

PROPOSED REVISIONS TO THE PILING STANDARD

THE EFFECT OF GEOTECHNICAL INVESTIGATIONS AND TEST LOADS

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ABSTRACT

Proposed revisions to the current version of the Australian Piling Standard will affect the way that the geotechnical and structural engineering professions and the pile construction industry will consider the geotechnical capacity of piled foundations. Significant changes are to the manner in which geotechnical investigations and test load programmes affect the geotechnical strength reduction factor, which are generally lower than the current standard. The proposed changes also reduce the permissible settlement under test load. Special consideration will be required for the structural capacity of piles which are to be test loaded to prove ultimate geotechnical capacity.

This paper discusses some of the proposed changes and compares them to the current requirements. The general emphasis will be for piles for normal industrial, commercial and residential structures. The developers of large infrastructure and heavy industrial projects usually recognize the importance of comprehensive investigation and test programmes and require little incentive to implement them.

1 BACKGROUND

The current version of the Australian Piling Standard, AS 2159, has been in effect since 1995. Since that time there have been significant advances in design analysis and construction of many forms of piling. In 2005, the Standards Association called for comments on proposed revisions to the Standard, (DR05506), designed to reflect these advances. So many comments were received that it has taken almost 3 years to consider them all and to modify the draft where necessary. It is expected that the new version of AS 2159 will be issued in the near future and it is therefore opportune to discuss some of the proposed revisions.

2 FORMAT

The current version of the Australian Standard “Piling – Design and installation, AS2159 – 1995) will be known in this paper as “the Standard” and Supplement 1 to the Standard will be known as the “Supplement”. The draft revisions to the Standard will be known as the “Draft”. The Draft discussed in this paper is dated May 2008. At the time of preparing this paper there is no supplement to the Draft.

The Draft addresses geotechnical capacity, structural capacity and construction aspects of piling. This paper is limited to some of the geotechnical requirements only.

The Draft is a Limit State Design document and this format is used in this paper. The current practice of geotechnical engineers in Sydney of suggesting design “working” pressures will not comply with the Draft (nor with the Standard) and is to be discouraged.

The purpose of this paper is to demonstrate the proposed geotechnical and test changes, not to evaluate them all in detail. As a consequence, many of the procedures and tables are abbreviated to show only sufficient information deemed necessary for this purpose.

3 FACTORS AFFECTING THE GEOTECHNICAL STRENGTH REDUCTION FACTOR IN THE STANDARD

At equation 4.2 the **design geotechnical strength**, R_g^* , is related to the **ultimate geotechnical strength**, R_{ug} , and the **geotechnical strength reduction factor**, Φ_g , as -

$$R_g^* = \Phi_g \cdot R_{ug}$$

Ranges for values of Φ_g are given in Table 4.1 of the Standard, part of which is reproduced as Table 1.

Table 1: Extract from Table 4.1 of AS 2159-1995.

Method of assessment of ultimate geotechnical strength	Range of values of Φ_g
Static load testing to failure	0.70 – 0.90
Dynamic load testing to failure not supported by signal matching	0.50 – 0.70
Static analysis using CPT data	0.45 – 0.65
Dynamic analysis using driving formula for piles in sand	0.45 – 0.55

Guides for the selection of the value of Φ_g are given in Table 4.2 of the Standard, an extract from which is reproduced as Table 2.

Table 2: Extract from Table 4.2 of AS 2159-1995.

Circumstances in which lower end of range may be appropriate	Circumstances in which higher end of range may be appropriate
Less than 1% piles statically tested	3% or more piles statically tested
Less than 3% piles dynamically tested	15% or more piles dynamically tested
Use of published correlations for design parameters	Use of site specific correlations for design parameters
Simple method of calculations	More sophisticated design method.
Limited site investigation	Comprehensive site investigation

There is only one term for ultimate geotechnical strength, although it may be obtained by one or more methods of calculation or test.

There is also only one term for Φ_g , values of which vary from a minimum of 0.45 to a maximum of 0.9, however, in most cases the selection of a design value is subjective. For example, a small contractor may consider its design method to be sophisticated whilst the same method would be considered simple by a large organisation and the two may select substantially different values.

