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Bridge design—Foundations and soil-supporting structures—Commentary (Supplement to AS 5100.3—2004)

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PREFACE

This Commentary was prepared by the Standards Australia Committee BD-090, Bridge Design, to supersede HB 77.3 Supp 1—1996, *Australian Bridge Design Code—Foundations—Commentary (Supplement to SAA HB 77.3—1996)*.

The objective of this Commentary is to provide users with background information and guidance to AS 5100.3—2004. This Commentary differs from its predecessor in that many equations and analytical methods are not presented. The Commentary instead focuses on design principles and practical considerations and provides references that can be used for guidance.

This Commentary includes advice on site investigation techniques and worked examples, which can be found at the end of the document.

The Standard and Commentary are intended for use by bridge design professionals with demonstrated engineering competence in their field and geotechnical engineers involved with the investigation, analysis and design of bridge foundations and related soil-supporting structures.

In this Commentary, AS 5100.3 is referred as ‘the Standard’ and the Commentary itself is referred to as ‘the Commentary’.

The clause numbers and titles used in the Commentary match those in AS 5100.3. To avoid possible confusion between the Commentary and the Standard, a commentary clause is referred to as ‘Clause C……’ in accordance with Standards Australia policy.

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C1 SCOPE

The Standard provides procedures for the design of foundations and soil-supporting structures commonly encountered by engineers involved in the detailed design of road and railway bridges and associated structures. The Standard uses limit state methods. Strength, stability, serviceability and durability limit state requirements have to be satisfied.

The design and construction of reinforced soil structures is not covered by the Standard. Guidance may be found in BS 8006 (Ref. 1) and Elias, Christopher and Berg (2001) (Ref. 2) or State Road and Railway Authority specifications.

C2 APPLICATION

The Standard provides the analytical procedures to be adopted and the numerical values for the required relevant geotechnical strength reduction factors. The loads to be applied to structures are those specified in AS 5100.2, including earth pressure loadings. However, design engineers should recognize the following:

(a) AS 5100.2 specifies that soil-imposed loads on retaining walls and the like have to be obtained from AS 4678. The design of foundations and soil-supporting structures, such as earth-retaining bridge abutments for bridges and other road and rail-related structures, has to be carried out in accordance with AS 5100.2 and AS 5100.3, not AS 4678.

    Where factoring of loads is specified, the density of soils is factored by the factor (γ_{ge}) given in AS 5100.2.

(b) AS 4678 uses factored loads and factored characteristic values of soil and rock parameters when calculating ground related actions (e.g., active or at-rest ‘disturbing’ forces) and resistances (e.g., bearing capacity, passive force, sliding resistance and the like). This is different from the requirements of the Standard.

(c) For the strength and stability design of foundations, the Standard requires a similar approach to that of AS 2159 where loads and action effects are factored prior to carrying out the analysis, using unfactored characteristic values of soil and rock material parameters (see Clause 7.3.2(c)) with the calculated resistances subsequently factored and the design inequality compared to verify that the factored resistances are greater than the calculated design action effects.

(d) For the strength and stability design of soil-supporting structures, the Standard requires the geotechnical analysis to be carried out using unfactored loads and unfactored characteristic values of soil and rock material parameters (see Clause 7.3.3(d)) with the design action effects and resistances subsequently factored and the design inequality compared to verify that the factored resistances are greater than the calculated design action effects.

The design engineer also has to demonstrate that all other limit state requirements of the Standard are satisfied.

Item (a) should be taken to mean only that the characteristic values of soil and rock material parameters given in AS 4678 may be used in the absence of more reliable site-specific data for calculating the loads and resistances required by the Standard.

Items (b), (c) and (d) are philosophically different and great care needs to be taken to ensure consistency in any one analysis or design. Items (b), (c) and (d) should not be mixed or confused.

The approach taken for the design of soil-supporting structures described in Item (d) is intended to ensure that the designer is working with realistic values of soil and rock parameters to give realistic analytical results, which can then be compared with limiting strength parameters for the soils and rocks at the site. Unlike most structural analysis, which usually assumes linearly elastic behaviour, geotechnical analysis should accommodate non-linear soil and rock behaviour under imposed loads and deformations, with behaviour largely dominated by the soil friction angle (ϕ').

Any design engineer who is not clear about the different approaches of Items (b), (c) and (d) should seek guidance from a more experienced design engineer before undertaking design in accordance with the Standard.

Because the strength and stability limit states are checked using unfactored loads and material parameters, the serviceability limit state can also be readily checked using the same analytical model.

