ROCSCIENCE

RSPile

Driven Pile

Theory Manual

April 5, 2022

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Symbols

K_δ	coefficient of lateral earth pressure at depth z
C_f	correction factor for K_δ when $\delta \neq 0$
p_d	effective overburden pressure at midpoint of layer
δ	pile-soil interface friction angle
ω	pile taper angle
d_{top}	diameter of the top of the pile
d_{bot}	diameter of the bottom of the pile
L	length of pile taper
d_{UB}	diameter at the upper layer
d_{LB}	diameter of the lower part of the shaft-soil contact surface
u	unit length of the pile
A_p	cross-sectional area of the pile
q_p	bearing capacity at pile tip
$\bar{q}$	effective overburden pressure at pile toe
α_t	coefficient based on pile geometry
N'_q	bearing capacity factor
f_s	unit shaft friction
A_t	pile area at pile toe bearing
c_a	adhesion value based on Tomlinson's charts
α	adhesion factor based on Tomlinson's charts
c_u	undrained shear strength
A_t	pile area at pile toe bearing
c_u	undrained shear strength
N_c	dimensionless parameter (typically $N_c = 9$)
$Q_{u,driving}$	driving total capacity
$Q_{s,restrike}$	restrike shaft capacity
$\%DL$	percent driving strength losses
Q_p	pile toe capacity

Figures

1. Introduction

The purpose of this manual is to describe in detail the FHWA method of axial pile capacity calculation used by DRIVEN, which is implemented in the driven pile section of **RSPile**.

1.1. Calculated Capacities

The following capacities are calculated by the program:

Restrike – computes static skin and end bearing resistance for the entire soil profile. Restrike computations do not consider the effects of soft soils or scour conditions.

Driving – The user may enter a loss of soil strength in the soil profile for each soil layer due to the effects of driving. The driving computations are based upon the restrike calculations minus the soil strength loss due to driving.

Ultimate – Ultimate capacity computations consider the effects of soft soil conditions or scour. This is the ultimate capacity available to resist applied loads.

1.2. Special Design Considerations

The following design considerations are mutually exclusive. They cannot both be used at the same time.

1.2.1. Scour

There are two types of scours that can be considered: long-term and short-term (local) scour. For short-term scour, the shear stress is simply reduced to zero. This occurs due to erosion around the pile. The effective overburden pressure σ_v' is not affected due to the presence of soil away from the local pile area. No end bearing can be placed above this level.

For long-term scour, the effective overburden stress is reduced to zero until the scour consideration depth. This is due to soil eroding over a large area, reducing the effective overburden stress. DRIVEN stacks the effects of both scour types, where long-term scour is first considered then local scour is applied below the long-term scour depth.

1.2.2. Soft Compressible Soils / Negative Skin Friction

A depth of soft compressible soil at the top of the soil profile can be specified. For ultimate calculations, the shaft resistance from the soft soil layer can be considered as soft compressible soil or as negative skin friction.

If the shaft resistance is considered to be soft soil, the skin friction for the layer is not included in the ultimate skin friction capacity. If negative skin friction is considered, the skin friction from the soft soil layer is considered to be negative and is subtracted from the total skin friction for ultimate capacity computations.

1.3. Ultimate Vertical Load Capacity

The load-carrying capacity of a single pile comes from the frictional resistance of the soil around the shaft and bearing capacity at the pile tip:

$$Q = Q_p + Q_s$$

where,

$$Q_p = A_p * q_p$$

and

$$Q_s = \int_0^L f_s C_d dz$$

in which:

A_p = area of pile tip

q_p = bearing capacity at pile tip

f_s = ultimate skin resistance per unit area of shaft

C_d = effective perimeter of pile

L = length of pile in contact with soil

z = depth

The main requirement for design is to estimate the magnitude of f_s with depth for friction piles and q_p for end bearing piles.

