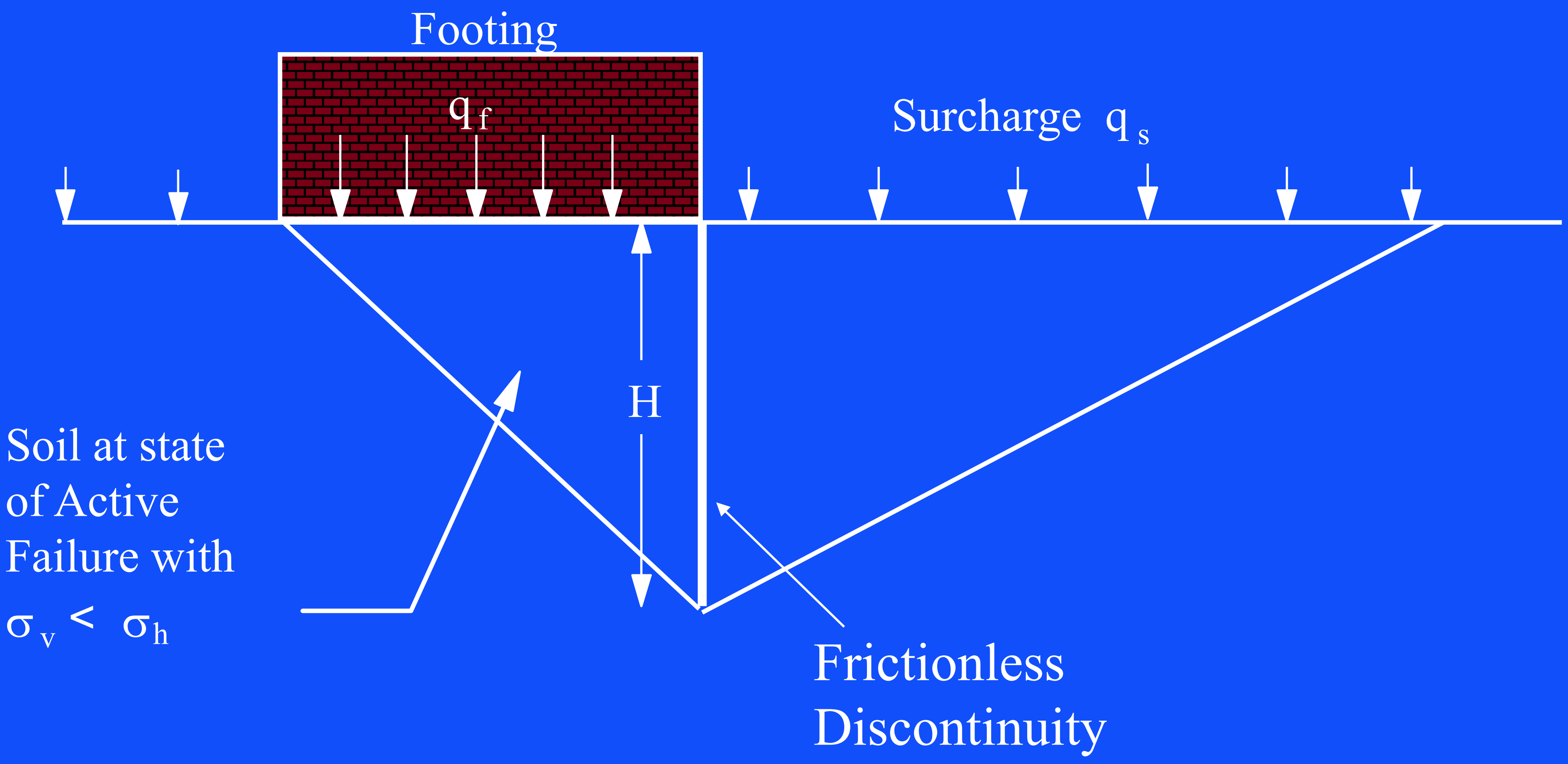
Shallow Foundations



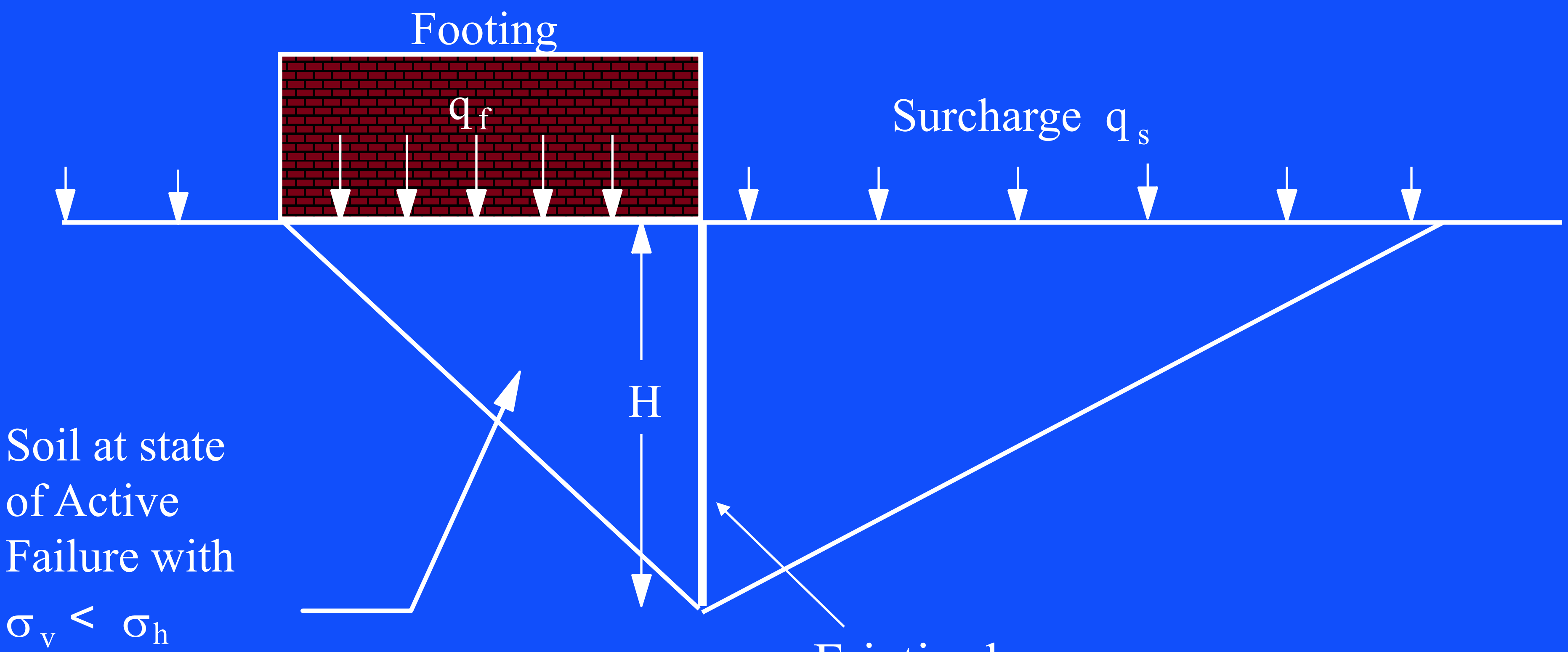
Shallow Foundations



Shallow Foundations

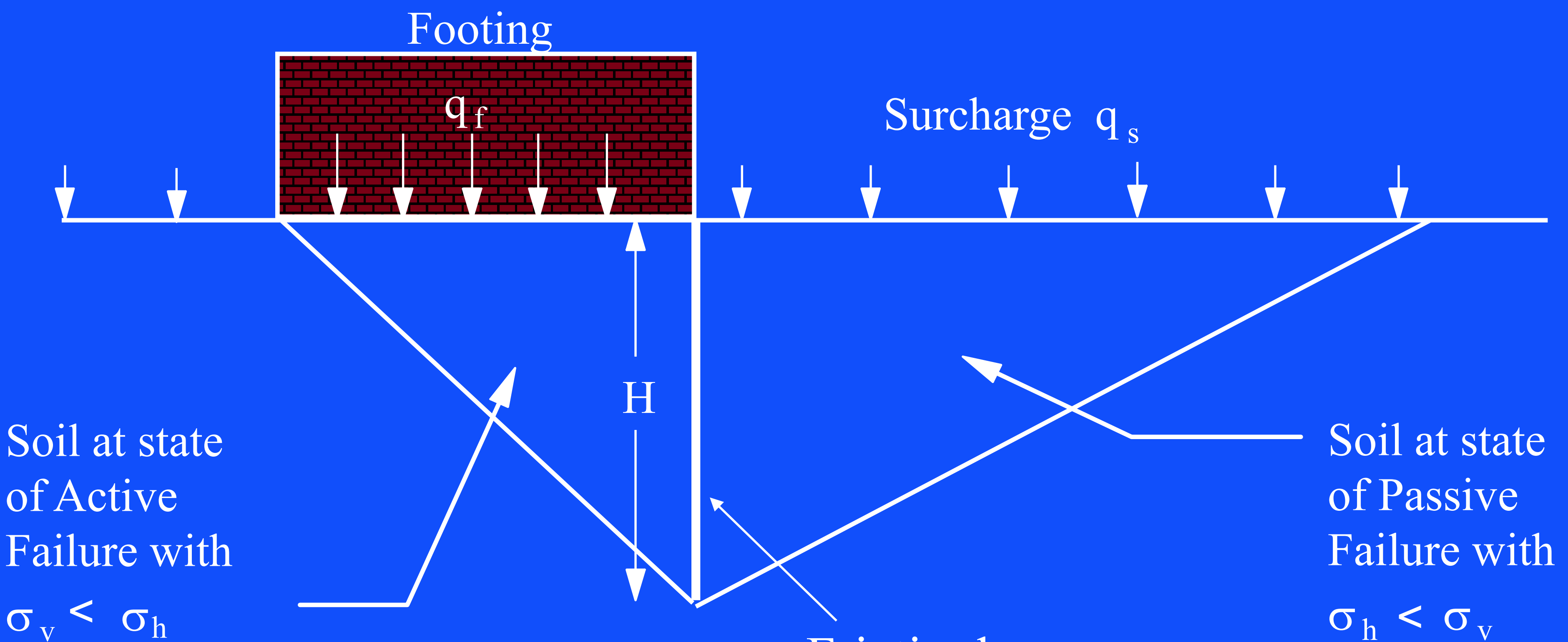


Shallow Foundations



$$\sigma_1 = N_\phi \sigma_3 + 2c\sqrt{N_\phi}$$

Shallow Foundations



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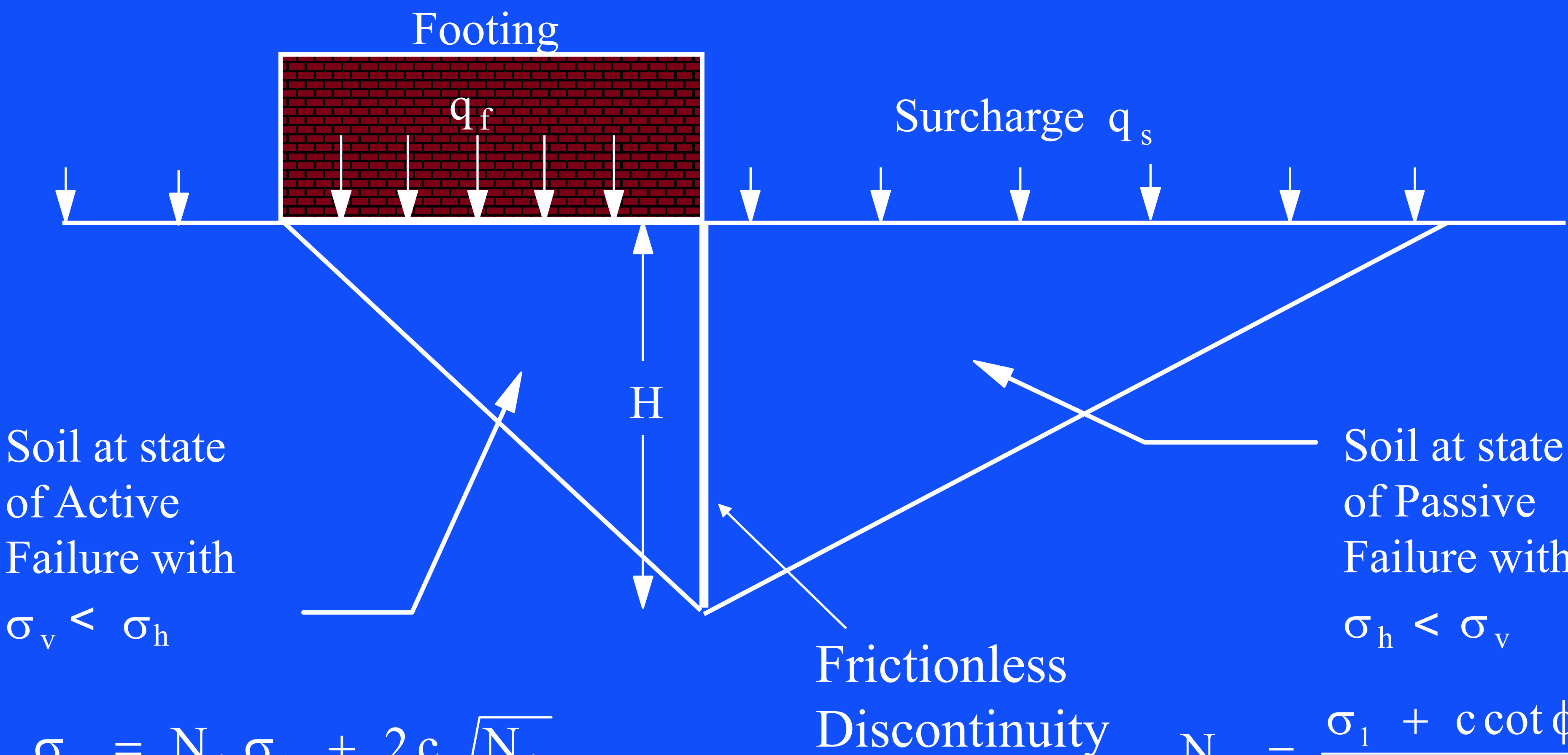
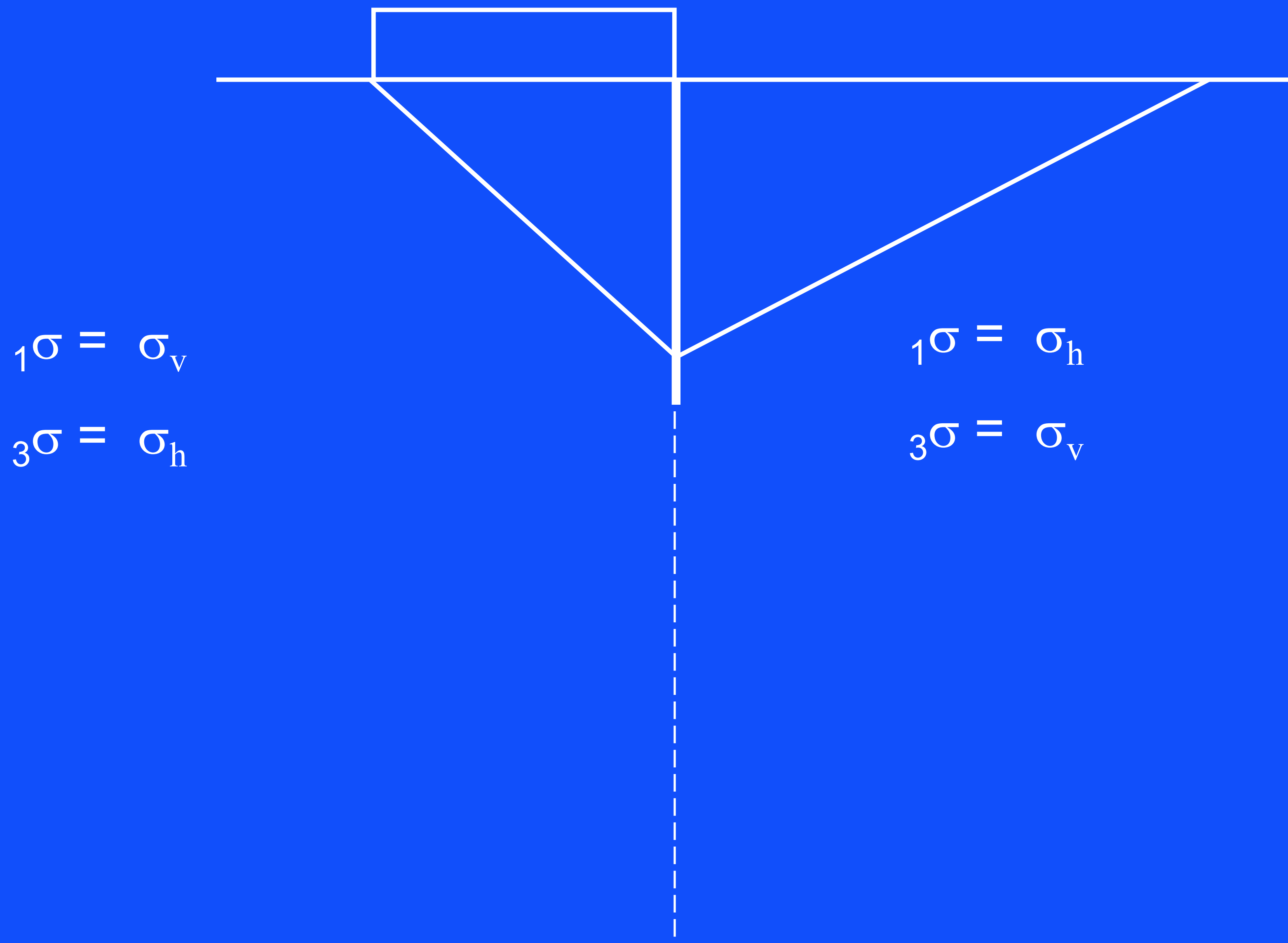
Shallow Foundations



