

Australian Standard[®]

Earth-retaining structures



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 - Australian Industry Group
 - Australian Geomechanics Society
 - AUSTROADS
 - Cement and Concrete Association of Australia
 - Concrete Institute of Australia
 - Concrete Masonry Association of Australia
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 - University of New South Wales
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-

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Earth-retaining structures

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PREFACE

This Standard was prepared by the Standards Australia Committee, CE-032, Reinforced Soils and Retaining Structures, in response to a call from the building industry for the establishment of a Standard on earth-retaining systems, including reinforced soils.

This Standard incorporates Amendment No. 1 (July 2003) and Amendment No. 2 (August 2008). The changes required by the Amendment are indicated in the text by a marginal bar and amendment number against the clause, note, table, figure or part thereof affected.

The objective of this Standard is to provide designers of earth-retaining structures with design criteria and guidance for use in design applications.

The terms ‘informative’ has been used in this Standard to define the application of the appendix to which it applies. An ‘informative’ appendix is only for information and guidance.

As far as practicable, this Standard has been made consistent with the approach taken in the loading code for structures, AS 1170, *Minimum design loads on structures*. This enables the Standard to be used in combination with structure design Standards such as AS 1720, *Timber Structures*, AS 3600, *Concrete Structures*, AS 4100, *Steel Structures*, and AS 3700, *Masonry structures*. Some specific applications are covered by other Standards and documents. For example, HB 77, *Australian Bridge Design Code*, should be used to design earth-retaining structures associated with road bridges.

CONTENTS

	<i>Page</i>
SECTION 1 SCOPE AND GENERAL	
1.1 SCOPE	5
1.2 APPLICATION	6
1.3 REFERENCED DOCUMENTS	7
1.4 DEFINITIONS	7
1.5 NOTATION	11
SECTION 2 INVESTIGATION AND TESTING	
2.1 INVESTIGATIONS	15
2.2 TESTING	17
SECTION 3 DESIGN REQUIREMENTS	
3.1 GENERAL	18
3.2 DESIGN CONSIDERATIONS FOR ULTIMATE LIMIT STATE.....	18
3.3 DESIGN CONSIDERATIONS FOR SERVICEABILITY LIMIT STATE.....	19
3.4 DESIGN LIFE	27
3.5 DURABILITY AND PERFORMANCE OVER TIME.....	28
3.6 DRAINAGE	28
3.7 INFLUENCE OF CONSTRUCTION ON ADJACENT GROUND AND STRUCTURES.....	29
3.8 SUBMERGED STRUCTURES.....	29
3.9 CONNECTIONS	30
SECTION 4 DESIGN LOADS	
4.1 LOADS.....	31
4.2 LOAD COMBINATIONS	32
SECTION 5 MATERIAL DESIGN FACTORS	
5.1 GENERAL	33
5.2 MATERIAL STRENGTH FACTORS FOR SOIL SHEAR STRENGTH.....	33
5.3 MATERIAL FACTORS FOR STRUCTURAL COMPONENTS.....	34
5.4 STRUCTURE CLASSIFICATION FACTOR.....	34
5.5 STRENGTH FACTORS FOR SOIL REINFORCEMENT	35
SECTION 6 CONSTRUCTION	
6.1 GENERAL	39
6.2 CONSTRUCTION TOLERANCES	39
6.3 SPECIFIC REQUIREMENTS.....	40
SECTION 7 PERFORMANCE MONITORING	
42	
APPENDICES	
A STRUCTURE CLASSIFICATION	43
B GROUND ANCHORS	46
C SOIL NAILING FOR EARTH-RETAINING STRUCTURES	55
D SOIL AND MATERIAL PROPERTIES.....	61
E DESIGN MODELS AND METHODS	70
F MATERIAL SELECTION AND DURABILITY	77

	<i>Page</i>
G DRAINAGE OF EARTH-RETAINING STRUCTURES	80
H REINFORCED SOIL FACING SYSTEM CONNECTION LOADS	92
I EARTHQUAKE DESIGN	93
J LOAD COMBINATIONS	104
K PARTIAL MATERIAL STRENGTH FACTOR DETERMINATION FOR SOIL REINFORCEMENT	119

STANDARDS AUSTRALIA

Australian Standard

Earth-retaining structures

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard sets out requirements and recommendations relating to the design and construction of structures required to retain soil, rock and other materials. It also includes requirements and recommendations for the reinforcement of soil and rock materials.

This Standard does not prescribe specific methods of analysis.

NOTE: Various organizations and authorities may develop detailed guides and specifications based on the principles set out in this Standard.

This Standard is in limit state format.

This Standard does not provide requirements and recommendations for 'revetment type' structures, which are sometimes used to retain soil, rock and other materials at slopes steeper than that which the soil, rock or other material would naturally assume.

The retaining structures encompassed by this Standard are indicated in Figure 1.1.

A1 | Facings constructed up to 800 mm high in a Type 3 structure application are not covered by this Standard.

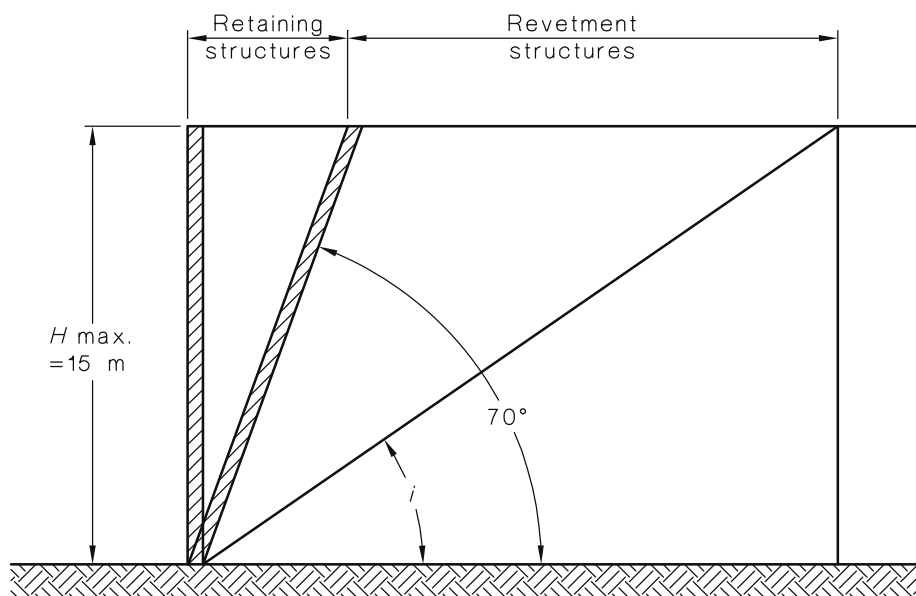


FIGURE 1.1 RETAINING AND REVETMENT STRUCTURES

A1

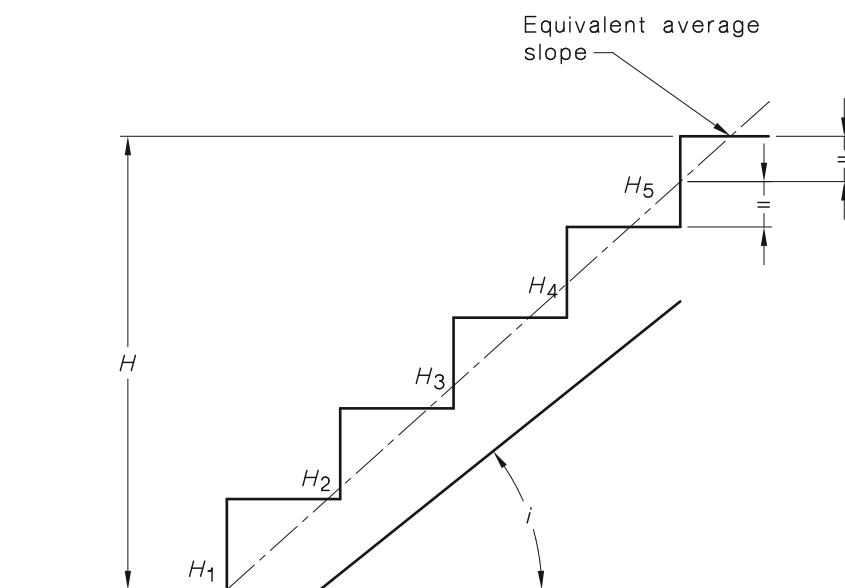


FIGURE 1.2 TERRACED STRUCTURES

1.2 APPLICATION

1.2.1 General

This Standard is applicable to retaining structures and reinforced soil structures that are commonly constructed for engineering works and infrastructure. Such structures are typically up to 15 m in height.