Again, for any site there would be no common view on what is a “comprehensive” site investigation in the above table. Neither the Supplement nor AS1726, “Geotechnical site investigations” provide real guidance into this matter. The Supplement, at Clause 2.4 merely states “*The number of boreholes or tests on any site will be a function of site variability, pile type proposed*”.

4 FACTORS AFFECTING THE GEOTECHNICAL STRENGTH REDUCTION FACTOR IN THE DRAFT

The Draft is more explicit in recommendations for values of Φ_g although there are still some subjective elements. Its derivation is a multi-stage process, not just the simple method given in Tables 4.1 and 4.2 of the Standard.

4.1 GEOTECHNICAL STRENGTH REDUCTION FACTOR

The first stage of determining Φ_g is to calculate the **basic geotechnical strength reduction factor**, Φ_{gb} , using a defined risk assessment procedure. The steps in the procedure are:

- Rate each risk factor in (Table 4.1) on a scale of 1 to 5. ... This will produce an **Individual risk rating (IRR)** according to the assessed level of risk set out in (Table 4.2).
- Determine the **design average risk rating (ARR)** using the weighted average of the product of the IRR and the **risk weighting factor**, w_i , shown in (Table 4.1), as $ARR = \Sigma(w_i \cdot IRR_i) / \Sigma w_i$
- Determine the **basic geotechnical strength reduction factor**, Φ_{gb} , from (Table 4.3).

Selected sections of Tables 4.1, and Tables 4.2 and 4.3 of the Draft are shown as Tables 3, 4 and 5 respectively.

Table 3: Extract from Table 4.1 of The Draft

Risk Factor	Weighting Factor (w _i)	Typical description of risk circumstances for individual risk rating (IRR)		
		1 (Very low risk)	3 (Moderate Risk)	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 bore-holes extending to at least 5 pile diameters below the base of the proposed pile foundation level	Very limited investigation with few shallow bore-holes
Amount and quality of geotechnical data	2	Detailed information on strength and compressibility of the main strata	CPT probes over full depth of proposed piles or bore-holes 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 and geology	1.5			
Assessment of geotechnical parameters for design	2			
Design method	1			
Method of utilising results of <i>in situ</i> test data and installation data	2			
Installation				
Construction control	2			
Performance monitoring of supported structure	0.5			

Table 4: Table 4.2 of The Draft.

Risk Level	Individual Risk Rating (IRR)
Very low	1
Low	2
Moderate	3
High	4
Very High	5

Table 5: Table 4.3 of The Draft

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
ARR > 4.5	Very High	0.40	0.47

The determination of the geotechnical strength reduction factor will now be a defined process. No longer will geotechnical and structural engineers be able to complacently use a “safe working pressure” for pile design. Nor, for most building projects, will one party be able to derive the factor. An inspection of the Risk Factors in Table 3 shows that, where the foundations are designed by the structural engineer, input should also be required from the geotechnical engineer. When the foundations are designed by a piling contractor the structural and geotechnical engineers should have input or, at least, the right to review and modify the design. These scenarios will require degrees of communication and cooperation not often demonstrated at present.

4.2 EFFECTS OF GEOTECHNICAL INVESTIGATION ON THE BASIC GEOTECHNICAL STRENGTH REDUCTION FACTOR, Φ_{GB}

The numerical effects of the scope of the geotechnical investigation on Φ_{gb} are demonstrated by using an example. Three investigations scopes are considered as described below :-

- The Site. The site is level and has an area of 4000 sq.m. The expected geology is for medium to very dense sands to a depth of about 6 metres, very stiff to hard clays to 12 metres, underlain by highly to moderately weathered shale
- The Project. The proposed development is a 4 level concrete frame structure with limit state column design loads in the order of 2500kN.
- Scope of Investigations. The scope for Method 1 comprised 2 bore holes with SPT’s. One bore hole was drilled to rock, the second only to the surface of the clay.
- For Method 2. the Method 1 investigation was extended by 2 CPT’s pushed to rock and 2 only to the clay. The purpose of the additional work was to confirm that groups of piles may be founded at a shallow level or single piles may be installed to rock and to empirically estimate settlements.
- For Method 3. the Method 2 investigation was supplemented by pressure meter testing and laboratory testing to obtain modulus values for settlement calculations.