2. Capacity Calculations

2.1. Sand Layers

2.1.1. Shaft Resistance

Nordlund (1963,1979) suggests the following equation for calculating the ultimate skin resistance per unit area:

$$f_s = K_\delta C_f p_d \frac{\sin(\delta + \omega)}{\cos \omega}$$

where:

K_δ = coefficient of lateral earth pressure at depth z

C_f = correction factor for K_δ when $\delta \neq 0$

p_d = effective overburden pressure at midpoint of layer

δ = pile-soil interface friction angle

ω = pile taper angle

Based on the Nordlund equation, the frictional resistance of the soil around the pile shaft is calculated as:

$$Q_s = \int_0^L K_\delta C_f p_d \frac{\sin(\omega + \delta)}{\cos(\omega)} C_d dz = \sum_{i=1}^{n} K_{\alpha i} C_{fi} p_{di} \frac{\sin(\omega + \delta)}{\cos(\omega)} C_{di} D_i$$

where:

C_d = effective pile perimeter

2.1.1.1 ω, Pile Taper Angle

If the pile is not tapered, $\omega = 0$. For tapered piles, the pile taper angle is calculated as shown below:

$$\omega = \tan^{-1} \frac{d_{top} - d_{bot}}{2L}$$

where:

d_{top} = diameter of the top of the pile

d_{bot} = diameter of the bottom of the pile

L = length of pile taper

2.1.1.2 K_δ, Coefficient of Lateral Stress

The coefficient of lateral stress is calculated from the figures below.

The volume displacement rate is the volume of soil displaced per unit length of pile (e.g., m^3/m).

For uniform piles:

$$V = A_p$$

where:

A_p = cross-sectional area of the pile.

For circular tapered piles, the volume is determined from the average diameter within the layer in question:

$$V = \pi\left(\frac{\frac{d_{UB}}{2}+\frac{d_{LB}}{2}}{2}\right)^2 u$$

where:

d_{UB} = diameter at the upper layer

d_{LB} = diameter of the lower part of the shaft-soil contact surface

u = unit length of the pile

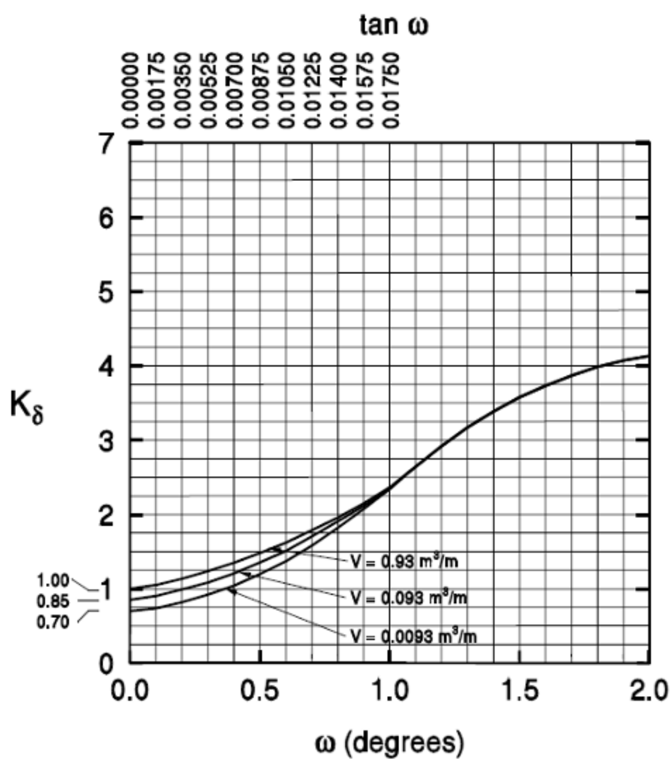


Figure 1.0: Design curves for evaluating K_δ for piles when $\phi = 25°$

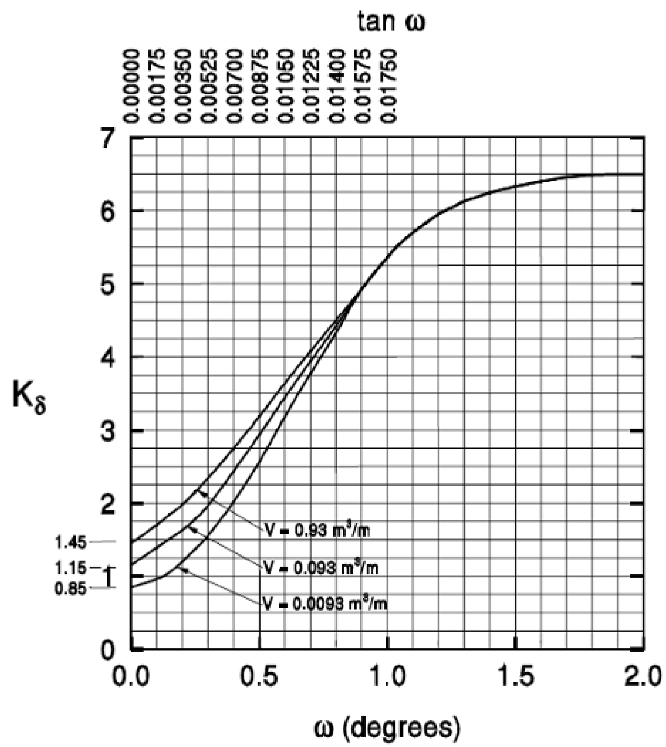


Figure 2.0: Design curves for evaluating K_δ for piles when $\phi = 30°$

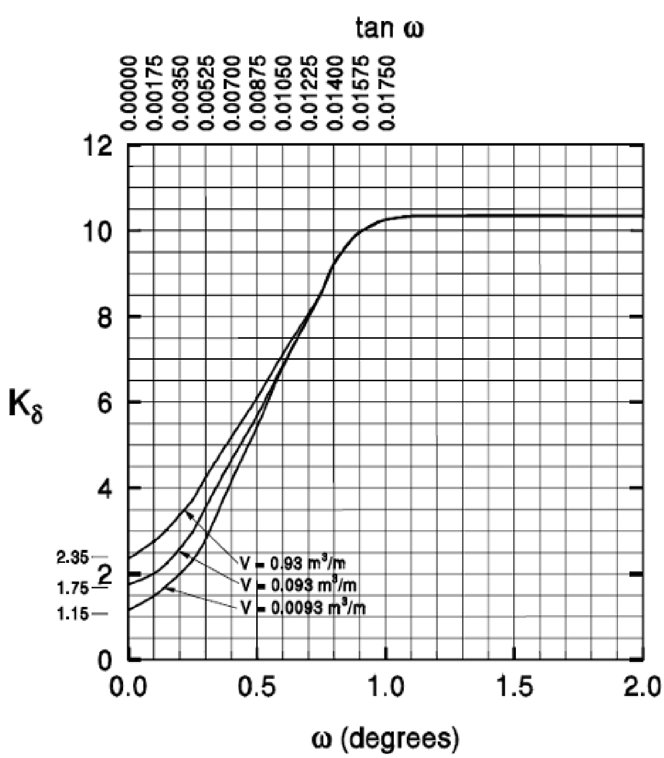


Figure 3.0: Design curves for evaluating K_δ for piles when $\phi = 35°$

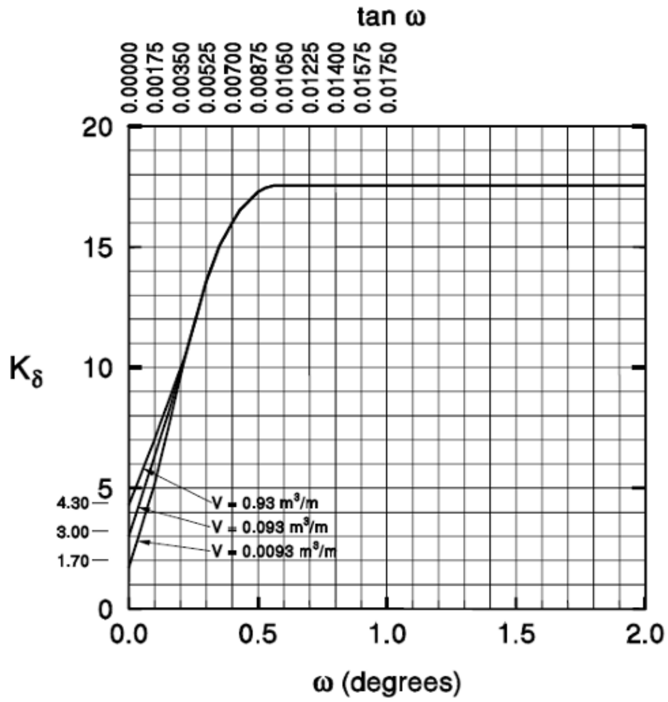


Figure 4.0: Design curves for evaluating K_δ for piles when $\phi = 40°$

2.1.1.3 δ, Pile-Soil Interface Friction Angle

The pile-soil interface friction angle is determined using the figure below.