Structures of unusual shape, of large retained heights (in excess of 15 m) or founded in unusual ground conditions (such as soft ground, land slips, steep sides or deeply inclined gullies), together with structures subject to sustained cyclic loading, are outside the provisions of this Standard.

This Standard does not apply to the design and construction of water-retaining structures (such as dams and reservoirs) or bridge structures.

1.2.2 Structure classification

Structures shall be classified in accordance with Table 1.1.

NOTE: 'Not applicable'

TABLE 1.1
STRUCTURE CLASSIFICATION

Classification	Examples of structures
C	Where failure would result in significant damage or risk to life
B	Where failure would result in moderate damage and loss of services
A	Where failure would result in minimal damage and loss of access

NOTES:

- Classification B includes structures not covered by Classifications A or C
- For more information on structure classification, see Appendix A.

Structures where failure would result in minimal damage and loss of access where the wall height (H) is greater than 1.5 m are deemed to be classification B structures.

1.3 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS

- 1170 Minimum design loads on structures (known as SAA Loading Code)
- 1170.1 Part 1: Dead and live loads and load combinations
- 1170.2 Part 2: Wind loads
- 1170.4 Part 4: Earthquake loads
- 1289 Methods of testing soils for engineering purposes
- 1289.6.3 Method 3: Determination of the penetration resistance of a soil
- 1720 Timber Structures (all parts)
- 1726 Geotechnical site investigations
- 2159 Piling—Design and installation
- 2439 Perforated plastics drainage and effluent pipe and fittings (all parts)
- 2870 Residential slabs and footings
- 2870.1 Part 1: Construction
- 3500 National Plumbing and Drainage Code (set)
- 3600 Concrete structures
- 3700 Masonry structures
- 4100 Steel structures

SAI

- HB 77 Australian Bridge Design Code

BS

- 8006 Code of practice for strengthened/reinforced soils and other fills

1.4 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.4.1 General

1.4.1.1 *Action*

A cause of stress, dimensional change, or displacement in a structure or component of a structure.

1.4.1.2 *Action effect*

The internal force, moment, deformation, crack, or the like effect caused by one or more actions.

1.4.1.3 *Batter*

A slope of a cut or fill.

1.4.1.4 *Characteristic value*

Representative value of a soil, rock or a material property.

NOTE: For soil properties, the characteristic value is a cautious estimate, that is, close to but not greater than, of the mean value, (see Clause 5.2.3). The strengths of materials, such as concrete, steel, plastic and masonry, are contained in the appropriate Standards.

1.4.1.5 *Dead load*

The load determined in accordance with this Standard imposed by the components of the self-weight of the structure and retained soil or rock.

1.4.1.6 *Design life*

The intended period of time over which the structure is required to fulfil its function and remain in a serviceable state.

1.4.1.7 *Design load (action)*

The appropriate combination of loads (actions) and load factors as specified in this Standard.

1.4.1.8 *Ground anchor*

A tensile reinforcement, wire or bar, and its associated components that transmit force into soil or rock through bond over part of its length.

NOTE: Appendix B gives guidance on design of ground anchors.

1.4.1.9 *Limit state*

Any limiting condition for which structures are designed.

NOTE: The limit states design criteria considered in this Standard are strength limit state, stability limit state and serviceability limit state.

1.4.1.10 *Live load*

The load as defined in this Standard assumed to arise from the intended use of the structure including distributed, concentrated, impact and inertia loads, but excluding wind, snow, and earthquake loads.

1.4.1.11 *Load factor*

A factor specified in this Standard for structural design to be used with the loads (or actions) in deriving design loads (or design actions).

1.4.1.12 *Resistance effect*

The characteristic strength multiplied by the appropriate reduction factors for ultimate or serviceability limit state analysis.

1.4.1.13 *Rock bolt*

A tensile reinforcement, typically a bar of 15 to 50 mm in diameter, of steel or high strength polymer, which is inserted into a drill hole in rock and fixed in position by grout or mechanical anchorage.

NOTE: An initial tension is applied equal to or greater than 5%, and usually about 50% to 60%, of the ultimate tensile strength of the bar.

1.4.1.14 *Rock dowel*

As for rock bolt except that the applied tension is less than 5% of the ultimate tensile strength of the material used in the bar.

1.4.1.15 *Serviceability limit state*

A limit state for acceptable in-service conditions.

1.4.1.16 *Stressed ground anchor*

A tensile reinforcement, typically high tensile steel strand or wire or bar, and its associated components that transmit force into soil or rock through bond over part of its length. An initial tension is applied and the minimum capacity is usually checked by proof loading.

1.4.1.17 *Soil dowel*

A relatively stiff structural element used to take load in soils principally by shear action.

1.4.1.18 *Soil nail*

A tensile reinforcement, typically a steel bar or high strength polymer bar, placed in the ground and bonded for all or a majority of its full embedded length.

NOTE: Soil nails normally have no applied or nominal initial tension and mobilize axial force by relative movement with the soil. For more information on soil nailing for earth-retaining structures, see Appendix C.

1.4.1.19 *Strength limit state*

A limit state of collapse or loss of structural integrity.

1.4.1.20 *Stability limit state*

A limit state corresponding to the loss of static equilibrium of a structure or part of structure considered as a rigid body.

1.4.1.21 *Sprayed concrete*

A mixture of cement, aggregate and water (it may also include fibres and/or cement mixtures), conveyed through a hose, and projected at high velocity from a nozzle into place, to produce a dense homogeneous mass and may be applied by either a dry-mix, or a wet mix process.

1.4.1.22 *Facing*

Unit for erosion protection or aesthetic purposes constructed in front of an otherwise stable slope.

NOTE: The facing may or may not include drainage consideration.

1.4.1.23 *Stable slope angle (i)*

The angle that the soil, rock or other material would naturally assume in the long term under the expected variety of external (e.g., environmental), and internal (e.g., seepage) conditions.

1.4.1.24 *Wall height*

The overall height between the top and the toe of the wall where the line between the points is sloped equal to or greater than 70 degrees from the horizontal.

1.4.1.25 *Wall height for terraces*

The overall wall height for terraces is the height between the top of the top wall and the bottom of the bottom wall, except where the terraces are spaced sufficiently far apart horizontally so that the equivalent average slope of the terraced wall thus formed is below the stable slope angle, i (see Figure 1.2). In such cases the walls are considered separately.

1.4.2 **Geosynthetic materials**

1.4.2.1 *Geocomposite*

A composite geosynthetic material made up from geotextiles, geogrid and related products, as appropriate, to form a composite geosynthetic material.

1.4.2.2 *Geogrid*

A planar structure consisting of elements in an open grid pattern, used for ground reinforcement.

1.4.2.3 *Geosynthetic reinforcement*

A generic term that encompasses flexible synthetic materials used in geotechnical engineering, such as geogrids and geotextiles.

1.4.2.4 *Geosynthetic subsurface drainage system*

A pervious subsurface drainage system prefabricated from synthetic materials

1.4.2.5 *Geotextile*

A permeable, polymeric material which may be woven, non-woven or knitted.

1.4.3 Soil and rock materials

1.4.3.1 *Cohesive fill*

Naturally occurring or processed materials with greater than 50% passing the 75 μm AS sieve and a plasticity index of less than 30% and liquid limit of less than 45%.