Table 6: An Example of the Effect of the Scope of Geotechnical Investigations on Φ_{gb} .

Risk Factor	Weighting Factor w_i	Investigation Method 1.		Investigation Method 2.		Investigation Method 3.	
		IRR	$w_i \cdot IRR$	IRR	$w_i \cdot IRR$	IRR	$w_i \cdot IRR$
SITE							
Geological complexity	2	3	6	3	6	3	6
Extent of ground investigation	2	5	10	3	6	1	2
Amount and quality of geotechnical investigation	2	5	10	3	6	1	2
DESIGN							
Experience with pile type in similar conditions	1.5	3	4.5	3	4.5	3	4.5
Method of assessment of geotechnical parameters	2	5	10	3	6	3	6
Design method adopted	1	3	3	3	3	3	3
Utilisation of test data and installation data	2	3	6	3	6	3	6
INSTALLATION							
Level of construction control	2	3	6	3	6	3	6
Performance monitoring of supported structure	0.5	5	1.5	5	1.5	5	1.5
TOTAL	15	35	52	29	40	23	13
AVERAGE RISK RATING		3.47		2.67		2.07	
Φ_{gb} - LOW REDUNDANCY		0.48		0.52		0.56	
Φ_{gb} - HIGH REDUNDANCY		0.56		0.60		0.64	

The IRR for factors affected by the scope of the investigations are shown in Table 6 in bold type. For these purposes the IRR’s for other factors in Table 3, have been selected by the author as being typical or average values. They are kept constant for all investigation scopes so that the only changes to Φ_{gb} are due to the investigations.

If the final design solution is to be single piles the values of Φ_{gb} should be those for low redundancy systems; the higher values should be used for pile groups. This exercise shows that increasing the scope of the investigation from a low cost (method 1) option to a “normal” one may increase the value of the factor by an average of 8%, while having an expensive option may increase it by 15%. The cost of the foundations would be expected to be reduced by a similar percentage.

4.3 TEST LOADING

A further effect to be considered here is that of a test loading programme on the value of Φ_g . If there is to be no test loading programme the following equation infers that this step may be omitted and that $\Phi_g = \Phi_{gb}$.

In Section 4.3 of the Draft, General Principles of Geotechnical Strength Design, an equation (not numbered) states:

$$\Phi_g = \Phi_{gb} + (\Phi_{tf} - \Phi_{gb}) \cdot K \geq \Phi_{gb}$$

where :

- Φ_{gb} = basic geotechnical strength reduction factor
- Φ_{tf} = intrinsic test factor.
- K = testing benefit factor
 = $1.13p/(p + 1.33) \leq 1$ for static or rapid load testing,
 = $1.13p/(p + 6.67) \leq 1$ for dynamic load testing.
 p = percentage of piles that are tested and meet the acceptance criteria.

Typical values recommended for the Intrinsic test factor are:

- 0.9 for static test loading
- 0.8 for dynamic test loading of preformed piles
- Φ_{gb} for no testing

Recommended values of Φ_{gb} , discussed later, range from 0.4 to 0.76. The effects of test load programmes on the values of Φ_g for static load test and dynamic test load programmes on preformed piles are shown in Table 6.

Table 7: Effect of test loading on the geotechnical strength reduction factor.

1) Static Load Tests, Preformed Piles								
Φ_{gb}	Value of Φ_g/Φ_{gb} for percentage of piles test loaded							
	0%	1%	2%	3%	4%	5%	10%	20%
0.40	1.00	1.61	1.85	1.98	2.06	2.12	2.25	2.25
0.50	1.00	1.39	1.54	1.63	1.68	1.71	1.80	1.80
0.60	1.00	1.24	1.34	1.39	1.42	1.45	1.50	1.50
0.70	1.00	1.14	1.19	1.22	1.24	1.26	1.28	1.29
0.76	1.00	1.09	1.13	1.14	1.16	1.16	1.18	1.18
2) Dynamic Load Tests, Preformed Piles								
Φ_{gb}	Value of Φ_g/Φ_{gb} for percentage of piles test loaded							
	0%	1%	2%	3%	4%	5%	10%	20%
0.40	1.00	1.15	1.26	1.35	1.42	1.48	1.68	1.85
0.50	1.00	1.09	1.16	1.21	1.25	1.29	1.41	1.51
0.60	1.00	1.05	1.09	1.12	1.14	1.16	1.23	1.28
0.70	1.00	1.02	1.04	1.05	1.06	1.07	1.10	1.12
0.76	1.00	1.01	1.01	1.02	1.02	1.03	1.04	1.04