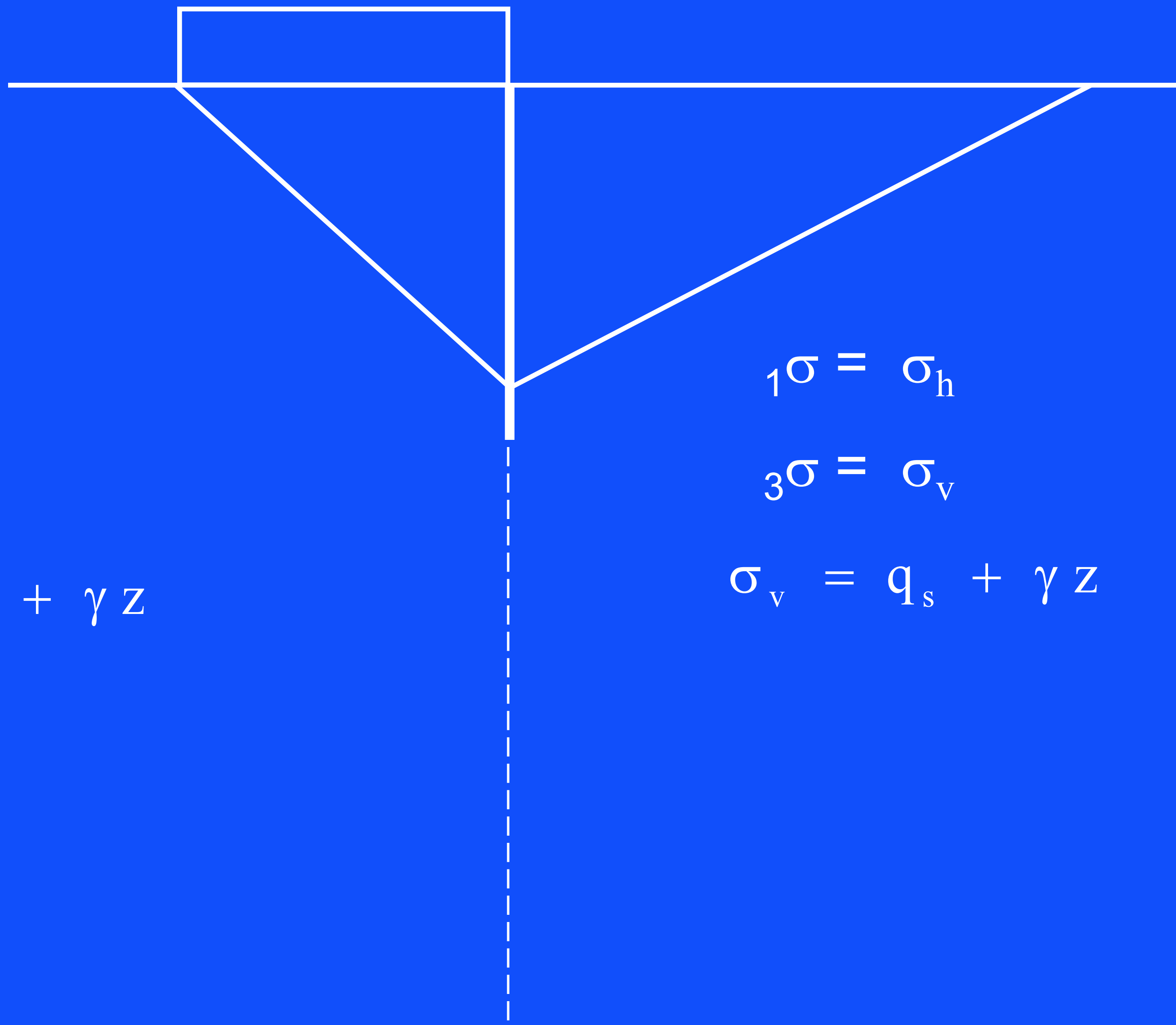
$$\sigma_1 = N_\phi \sigma_3 + 2c\sqrt{N_\phi}$$

$$N_\phi = \frac{\sigma_1 + c\cot\phi}{\sigma_3 + c\cot\phi}$$

Shallow Foundations



Shallow Foundations



$_1\sigma = \sigma_v$

$_3\sigma = \sigma_h$

$\sigma_v = q_f + \gamma z$

$_1\sigma = \sigma_h$

$_3\sigma = \sigma_v$

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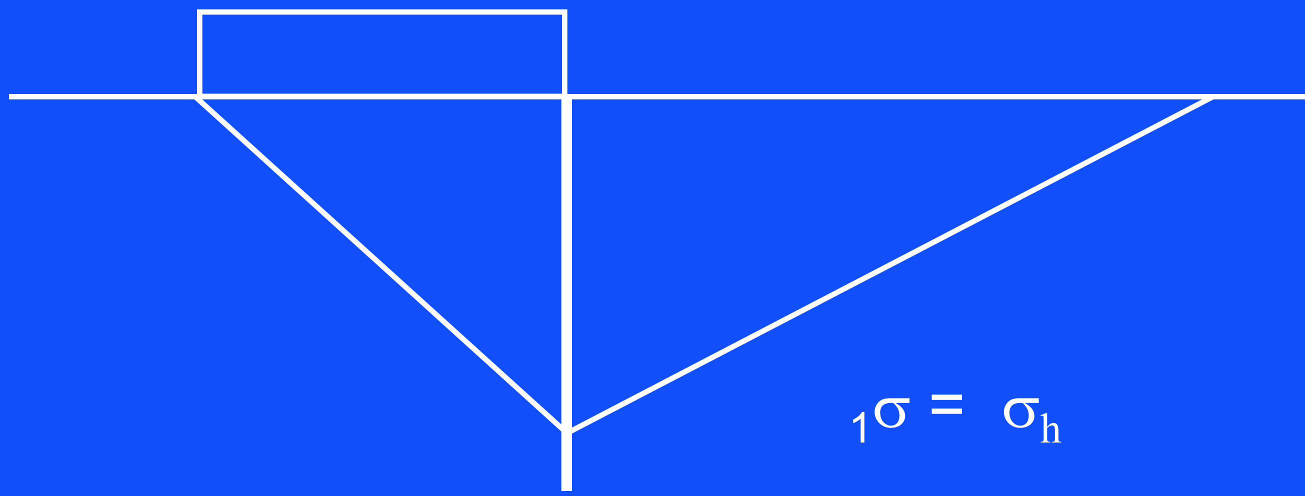
Shallow Foundations