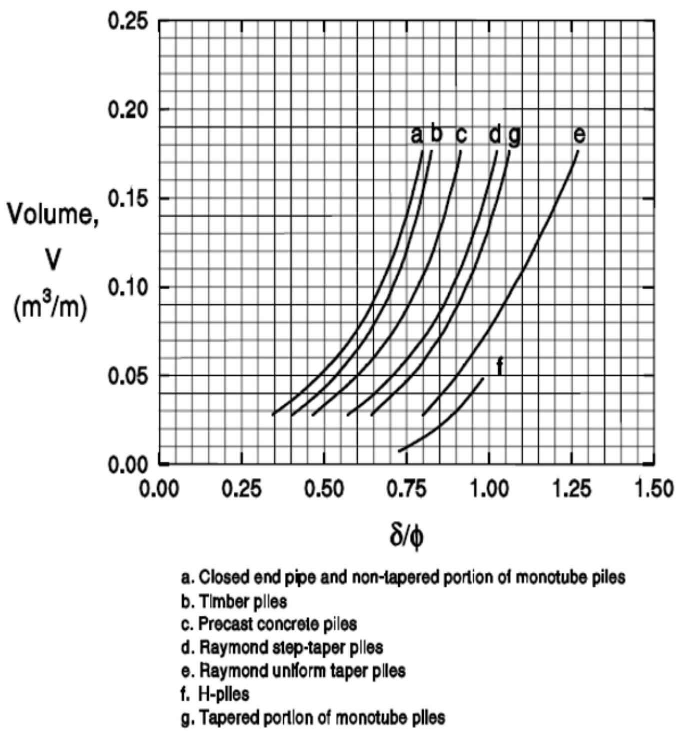


Figure 5.0: δ/ϕ relationship with pile type and volume

2.1.1.4 C_f, Correction factor for K_δ

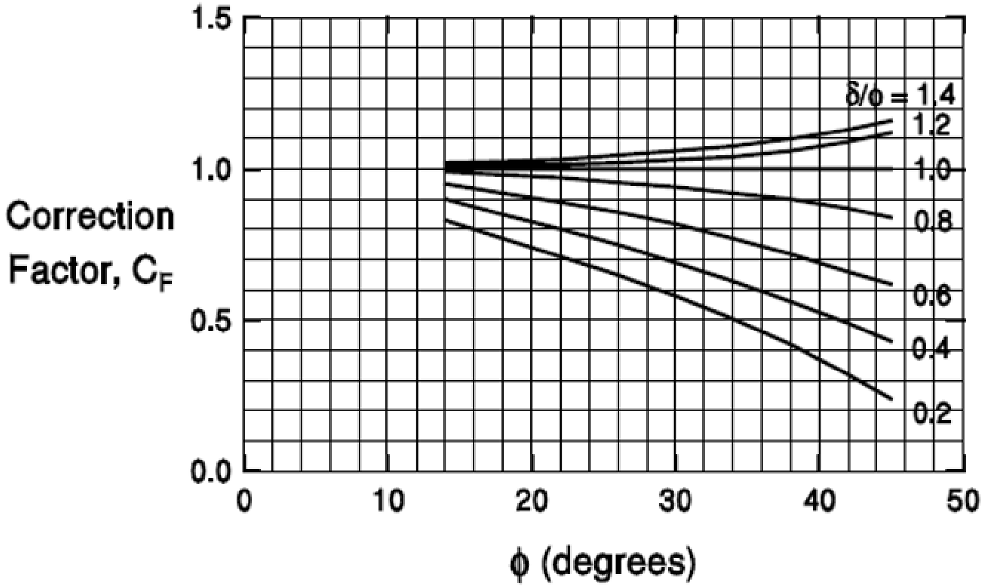


Figure 6.0: Correction factor for K_δ when $\delta \neq 0$

2.1.2. End Bearing Capacity

The calculation of the end bearing capacity also requires obtaining values from graphs. A limiting value for end bearing capacity is also obtained graphically.

$$Q_p = A_p q_p$$

where:

A_p = area of pile tip for bearing

