STAND 17

New Draft AS - Earth Retaining Structures (including reinforced soils)

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Summary The proposed new standard intends to promote good practice applicable to earth retaining structures, including reinforced soil. The standard is based on the principles of limit state design, generally formulating requirements in terms of factored loads and material properties multiplied with reduction factors. This approach delivers guidelines which ensure that all soil retaining structures provide a comparable minimum overall safety factor (or reliability) over the stipulated design life, although they may be made of widely different materials, such as steel and geosynthetics. The new design philosophy is also expected to have positive impacts on the overall management of geotechnical projects.

1. INTRODUCTION

When Standards Australia issued the Draft British Standard BS 8006 *Strengthened/reinforced soils and other fills* as the Australian Draft Standard DR 91273 (December 1991), they were responding to a need for retaining wall and reinforced soil guidelines in the civil engineering industry. Committee CE/32 was then formed to assess the Public Comments up to the deadline of 31st January 1992. Members of this committee represented a cross-section of the engineering profession interested in retaining structures.

In the light of the comments received, the committee abandoned the idea of a wholesale acceptance of BS 8006, which may possibly have been followed by BS 8002 *Earth retaining structures* at at a later date. Committee CE/32 decided instead to first develop a simpler, shorter general code applicable to all types of conventional and reinforced soil structures. It was decided that the proposed new general code was to give practical guidelines with respect to site and materials investigations, loading, design parameters, construction demands and performance monitoring, without evolving into a textbook of alternative mathematical procedures for analysis.

Originally entitled *Reinforced soils and retaining structures*, the new draft standard is expected to appear in mid-1996 undert the title *Earth retaining structures (including reinforced soils)*. Please note that at the time of writing this paper, some issues remained unresolved and notation was still subject to change.

2. THE NEW STANDARD'S STRUCTURE AND LINKS

The new standard has links with previous Australian Standards, such as the ones on *Piling - Design and installation* (AS 2159-1995), *Geotechnical site investigations* (AS 1726-1993), Guidelines on earthworks for commercial and residential developments (AS 3798), *the Loading code* (AS 1170) and others. However, none of these standards tackled the complexity of applying the limit state design approach for geotechnical problems to the same depth as the new standard. It was therefore necessary to seek guidance from Eurocode 7 (1994) and adopt many concepts from BS 8006.

There are seven main sections (complemented with informative appendices) covering

- Scope and General
- Investigation and Testing
- Design requirements
- Design loads
- Material design factors
- Construction
- Performance monitoring

This paper gives background information on the application of the limit state analysis to retaining structures and reinforced soil and shows that the adoption of the limit state design philosophy has positive effects on the management of geotechnical project as a whole.

3. DESIGN REQUIREMENTS

Design requirements are formulated in some ten subsections of the new standard, often with references to informative appendices. The latter are non-obligatory guidelines which assist design engineers without unduly restricting the introduction of alternative, possibly innovative and better methods and parameters. A brief outline of major design considerations follows below.

3.1. Safety

With respect to stability and strength, there are basically three deterministic approaches to geotechnical design. Safe design is expressed in terms of:

1. A total factor of safety (F)
2. Partial factors of safety ΔF_i
3. Factored loads and resistances (LRFD = Load and Resistance Factored Design).

All these design methods attempt to ensure that the stresses in the structure are adequately safe with respect to the particular failure mode considered. For the same mechanistic model of failure, however, these three approaches vary in the degree with which they consider the variability of loads and material properties. The LRFD approach adopted in the new standard is the most sophisticated and should lead to the most consistent structural reliability (or risk of failure).

The next level up in complexity are pure probabilistic approaches, in which the safety of an earth structure is expressed only in terms of reliability or probability of failure, and where material properties include parameters describing their variability. However, a meaningful probabilistic solution requires extensive material and structural performance data and is often too costly or too complex to be feasible.

Note that the traditional *limit equilibrium* approach (or limit analysis) in geotechnical engineering considers the same failure mechanisms as defined by the ultimate limit states. However, by also covering serviceability (see 4.2) and durability issues the term *limit state analysis* covers a wider range of problems.

3.2. Durability

Both ultimate and serviceability limit states may be affected by the *durability* of the materials with respect to wear, creep and corrosion or chemical degradation with time. In the past, global factors of safety often have intrinsically covered durability issues with conventional building materials such as concrete. However, with the introduction of thin steel reinforcing elements and geosynthetics embedded in soil, durability issues have demanded closer examination.

