# Pile Foundations

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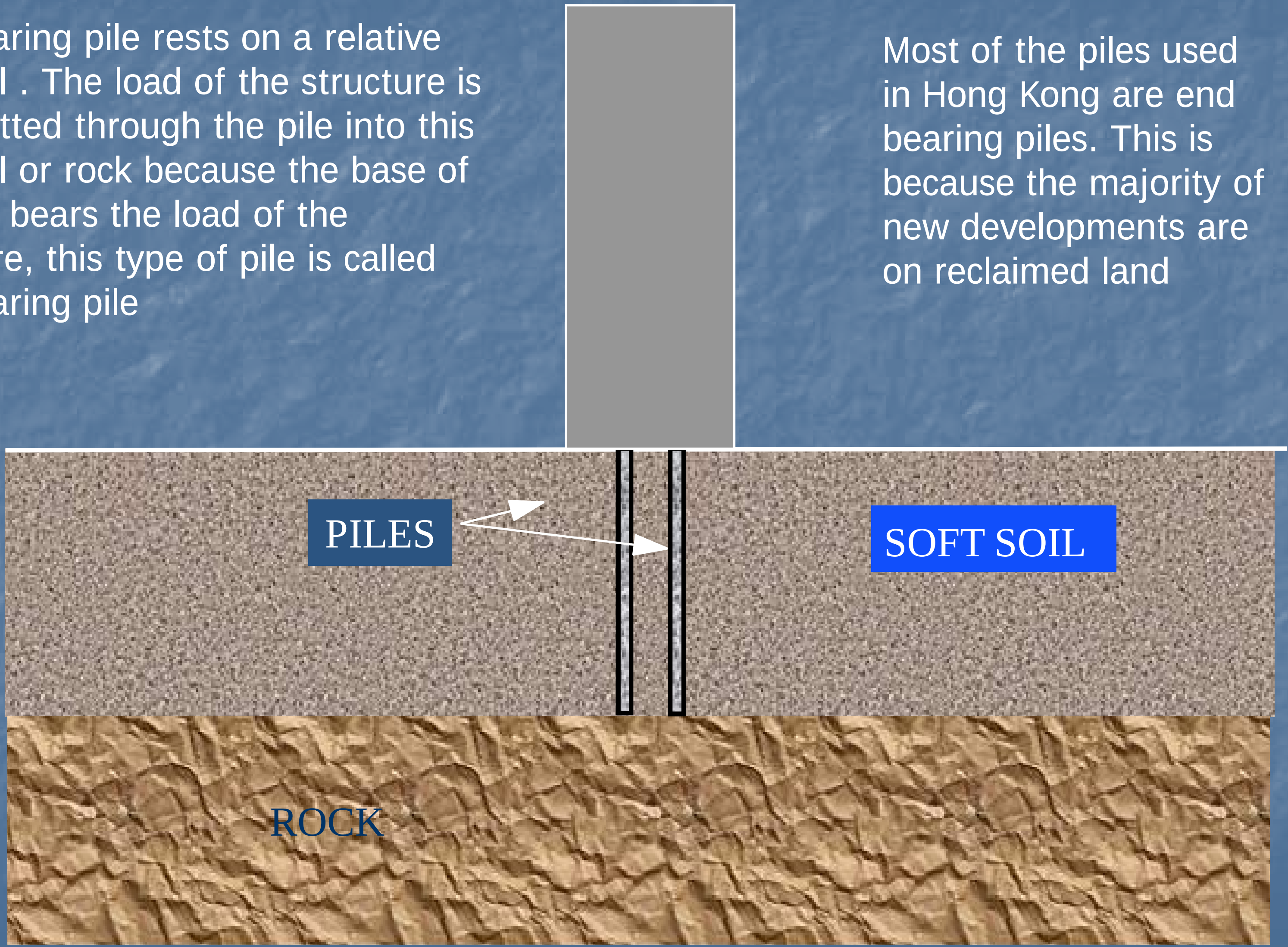
- BS8004 defines deep foundation with D>B or D>3m.
- Pile foundation always more expensive than shallow foundation but will overcome problems of soft surface soils by transferring load to stronger, deeper stratum, thereby reducing settlements.
- Pile resistance is comprised of
  - end bearing
  - shaft friction
- For many piles only one of these components is important. This is the basis of a simple classification