$$\sigma_1 = \sigma_v$$

$$\sigma_3 = \sigma_h$$

$$\sigma_v = q_f + \gamma z$$

$$N_\phi = \frac{q_f + \gamma z + c\cot\phi}{\sigma_h + c\cot\phi}$$

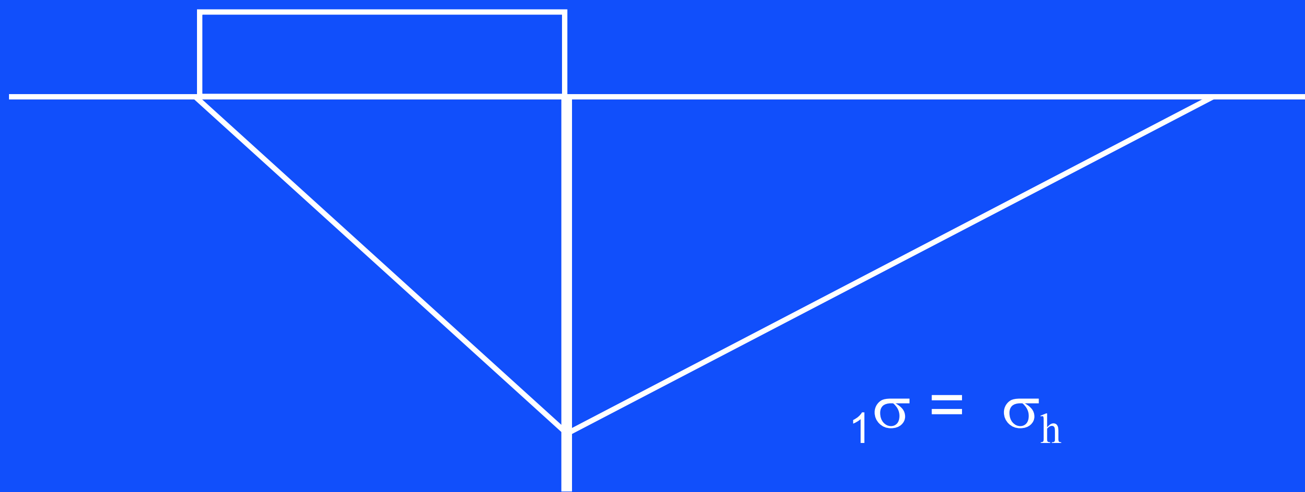
$$\sigma_1 = \sigma_h$$

$$\sigma_3 = \sigma_v$$

$$\sigma_v = q_s + \gamma z$$

$$N_\phi = \frac{\sigma_h + c\cot\phi}{q_s + \gamma z + c\cot\phi}$$

Shallow Foundations



$$\sigma_1 = \sigma_v$$

$$\sigma_3 = \sigma_h$$

$$\sigma_v = q_f + \gamma z$$

$$N_\phi = \frac{q_f + \gamma z + c\cot\phi}{\sigma_h + c\cot\phi}$$

$$\sigma_h = \frac{1}{N_\phi}(q_f + \gamma z + c\cot\phi) - c\cot\phi$$

$$\sigma_1 = \sigma_h$$

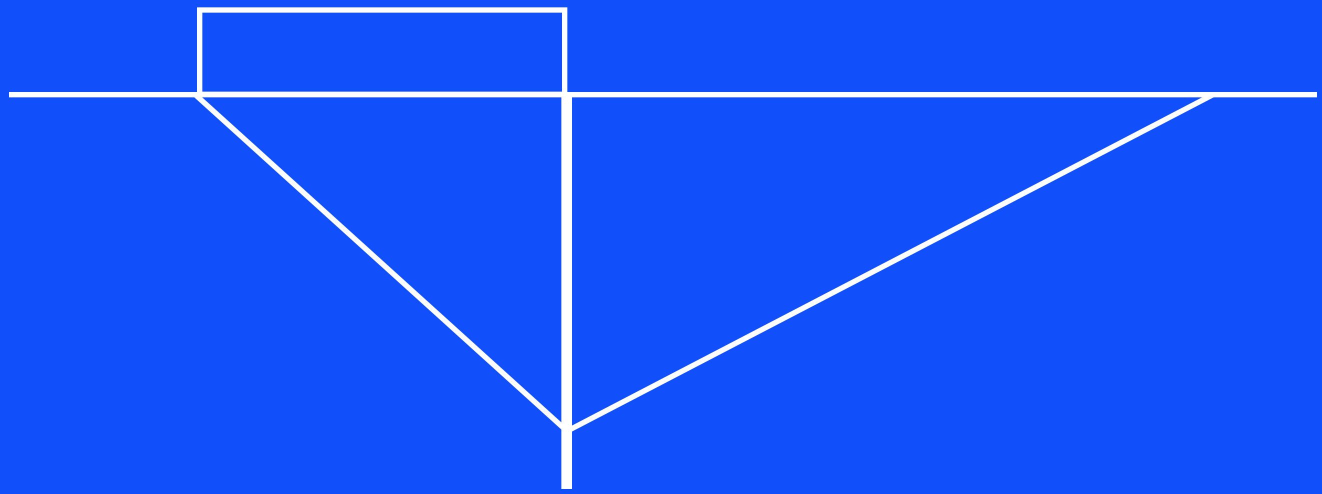
$$\sigma_3 = \sigma_v$$

$$\sigma_v = q_s + \gamma z$$

$$N_\phi = \frac{\sigma_h + c\cot\phi}{q_s + \gamma z + c\cot\phi}$$

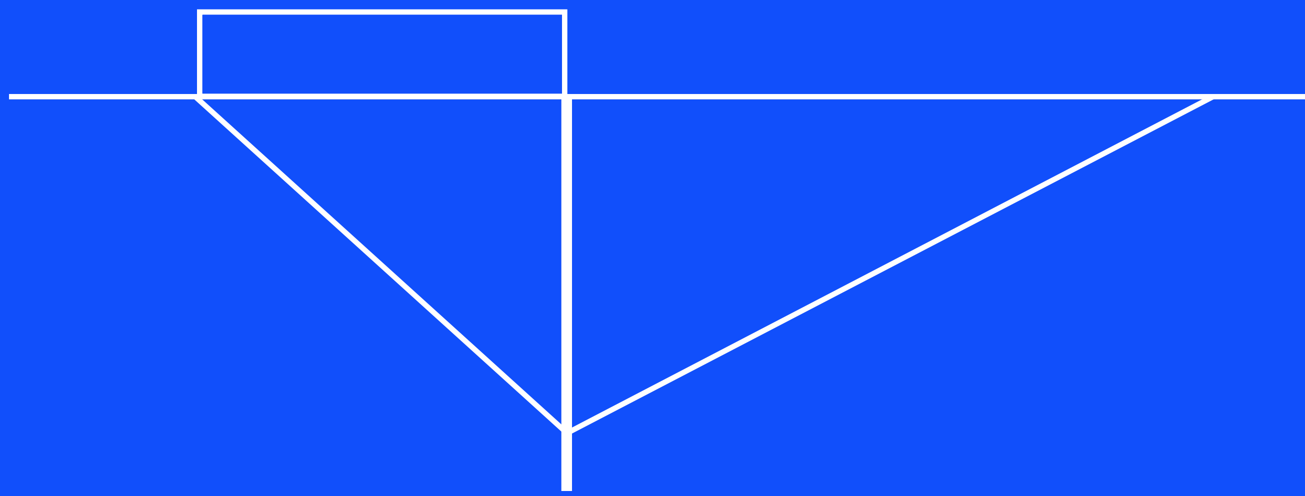
$$\sigma_h = N_\phi (q_s + \gamma z + c\cot\phi) - c\cot\phi$$

Shallow Foundations



$$\int_0^H (\sigma_h)_{active}\, dz = \int_0^H (\sigma_h)_{passive}\, dz$$

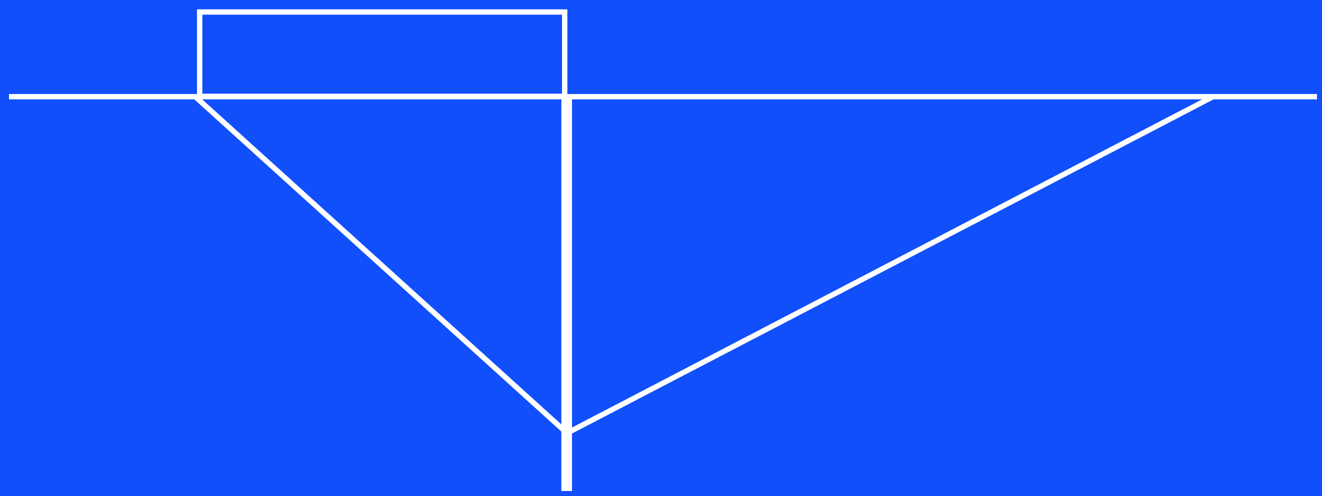
Shallow Foundations



$$\int_0^H (\sigma_h)_{active}\, dz = \int_0^H (\sigma_h)_{passive}\, dz$$

$$\frac{1}{N_\phi}\left[q_f H + \frac{\gamma H^2}{2} + c \cot\phi H\right] = N_\phi\left[q_s H + \frac{\gamma H^2}{2} + c \cot\phi H\right]$$

Shallow Foundations



$$\int_0^H (\sigma_h)_{active}\, dz = \int_0^H (\sigma_h)_{passive}\, dz$$

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$$q_f = q_s N_\phi^2 + \frac{\gamma H}{2}\left(N_\phi^2 - 1\right) + c \cot\phi\left(N_\phi^2 - 1\right)$$

Shallow Foundations

$$q_f = q_s N_\phi^2 + \frac{\gamma H}{2}\left(N_\phi^2 - 1\right) + c \cot\phi \left(N_\phi^2 - 1\right)$$

- This solution will give a lower bound to the true solution because of the simplified stress distribution assumed in the soil
- Similar terms occur in all bearing capacity expressions. They are functions of the friction angle and
- the surcharge applied to the soil surface
- the self weight of the soil
- cohesion

Shallow Foundations

- A general bearing capacity equation can be written

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

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- The terms N_q, N_γ and N_c are known as the bearing capacity factors