1.4.3.2 *Controlled fill—Class I*

Soil rock or other inert material that has been placed at a site in a controlled fashion and under appropriate supervision to ensure the resultant material is consistent in character, placed and compacted to an average density equivalent to 98% (and no test result below 95%) of the maximum dry density (standard compactive effort) for the material when tested in accordance with AS 1289.5.1.1.

NOTE: For cohesionless soils, material compacted to at least 75% Density Index is satisfactory.

1.4.3.3 *Controlled fill—Class II*

Soil rock or other inert material that has been placed at a site in specified layers in controlled fashion to ensure that the resultant material is consistent in character placed and compacted to an average density equivalent to 95% (and no test result below 92%) of the maximum dry density (standard compactive effort) for the material when tested in accordance with AS 1289.5.1.1.

NOTE: For cohesionless soils, material compacted to at least 65% Density Index is satisfactory. Generally the layer thickness is specified as a maximum of 300 mm.

1.4.3.4 *In situ material*

Natural soil, weathered rock and rock materials.

1.4.3.5 *Other fill*

Materials that are chemically unstable or physically decomposable, which may include blast furnace slag, fly ash and topsoil.

1.4.3.6 *Reinforced soil*

The material in a reinforced soil structure in which reinforcing elements are installed to act through interface friction, or other means, to improve the stability of the soil or rock materials.

1.4.3.7 *Reinforced soil structure (RSS)*

A structure formed by reinforced soil, facing materials, drainage and associated foundation systems.

1.4.3.8 *Retained backfill*

The fill material located behind a retaining structure.

1.4.3.9 *Select fill*

A soil, rock or other inert material that is selected from various materials, that may be available on a site, and that has particular properties specified by a designer.

NOTE: Select fill will also generally be a soil or rock material that does not include highly plastic clays, topsoil, large boulders or waste products.

1.4.3.10 *Uncontrolled fill*

Soil, rock or other inert material that has been placed at a site and that does not fall under the definitions for materials in Clauses 1.4.3.2 and 1.4.3.3.

1.4.4 Drainage

1.4.4.1 Piped drains

A system of impervious pipes designed to lead drainage away from the retaining structure.

1.4.4.2 Subsoil drain

A system of pervious subsurface pipes, which is used in soil materials to collect ground water.

1.4.4.3 Subsurface drainage system

A system of drainage measures designed to remove water and seepage from the ground, which may include all, or a combination of, pervious granular materials, geocomposite, subsoil drains and piped drains.

1.4.4.4 Vertical structure drain

A vertical drainage system located behind and adjacent to a retaining wall, reinforced soil structure or its facing, comprising a pervious medium for the dewatering of the retained soil mass.

1.5 NOTATION

The following symbols are used in this Standard:

A_c = corrosion loss at $t = 1$ year

A_o = original cross-section area

a = acceleration coefficient derived in accordance with AS 1170.4

a_h = horizontal coefficient of acceleration (pseudo-static)

A1 | **‘Not applicable’**

a_m = maximum wall acceleration coefficient at centroid

a_{mh} = average amplified horizontal acceleration coefficient

a_{mv} = average amplified vertical acceleration coefficient

a_v = vertical coefficient of acceleration (pseudo-static)

B = base width

c = characteristic cohesion of a soil, which is a parameter in the Mohr-Coulomb failure law, also referred to as the cohesion intercept

c' = characteristic effective cohesion of a soil

c_u = characteristic undrained cohesion of a soil

c^* = design cohesion value

E_{ac} = external dynamic earth pressure load

A1 | E_i = inertia force

‘Not applicable’

F_{eq} = earthquake loads calculated in accordance with AS 1170.4

A1 | **‘Not applicable’**

G = dead load

G^R = part of the dead load tending to resist stability

G_s = specific gravity of the soil

	G_1	= dead load of structure
	G_2	= dead load of fill on structure
	G_3	= earth pressure due to fill behind structure
	G_4	= dead load of fill in front of structure
A2	g	= gravitational constant (9.81 m/s^2)
	H	= height of wall = overall height of wall from top to toe of wall at 70 degrees or greater (see 'Wall height' and 'Wall height for terraces')
	H_w	= height of water in front of wall
A1	i	= slope angle; or = stable slope angle
	'Not applicable'	
	I_p	= plasticity index
	k_A	= parameter relating to angularity
	k_B	= parameter relating to grading
	k_C	= parameter relating to density
	K_a	= static active earth pressure coefficient
	K_{ac}	= total active earth pressure coefficient (including seismic effects)
	k_h	= horizontal seismic coefficient
	k_v	= vertical seismic coefficient
	n	= constant representing rate of change of corrosion rate
	N'	= design number of blows from the standard penetration test
A1	'Not applicable'	
	P_p	= proofload during anchor load
	P_w	= calculated working load of the anchors (after all losses)
	p_{wd}	= resultant dynamic water pressure
	Q	= live loads (including impact, if any)
A1	'Not applicable'	
	Q_1	= traffic or other live load on structure
	Q_2	= traffic or other live load behind structure
	Q_3	= traffic or other live load in front of structure
A1	'Not applicable'	
	R^*	= design resistance effect
	S	= site factor for structure in accordance with AS 1170.4
	S^*	= design action effect
A1	'Not applicable'	
	T_c	= connection strength determined by test

A1	T_{cd}^*	= design connection strength
A1	T_{cj}^*	= design connection force at the j^{th} layer
	T_d^*	= design tensile strength of reinforcement
A1	‘Not applicable’	
	T_{di}^*	= design soil/reinforcement interaction strength
	T_{ij}	= soil/reinforcement interaction capacity of the reinforcement
A1	T_j^*	= design maximum tensile force resisted by the j^{th} layer of reinforcement
	T_{ij}^*	= design soil interaction force at the j^{th} layer
	T_u	= short-term ultimate tensile strength
	T_o	= original tensile strength
	t	= time in years
A1	‘Not applicable’	
	W	= weight of the structure and its superstructure
	W_s	= wind load for strength limit state
	W_u	= wind load for serviceability limit state
	ΔK_{ac}	= the incremental increase in active earth pressure coefficient
	ΔT	= loss of tensile strength
A1	ΔA	= loss of section area
	θ	= arc tan $[k_h/(1 \pm k_v)]$
A1	δ	= external friction angle between soil and structure
	ϕ	= characteristic internal friction angle of a soil, which is a parameter in the Mohr-Coulomb failure criteria, also referred to as the internal friction angle, or simply friction angle
	ϕ'	= effective internal friction angle of a soil
	ϕ_{cv}	= constant volume internal friction angle of a soil
	ϕ_r	= residual internal friction angle of a soil
	ϕ_u	= undrained internal friction angle of a soil
	ϕ^*	= design internal friction angle
	Φ_b	= partial material reduction factor for anchor bond
	Φ_k	= partial importance category factor for anchor pull out
	Φ_t	= partial material reduction factor for anchor tendon strength
	Φ_n	= structure classification factor
	Φ_r	= reduction factor
	Φ_{rc}	= partial material creep reduction factor
	Φ_{ri}	= partial material reduction factor due to construction or installation
	Φ_{rs}	= partial material strength reduction factor