# End Bearing Piles

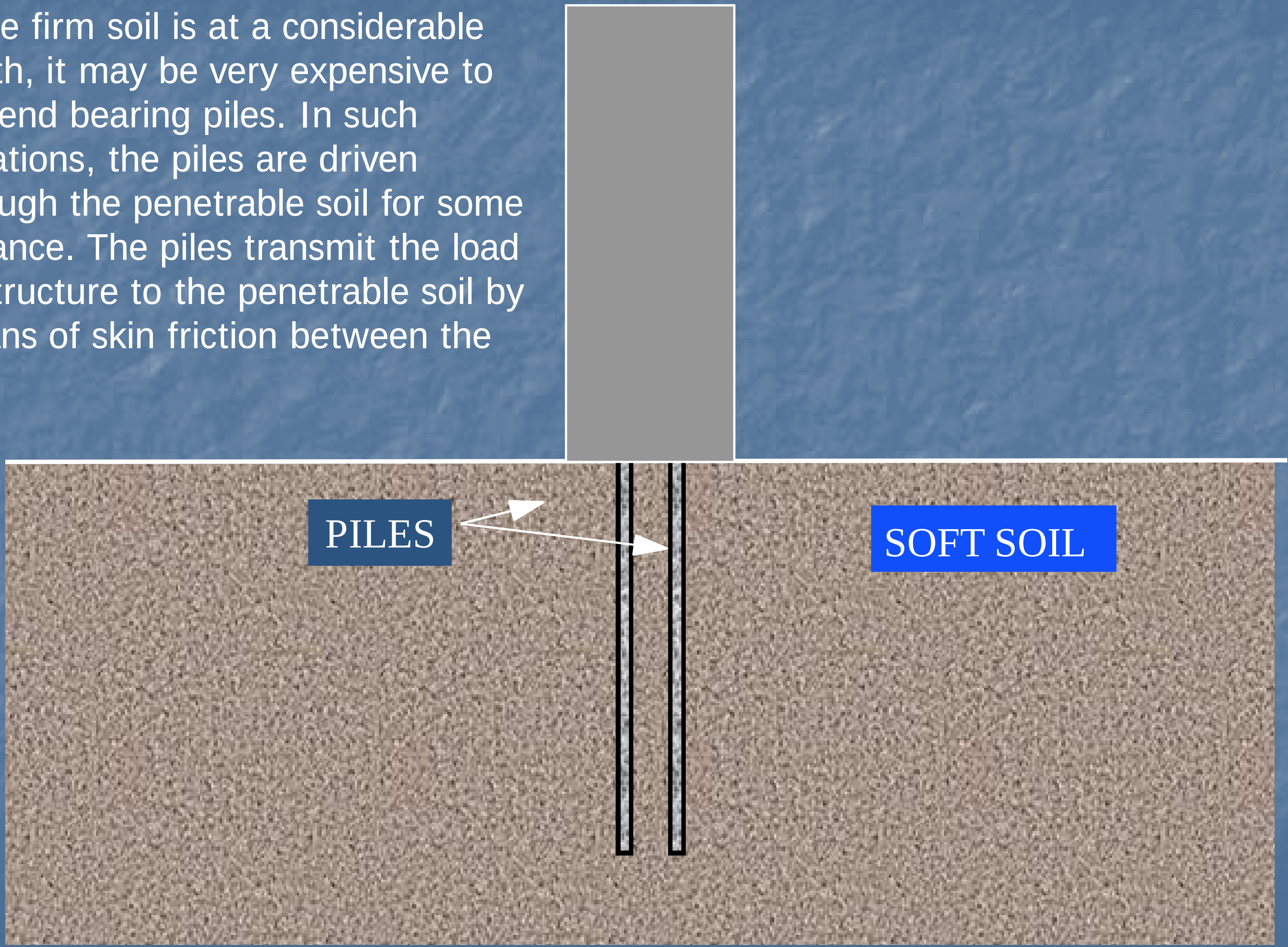
End bearing pile rests on a relative firm soil . The load of the structure is transmitted through the pile into this firm soil or rock because the base of the pile bears the load of the structure, this type of pile is called end bearing pile

Most of the piles used in Hong Kong are end bearing piles. This is because the majority of new developments are on reclaimed land