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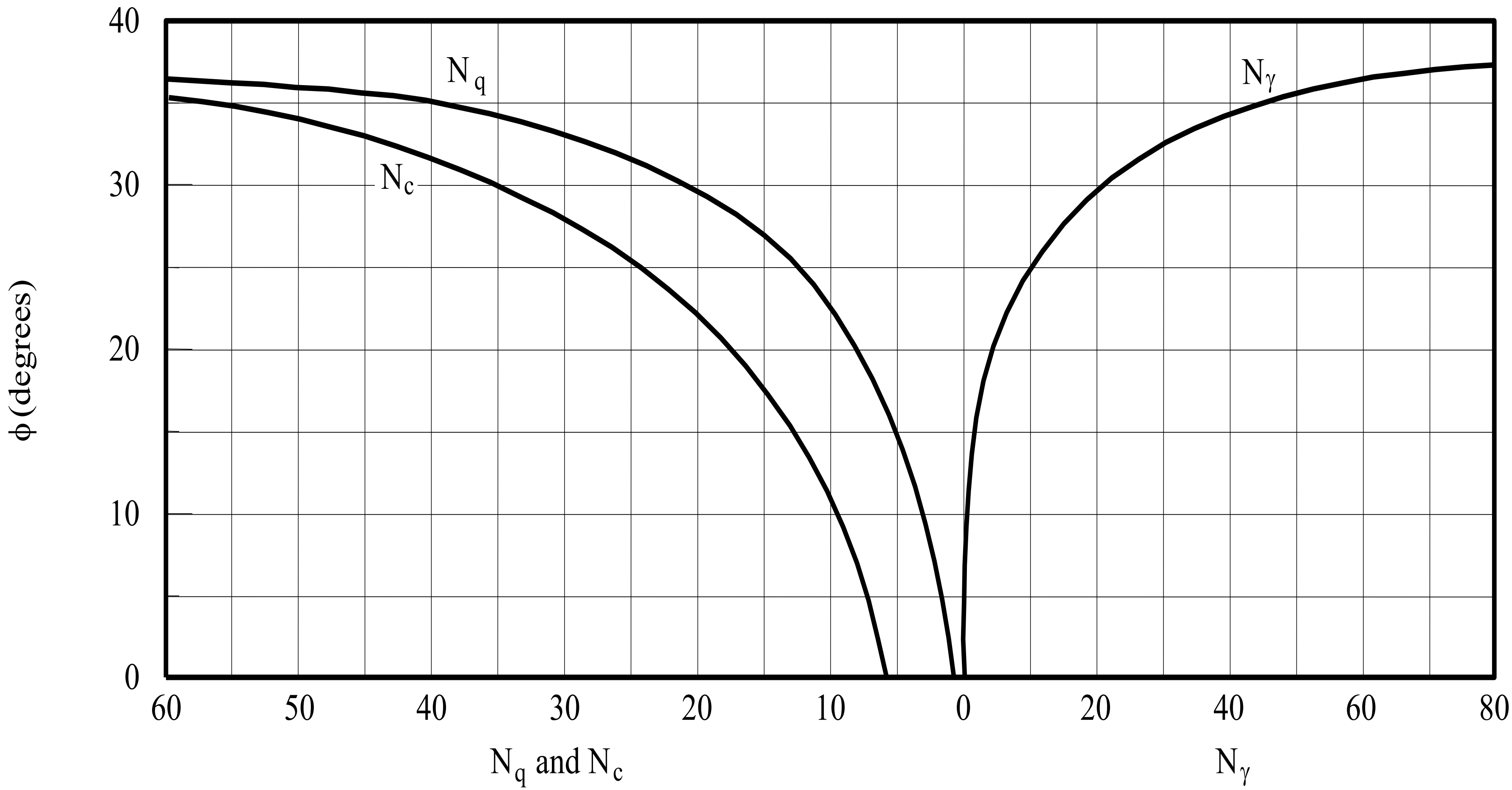
- The terms N_q, N_γ and N_c are known as the bearing capacity factors

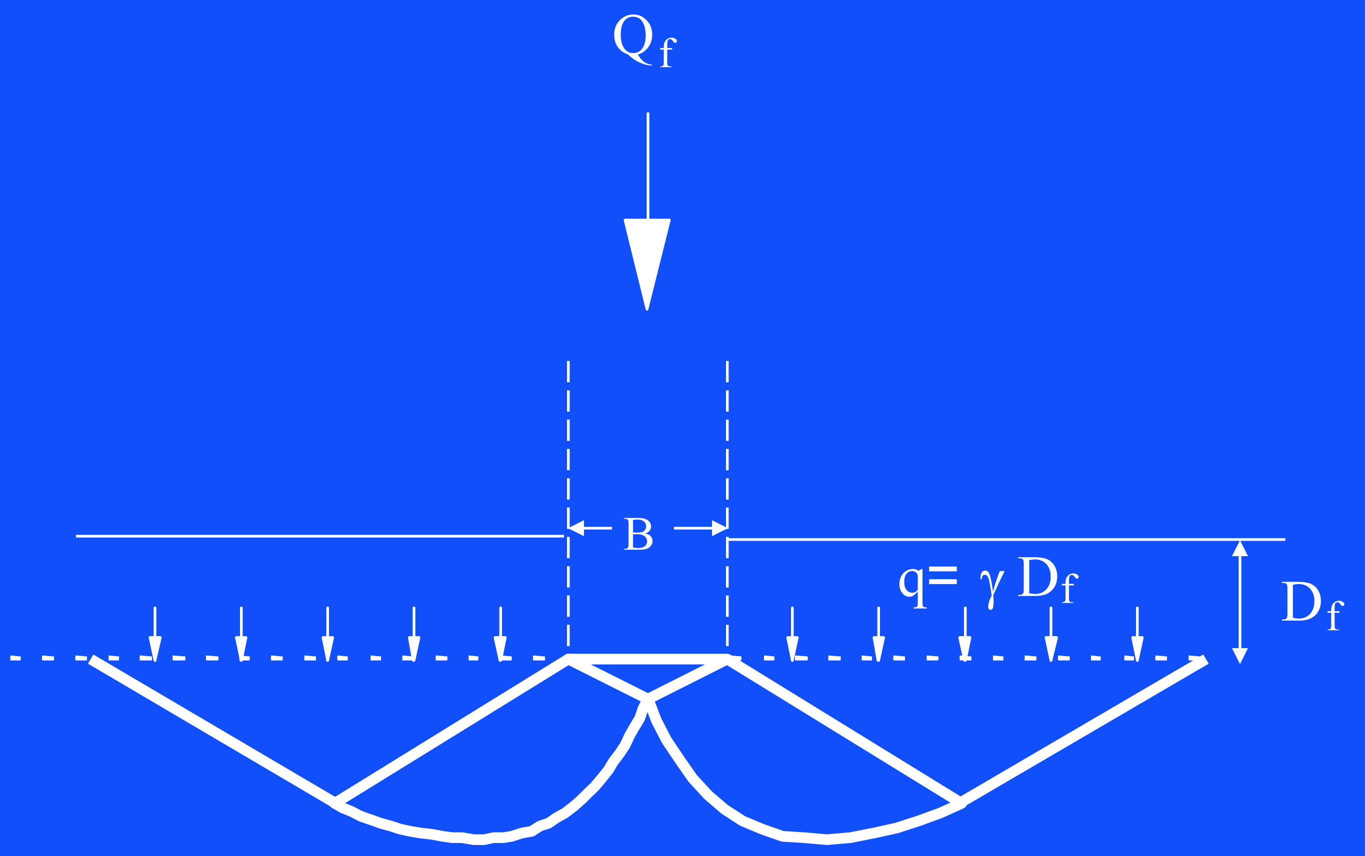
- Values can be determined from charts

Shallow Foundations



BEARING CAPACITY FACTORS [After Terzaghi and Peck (1948)]

Shallow Foundations



Mechanism analysed by Terzaghi

Effect of Foundation Shape

Continuous strip footing

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

Effect of Foundation Shape

Continuous strip footing

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

Square footing

$$q_f = q_s N_q + 0.4 \gamma B N_\gamma + 1.3 c N_c$$

Effect of Foundation Shape

Continuous strip footing

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

Square footing

$$q_f = q_s N_q + 0.4 \gamma B N_\gamma + 1.3 c N_c$$

Circular footing

$$q_f = q_s N_q + 0.6 \gamma B N_\gamma + 1.3 c N_c$$

Effective Stress Analysis

- Effective stress analysis is needed to assess the long term foundation capacity.

- Total and effective stresses are identical if the soil is dry. The analysis is identical to that described above except that γ_{dry} rather ,´the parameters used in the equations are c´, ϕ .γ_{sat} ,ϕ_u ,than c_u

- If the water table is more than a depth of 1.5 B (the footing width) below the base of the footing the water can be assumed to have no effect.

Effective Stress Analysis

- If the soil below the base of the footing is saturated, the analysis must account for the water pressures.

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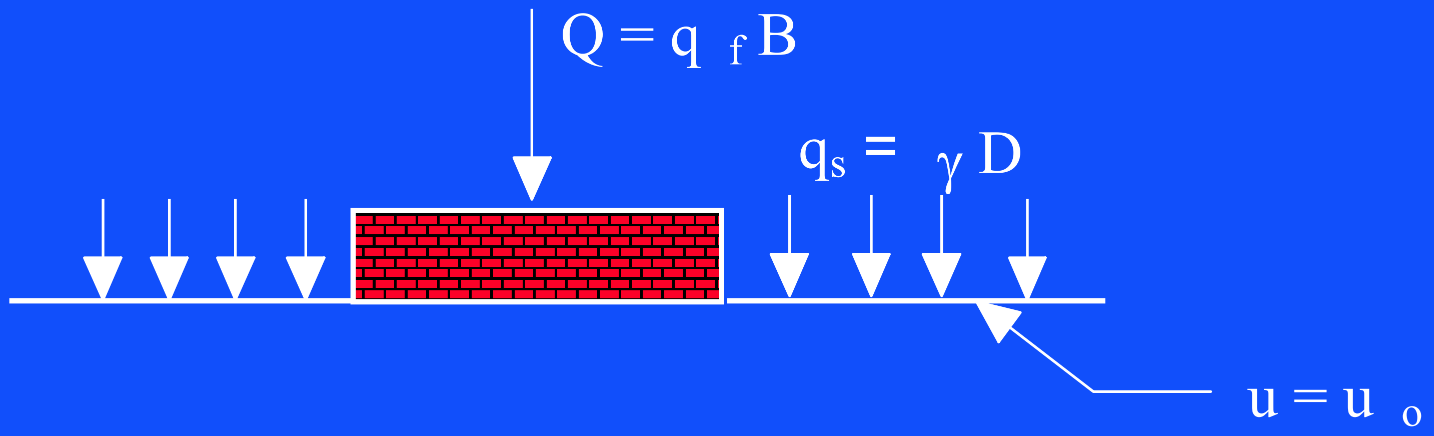

Effective Stress Analysis

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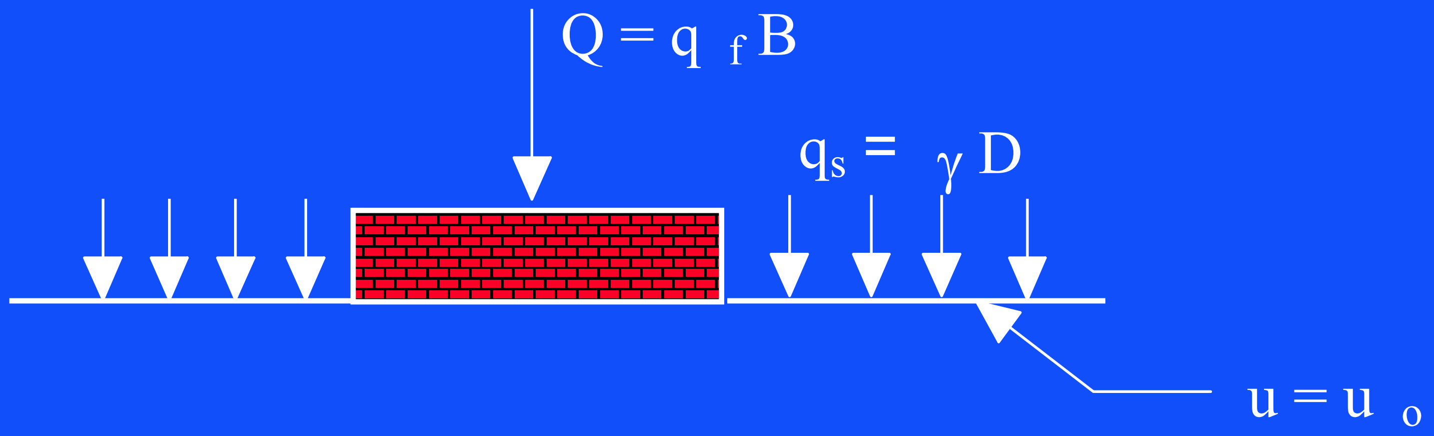

