4.3 GENERAL PRINCIPLES OF GEOTECHNICAL STRENGTH DESIGN

4.3.1 Design geotechnical strength

A pile shall be proportioned such that the design geotechnical strength ($R_{d,g}$) is not less than the design action effect (E_d) as detailed in Clause 3.2.2, that is—

$$R_{d,g} \geq E_d \qquad \ldots 4.3.1(1)$$

The design geotechnical strength ($R_{d,g}$) shall be calculated as the design ultimate geotechnical strength ($R_{d,ug}$) multiplied by a geotechnical strength reduction factor (ϕ_g), according to the following equation:

$$R_{d,g} = \phi_g R_{d,ug} \qquad \ldots 4.3.1(2)$$

The geotechnical strength reduction factor (ϕ_g) shall be determined as follows:

$$\phi_g = \phi_{gb} + (\phi_{tf} - \phi_{gb})K \geq \phi_{gb}$$

where

ϕ_{gb} = basic geotechnical strength reduction factor as given in Clause 4.3.2

ϕ_{tf} = intrinsic test factor

= 0.9, for static load testing (see Section 8)

= 0.75, for rapid load testing (see Section 8)

= 0.8, for dynamic load testing of preformed piles (see Section 8)

= 0.75, for dynamic load testing of other than preformed piles (see Section 8)

= 0.85, for bi-directional load testing (see Section 8)

= ϕ_{gb}, for no testing

K = testing benefit factor

= $1.33p/(p + 3.3) \leq 1$, for static or rapid load testing

= $1.13p/(p + 3.3) \leq 1$, for dynamic load testing

p = percentage of the total piles that are tested and meet the specified acceptance criteria

Where one or more piles tested fail to meet the specified acceptance criteria, the procedure set out in Clause 8.3.4 shall be followed.

NOTES:

1 The geotechnical strength reduction factor for dynamic load testing relates to high-strain dynamic pile testing systems that involve direct measurement of strain and acceleration at the pile head, and a signal matching process involving simulation of the measured upward travelling stress wave. Alternative dynamic testing systems may be used, but in such cases a geotechnical strength reduction factor should be adopted based on a demonstration of the uncertainties of those systems relative to the high-strain dynamic testing systems described. In no case shall the geotechnical strength reduction factor adopted be higher than the stipulated value for high strain dynamic testing.

2 Where there is a satisfactory correlation between static and dynamic tests, ϕ_{tf} may be increased by 0.05.

4.3.2 Assessment of basic geotechnical strength reduction factor (ϕ_{gb})

The basic geotechnical strength reduction factor (ϕ_{gb}) shall be calculated using a risk assessment procedure as set out below:

(a) Rate each risk factor in Table 4.3.2(A) on a scale from 1 to 5 for the nature of the site, the available site information and the pile design and installation procedures adopted. This will produce an individual risk rating (IRR) according to the assessed level of risk, as set out in Table 4.3.2(B)

(b) Determine the overall design average risk rating (ARR) using the weighted average of the product of all of the risk weighting factors (w_i) shown in column 2 of Table 4.3.2(A) times the relevant individual risk rating (IRR), as follows:

$$ARR = \Sigma(w_i \text{IRR}_i)/\Sigma w_i \qquad \ldots 4.3.2$$

(c) Determine the basic geotechnical strength reduction factor (ϕ_{gb}) from Table 4.3.2(C) depending on the level of redundancy in the piling system. Systems with a high degree of redundancy would include large pile groups under large caps, piled rafts and pile groups with more than 4 piles. Systems with a low level of redundancy would include isolated heavily loaded piles and piles set out at large spacings.

TABLE 4.3.2(A)

WEIGHTING FACTORS AND INDIVIDUAL RISK RATINGS FOR RISK FACTORS

Risk factor	Weighting factor (w_i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate)	5 (Very high risk)
Site				
Geological complexity of site	2	Horizontal strata, well-defined soil and rock characteristics	Some variability over site, but without abrupt changes in stratigraphy	Highly variable profile or presence of karstic features or steeply dipping rock levels or faults present on site, or combinations of these
Extent of ground investigation	2	Extensive drilling investigation covering whole site to an adequate depth	Some boreholes extending at least 5 pile diameters below the base of the proposed pile foundation level	Very limited investigation with few shallow boreholes
Amount and quality of geotechnical data	2	Detailed information on strength compressibility of the main strata	CPT probes over full depth of proposed piles or boreholes confirming rock as proposed founding level for piles	Limited amount of simple in situ testing (e.g., SPT) or index tests only
Design				
Experience with similar foundations in similar geological conditions	1	Extensive	Limited	None