# Friction Piles

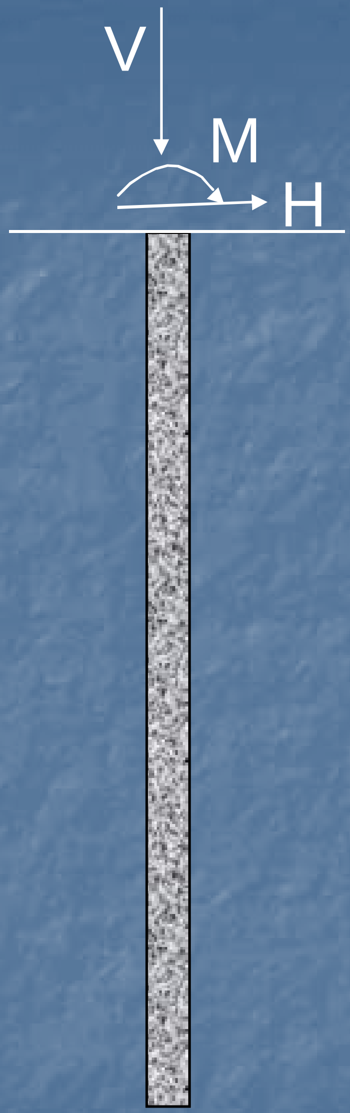
If the firm soil is at a considerable depth, it may be very expensive to use end bearing piles. In such situations, the piles are driven through the penetrable soil for some distance. The piles transmit the load of structure to the penetrable soil by means of skin friction between the soil.



# Types of Pile

- The pile installation procedure varies considerably, and has an important influence on the subsequent response
- Three categories of piles are classified by method of installation as below:
  - Large displacement piles
    - They encompass all solid driven piles including precast concrete piles, steel or concrete tubes closed at the lower end
  - Small displacement piles
    - They include rolled steel sections such as H-pile and open-end tubular piles
  - Replacement piles
    - They are formed by machine boring, grabbing or hand-digging.

# Loads applied to Piles




- Combinations of vertical, horizontal and moment loading may be applied at the soil surface from the overlying structure
- For the majority of foundations the loads applied to the piles are primarily vertical
- For piles in jetties, foundations for bridge piers, tall chimneys, and offshore piled foundations the lateral resistance is an important consideration
- The analysis of piles subjected to lateral and moment loading is more complex than simple vertical loading because of the soil-structure interaction.
- Pile installation will always cause change of adjacent soil properties, sometimes good, sometimes bad.

# Modes of failure

- The soil is always failure by punching shear.
- The failure mode of pile is always in buckling failure mode.

# Total and Effective Stress Analysis

- To determine drained or undrained condition, we may need to consider the following factors:
  - Drainage condition in the various soil strata
  - Permeability of soils
  - Rate of application of loads
  - Duration after the application of load
- A rough indicator will be the Time Factor ($T_v = c_v t/d^2$)

# Displacement Pile (A/D)

| Advantage | Disadvantages |
| --- | --- |
| Pile material can be inspected for quality before driving | May break during driving |
| Construction  operation affect by ground water | Noise and vibration problems |
| Can driven in very long lengths | Cannot be driven in condition of low headroom |
| Construction operation not affected by ground water | Noise may prove unacceptable. Noise permit may be required |
| Soil disposal is not necessary | Vibration may prove unacceptable due to presence of sensitive structures, utility installation or machinery |

# Replacement Pile (A/D)

| Advantage | Disadvantages |
| --- | --- |
| Less noise or vibration problem | Concrete cannot be inspected after installation |
| Equipment can break up practically all kinds of obstructions | Liable to squeezing or necking |
| Can be installed in conditions of low headroom | Raking bored pile are difficult to construct |
| No ground heave | Drilling a number of pile groups may cause ground loss and settlement of adjacent structures |
| Depth and diameter can varied easily | Cannot be extended above ground level without special adaptation |

# Ultimate capacity of axially load single pile in soil

Estimated by designer based on soil data and somewhat empirical procedures. It is common practice that the pile capacity be verified by pile load test at an early stage such that design amendment can be made prior to installation of the project piles. The satisfactory performance of a pile is, in most cases, governed by the limiting acceptable deformation under various loading conditions. Therefore the settlement should also be checked.