Φ_{rt}	= partial material thickness reduction factor
Φ_{rst}	= partial material temperature reduction factor
Φ_u	= uncertainty factor for soil/reinforcement interaction
Φ_{ua}	= partial material uncertainty factor for soil/reinforcement interaction
Φ_{uc}	= partial design uncertainty factor for cohesion of the soil and backfill materials
Φ_{ud}	= partial material uncertainty factor for overall degradation
Φ_{ue}	= partial material extrapolation uncertainty factor
Φ_{up}	= partial material product uncertainty factor
Φ_{ucon}	= uncertainty factor for connection strength
$\Phi_{u\phi}$	= partial design uncertainty factor for friction of the soils and backfill materials
ΦR	= design capacity of the structural component
γ_1	= characteristic value for weight per unit volume of structure
γ_2	= characteristic value for weight per unit volume of fill behind structure
γ_3	= characteristic value for weight per unit volume of fill above structure
γ_4	= characteristic value for weight per unit volume of fill in front of structure
γ_b	= bulk unit weight of the fill behind the wall
γ_{g1}	= load factor for γ_1
γ_{g2}	= load factor for γ_2
γ_{g3}	= load factor for γ_3
γ_{g4}	= load factor for γ_4
γ_{gw}	= load factor for γ_w
γ_{q1}	= load factor for Q_1
γ_{q2}	= load factor for Q_2
γ_{q3}	= load factor for Q_3
γ_w	= density of water
γ_m	= moist bulk weight in kilonewtons per cubic metre
γ_s	= saturated bulk weight in kilonewtons per cubic metre
Ψ_c	= live load combination factor used in assessing the design load for strength limit state
A1 *	= superscript indicates design value (e.g., factored capacity (resistance))

SECTION 2 INVESTIGATION AND TESTING

2.1 INVESTIGATIONS

2.1.1 Site and geotechnical data

The design of earth-retaining structures requires adequate information on the physical conditions in the vicinity of the structure including the topography, site layout, nature of soil, foundation bearing capacity and the ground water conditions (including tidal conditions when appropriate), together with information on any adjacent structures and services that may be affected. The investigation shall include an assessment of the regional geotechnical conditions (e.g. the potential for slope instability) where they may impact on the proposed development.

All site investigations shall be carried out on the basis of a suitable scope of work, taking into account the classification of the structure (see Table 1.1 and Table 2.1).

2.1.2 Extent of investigation

The extent and complexity of the site investigations shall be related to the size, complexity and form of the structure to be designed. Attention shall also be paid to the properties of the soils in the immediate vicinity of the structure as well as underneath the structure.

The depth of the investigation shall be related to the structure type and size as well as the site geology. Where appropriate, careful attention shall be paid to both the overall geology and local geology, including geological defects and discontinuities, bedding planes, joints and faults. Account shall be taken of conditions such as reactive soils and uncontrolled fill. Special consideration shall be given to areas of landslip, any tendency of the site to shift, creep or settle, and areas of possible mine subsidence.

Where a site has been filled, it shall be ascertained whether or not the fill has been placed as a Class I or Class II ‘controlled fill’ (see Clauses 1.4.3.2 or 1.4.3.3), uncontrolled fill (see Clause 1.4.3.10) or ‘other fill’ (see Clause 1.4.3.5).

Due to the possibility that even with a careful site investigation unexpected conditions may be revealed during construction, appropriate inspections shall be carried out during the course of the construction process to ensure that the conditions revealed during the construction are in accordance with the assumption made during the design. If the conditions are not in accordance with these assumptions, then necessary alterations shall be made to the design to take account of the observed new conditions.

Of special importance to all types of retaining structures is the determination of ground water, site seepage and surface run off. The investigation of all types of retaining structures shall include—

- (a) a study of the ground water regime in the vicinity of the structure, including sources, directions of lateral flows, and seasonal or tidal variations;
- (b) chemical composition of the ground water; and
- (c) the effect of the proposed retaining structure construction on the ground water regime.

The effect of water discharge from any drains, pipes, and the like on the site conditions shall also be considered. An assessment should be made of the effects of ground water and site seepage over the design life of the structure.

2.1.3 General investigation requirements

The extent and amount of detailed information obtained in a particular investigation shall include the considerations given in Table 2.1.

TABLE 2.1
INVESTIGATION CONSIDERATIONS

A1

Investigation considerations	Structure classification		
	C	B	A
Substrata type	●	●	●
Effect of drainage discharge onto surrounding site	●	●	●
Nature of retained material	●	●	●
Site topography	●	●	●
Foundation and embankment strength parameters	●	●	○
Existing ground water levels and seepage	●	●	○
Effect of excavations or filling	●	●	○
Location of existing or proposed adjacent structures	●	●	○
Effect of modified water table on surrounding site	●	○	○
Global stability	●	○	○
Impact of structure 'zone of influence'	●	○	○
Ground movement	●	○	○

● denotes detailed site-specific information required.

○ denotes only general consideration of the item required.

2.1.4 Investigations for reinforced soil structures

2.1.4.1 General

In addition to the general investigation requirements (see Clause 2.1.3), as the soil material used in a reinforced soil structure acts as part of the structure itself, consideration shall be given to the properties of the material that forms the reinforced soil mass.

2.1.4.2 Fill materials

Fill materials for reinforced soil structures shall be selected fill materials, placed and compacted as a controlled fill (see Clauses 1.4.3.2 and 1.4.3.3).

NOTE: Guidance on the selection of fill material for reinforced soil structures is given in Appendix D.

2.1.4.3 Fill properties

Where appropriate, testing shall be undertaken to confirm the following properties and characteristics of the proposed fill:

- (a) Physical characteristics (size, grading and the like).
- (b) Strength parameters.
- (c) Chemical properties.
- (d) Electrochemical properties (appropriate when metallic soil reinforcement is proposed).
- (e) Compaction characteristics.

The testing of representative samples shall be carried out in accordance with the relevant test method of AS 1289 and with any special test procedures defined in this Standard.

2.1.4.4 *Investigations for in situ reinforced soil structures*

Additional investigations are required for in situ reinforced soil structures. Where appropriate, investigations shall include the following:

- (a) Identification of the site geology, joints, relic joints, defects, bedding planes, seepage and water paths, in situ stresses, watertable and the like.
- (b) Determination of structural discontinuities and orientation of defects.
- (c) Identification of all active and inactive services (e.g. water, sewer, power and communications) and structures within the 'zone of influence' of the structure.
- (d) Assessment of the effect of any movement, or deformation, of the reinforced soil structure on nearby developments or buildings.

2.2 TESTING

2.2.1 Fill materials

Sampling of proposed fill materials for an earth-retaining structure shall be undertaken to ensure that the samples are truly representative of the materials to be used in the structure and that their condition duplicates, as far as is practicable, the design conditions in the actual structure. In particular, materials that are susceptible to crushing under compaction (e.g. crushed sandstone) shall be pretreated prior to testing to simulate their in-service condition.

NOTE: Some types of walls need careful attention paid to the type and compaction of the fill in the wall structure (e.g. crib walls).

2.2.2 In situ materials

Where the properties of in situ materials and existing fill forming the foundations, as well as the in situ reinforced areas, are critical to the performance or stability of the structure, then sampling and testing shall be carried out by the relevant undisturbed sampling and testing procedures set out in AS 1289.

Where the in situ materials or existing fill are suspected to have significant shrink/swell characteristics (i.e. the site, as defined in AS 2870.1, is a Class M or higher), then the impact of shrink/swell characteristics of the in situ and fill materials shall be considered.

2.2.3 Laboratory testing

Unless otherwise specified, the laboratory tests shall be undertaken in accordance with the relevant test method of AS 1289.

SECTION 3 DESIGN REQUIREMENTS

3.1 GENERAL

3.1.1 Introduction

This Section sets out the requirements for the design of earth-retaining structures to ensure that strength, stability and serviceability are achieved over the intended life of such structures. Drainage aspects and the influence of construction on the adjacent ground shall be considered. In the initial design process, the selection of an appropriate retaining structure shall consider anticipated site conditions, the constructability of the structure and the need for temporary support measures.

3.1.2 Design principles

For the purpose of reinforced soils and retaining structures design, a limit state is deemed to be reached when one of the following occurs:

- (a) *Ultimate limit state (strength and stability)*—collapse or major damage as a result of rupture or instability of the structure, ground, reinforced soils, reinforcement or other components.
- (b) *Serviceability limit state*—movement or damage in excess of stated design limits.

For both limit states, the design resistance effect (R^*) shall be greater than or equal to the design action effect (S^*) for the most critical loads and combinations, i.e.,

$$R^* \geq S^*$$

where R^* and S^* are appropriately factored.