On the small proportion of projects where test loads are required, specifications typically require between 1% and 3 % of piles to be statically tested. The table shows that the geotechnical strength of piles designed with a low value of Φ_{gb} , 0.40, may be increased by 61% to 98% if such programs are implemented. For cases with a very high value of Φ_{gb} , 0.76, the increases reduce to 9% to 14% if such programs are implemented.

Similarly, when dynamic test loads are required, specifications typically require between 5% and 20 % of piles to be tested. The table shows that the geotechnical strength of piles designed with a low value of Φ_{gb} of 0.40 may be increased by 48% to 85% if such programs are implemented. For cases with a very high value of Φ_{gb} of 0.76 the increases reduce to 3% to 4% if such programs are implemented.

It must be emphasised that these higher factors can only be adopted if the tested piles meet the specified acceptance criteria.

5 TEST LOAD PROGRAMMES

The test loads required to take advantage of the above provisions are to be to the design geotechnical strength or, preferably, the ultimate geotechnical strength, as described in Section 8 of the Draft. In addition to the effects of test loading programmes on the strength reduction factor, some significant changes are proposed to the section of the standard that deals with the methods of testing and performance assessment.

5.1 TEST LOAD REQUIREMENTS IN THE STANDARD

There is no specific requirement for test loads in the Standard, although there are general statements promoting their use.

5.2 TEST LOAD REQUIREMENTS IN THE DRAFT

The Draft proposes a new clause, 8.1.5, Requirement to test. In part this clause states:

- a *“...If the design ultimate geotechnical strength is not verified by pile testing, the basic geotechnical strength reduction factor as given (above) shall be adopted in design.”*
- b *“Where the geotechnical strength reduction factor is 0.4 or less, no testing is required, unless otherwise specified, ...”*
- c *“Where the geotechnical strength reduction factor is greater than 0.4 the following testing shall be undertaken.”*

The testing in subclause (c) specifies testing requirements for serviceability for piles where the ARR exceeds 2.5, as shown in Table 8. The serviceability load is typically accepted as being 75% of the design load for strength. These may be static or dynamic tests with the same acceptance criteria as discussed below. There are additional tests required for integrity and construction control purposes that are not discussed here.

Table 8: Table 8.1 from Draft: Pile testing requirements for serviceability.

Average risk rating	2.50-2.99	3.00-3.49	3.50-3.99	4.00-4.49	≥4.5
Percentage of piles to be tested for serviceability	1	2	3	5	10

5.3 ACCEPTANCE CRITERIA IN THE STANDARD

The acceptance criteria for piles statically tested in compression are given in its Table 8.2 and for piles dynamically tested in Clause 8.6. These are shown together in Table 9 below.

Table 9: Acceptance criteria for test loads in compression from the Standard

Load	Maximum Deflection - mm	
	Static Tests	Dynamic Tests
Serviceability load	15	12
0 (after removing serviceability load)	7	
1.5 x design action effect (S*)	50	35
0 (after removing 1.5 x design action effect)	30	

5.4 ACCEPTANCE CRITERIA IN THE DRAFT

The proposed acceptance criteria include for the stiffness of the pile shaft as shown in Table 10. For this purpose the effects of negative skin friction have been omitted.