## Basic Concept

The ultimate bearing capacity ($Q_u$ )of a pile may be assessed using soil mechanics principles. The capacity is assumed to be the sum of skin friction and end-bearing resistance, i.e

$Q_u = Q_b + Q_s - W$ ……………………….(1)

where

$Q_u$ total pile resistance,

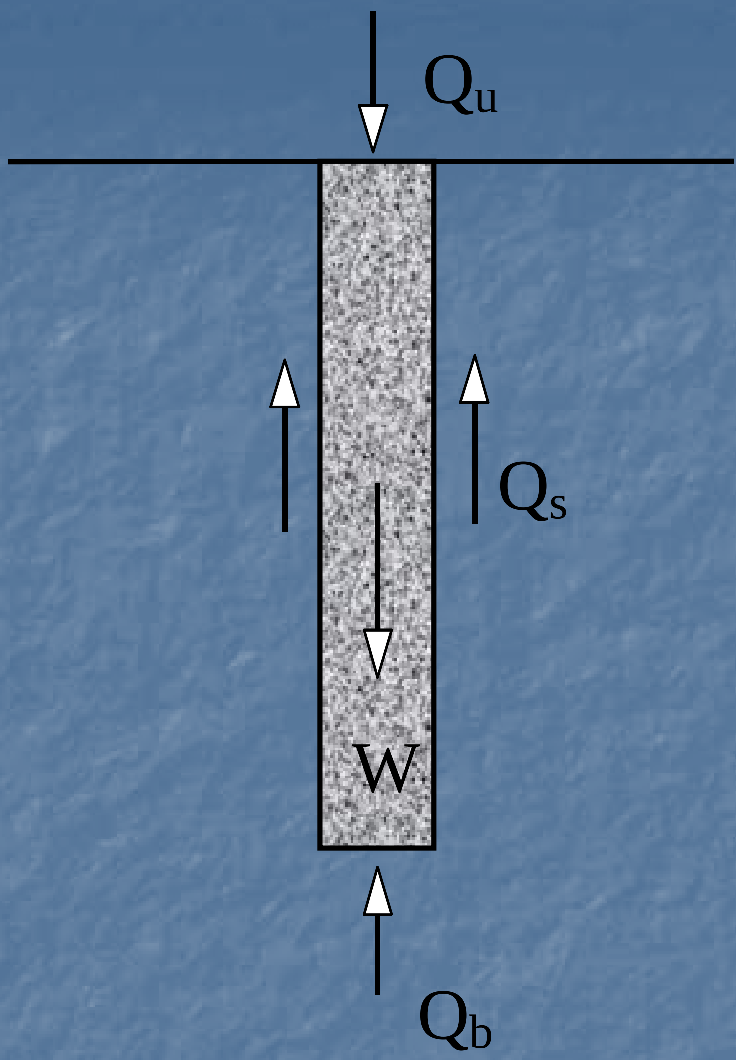
$Q_b$ is the end bearing resistance and

$Q_s$ is side friction resistance

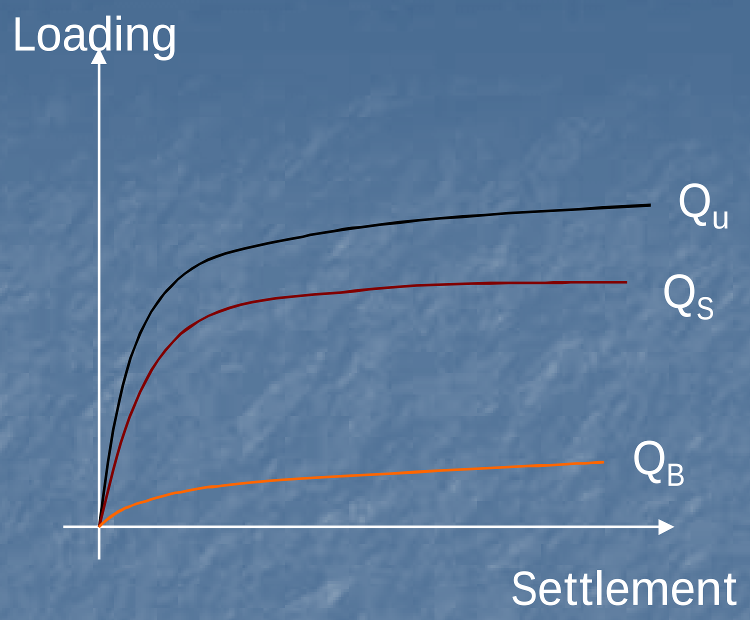
## General behaviour

Shaft resistance fully mobilized at small pile movement (<0.01D)