(*continued*)

TABLE 4.3.2(A) (*continued*)

Risk factor	Weighting factor (w_i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate)	5 (Very high risk)
Method of assessment of geotechnical parameters for design	2	Based on appropriate laboratory or in situ tests or relevant existing pile load test data	Based on site-specific correlations or on conventional laboratory or in situ testing	Based on non-site-specific correlations with (for example) SPT data
Design method adopted	1	Well-established and soundly based method or methods	Simplified methods with well-established basis	Simple empirical methods or sophisticated methods that are not well established
Method of utilizing results of in situ test data and installation data	2	Design values based on minimum measured values on piles loaded to failure	Design methods based on average values	Design values based on maximum measured values on test piles loaded up only to working load, or indirect measurements used during installation, and not calibrated to static loading tests
Installation				
Level of construction control	2	Detailed with professional geotechnical supervision, construction processes that are well established and relatively straightforward	Limited degree of professional geotechnical involvement in supervision, conventional construction procedures	Very limited or no involvement by designer, construction processes that are not well established or complex
Level of performance monitoring of the supported structure during and after construction	0.5	Detailed measurements of movements and pile loads	Correlation of installed parameters with on-site static load tests carried out in accordance with this Standard	No monitoring

NOTE: The pile design shall include the risk circumstances for each individual risk category and consideration of all of the relevant site and construction factors.

TABLE 4.3.2(B)

INDIVIDUAL RISK RATING (IRR)

Risk level	Individual risk rating (IRR)
Very low	1
Low	2
Moderate	3
High	4
Very high	5

TABLE 4.3.2(C)

BASIC GEOTECHNICAL STRENGTH REDUCTION FACTOR (ϕ_{gb}) FOR AVERAGE RISK RATING

Range of average risk rating (ARR)	Overall risk category	ϕ_{gb} for low redundancy systems	ϕ_{gb} for high redundancy systems
ARR ≤1.5	Very low	0.67	0.76
1.5 < ARR ≤2.0	Very low to low	0.61	0.70
2.0 < ARR ≤2.5	Low	0.56	0.64
2.5 < ARR ≤3.0	Low to moderate	0.52	0.60
3.0 < ARR ≤3.5	Moderate	0.48	0.56
3.5 < ARR ≤4.0	Moderate to high	0.45	0.53
4.0 < ARR ≤4.5	High	0.42	0.50
>4.5	Very high	0.40	0.47

4.3.3 Assessment of design ultimate geotechnical strength ($R_{d,ug}$)

The design ultimate geotechnical strength of a pile ($R_{d,ug}$) shall be assessed by one or more of the following procedures:

(a) Analysis using data from a site investigation.

(b) Analysis based on dynamic data obtained during installation of test or working piles, via—

  (i) a pile driving formula;

  (ii) a wave equation analysis based on measured blow counts;

  (iii) a closed form dynamic solution based on measured dynamic force and velocity data; or

  (iv) analysis based on stress-wave matching of dynamic test data.

(c) Analysis using data collected during pile installation.

(d) Analysis using data from a static, rapid or bi-directional load test.

NOTE: Procedures (b) and (c) above are generally applicable for the design ultimate geotechnical strength for axial loading only.

For proprietary piling systems that use indirect correlations with measured pile installation parameters to estimate the ultimate strength of a pile, such correlations shall be supported by appropriate data obtained from static load tests carried out at the site or in-ground conditions that can be demonstrated to be similar to those at the site, in accordance with Section 8.

$R_{d,ug}$ shall be computed as set out in Clauses 4.4.1 to 4.4.7. Consideration shall also be given to the factors in Clauses 4.4.8 to 4.4.10.

4.4 DESIGN REQUIREMENTS FOR STRENGTH

4.4.1 Design ultimate geotechnical strength in compression

The design ultimate geotechnical strength of a pile ($R_{d,ug}$) loaded in compression shall be determined as follows:

$$R_{d,ug} = f_{m,s}A_s + (f_b + p_o)A_b - W \qquad \text{. . . 4.4.1(1)}$$

NOTE: It is often sufficiently accurate to assume that $W = A_b p_o$ so that Equation 4.4.1(1) becomes—

$$R_{d,ug} = f_{m,s}A_s + f_b A_b \qquad \text{. . . 4.4.1(2)}$$