Linked with durability is a concious decision with respect to the design life of a structure. Design life as well as a the consequences of structural failure impact on the safety requirements. The new standards gives an indication of the expected design life of typical structures and recommends design factors recognising their importance with respect to economic values and human life. The latter is achieved by a structure classification system.

3.3. Drainage and constructability

The new standard emphasises that all conventional and reinforced soil retaining structures shall be provided with adequate drainage. The importance of the provision of long term drainage for retaining walls is evident from the standard's stated design requirements and the inclusion of design examples in an appendix. An extract is shown in Fig. 1.

Drawings need to give sufficient detail for satisfactory construction, specifying maintenance and monitoring programs where required. It is hoped that by more fully addressing the question of "constructability" in the design, the incidence of failures in temporary and short life structures can be reduced.

3.4. Investigation and performance evaluation

Structure classification also impacts on the extent of the site investigation before construction and the required performance monitoring after construction. The standard provides convenient checklists for the planner, designer or owner of a structure.

4. LIMIT STATE ANALYSIS

The term *ultimate limit states* refers to conditions involving loss of stability or rupture caused by the applied forces exceeding the strength of the materials.

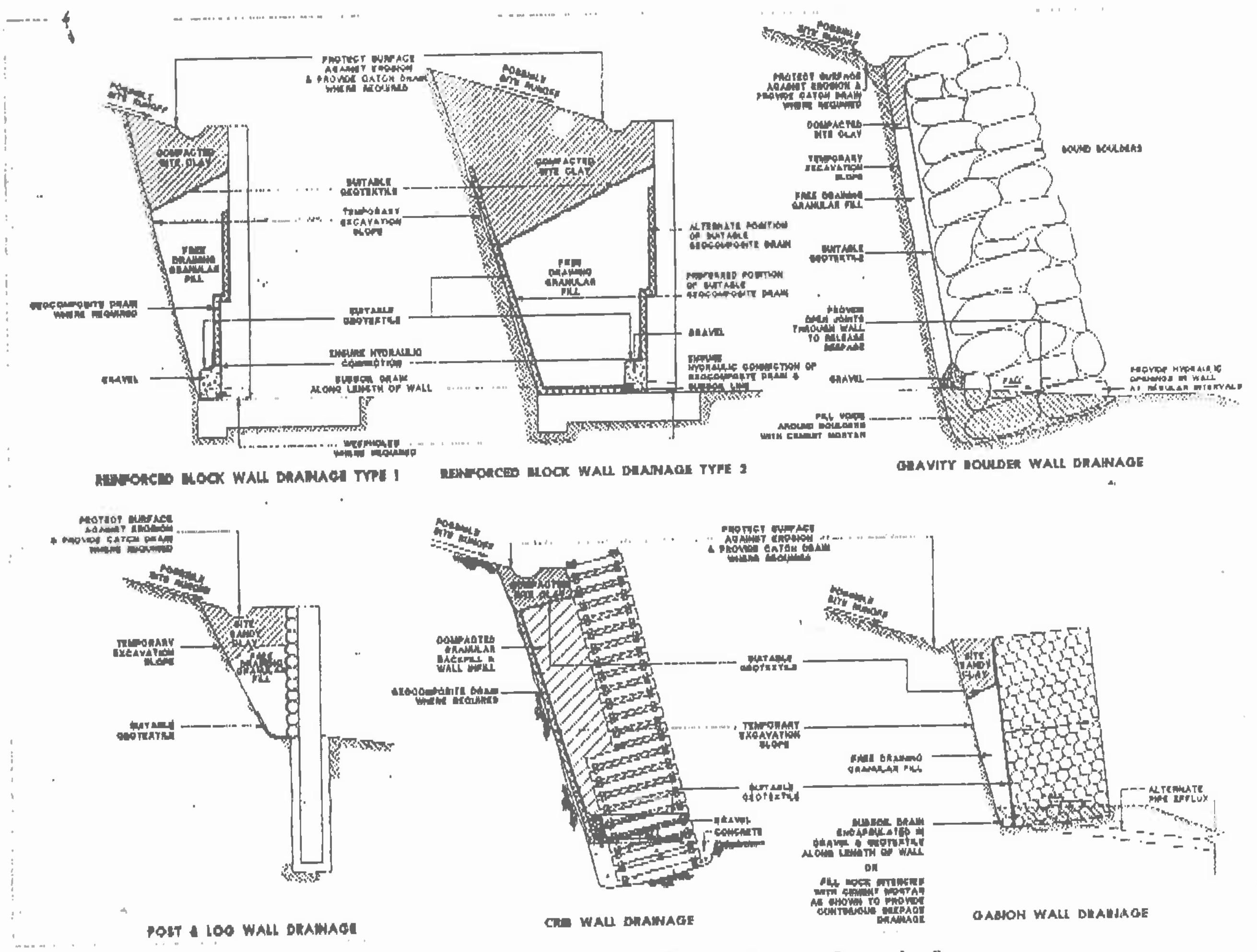


Fig. 1. Typical drainage details for earth retaining structures (extract from draft standard)

Serviceability states are those related to excessive deformations or vibrations or other factors which interfere in an unacceptable way with the structures itself or the people using it.

In the LRFD approach for ultimate limit states structural resistances R_i are reduced to safe levels by multiplication with material design factors Φ_i and loads S_i are factored by ψ_i (load factors). Design is then based on satisfying the equation

$$\Sigma\, \Phi_i R_i \quad \geq \quad \Sigma\, \psi_i S_i$$

or simply

$$R_d \quad \geq \quad S_d$$