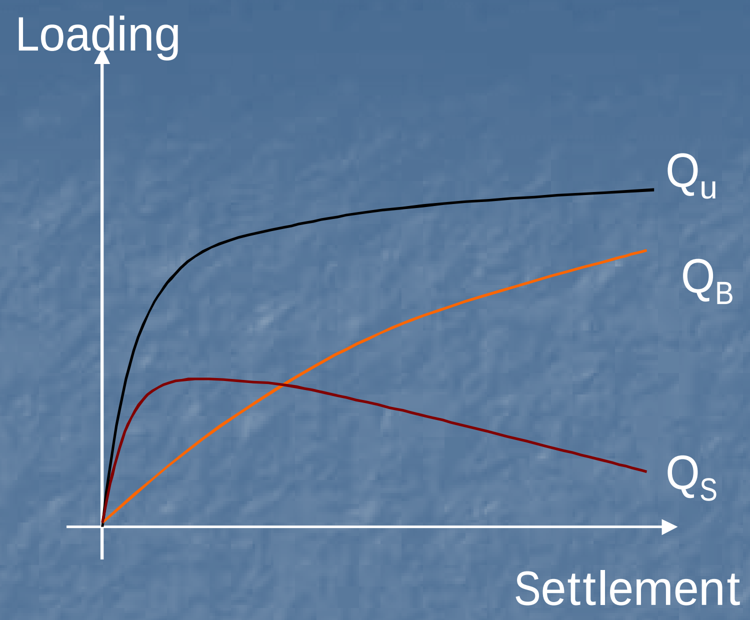
Base resistance mobilized at large movement (0.1D)




$$Q_u = Q_s + Q_b - W$$




Behaviour of Frictional Pile




Behaviour of End Bearing Pile

- Piles founded on dense soils
  - Important to adopt good construction practice to enhance shaft friction and base resistance
  - Shaft and base grouting useful in enhancing pile capacity

- Piles founded on strong stratum
  - Not much benefit in enhancing base resistance
  - Important to adopt good construction practice to enhance shaft friction
  - Shaft grouting useful in enhancing pile capacity

# Ultimate Limit State Design

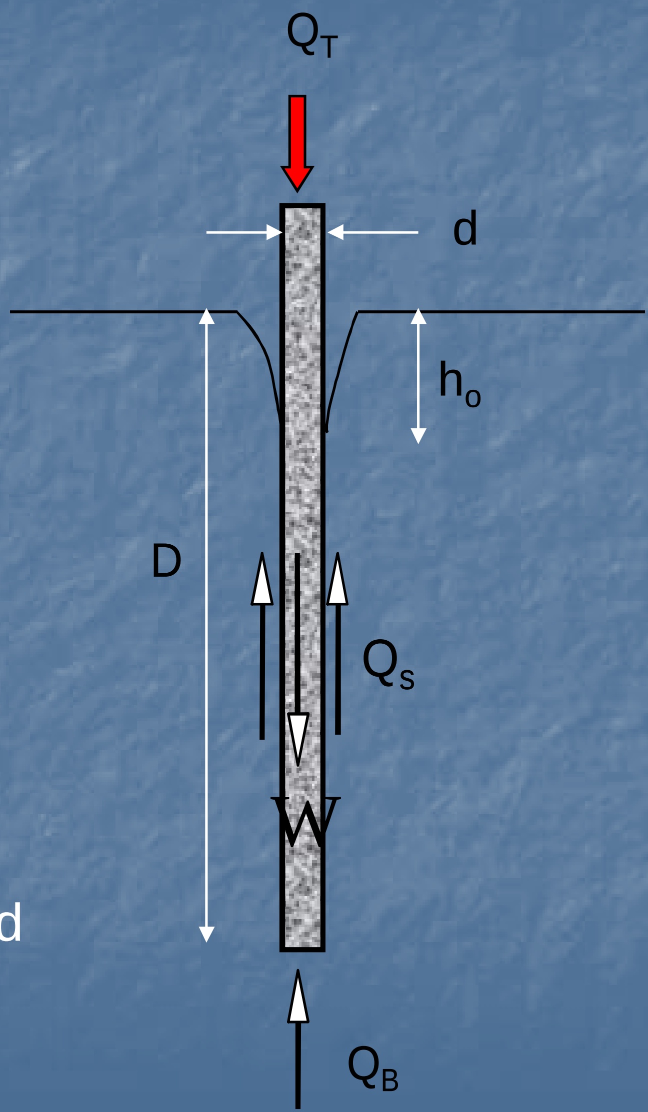
$$Q_{DES} = Q_B/F_B + Q_s/F_s - W……(2)$$

Where $F_B$ and $F_S$ is the factor of safety of components of end bearing strength and shaft friction strength

$$Q_U = Q_B + Q_s - W……(3)$$

$$Q_b = A_b[c_b N_c + P_o(N_q - 1) + \gamma d/2 N_\gamma + P_o] - W_p$$

Where $A_b$ is the area of the base , $c_b$ is the cohesion at the base of the pile, $P_o$ is the overburden stress at the base of the pile and d is the width of the pile.