3.1.3 Partial factor method

The requirements of Clauses 3.1, 3.2 and 3.3 are deemed to be met if the requirements of Sections 4 and 5 are complied with.

3.1.4 Design using other methods

The requirements of Clause 3.1, 3.2 and 3.3 may be met by the adoption of engineering principles and appropriate loads, resistances and factors.

NOTE: For information on design models and methods see Appendix E.

3.2 DESIGN CONSIDERATIONS FOR ULTIMATE LIMIT STATE

Structure classification (see Table 1.1), design life, durability and maintenance of the structure shall be considered as part of the design process.

The design for ultimate limit state shall take into consideration, but not necessarily be limited to, the following six ultimate limit state modes:

- (a) *Limit Mode U1* Sliding within or at the base of the retaining structure (see Figure 3.1(A)).
- (b) *Limit Mode U2* Rotation of the structure (see Figure 3.1(B)).
- (c) *Limit Mode U3* Rupture of components and connections (see Figure 3.1(C)).
- (d) *Limit Mode U4* Pull-out of reinforcing elements or anchors (see Figure 3.1(D)).
- (e) *Limit Mode U5* Global failure mechanisms (see Figure 3(E)).
- (f) *Limit Mode U6* Bearing failure (see Figure 3.1(F)).

3.3 DESIGN CONSIDERATIONS FOR SERVICEABILITY LIMIT STATE

The design for serviceability limit state shall be adequate in that movement of the foundation, retaining wall, or reinforced soil structure does not cause local damage to the structure, which could shorten the structure's intended life or incur excessive maintenance costs. Possible deformation modes involving rotation, translation or bulging and settlement are shown, but not necessarily limited to, the following three serviceability limit state modes:

- (a) *Limit Mode S1* Rotation of the structure (see Figure 3.2(A)).
- (b) *Limit Mode S2* Translation or bulging of the retaining structure (see Figure 3.2(B)).
- (c) *Limit Mode S3* Settlement of the structure (see Figure 3.2(C)).

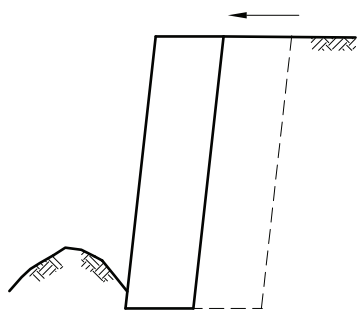
The concept of serviceability depends very much on the end use requirements of the structure. Normally, serviceability requirements for retaining structures are prescribed in terms of acceptable deformations. These limits will vary with the type of structure. In addition, the limits required will come into operation at different stages according to the type of structure.

NOTE: Deformations of reinforced soil structures are influenced as much by the construction process as by the design.

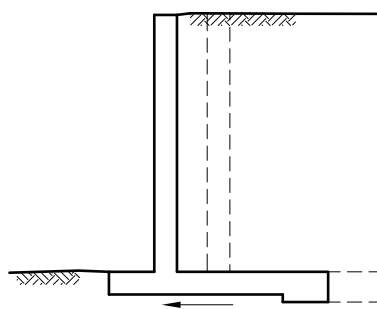
Post-construction deformations of the structure may be caused by, but not limited to, one or a combination of the following:

- (i) External ground movements (e.g. landslide).
- (ii) Foundation settlement.
- (iii) Creep extension of synthetic soil reinforcement.
- (iv) Creep movement of soil/reinforcement interface.
- (v) Consolidation of poorly compacted backfill.
- (vi) Displacement and deformation of the facing caused by the likes of construction equipment loading.
- (vii) Deterioration of the reinforcement due to metal corrosion or polymer degradation.

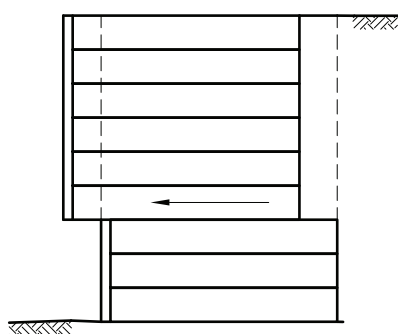
Where soils having significant shrink/swell characteristics are encountered at a site, then consideration of the effects of the shrink/swell movements shall be taken into account in the design of the structure.



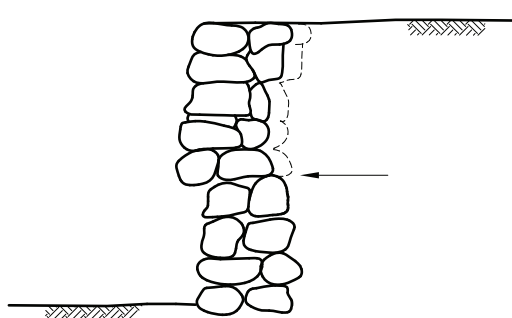
(a) Sliding at the base



(b) Sliding of cantilevered wall

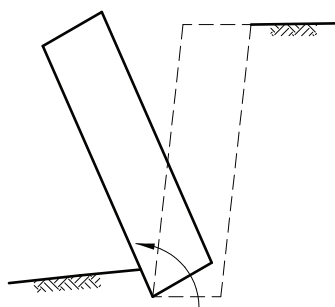


(c) Sliding within a wall

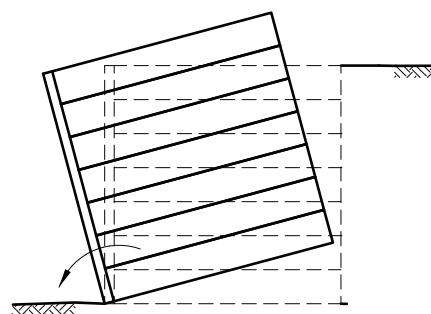


NOTE: These diagrams are illustrative of the failure mode.

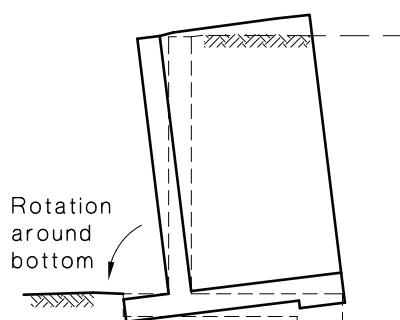
FIGURE 3.1(A) LIMIT MODE U1: SLIDING—ULTIMATE LIMIT STATE