Where R_d is the design capacity and S_d is termed the design action effect accounting for all the factored loads. For serviceability analysis, R_d could represent a function of the stress-strain modulus and S_d could be the tolerable deformation.

4.1. Ultimate limit states

The basic ultimate failure modes for retaining structures include sliding, rotation, rupture of components, pull-out of reinforcing elements, loss of bearing capacity and other local or global failure mechanisms with wedges or slip circles.

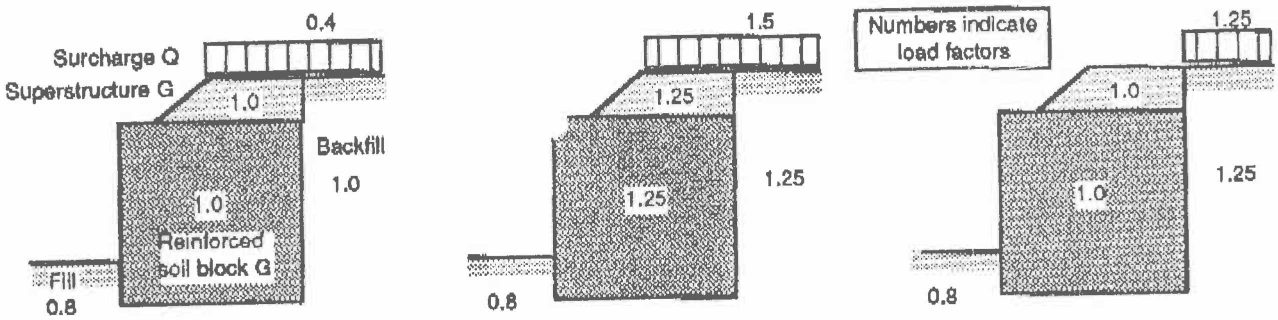
4.2. Serviceability limit states

Serviceability limit states of a retaining structure may occur with external slope instability, internal settlement and lateral movement, soil volume change, creep or increasing corrosion or degradation of reinforcing elements.

4.3. Design loads and load combinations

Dead load and live loads, including earth pressures and hydrostatic pressures are to be calculated generally according to AS 1170.1 but with the following modifications:

- There is to be a minimum surcharge of 5 kPa.



Load combinations for serviceability | Load combinations for strength | Load combinations for stability

Fig.2 Load combinations for limit states of retaining structures

- Earth pressures due to soil weight calculated using material reduction factors should only attract a load factor of 1.25, rather than 1.5.

Typical load combinations applicable to retaining structures are shown in Fig.2.

4.4. Material design factors

Design parameters are obtained by multiplying representative geotechnical and material properties by one or more factors falling into the following categories:

- Reduction factors Φ_r . These account for identified causes of decrease in soil or structural strength (creep, corrosion, temperature, ...)
- Uncertainty factors Φ_u. These reflect unknowns and uncertainties.
- Structure classification factors Φ_c. These relate to importance of the structure and the associated risks of failure.

Reduction factors and uncertainty factors are always less than 1. Structure classification factors may be more or less than one. Actual magnitudes depend on whether the representative properties are mean values or characteristic values, and whether the analysis concerns ultimate limit states or serviceability.