The effective bearing capacity $q'_f = q_f - u_o$

Effective Stress Analysis

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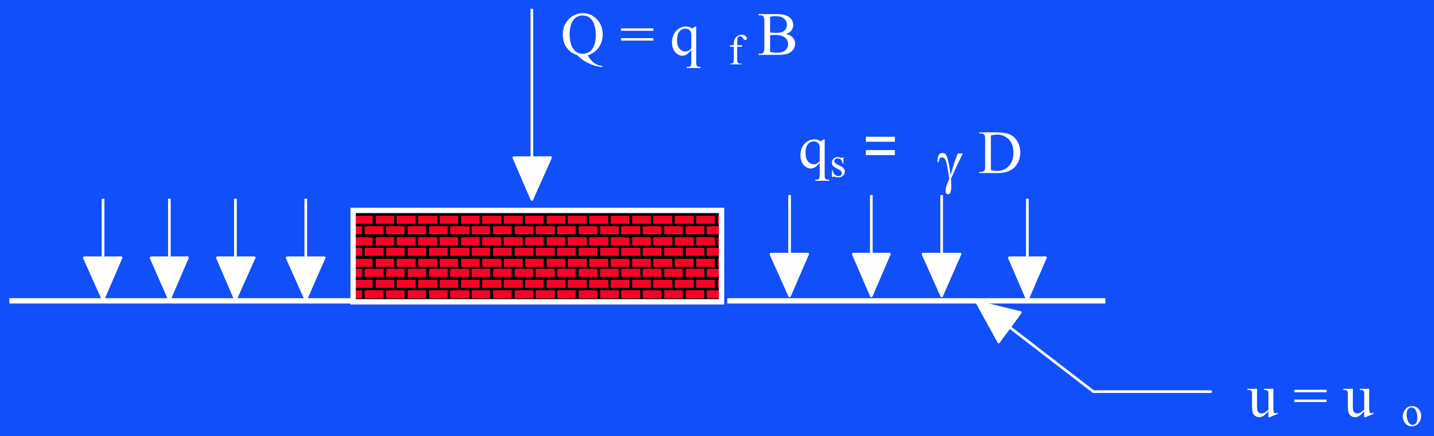
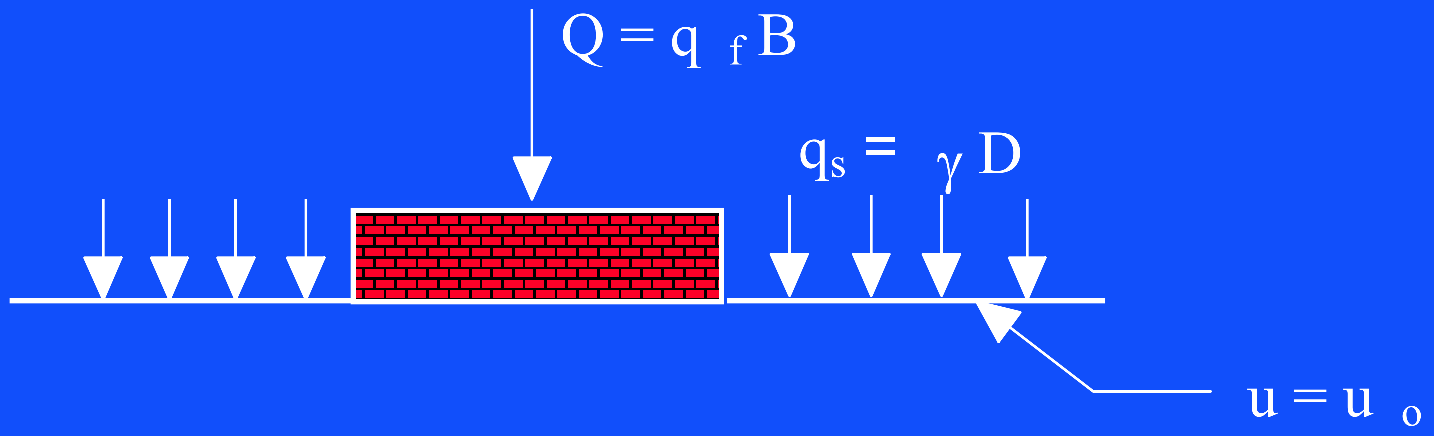


The effective bearing capacity $q'_f = q_f - u_o$

The effective surcharge $q'_s = q_s - u_o$

Effective Stress Analysis

- If the soil below the base of the footing is saturated, the analysis must account for the water pressures.



The effective bearing capacity $q'_f = q_f - u_o$

The effective surcharge $q'_s = q_s - u_o$

The effective (submerged) unit weight $\gamma' = \gamma_{sat} - \gamma_w$

Effective Stress Analysis

These effective quantities are required because Mohr Coulomb failure criterion must be expressed in terms of effective stress

$$N_{\phi} = \frac{\sigma_1' + c' \cot \phi'}{\sigma_3' + c' \cot \phi'}$$

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The total vertical stress, pore pressure and effective vertical stress at any depth z beneath the footing are

$$\sigma_v = q_f + \gamma z$$

Effective Stress Analysis

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The total vertical stress, pore pressure and effective vertical stress at any depth z beneath the footing are

$$\sigma_v = q_f + \gamma z$$

$$u = u_o + \gamma_w z$$

Effective Stress Analysis

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$$N_\phi = \frac{\sigma_1' + c' \cot \phi'}{\sigma_3' + c' \cot \phi'}$$

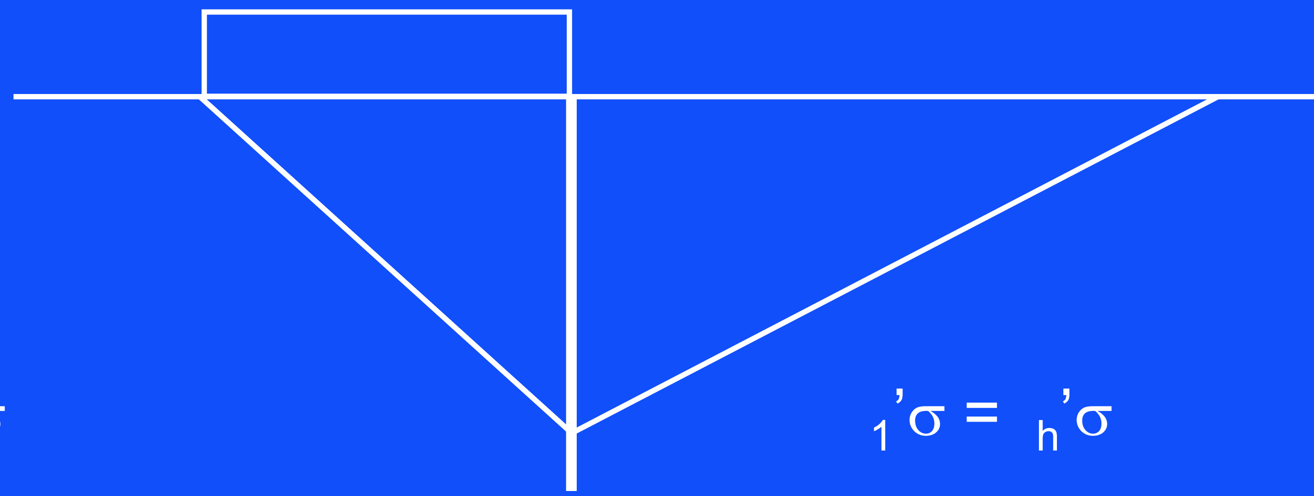
The total vertical stress, pore pressure and effective vertical stress at any depth z beneath the footing are

$$\sigma_v = q_f + \gamma z$$

$$u = u_o + \gamma_w z$$

$$\sigma_v' = \sigma_v - u = q_f' + \gamma' z$$

Effective Stress Analysis



$$\sigma'_1 = \sigma'_v$$

$$\sigma'_3 = \sigma'_h$$

$$\sigma'_v = q'_f + \gamma' z$$

$$N_\phi = \frac{q'_f + \gamma' z + c' \cot \phi'}{\sigma'_h + c' \cot \phi'}$$

$$\sigma'_h = \frac{1}{N_\phi}(q'_f + \gamma' z + c' \cot \phi') - c' \cot \phi'$$

$$\sigma'_1 = \sigma'_h$$

$$\sigma'_3 = \sigma'_v$$

$$\sigma'_v = q'_s + \gamma' z$$

$$N_\phi = \frac{\sigma'_h + c' \cot \phi'}{q'_s + \gamma' z + c' \cot \phi'}$$

$$\sigma'_h = N_\phi (q'_s + \gamma' z + c' \cot \phi') - c' \cot \phi'$$

Effective Stress Analysis

The simple analysis leads to

$$q'_f = q'_s N_\phi^2 + \frac{\gamma' H}{2}\left(N_\phi^2 - 1\right) + c' \cot\phi' \left(N_\phi^2 - 1\right)$$

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This is similar to the previous expression except that now all terms involve effective quantities.

As before a general expression can be written with the form

$$q'_f = q'_s N_q + \frac{\gamma' B}{2} N_\gamma + c' N_c$$

Effective Stress Analysis

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$$q'_f = q'_s N_\phi^2 + \frac{\gamma' H}{2}\left(N_\phi^2 - 1\right) + c' \cot\phi' \left(N_\phi^2 - 1\right)$$

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The Bearing Capacity Factors are identical to those from Total Stress Analysis

Effective Stress Analysis

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$$q'_f = q'_s N_\phi^2 + \frac{\gamma' H}{2}\left(N_\phi^2 - 1\right) + c' \cot\phi' \left(N_\phi^2 - 1\right)$$

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The Bearing Capacity Factors are identical to those from Total Stress Analysis

$_f + u_o$'Note that the Total Bearing Capacity $q_f = q$

Effective Stress Analysis

Analysis has so far considered

- soil strength parameters
- rate of loading (drained or undrained)
- groundwater conditions (dry or saturated)
- foundation shape (strip footing, square or circle)

Other important factors include

- soil compressibility
- embedment (D/B > 1)
- inclined loading
- eccentric loading
- non-homogeneous soil

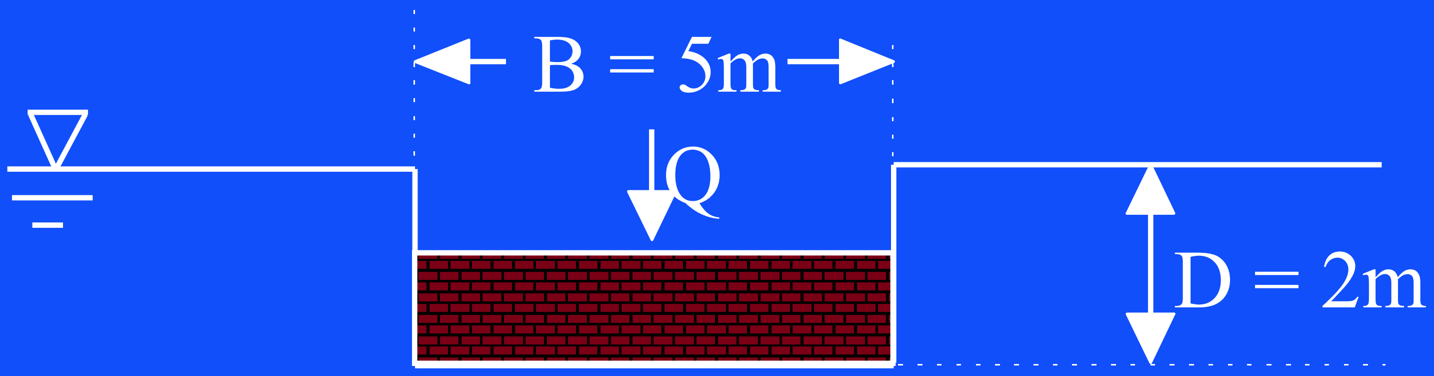
Effective Stress Analysis

- More theoretically accurate bearing capacity factors are given on pages 69 to 71 of the Data Sheets
- In practice the Terzaghi factors are still widely used.
- The bearing capacity equation assumes that the effects of c', γ, and ϕ' can be superimposed.
- This is not correct as there is an interaction between the three effects because of the plastic nature of the soil response.