Computer analysis has become the norm for geotechnical engineers in recent years, displacing the earlier reliance on design charts, tables and technical papers. Many of the available programs are on the face of it easy to use and yet most are complex, involve making specific assumptions about ground behaviour, and often require input parameters that cannot readily be determined from normal field and laboratory tests. Programs need to be used with care by design engineers who understand the assumptions made, the parameters being used and the basic principles relied on by the program. This will normally mean having undergone specific training, or having had a long familiarity with geotechnical methods of analysis. Comparison of output values with limiting values should be carried out to assess whether the requirements of the Standard are met.

Computer output is not necessarily in a form that readily indicates whether the requirements of the Standard have been met. As an example, output from a typical retaining wall design or finite element program may give—

(i) an indication that equilibrium has been achieved;

(ii) the calculated deflections over the full height of the wall (and surrounding ground in the case of a finite element and other sophisticated analytical programs);

(iii) the stresses and deformations in the soil; and

(iv) the calculated stresses, shears and moments in the wall,

without directly providing information that allows the design engineer to determine either R_{ug} or S^*. In this case, comparisons of the output using hand calculations or spreadsheets with limiting values of the relevant design action effects may be required to demonstrate that the requirements of the Standard are satisfied.

R_{ug} and S^* being design actions effects are not necessarily forces and could be stresses, deformations or any other output parameter. If the program does not provide relevant limiting values for these parameters, then they can usually be readily calculated using basic soil parameters such as ϕ', c', σ_z and the like using equations and formulas found in relevant and reliable texts.

C3 REFERENCED DOCUMENTS

Standards referred to in the Standard and this Commentary are subject to revision from time to time and the current edition should always be used. The currency of any Standard may be checked with Standards Australia.

The predecessors of the Standard and their commentaries generally provided full details of published methods of analysis, but most of those methods have been superseded following ongoing research and development. In keeping with a focus on computer methods, most of the previously published methods have been replaced by references to general texts which contain many of the original references, but also provide a broader overview of the earlier work, putting it into context and recommending approaches to geotechnical analysis that have been found by experience to be the most useful or relevant.

C4 DEFINITIONS

Technical definitions are generally provided in a Standard. Technical definitions that are applicable to only one clause are usually given in the clause to which they are relevant.

In the Commentary, the terms 'substructure' and 'substructure element' are used to mean any footing, piled foundation, abutment or retaining wall that forms part of a bridge or associated road or railway structure.

The term 'hand calculation' is used to mean traditional methods of analysis using design charts, tables and simple numerical analysis (including spreadsheets), as opposed to commercially available geotechnical computer programs.

C5 NOTATION

The basis of the notation is generally in accordance with ISO 3898, *Bases for design of structures—Notations—General symbols*. Standards Australia's policy is to use ISO recommendations for notation wherever practicable in structural design standards. A general summary can be found in AS/NZS 1170.0.

C6 SITE INVESTIGATION

C6.1 General

As specified in the Standard, site investigation should be carried out as a routine procedure to provide the information necessary for the design and construction of foundations and soil-supporting structures. It is desirable to have completed site investigation before design begins, but investigations can sometimes be in stages as discussed further in Clause C6.2.

The objectives of a site investigation are to—

(a) develop a geological/geotechnical model of the site. This should clearly indicate stratification and structure of the soils and rocks on the site and identify pre-existing features (e.g., an old landslide or karst formations) that could adversely impact on the proposed construction;

(b) determine geotechnical parameters needed for the analysis and design of the substructure elements and their likely variability;

(c) locate the groundwater table, if it is likely to affect foundation construction or performance; and

(d) assess likely water inflows to excavations where they could impact on construction.

The site investigation needs to be of sufficient extent to be used to evaluate the effect of the proposed construction on adjacent structures and properties.

Ground is inherently variable and, as a result, never totally predictable. Unknowns should be reduced, as far as is reasonably possible, by investigation. Close liaison between the bridge design engineer and the geotechnical engineer is desirable from the start of all but the simplest of projects. Working together, they should plan the site investigation and testing program, taking into account the specific requirements of the proposed structure (e.g., likely foundation loads, sensitivity of the structure to differential settlement, preferred construction method and the like) and of the site (e.g., access difficulties, anticipated geology, environmental considerations and the like). Having understood and agreed what design information is required, the geotechnical engineer should undertake the investigation and testing, interpret the data and prepare a geotechnical report.