Sometimes a large number of factors are involved in arriving at a design resistance. For example, the design strength of a soil reinforcing element is given by

$$T_d = T_u \Phi_{up} \Phi_{rc} \Phi_{ue} \Phi_{ri} \Phi_{rt} \Phi_{rs} \Phi_{rst} \Phi_{ud} \Phi_c$$

where T_d = design tensile strength
T_u = short term strength
Φ_{up} = product uncertainty factor

Note: This value depends on whether T_u is a characteristic strength or a guaranteed minimum.

Φ_{rc} = creep reduction factor
Φ_{ue} = extrapolation uncertainty factor
Φ_{ri} = reduction factor (installation damage)
Φ_{rt} = reduction factor (thickness)
Φ_{rs} = reduction factor (strength)
Φ_{rst} = reduction factor (temperature)
Φ_{ud} = uncertainty factor (overall degradation)
Φ_c = structure classification factor

Which ones of the factors are relevant and their actual values will depend on the material involved (steel, geosynthetics, etc). Because of the great variety of reinforcement products on the market and their continuous development, it cannot be expected that a standard or code of practice prescribes design factors for all possibilities, except perhaps conservative minimum figures. It is thus up to the manufacturers to demonstrate that they have done enough research for less safe but more economic factors to be applied.

5. DESIGN FACTORS FOR GEOTECHNICAL ANALYSIS

Although limit state design has been around for some time, many aspects of its formulation, notation and details of application to geotechnical problems remain non-uniform. Indeed, some issues are not yet resolved to the satisfaction of all engineering practitioners, as the problems raised below illustrate.

5.1. Mean, characteristic and design values

Fig.3 shows the distribution of S-values (actions, loads) and R-values (resistance, capacity) for a particular problem. Total (or global) factors of safety are generally formulated in terms of mean values. In

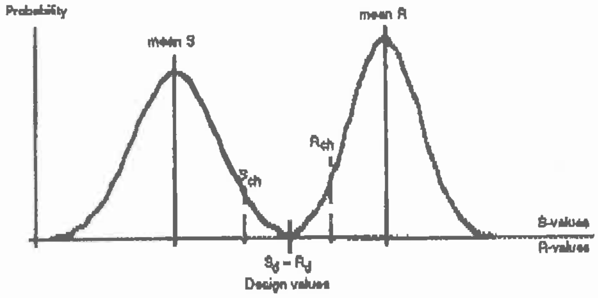


Figure 3. Distribution of action values and material properties

the LRFD approach a conscious decision has to be made whether the design values S_d and R_d are to be obtained by factoring the mean or the characteristic values. In statistical terms, the characteristic resistance R_{ch} is often defined as the value which is exceeded by 95% of the test results; the characteristic action effect S_{ch} would be larger than 95% of the expected action effects. Where statistical information is not available, the characteristic value could be replaced by a "cautious estimate of the mean". The latter wording has been adopted in several European codes. It is debatable whether characteristic soil properties estimated by geotechnical engineers generally correspond to 95% probabilities or lesser values.

The most economic or most acceptable design dimensions or ground modifications are then derived from the equation $S_d = R_d$, where the design action effect is set equal to the design capacity.

In practice, design values are mostly determined using relatively conservative empirical reduction factors, but for major projects with an extensive site investigation program, more elaborate statistical methods may be feasible. This extra effort may bring worthwhile economies to the project since the simplistic approach may lead to overly safe design.

5.2. Factoring soil parameters or resultant forces

The proposed Australian standard for earth retaining structures (including reinforced soil) suggests to use factored characteristic soil strength parameters to calculate earth pressures and shear resistance. In contrast, the new draft Australian piling standard (AS 2159-199X) simply gives the geotechnical design capacity R_d of a pile in the form

$$R_d = \Phi_g R_{ug}$$

where the ultimate geotechnical capacity R_{ug} is multiplied by a single geotechnical reduction factor Φ_g which varies mainly depending on the method of analysis used.

For conventional static pile analysis the recommended range of Φ_g is 0.45 to 0.55. The ultimate capacity R_{ug} is to be computed by means of an "appropriate analysis, using the results of suitable field and laboratory tests".