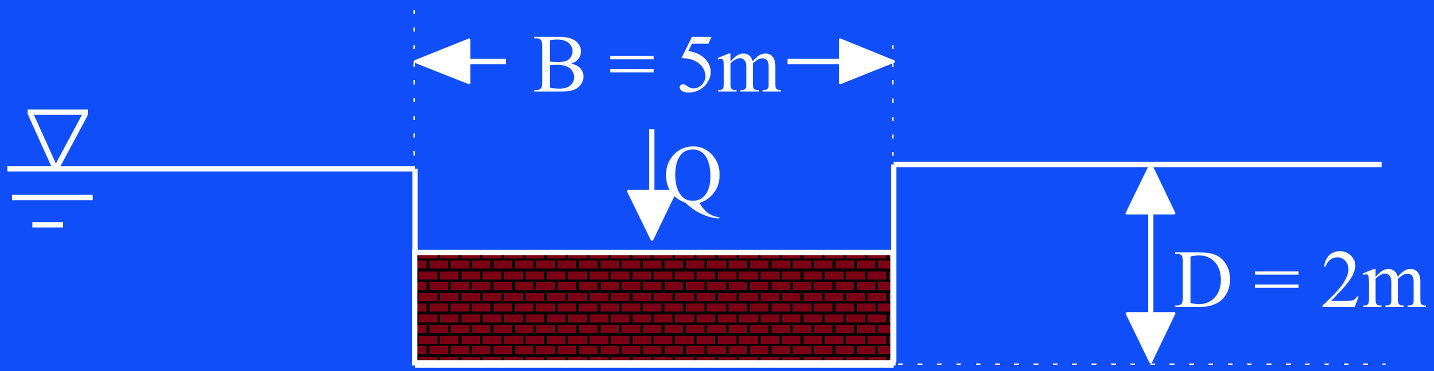
Effective Stress Analysis

- The formulae give the ultimate bearing capacity
- Significant deformations and large settlements may occur before general bearing failure occurs
- Local failure (yield) will occur at some depth beneath the footing at a load less than the ultimate collapse load
- The zone of plastic (yielding) soil will then spread as the load is increased. Only when the failure zone extends to the surface will a failure mechanism exist.
- A minimum load factor of 3 against ultimate failure is usually adopted to keep settlements within acceptable bounds, and to avoid problems with local failure.

Example



Example

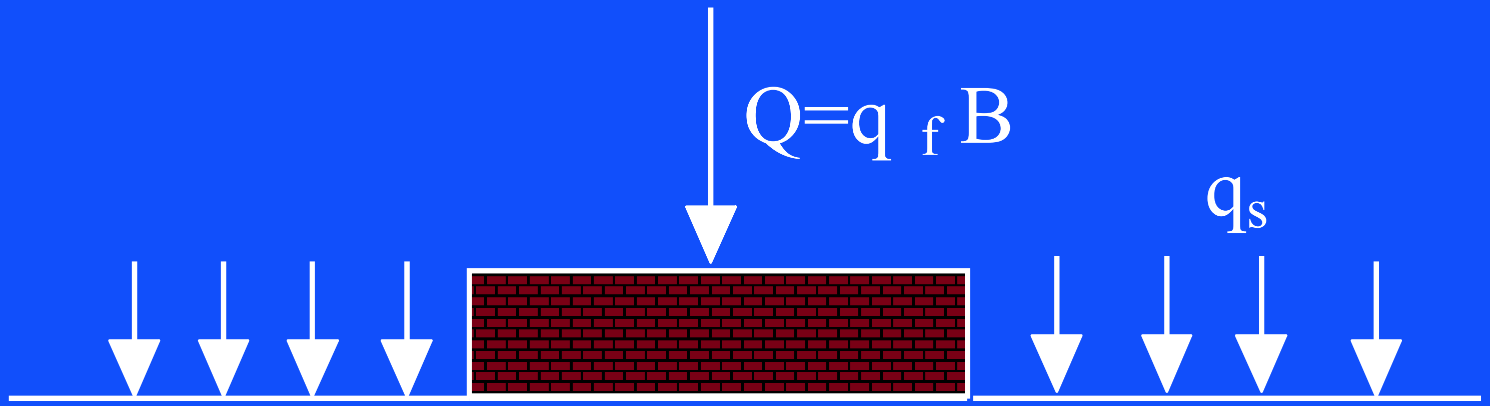


Determine short term and long term ultimate capacity given

$c_u = 25\ kN/m^2$, $\phi_u = 0$, $c' = 2\ kN/m^2$,
$\phi' = 25^o$, and $\gamma_{sat} = 15\ kN/m^2$.

Example

Equivalent surface footing



Example

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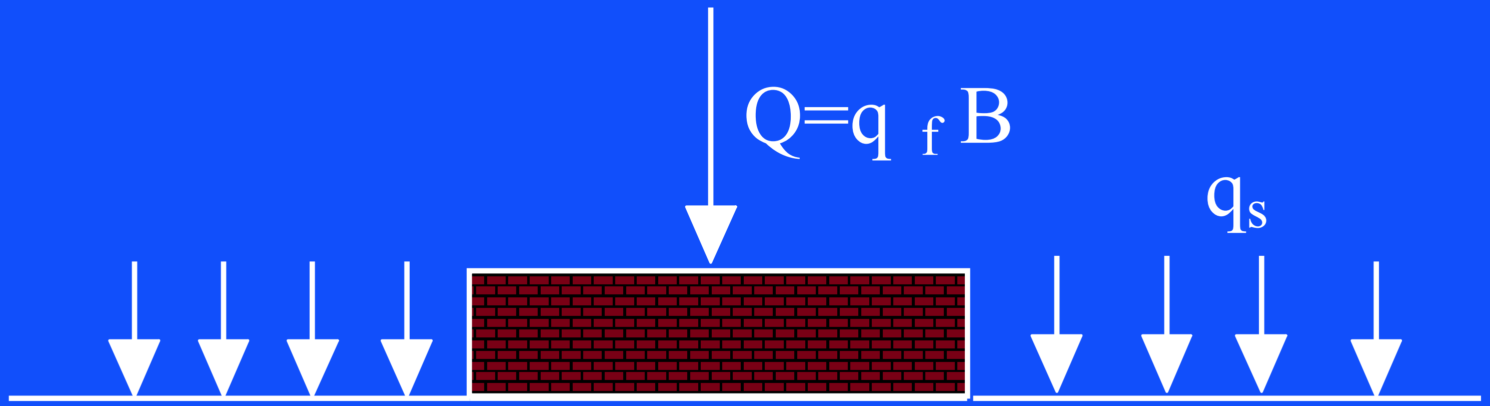
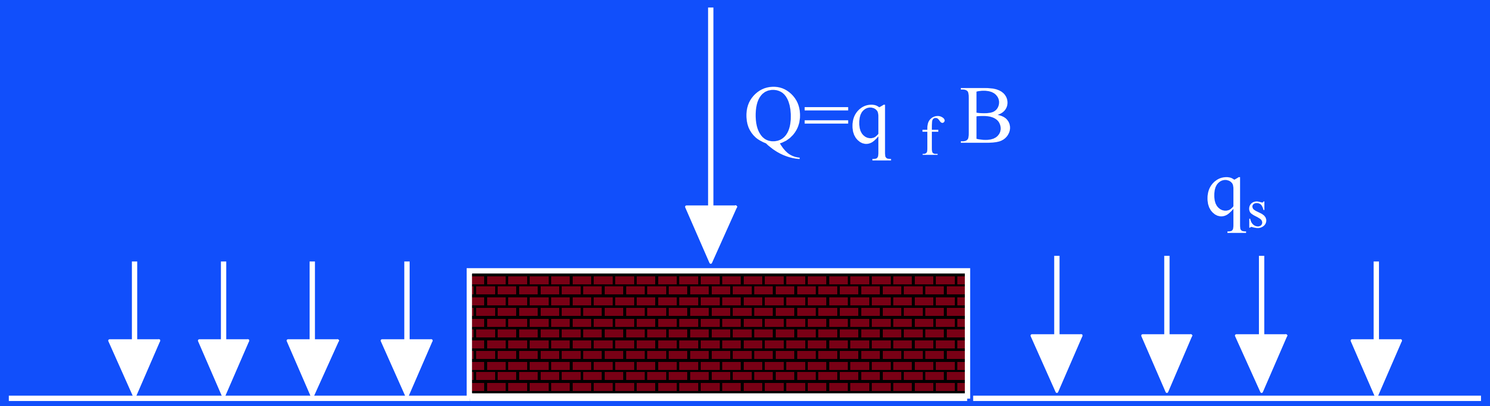