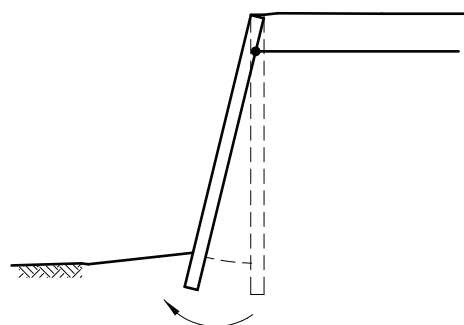
(a) Rotation of gravity wall



(b) Rotation of reinforced soil wall



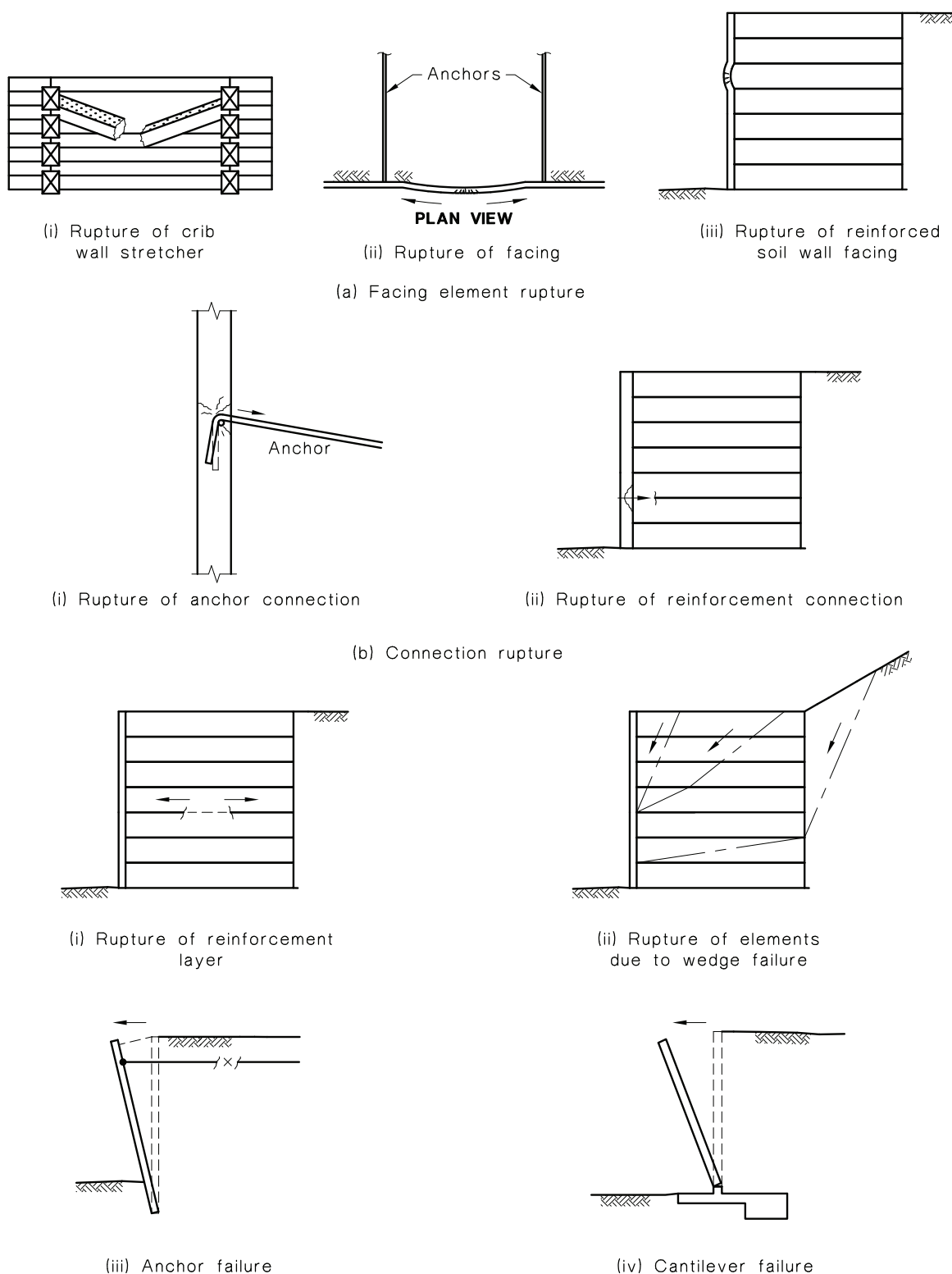
(c) Rotation of cantilevered wall about base



(d) Rotation of toe of wall about top

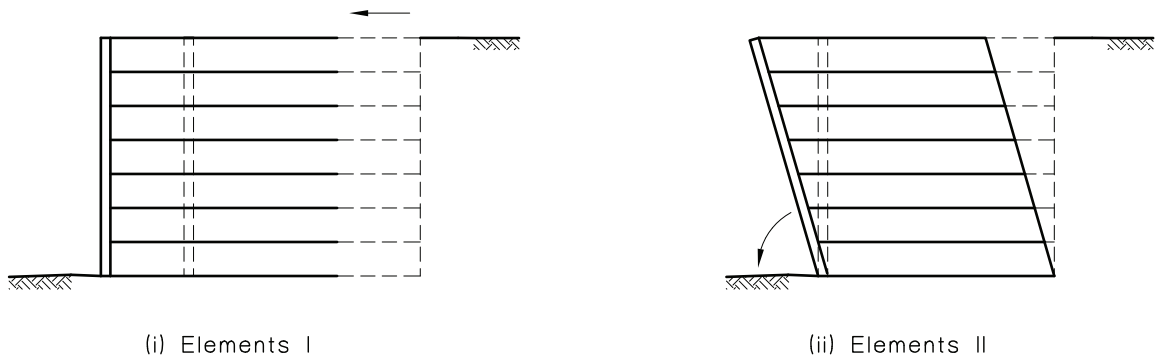
NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.1(B) LIMIT MODE U2: ROTATION—ULTIMATE LIMIT STATE

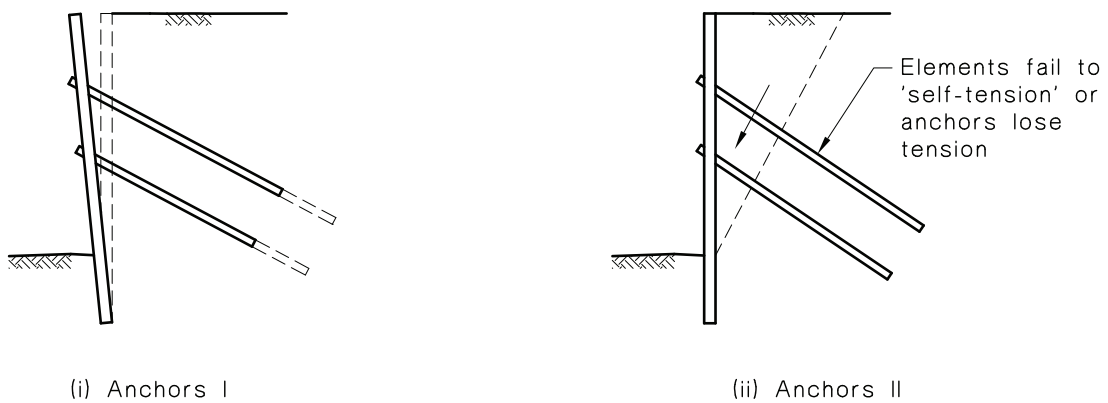


NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.1(C) LIMIT MODE U3: RUPTURE OF COMPONENTS AND CONNECTIONS—ULTIMATE LIMIT STATE