Table 10: Acceptance criteria for test loads in compression according to the Draft

Load	Maximum Deflection - mm	
	Static Load Tests	Dynamic Load Tests
Design serviceability load, P_s	$P_s L/AE + 0.1d$	$P_s L/AE + \max(0.1 d_b, 5)$
0 (after removing P_s)	$\max(0.1d_b, 5)$	$\max(0.1 d_b, 5)$
Maximum test load for assessment of geotechnical ultimate limit state, P_g	$P_g L/AE + 10 + 0.5d$	$P_s L/AE + 10 + 0.5 d_b$
0 (after removing P_g)	$10+0.05 d$	$10+0.05 d_b$

For a 450mm diameter pile, at typical pile stresses (P/A) of 10 MPa at serviceability load and 25 MPa at ultimate geotechnical capacity and a modulus of 30 GPa, the acceptance criteria for pile lengths of 5 m, 10 m and 15 m are shown in Table 11.

Table 11: Typical acceptance criteria for test loads in compression on concrete piles according to the Draft

Load	Acceptable Deflection - mm					
	Static Load Tests			Dynamic Load Tests		
	5 m long	10 m long	15 m long	5 m long	10 m long	15 m long
Design serviceability load, P_s	6.2	7.8	9.5	6.7	8.3	10.0
0 (after removing P_s)	5.0	5.0	5.0	5.0	5.0	5.0
Maximum test load for assessment of geotechnical ultimate limit state, P_g	36.7	40.8	45.0	36.7	40.8	45.0
0 (after removing P_g)	32.5	32.5	32.5	32.5	32.5	32.5

All values are considerably less than the Standard.

5.5 A CAUTIONARY NOTE REGARDING TEST PILES.

There are two separate parts to the design of piles – geotechnical and structural. The strength reduction factors used in the structural design are higher than those used for the geotechnical design, so that the ultimate geotechnical strength should be greater than the structural strength. Consequently, a working pile should only be selected for testing to assess its serviceability or adequacy of the construction method. If a pile is to be tested to the design geotechnical strength or the ultimate geotechnical strength it should be specially designed and constructed to ensure that the purpose of the test is achieved. For example, for concrete piles the compressive strength of the concrete may be increased or additional reinforcement used; in the case of steel screw piles the thickness of the helix should be increased. The principal pile dimensions are to be the same as the working piles and the certifying authority should also ensure that the field installation criteria (i.e. set, torque etc.) are the same as for the working piles.

6 CONCLUSIONS

The proposed amendments to the Piling Standard will make the installation of piles more expensive than at present. The major influences will be:

- The introduction of Risk Ratings to assess the strength reduction factor is, in the author’s opinion, a welcome addition to the Piling Standard. However, in the majority of projects, the geotechnical strength reduction factor will be less than the Standard. Members of the Piling Federation have confirmed this after comparative studies on several projects. This means that piles must be larger and or deeper to achieve the same design strength.
- The design geotechnical capacity may be improved by test loading programmes. Table 7 indicates that this may be cost effective for small percentages of static test loads where the strength reduction factor would otherwise be low but would not be cost effective for high percentages nor for any case where the strength reduction factor is high. The cost effectiveness of dynamic load tests appears to be considerably lower. (The author understands that the formula for “K” is currently under review to adjust the relative economic imbalance between static and dynamic testing. Nevertheless, the benefits will remain with those projects where the strength reduction factor is low.)
- The requirement for serviceability load tests for projects with a strength reduction factor higher than 0.4 will add a cost that does not occur at present. This can be eliminated by using a strength reduction factor of 0.4 on all projects, reducing all work to that of the lowest standard. This cannot be helpful to any industry.

- In addition to the reduction in design capacity the Draft specifies reduced acceptable settlements. Thus the design process is to be doubly affected.

In the author's opinion, this is unnecessary. The author is not aware of any structure, where the piles were designed and tested to the Standard, which has suffered structural damage due to excessive settlement.

- Revisions to the structural design sections of the Draft will also result in higher cost

Some of the additional piling costs can be offset by improving the general standard of geotechnical investigation and it is to be hoped that this will be the result. In the previous example, it is unlikely that the scope of Method 3 would be economically justified on a relatively small project. However, Method 2 would provide a more economical foundation at a reasonable cost and with a better return for the developer. On medium size projects a combination of improved geotechnical investigation together with a test loading programme will be the most cost effective method.

7 FUTURE AMENDMENTS

This review of proposed changes to the Australian Piling Standard is based on the latest available draft. All of the factors and terms are subject to change before final publication.

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