q_p = bearing capacity at pile tip

The bearing capacity at the pile tip is calculated as:

$$q_p = \bar{q}\alpha_t N_q' \leq q_L$$

where:

$\bar{q}$ = effective overburden pressure at pile toe

α_t = coefficient based on pile geometry

N_q' = bearing capacity factor

2.1.2.1 α, Modification Factor

The coefficient $\boldsymbol{\alpha}$ is obtained using the figure below.

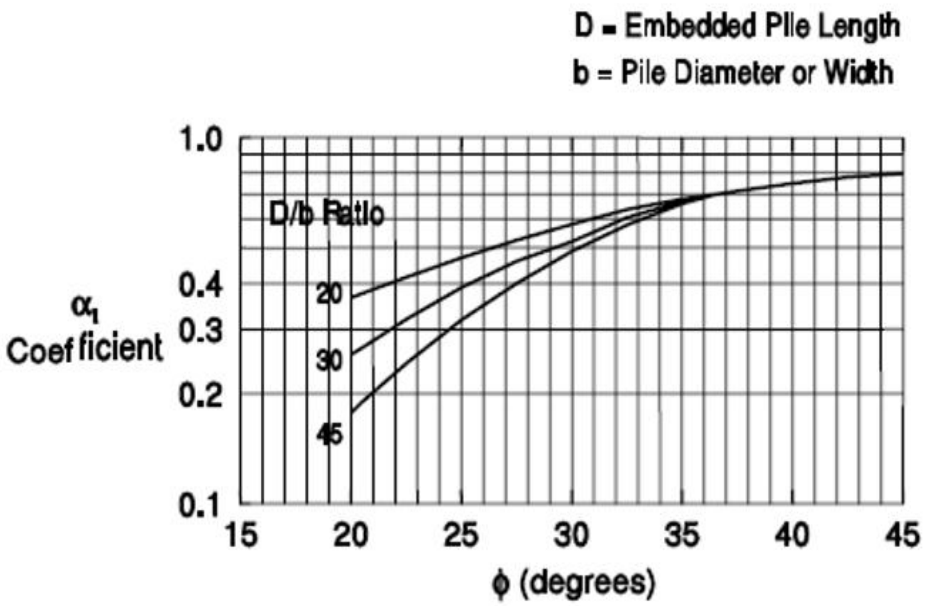
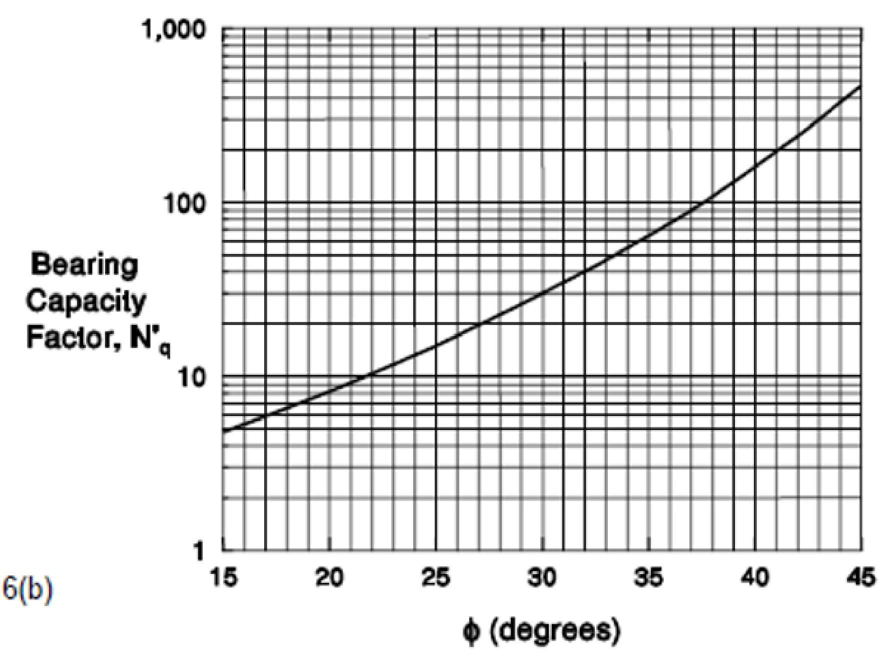