For foundations bearing on refuse, uncompacted fill or soft, loose or highly compressible soils, rigorous investigation, testing and analysis will be required unless foundations are to be founded beneath the problem ground. If problems involving hydrology, vegetation, surface water, mine subsidence, acid sulfate soils or environmental factors are encountered or suspected, the investigation should specifically look at these aspects.

Be conscious of what might not be known about a site. For sites with complex or initially unknown geotechnical conditions, the approach to the site investigation should be flexible, with a willingness to vary the approach depending on the findings. Where the design investigation indicates there is still uncertainty, additional investigation and proving of ground conditions may be required during construction.

C6.2 Design investigations

AS 1726 specifies details of available investigation and testing techniques. In particular, AS 1726 provides—

(a) a list of available field test methods;

(b) a list of laboratory examination and testing methods; and

(c) an outline brief for a geotechnical investigation, which can be used to guide the design engineer or the geotechnical engineer, or both, when planning a site investigation.

The Clause and the ‘Advice on Site Investigation Techniques’ at the end of the Commentary are provided to assist design engineers to evaluate site investigation requirements and methods. Within reason, site investigation costs should be considered to be of secondary importance to getting the right information for design. In deciding what is required of a site investigation, consideration should be given to the consequences of getting the answers wrong.

As specified in the Standard, a preliminary investigation is often a help on a major project, since it can provide an initial indication of preferred foundation type and cost during concept design. On major projects, it is sometimes beneficial to undertake site investigation as a progressive process, with data acquisition keeping pace with the level of detail of the design. All site investigation data is useful and none should be ignored unless it can be shown to be erroneous.

The only site investigation requirements specified in the Standard are the minimum number of boreholes for bridge foundations (Clause 6.2(a)) and for culverts, retaining walls and the like (Clause 6.2(b)). It should be noted in relation to what follows that the word borehole should be taken to include any site investigation method chosen for the particular project. As a further guide:

Variability

- The number of boreholes should normally be increased when ground conditions are uncertain or, from a knowledge of the local geology, are expected to be variable.

Borehole depth

- Borehole depths should be sufficient to penetrate all strata likely to influence foundation behaviour. This requires the investigation to extend below the anticipated founding level. Low strength or highly compressible strata below the founding level should be identified and properties determined.
- For spread footings and pile groups, borehole depths should normally extend below the founding/pile toe level to at least 1.5 times the width of the substructure element, for nearly square substructures, and to at least 3 times the width when the length/breadth ratio of the substructure exceeds 3.
- Where individual piles, as opposed to pile groups, are to be used, the site investigation should extend to at least 10 times the pile diameter below the founding level, or at least 5 m, whichever is the greater. Soft strata encountered below proposed pile toe levels should be fully investigated to obtain data needed to assess the potential for punching failure or excessive settlement.
- For embankments, investigation depth should normally extend below the founding level to at least 1.5 times the embankment width.
- In cuttings, boreholes should extend to a depth of at least 1 m beneath the base of the proposed excavation. Where excavation will leave substantial cut batters, boreholes should extend sufficiently far into the underlying soils to check slope stability.

Number of boreholes

- Where retaining walls will be constructed, additional boreholes should be drilled every 30 m along the centre-lines of the walls.
- In cuttings, site investigation should involve not less than four boreholes giving general coverage and a minimum spacing corresponding to one borehole for every 10 000 m^3 to be excavated. Additional boreholes should be drilled in areas where changes of excavation method could be required, such as where a soil/rock interface occurs, or the water table will be intersected. This information is not only needed for design purposes, but is also important for estimating quantities and the cost of different excavation and disposal methods.
- Where approach embankments are less than about 2 m in height, a minimum of one borehole per 100 m of embankment may be adopted. Where poor subsoil conditions (e.g., peat, soft clay, high water table, acid sulfate soils) are anticipated, this number should be increased in order to define the extent of the problem. Test pits may be substituted for boreholes where stiff to hard soils, or weathered rocks, exist close to the surface.
- Where approach embankments are more than 2 m in height, a minimum initial investigation of 2 boreholes per 100 m of embankment is recommended. Boreholes should be distributed across the embankment width in order to define differences in the depth of compressible strata. In situ and laboratory testing should be undertaken so embankment stability and settlement behaviour can be assessed. Additional boreholes and test pits may also be required.

Other considerations

- More than the minimum number of boreholes may be required.
- Where ground conditions could vary transversely, boreholes should be located either side of the centre-line to define the variation.