Short term - Undrained (total stress) analysis

Example

Equivalent surface footing

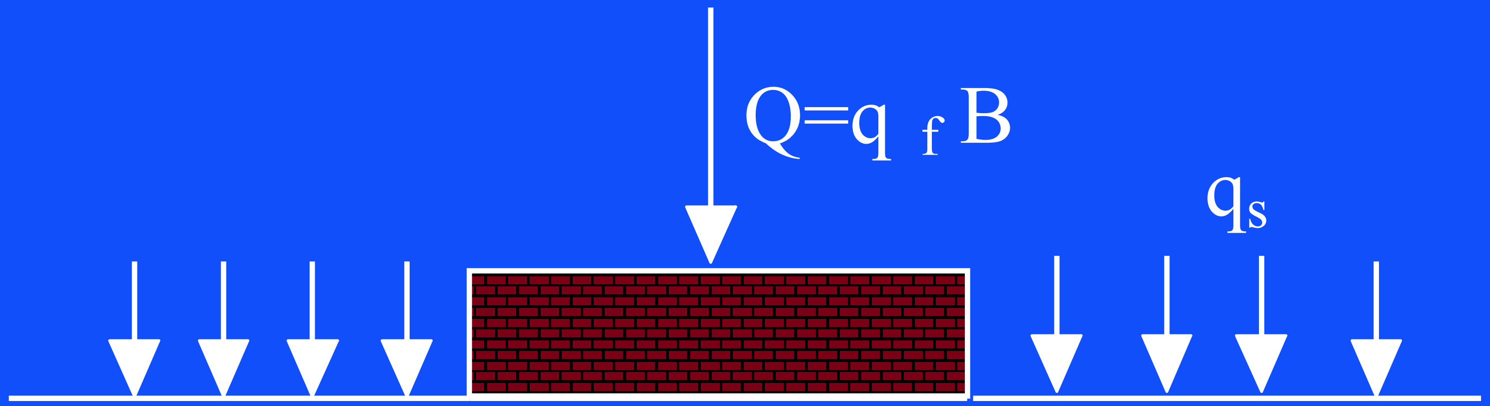


Short term - Undrained (total stress) analysis

Position of water table not important - soil must be saturated

Example

Equivalent surface footing

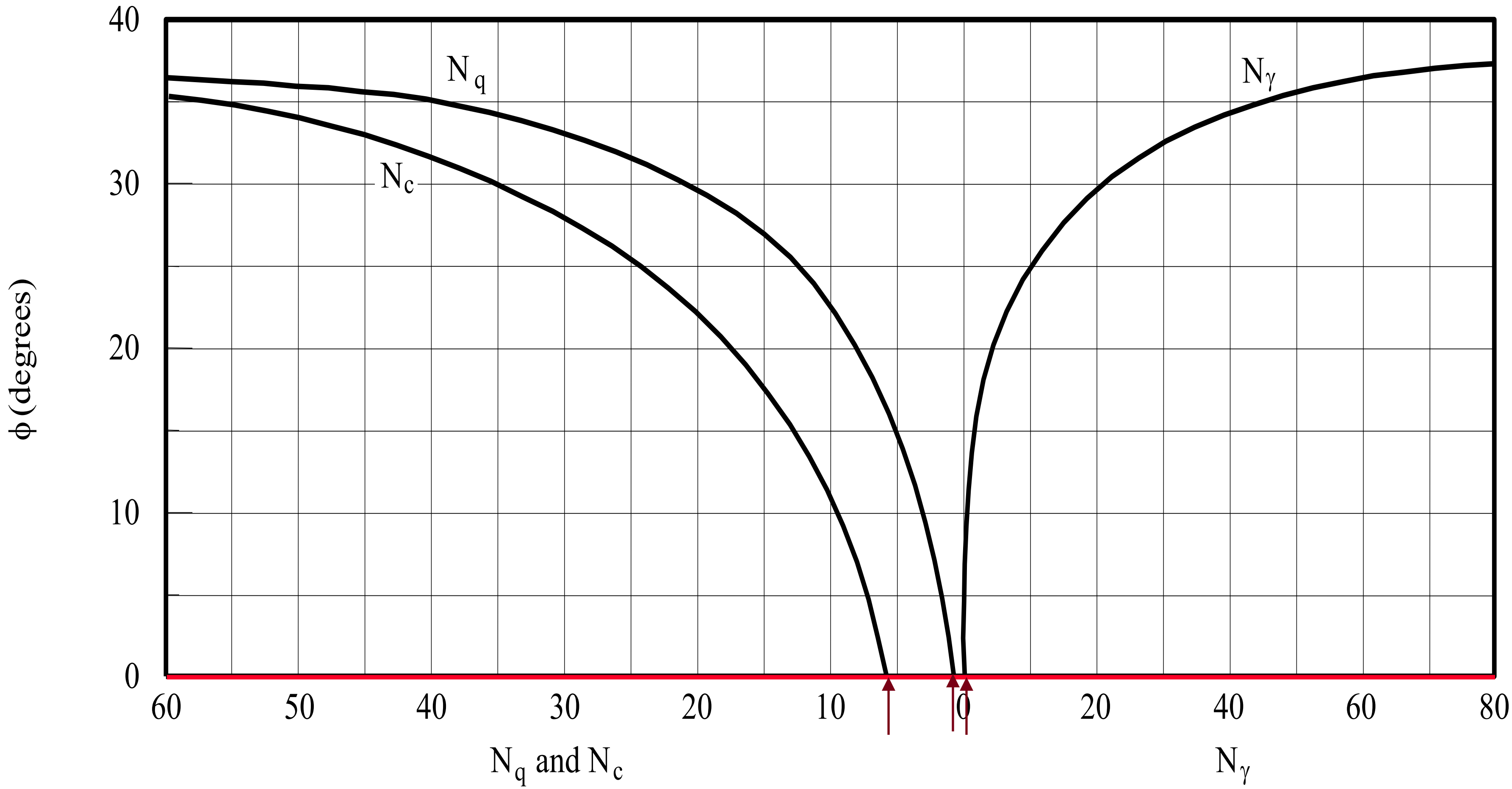


Short term - Undrained (total stress) analysis

Position of water table not important - soil must be saturated

$q_s = \gamma_{sat} D = 15 \times 2 = 30$ kPa

Example



5.14 = and N_c0 = , N_γ1 = N_q 0 = ϕ_u

Example

Short term capacity

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

Example

Short term capacity

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

q_f 30 = ´ 25 + 0 + 1 ´ kPa (Bearing capacity)158.5 = 5.14

Example

Short term capacity

$$q_f = q_s N_q + \frac{\gamma B}{2} N_\gamma + c N_c$$

q_f 30 = ´ 25 + 0 + 1 ´ kPa (Bearing capacity)158.5 = 5.14

Q = q_f ´ B = 158.5 ´ kN/m (Bearing Force)792.5 = 5

Example

Long term capacity

Effective stress (fully drained) analysis

Example

Long term capacity

Effective stress (fully drained) analysis

$q_s = 30$ kPa

Example

Long term capacity

Effective stress (fully drained) analysis

$q_s = 30 \text{ kPa}$

$u_o = 2 \times 9.8 = 19.6 \text{ kPa}$

Example

Long term capacity

Effective stress (fully drained) analysis

$q_s = 30$ kPa

$u_o = 2 \times 9.8 = 19.6$ kPa

$q'_s = 10.4$ kPa

Example

Long term capacity

Effective stress (fully drained) analysis

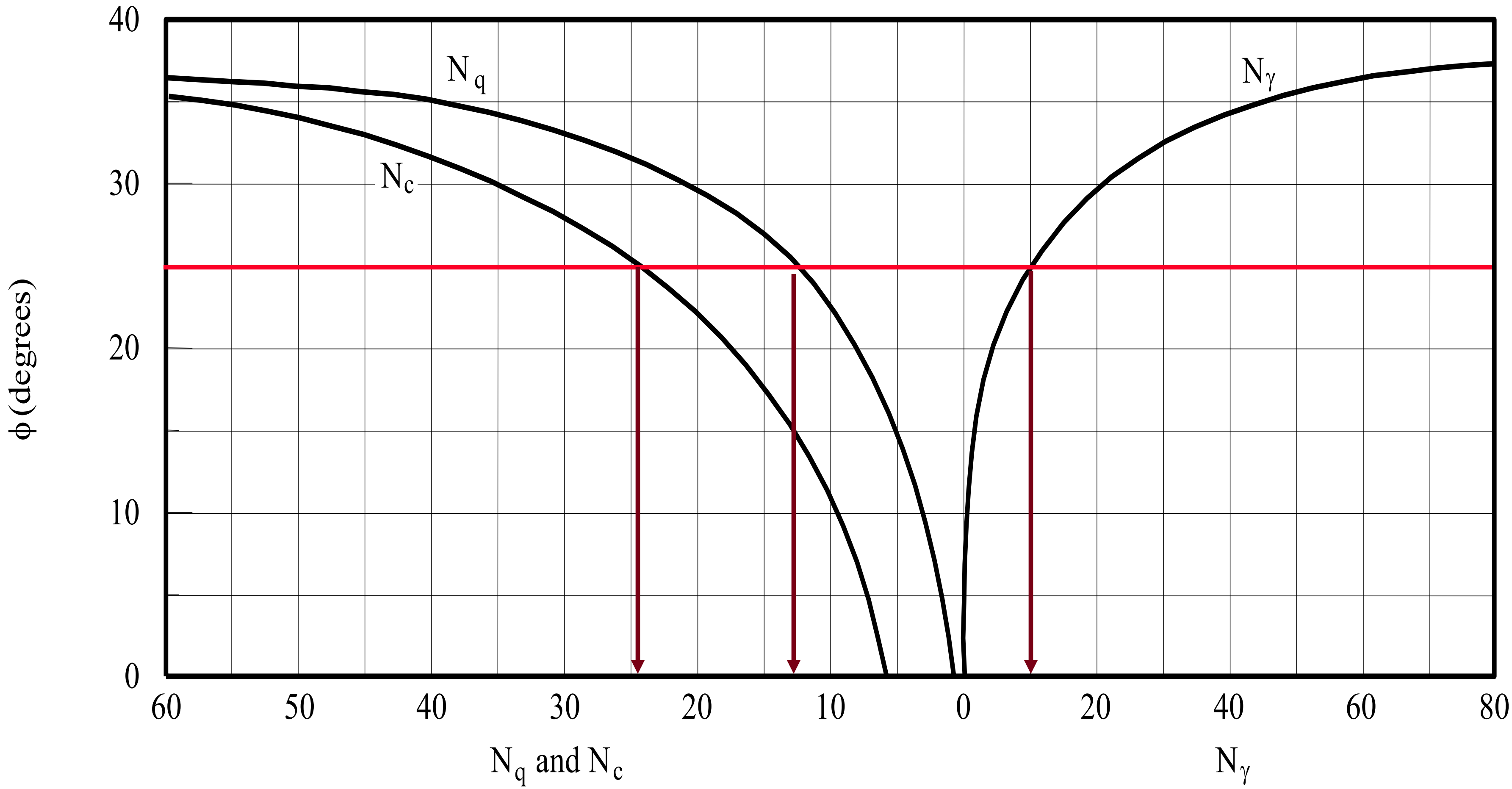
$q_s = 30$ kPa

$u_o = 2 \times 9.8 = 19.6$ kPa

$q'_s = 10.4$ kPa

$\gamma' = 15 - 9.8 = 5.2$ kPa

Example



24.5 = and N_c10 = , N_γ13 = N_q 25 = ’ϕ

Example

Long term capacity

$$q'_f = q'_s N_q + \frac{\gamma' B}{2} N_\gamma + c' N_c$$

$$q'_f = 10.4 \times 13 + 0.5 \times 5.2 \times 5 \times 10 + 2 \times 24.5 = 314.2 \text{ kPa}$$

Example

Long term capacity

$$q'_f = q'_s N_q + \frac{\gamma' B}{2} N_\gamma + c' N_c$$

$$q'_f = 10.4 \times 13 + 0.5 \times 5.2 \times 5 \times 10 + 2 \times 24.5 = 314.2 \text{ kPa}$$

$$q_f = 314.2 + 19.6$$

$$= 333.8 \text{ kPa}$$

Example

Long term capacity

$$q'_f = q'_s N_q + \frac{\gamma' B}{2} N_\gamma + c' N_c$$

$$q'_f = 10.4 \times 13 + 0.5 \times 5.2 \times 5 \times 10 + 2 \times 24.5 = 314.2 \text{ kPa}$$

$$q_f = 314.2 + 19.6$$

$$= 333.8 \text{ kPa}$$

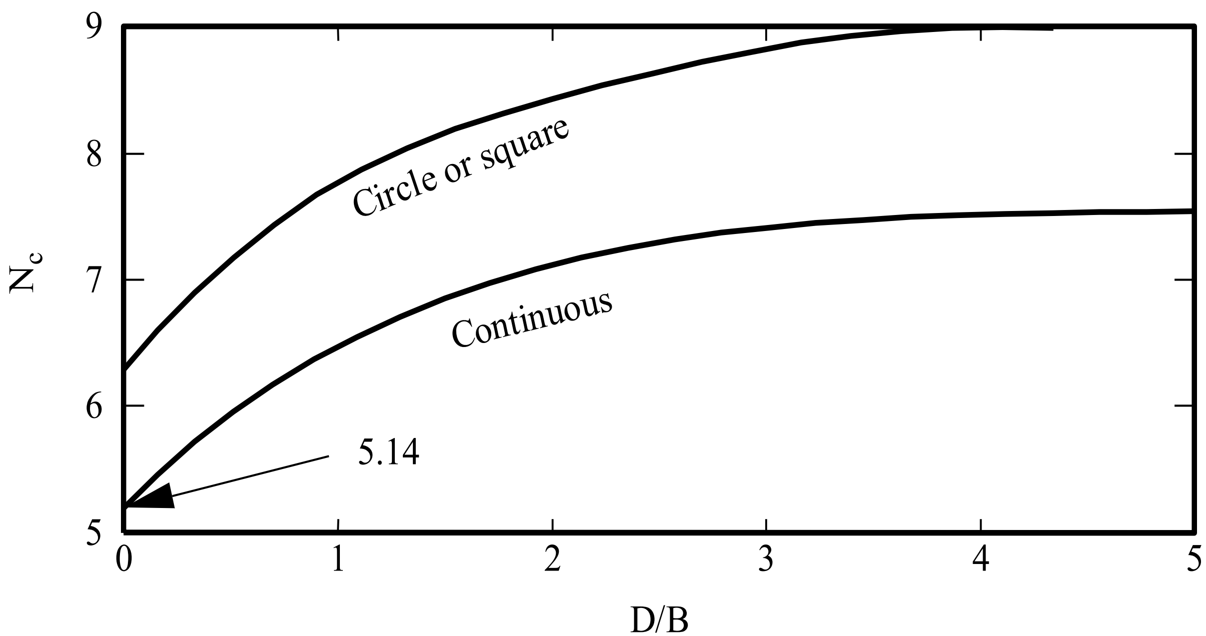
$$Q = 1669 \text{ kN/m}$$

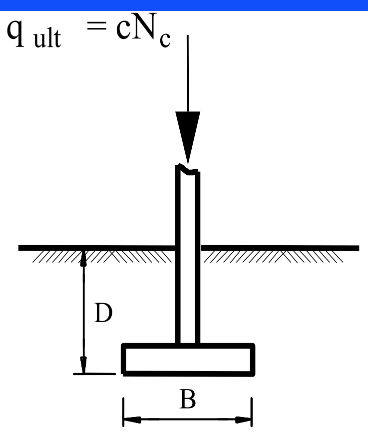
$\phi_u = 0$ Total Stress Analysis

$$q_f = N_c \, c_u + q_s$$

0 = Total Stress Analysis ϕ_u

$$q_f = N_c \, c_u + q_s$$





N_c (for rectangle)