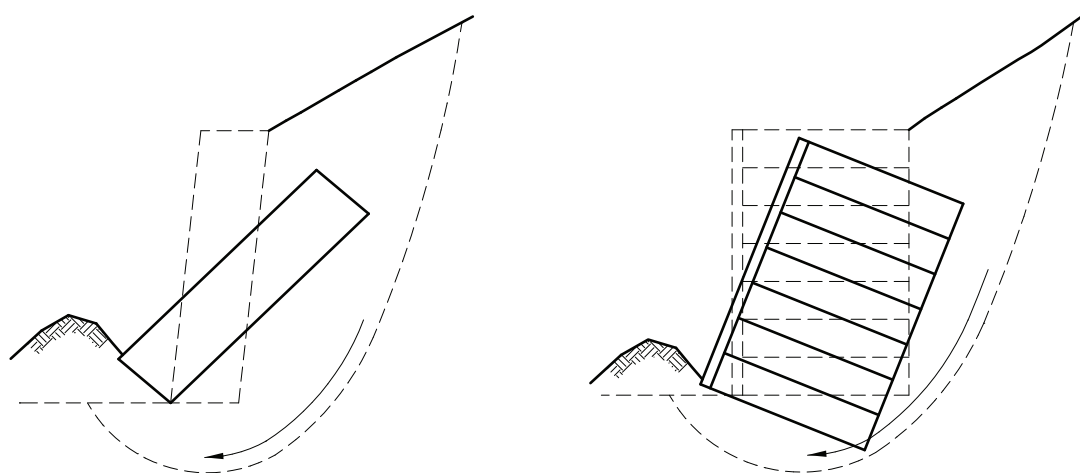
(a) Pull-out of reinforcing elements



(b) Pull-out of anchors

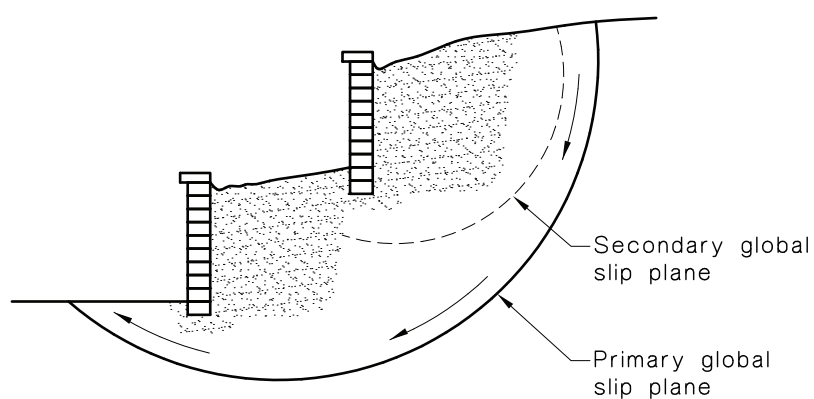
NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.1(D) LIMIT MODE U4: PULL-OUT OF ANCHORS OR REINFORCING ELEMENTS—ULTIMATE LIMIT STATE



(a) Global failure of gravity wall

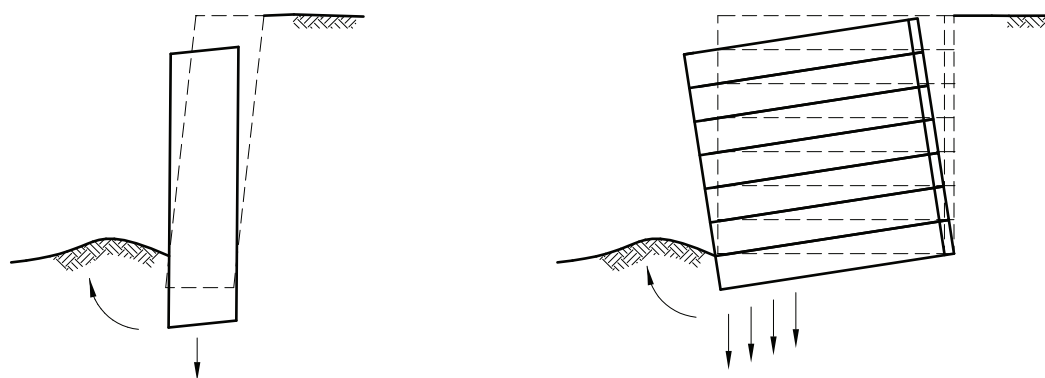
(b) Global failure of reinforced soil wall



(c) Global failure of gravity block wall

NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.1(E) LIMIT MODE U5: GLOBAL FAILURE (WEDGE OR SLIP SURFACE) ULTIMATE LIMIT STATE

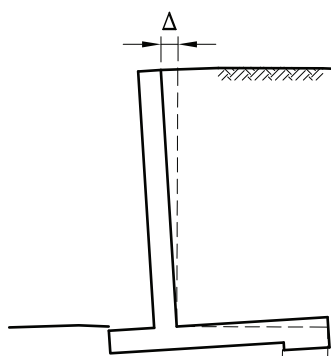


(a) Bearing failure of gravity wall

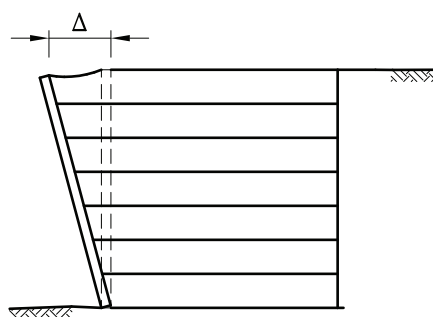
(b) Bearing failure of reinforced soil wall

NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.1(F) LIMIT MODE U5: BEARING FAILURE ULTIMATE LIMIT STATE



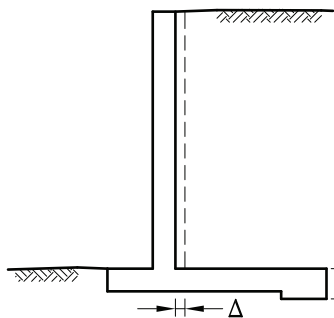
(a) Rotation of cantilevered wall



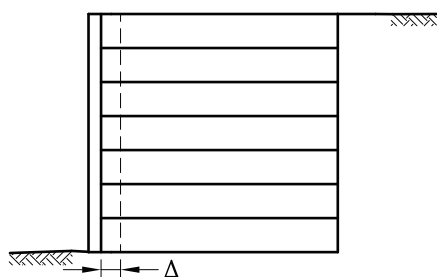
(b) Rotation of reinforced soil wall

NOTE: These diagrams are illustrative of the failure mode.

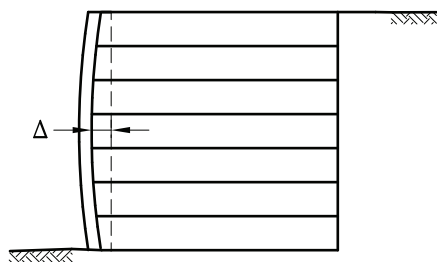
FIGURE 3.2(A) LIMIT MODE S1: ROTATION—SERVICEABILITY LIMIT STATE



(a) Translation of cantilevered wall



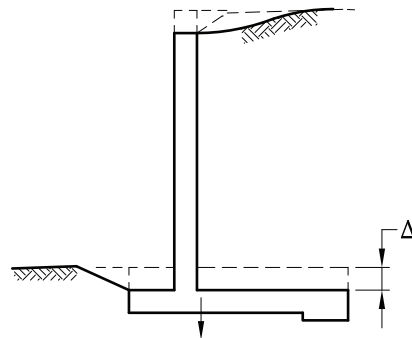
(b) Translation of reinforced soil wall



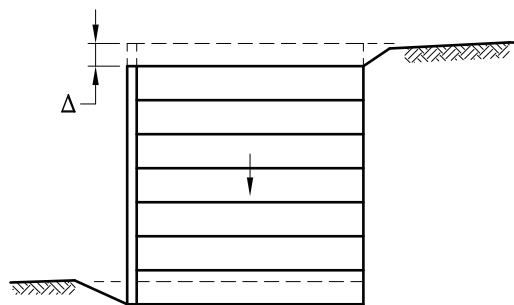
(c) Bulging of reinforced soil wall

NOTE: These diagrams are illustrative of the failure mode.

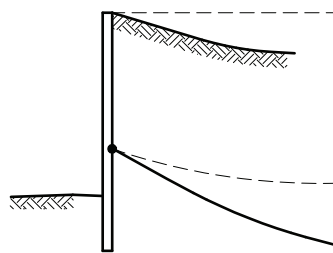
FIGURE 3.2(B) LIMIT MODE S2: TRANSLATION OR BULGING—SERVICEABILITY LIMIT STATE



(a) Settlement of cantilevered wall



(b) Settlement of reinforced soil wall



(c) Settlement of anchored structure

NOTE: These diagrams are illustrative of the failure mode.

FIGURE 3.2(C) LIMIT MODE S3: SETTLEMENT—SERVICEABILITY LIMIT STATE

3.4 DESIGN LIFE

3.4.1 General

Design life shall be considered in the design process.

Each component of an earth-retaining structure shall be durable enough to provide satisfactory performance over the design life of the structure.

In reinforced soil structures, the life of the reinforcing elements, associated facings and reinforcement connections shall have compatible durability requirements with the remainder of the structure, unless the reinforcement is required to function only for a shorter time while the surrounding ground gains strength.

Typical design life for various applications is given in Table 3.1.

3.4.2 Design life considerations

For increasing design life, consideration should be given to possible changes over time in the following:

- (a) Loads and load factors.
- (b) Material reduction factors appropriate to the structure classification.
- (c) Environmental considerations.
- (d) Durability and corrosion.