Figure 7.0: α coefficient for pile toe resistance

2.1.2.2 N'_q, Bearing Capacity Factor

The bearing capacity factor for pile toe resistance is obtained using the figure below.



9.16(b)

Figure 8.0: Bearing capacity factor for pile toe resistance

2.1.2.3 q_L, Limiting Unit Pile Toe Resistance

The limiting toe resistance is obtained using the figure below.

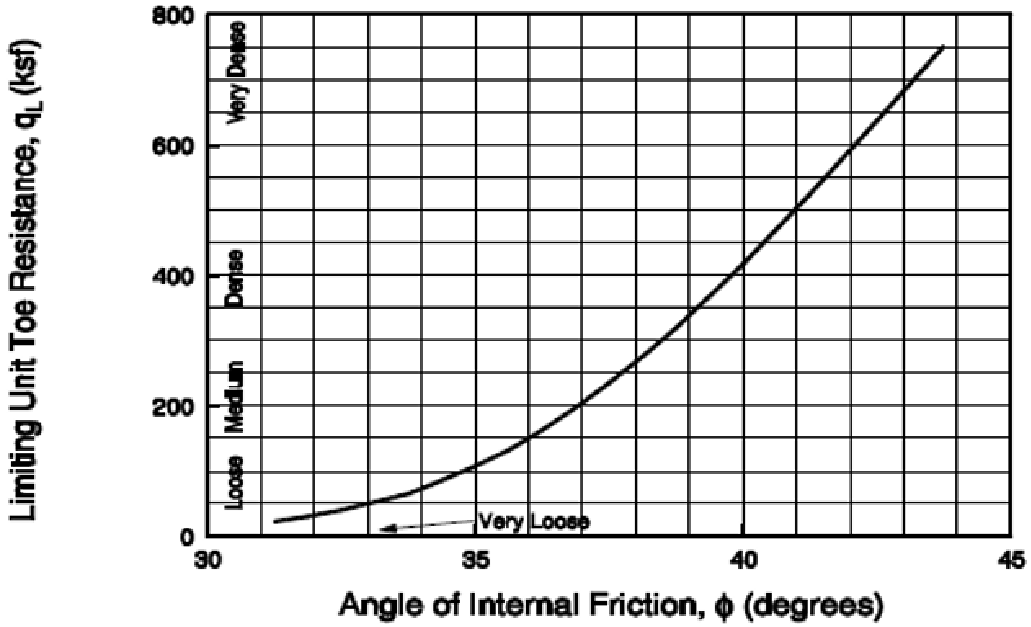


Figure 9.0: Limit factor on toe resistance

2.2. Clay Layers

2.2.1. Shaft Resistance

The FHWA recommends the α method for clays. To calculate α, a factor multiplied with undrained shear strength, Tomlinson's graphs are used. Tomlinson also supplies a general adhesion value as a function of normalized pile depth and undrained shear strength.