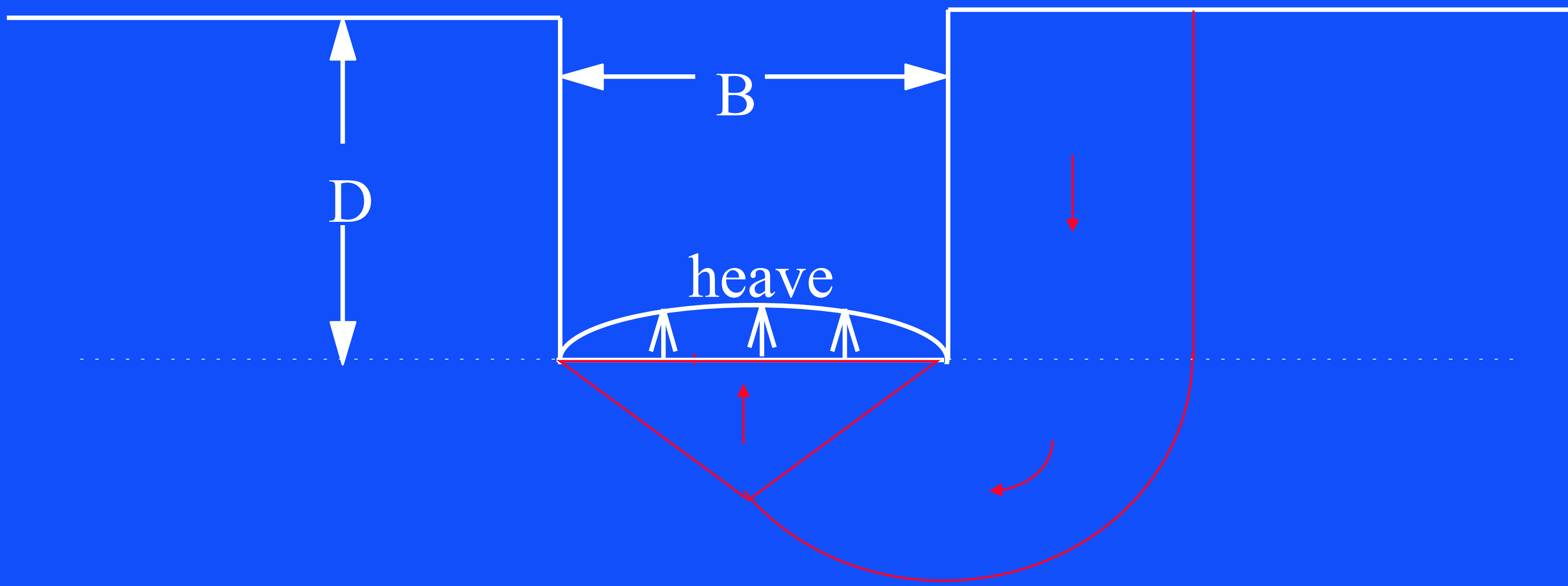
$= (0.84 + 0.16 \frac{B}{L}) N_c$ (square)

L= Length of footing

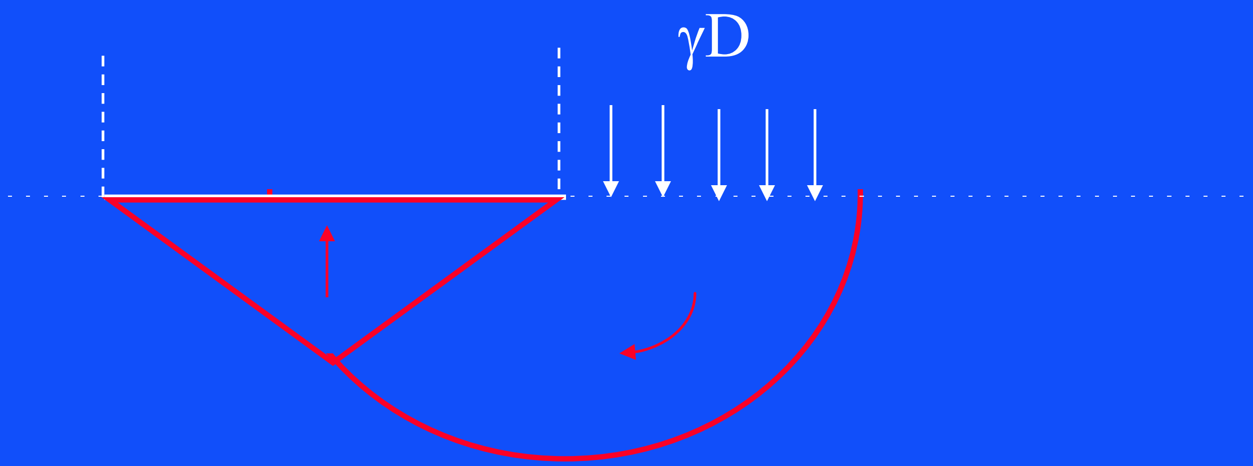
ULTIMATE BEARING CAPACITY OF CLAY ($\phi = 0$ only) (After A.W. Skempton)

$$q_f = cN_c + \gamma D$$

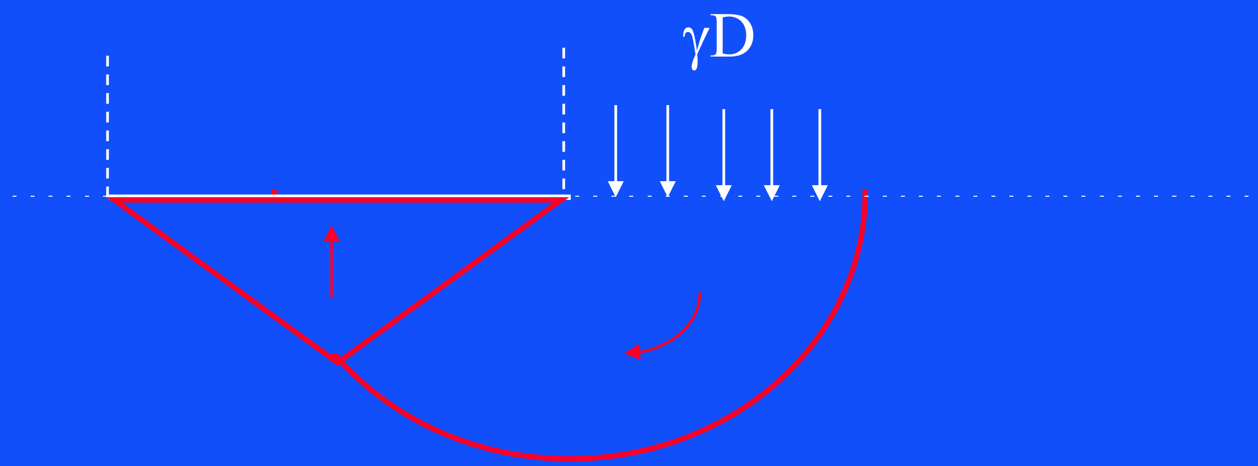
Bottom heave into excavations



Bottom heave into excavations



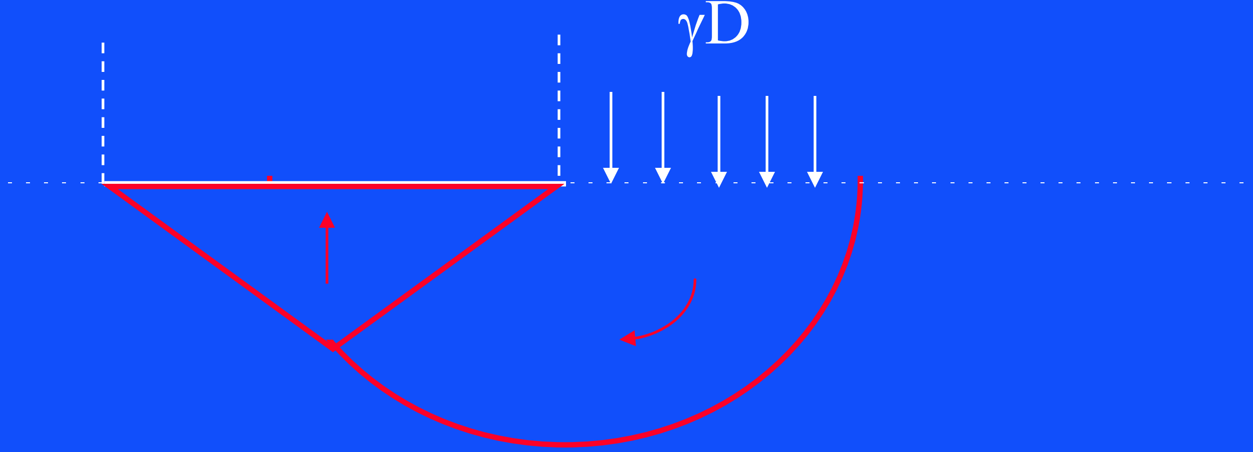
Bottom heave into excavations



For $\phi = 0$, and constant undrained strength c_u

The bearing capacity (pressure) = $c_u N_c$

Bottom heave into excavations

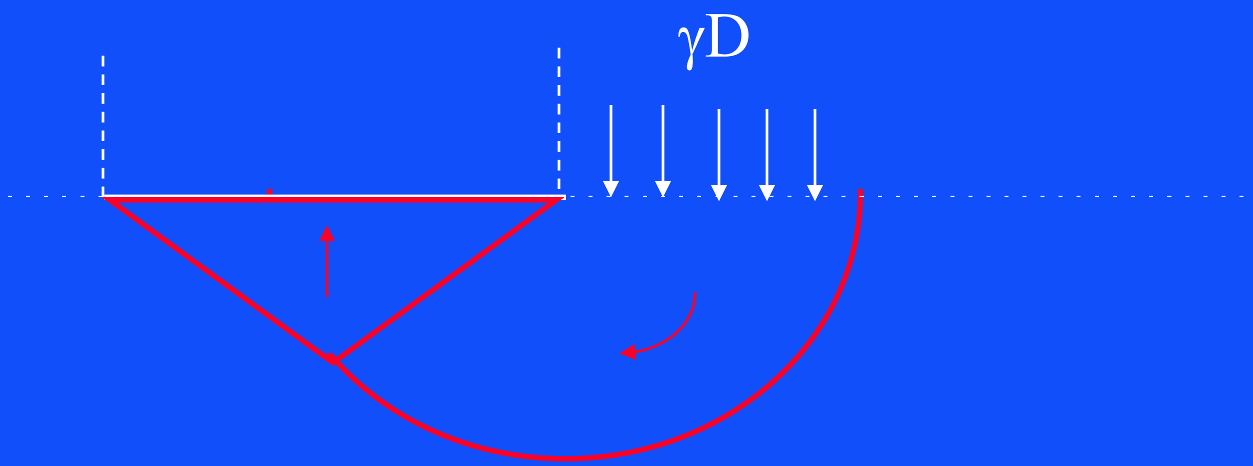


For $\phi = 0$, and constant undrained strength c_u

The bearing capacity (pressure) = $c_u N_c$

The driving pressure causing failure = γD

Bottom heave into excavations



For $\phi = 0$, and constant undrained strength c_u

The bearing capacity (pressure) $= c_u N_c$

The driving pressure causing failure $= \gamma D$

and the Factor of Safety $= \dfrac{\text{Bearing capacity}}{\text{Stress causing failure}} = \dfrac{c_u N_c}{\gamma D}$