# End Bearing Resistance

Assumptions

1. The weight of the pile is similar to the weight of the soil displaced of the pile

   $\Rightarrow W_p = A_b P_o$

2. The length (L) of the pile is much greater than its width d

   $\Rightarrow W_p = A_b P_o + A_b \gamma\, d N_\gamma / 2$

3. Similarly for $\phi > 0$, $N_q$ approximately equal to $N_q - 1$

$$Q_b = A_b[c_b N_c + P_o(N_q - 1) + \gamma d/2 N_\gamma + P_o] - W_p$$

$$\Rightarrow Q_b = A_b[c_b N_c + P_o N_q]$$

# End Bearing resistance for Bore pile in granular soils

Due to the natural of granular soil, the c' can be assumed equation to zero. The ultimate end bearing resistance for bored pile in granular soils may be express in terms of vertical effective stress, $\sigma'_v$ and the bearing capacity factors $N_q$ as :

$$Q_B = A_B \, N_q \, \sigma_v'$$

$N_q$ is generally related to the angle of shearing resistance $\phi'$. For general design purposed, it is suggested that the $N_q$ value proposed by Berezantze et al (1961) as presented in Figure ?? are used. However, the calculated ultimate base stress should conservatively be limited to 10Mpa, unless higher values have been justified by load tests.

# Shaft Friction Resistance

The ultimate shaft friction stress $q_s$ for piles may be expressed in terms of mean vertical effective stress as :

$$q_s = c' + K_s \sigma_v' \tan\delta_s$$

$$q_s = \beta\sigma_v' \text{ (when } c'=0)$$

Where

$K_s$= coefficient of horizontal pressure which depends on the relative density and state of soil, method of pile installation, and material length and shape of pile. Ks may be related to the coefficient of earth pressure at rest,

$K_0=1-\sin\phi$ as shown in Table 1.

$Q_v'$ = mean vertical effective stress

$\sigma_s'$ = angle of friction along pile/soil interface (see table2)

$\beta$= shafte friction coefficient (see Table 3)

$Q_s = pLq_s$

Where p is the perimeter of the pile and L is the total length of the pile

# Driven pile in Granular soils

The concepts of the calculation of end-bearing capacity and skin friction for bored piles in granular soils also apply to driven piles in granular soils. The pile soil system involving effects of densification and in horizontal stresses in the ground due to pile driving. In Hong Kong, it is suggested that the value of $q_b$ be range from 16 to 21Mpa.

# Bored pile in Clays

The ultimate end bearing resistance for piles in clays is often related to the undrained shear strength, $c_u$, as

$$q_B = N_c c_u$$

$$Q_B = A_B N_c c_u$$

where

$N_c$ = 9 when the location of the pile base below ground surface exceeds fours times the pile diameter

# Bored pile in Clays

The ultimate shaft friction ($q_s$) for soils in stiff over-consolidated clays may be estimated on the semi-empirical method as:

$q_s = \alpha C_u$

$\alpha$ is the adhesion factor (range from 0.4 to 0.9)

# Driven Pile in Clays

The design concepts are similar to those presented for bored piles in granular soils. However, based on the available instrumented pile test results, a design curve is put forward by Nowacki et al (1992)

# Prediction of Ultimate Capacity of Pile

## Pile Driving Formula

Pile driving formula relate the ultimate bearing capacity of driven piles to final set (i.e. penetration per blow). In Hong Kong, the Hiley formula has been widely used for the design of driven piles as:

$R_d=(\eta_h W_h d_h)/(s+c/2)$

Where

$R_d$ is driving resistance, $\eta_h$ is efficiency of hammer, $W_h$ is the weight of hammer, $d_h$ is the height of fall of hammer, s is permanent set of pile and c is elastic movement of pile

Note: Test driving may be considered at the start of a driven piling contract to assess the expected driving characteristics.

# Prediction of Ultimate Capacity of Pile

## Pile Load Test

Static pile load test is the most reliable means of determining the load capacity of a pile. The test procedure consists of applying static load to the pile in increments up to a designated level of load and recording the vertical deflection of the pile. The load is usually transmitted by means of a hydraulic jack placed between the top of the pile and a beam supported by tow or more reaction piles. The vertical deflection of the top of the pile is usually measured by mechanical gauges attached to a beam, which span over the test pile.