The shaft capacity for cohesive soils is:

$$Q_s = f_s A_t$$

where:

f_s = unit shaft friction

A_t = pile area at pile toe bearing.

2.2.1.1 f_s, Unit Shaft Capacity for Cohesive Soils

The unit shaft capacity is calculated as:

$$f_s = c_a = \alpha c_u$$

where:

c_a = adhesion value based on Tomlinson's charts

α = adhesion factor based on Tomlinson's charts

c_u = undrained shear strength

The adhesion values, c_a, and adhesion factor, c_u, are determined from the two figures below.

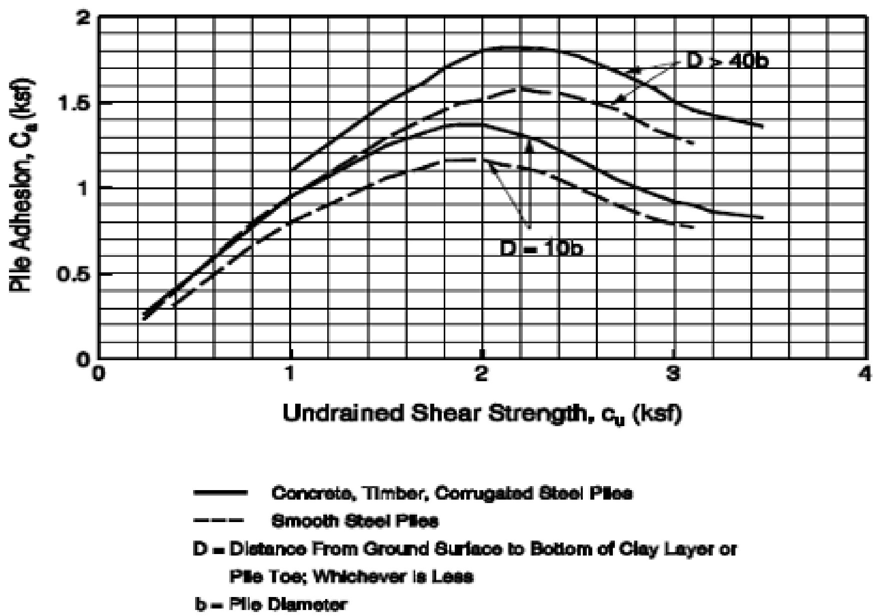


Figure 10.0: General Pile Shaft Adhesion Values (Tomlinson 1979)