5.3. Effect of reduction factors on failure models

According to basic earth pressure theory, the location of the critical failure plane in a cohesionless backfill is inclined at an angle of $45+\phi/2$ to the horizontal. If the friction angle ϕ used in the analysis is reduced by a reduction factor, the failure plane becomes less inclined. The consequences for the stability analysis may become even more serious if the rotation of the failure plane requires the inclusion of additional concentrated loads acting on the surface of the backfill, loads which previously were outside the failure wedge.

Similar thoughts arise in conventional slope stability analysis, where the critical circle varies with soil properties as well as methods of analysis. In addition the question arises whether the self-weight of the soil should attract load factors. Also, should load factors vary depending on whether the particular slice of the failure wedge has a stabilising or destabilising action?

The magnitude of the friction angle also affects the calculations of stresses created in a soil mass due to surface loads if spreading of the load is presumed to be a function of ϕ, as some simple rules suggest.

5.4. Choosing and calibrating partial factors

Design factors proposed in standards, codes, manuals and textbooks are based partly on experience and partly on probabilistic considerations. Geotechnical problems where traditional total factor of safety rules have been satisfactory can be used to "calibrate" newly introduced partial factors.

It should not be so that the introduction of the limit state analysis radically alters the economics of geotechnical activities or brings about a sudden increase in failures. The great benefit of using partial material factors is that the experience with existing designs using conventional materials can, in a rational way, be extended to new products and construction procedures.

6. CONCLUDING COMMENTS

6.1. Benefits of the LRFD in geotechnical engineering

The LRFD approach requires to show satisfactory performance of a structure with respect to ultimate limit states and serviceability limit states for a variety of action states deemed to be relevant for the project. A particular action state may involve specific sets of loads and/or environmental conditions. This design philosophy not only impacts on the engineering analysis and design, but has more general consequences on the project management overall.

Identifying the different limit states and selecting appropriate load and material factors requires a clear assessment of future uses of the structure, environmental influences, quality assurance during construction and performance monitoring thereafter.

The designer thus has to establish

- a plan for the use or operation of the earth structure or building over its design life
- a safety or risk management plan which may involve monitoring and warning systems and which could impact on operational procedures. (Example: A potentially unstable slope threatening railway operations)
- a quality assurance scheme for the construction phase
- a performance monitoring program after construction which may include measurement of settlement and lateral movement, pore pressures, seepage, anchor forces, etc.

The adoption of the LRFD philosophy therefore goes further than simply adopting a string of new factors in the analysis. It will have a significant impact on the methodology applied to the formulation of the objectives of an engineering project and the management of all the phases leading to its realisation: Investigation, analysis, design, construction and performance evaluation.

A more rigorous managerial control of a geotechnical projects initiated by the LRFD framework should go a long way towards avoiding failures which are not simply caused by inadequacies in existing methods of design, but are caused by

- non-recognition of a failure state
- unexpected loads or environmental influences
- inappropriate geological/geotechnical model
- unexpected variability of loads and material properties
- mistakes in the calculation
- inappropriate construction techniques or supervision

Rigorous probabilistic analysis and common sense will tell us that even after the adoption of the LRFD approach, failures will still be experienced. To paraphrase Ralph Peck (1966), it is still possible that nature will outwit us on occasions.

6.2. Review period: You will be invited to comment.

The new draft standard is expected to be open for review by mid-1996. Invariably it will challenge many traditional views and it may adversely affect the economy of some earth retaining systems. Considerable discussion will centre on the specific values of material reduction factors. However, the resulting discourse will no doubt contribute to improve current design procedures and will heighten the awareness of the importance of the overall management of geotechnical projects.

ACKNOWLEDGEMENTS

Committee CE/32 responsible for the proposed standard on earth retaining structures (including reinforced soil) has some 18 members representing 10 national organisations and 2 universities. Without their technical knowledge, willingness to contribute and sheer hard work, neither the new draft standard nor this paper would have been possible.

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KEY WORDS: Retaining structures, reinforced soil, limit state design.

ABSTRACT The proposed new standard intends to promote good practice applicable to earth retaining structures, including reinforced soil. The standard is based on the principles of limit state design, generally formulating requirements in terms of factored loads and material properties multiplied with reduction factors. This approach delivers guidelines which ensure that all soil retaining structures provide a comparable minimum overall safety factor (or reliability) over the stipulated design life, although they may be made of widely different materials, such as steel and geosynthetics. The new design philosophy is also expected to have positive impacts on the overall management of geotechnical projects.

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