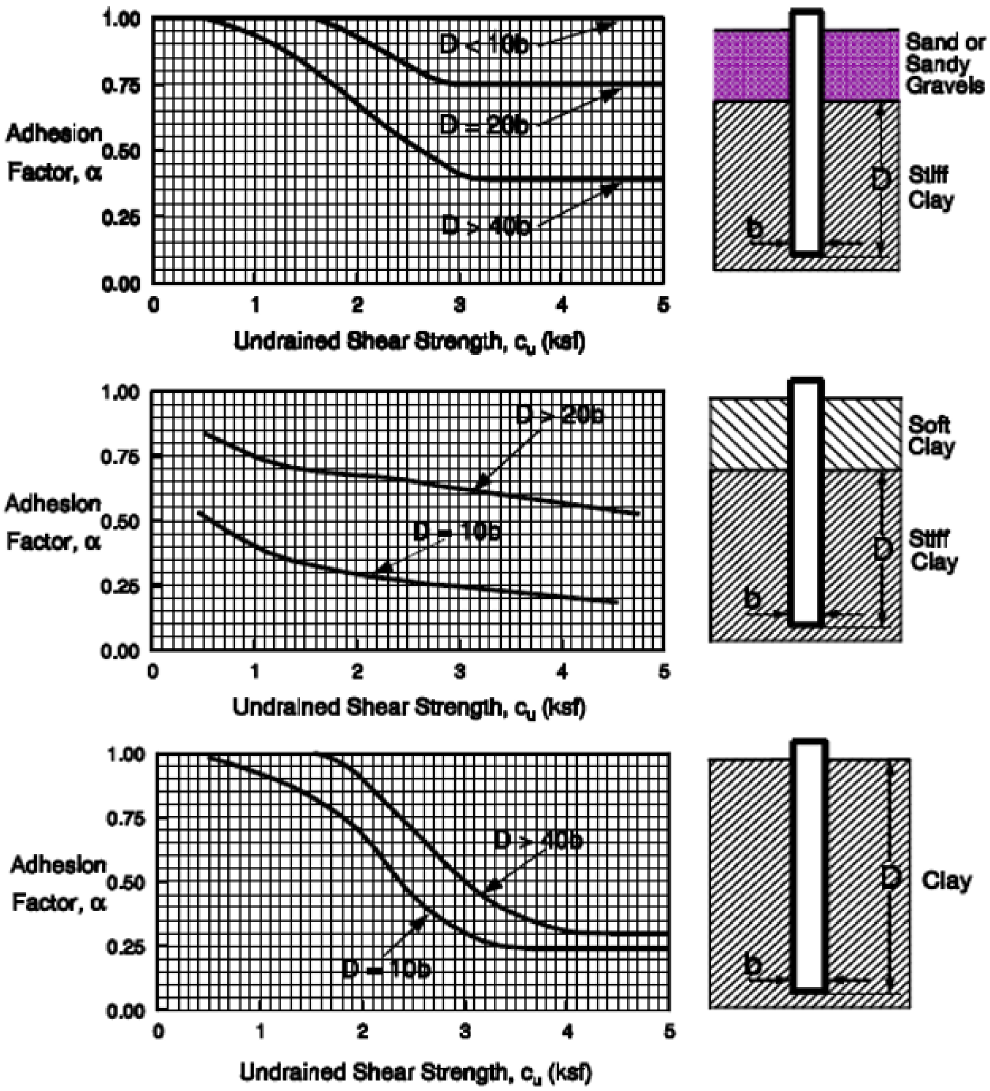


Figure 11.0: General Pile Shaft Adhesion Values (Tomlinson 1980)

2.2.2. End Bearing Capacity

The toe capacity for cohesive soils is

$$Q_p = A_t c_u N_c$$

where:

A_t = pile area at pile toe bearing

c_u = undrained shear strength

N_c = dimensionless parameter (typically $N_c = 9$).

2.3. Driving Capacity

The pile capacity with driving losses is calculated as:

$$Q_{u,driving} = \left(1 - \frac{\%DL}{100}\right) Q_{s,restrike} + Q_p$$

where:

$Q_{u,driving}$ = driving total capacity

$Q_{s,restrike}$ = restrike shaft capacity

$\%DL$ = percent driving strength losses

Q_p = pile toe capacity

2.4. Plugging

The following guidelines are used for the analysis of open-ended pipe piles with regards to plugging:

Table 1.0: Summary of guidelines for open-ended pipe piles analysis

	Restrike	**Driving**	**Ultimate**
Cohesionless – Shaft	L/B < 30, No plug L/B > 30, Plugged	L/B < 30, No plug L/B > 30, Plugged	L/B < 30, No plug L/B > 30, Plugged
Cohesionless – Pile Toe	Plugged	L/B < 30, No plug L/B > 30, Plugged	Plugged
Cohesive – Shaft	Plugged	No Plug, use alpha for L/B > 40 for Tomlinson charts	Plugged
Cohesive – Pile Toe	Plugged	Unplugged	Plugged

3. References

FHWA, Geotechnical Engineering Circular No. 12 – Volume I Design and Construction of Driven Pile Foundations". report No.FHWA-NHI-16-009, July 2016

Tomlinson, M.J. (1980), Foundation Design and Construction, Pitman Advanced Publishing, Boston, MA, 4th edition.