TABLE 3.1
DESIGN LIFE

Design life (years)		Typical application
Short	5	Temporary site works
Medium	{ 10	Mine structures
	{ 30	Industrial structures
Long	{ 60	River and marine structures, residential dwellings
	{ 90	Minor public works
	{ 120	Major public works

3.5 DURABILITY AND PERFORMANCE OVER TIME

Durability is the ability of the structure to resist loss of properties or wear such as erosion, corrosion, creep, chemical, biological and installation damage so that the required strength is maintained over the design life of the structure. The design shall take into account changes in relevant properties over time.

NOTES:

- 1 A check list for investigation of reinforcement products for reinforced soil structures is given in Table F1, Appendix F.
- 2 Factors affecting the durability and performance of earth-retaining structure materials are presented in Table F2, Appendix F.

3.6 DRAINAGE

3.6.1 General

Design of retaining structures shall consider the drainage aspects of the site, including the short- and long-term subsurface hydrological conditions of the site.

Drainage and the possible development of pore water pressure within a soil are amongst important considerations in the design of retaining structures because the presence of water behind an earth-retaining structure has a significant effect on the pressures applied to the structure. Even when there is no water in direct contact with the structure, increased pressures can occur on a retaining structure due to an elevated phreatic surface developed from water seepage into the failure wedge behind the structure.

NOTE: Additional information on drainage measures is given in Appendix G.

3.6.2 Design considerations

The design of an earth-retaining structure shall carefully consider the effects of water, water seepage and potential hydrostatic pressures in the design, as well as the long-term performance of any drainage system installed. In particular, the designer shall consider and allow for at least the following items in the design:

- (a) Existing site ground water conditions and how such conditions are likely to be affected by the construction of the structure.
- (b) Necessity for and specific details of any drainage systems to be provided behind the structure. Such details would normally include—
 - (i) the subsurface drainage system, including pipe drains and subsoil drains;
 - (ii) weep holes;
 - (iii) filters and geotextiles;
 - (iv) fill materials;
 - (v) other drainage details; and
 - (vi) any associated pipework, clean-out systems and method of drainage efflux.
- (c) The 'long-term' performance of the drainage system and the necessity for maintenance.

The design shall be based on the predicted 'long-term' condition of the drainage system rather than the expected performance of the system immediately after installation, including, if necessary, an assumption of failure or partial failure of the drainage system.

Where clean gravel screenings, pervious materials, geocomposites and the like are specified by the designer for installation behind the structure, then adequate provisions shall be made to ensure that surface and stormwater run-off does not overload, foul or clog the subsurface drainage system.

Where possible, surface water shall be directed away from the top of earth-retaining structures and not be allowed to pond behind the top of the wall or enter the subsurface drainage system.

3.7 INFLUENCE OF CONSTRUCTION ON ADJACENT GROUND AND STRUCTURES

Consideration shall be given to the possible adverse effect on the adjacent land or structures of the construction of an earth-retaining structure. This is particularly important on sloping ground where any excavation associated with the construction of the retaining wall may induce or reactivate slope instability.

3.8 SUBMERGED STRUCTURES

Structures, temporarily or permanently submerged, shall be designed with due consideration of the effect of static and transient pore water pressures both within and external to the structure. Other effects such as wave action, water flow and velocity (scour potential), piping and liquefaction require particular consideration. Typical situations include the following:

- (a) Sea walls.
- (b) Reclamation.
- (c) Earth bunds.
- (d) Abutments for river and creek crossings.

- (e) Flood-prone areas.

For temporarily or permanently submerged or tidally affected structures, consideration shall be given to the following where appropriate:

- (i) Draw-down effects, differential and residual watertables, and tidal lag.
- (ii) Piping or material loss from within the structure, the structure backfill or the foundations.
- (iii) Scour or erosion in front of the structure.
- (iv) Wave action, including overtopping.
- (v) Loss of backfill through the wall due to wave and tidal action.
- (vi) Durability of materials.

NOTE: The above factors require particular consideration on a case-by-case basis. The relevant methodologies are not covered in this Standard and appropriate specialist advice should be sought.

3.9 CONNECTIONS

The connection of the different elements of an earth-retaining structure shall be designed to take into account the load-carrying capacity of the connection system. Connections shall be designed to the same durability criteria as the overall structure and shall be compatible with the connected elements.

NOTES:

- 1 The facing of a reinforced soil structure is supported by the reinforced soil mass usually by connecting directly to the soil reinforcement. The overall stability of the reinforced soil structure is not necessarily reliant on the stability of the facing system; however, the stability of the facing system itself relies directly on the connection of the facing elements to the soil reinforcement elements. The effect of structure movement and load redistribution shall be considered in the design of the connection.
- 2 Guidelines for connection design of facings are given in Appendix H.

SECTION 4 DESIGN LOADS

4.1 LOADS

Earth-retaining structures shall be designed for the following loadings and other actions, during construction and in service:

- (a) Dead loads and live loads, including earth pressure and hydrostatic pressure, as specified in AS 1170.1 except that—

A1

- (i) all structures shall be designed for the live loads resulting from the intended use of the structure but not less than the values given in Table 4.1;
- (ii) for the strength and stability limit states, a load factor of 1.0 shall be applied to water pressure in lieu of the requirement in AS 1170.1 for a load factor of 1.25. The estimate of the height of the water table shall represent the worst credible location during the life of the structure; and
- (iii) for the strength and stability limit states, the requirement in AS 1170.1 for a load factor of 1.5 to be applied to earth pressures is deemed to be met by applying a load factor of 1.25 on the dead loads (including soil weight) and 1.5 on the live loads in combination with the material factors specified in Clause 5.2 of this Standard.

NOTE: Typically, earth pressure will be calculated by determining the total stresses deducting the pore water pressure and multiplying the residual by the appropriate load factor of 1.25.

- (iv) Lower partial load factors shall be used where the lower factors lead to a more critical limit state.
- (b) Wind loads as specified in AS 1170.2.
- (c) Earthquake loads calculated in accordance with AS 1170.4 and Appendix I.
- (d) Other loads that may act on the structure (e.g. snow and ice).

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TABLE 4.1
LIVE LOAD kPa

Classification	Backfill slope (horizontal/vertical)	
	Steeper than 4:1	4:1 or flatter
B, C	2.5	5
A	1.5	2.5

4.2 LOAD COMBINATIONS

The load combinations for strength, stability and serviceability shall be as specified in AS 1170.1. Where a reaction is generated by the application of a factored load, no further factor shall be applied.

NOTES:

- 1 For specific applications (such as structures associated with roads and highways), loads, load factors and loading combinations other than those set out in AS 1170 (all parts) may be appropriate. If other loads, load factors or loading combinations are used, it may also be appropriate to vary the associated material factors given in Section 5.
- 2 Appendix J gives guidance for determination of the appropriate loading combinations in greater detail than that given in AS 1170.1. The designer should determine whether such loads, load factors and loading combinations are still valid at the time the design is carried out.
- 3 The load factors specified in AS 1170.1 should be applied to the live loads specified in Clause 4.1.
- 4 The dead loads should include—
 - (a) self weight of the structure;
 - (b) backfill weight on top of the structure;
 - (c) imposed earth pressures acting behind the structure;
 - (d) imposed water pressures acting behind the structure; and
 - (e) static sill beam loadings (both vertical and horizontal) on earth-retaining structures designed as bridge abutments.
- 5 The live loads should include—
 - (a) traffic surcharge;
 - (b) bridge vertical live loads acting on the sill beam;
 - (c) transient loads acting on bridge sill beam, which might include vehicle braking and thermal effects; and
 - (d) impact loading.
- 6 The determination of earthquake design loads should require—
 - (a) assessment of the seismicity of the site and the potential for liquefaction; and
 - (b) determination of the response characteristics of the structure.
 - (c) AS 1170.4 may be used to determine earthquake-induced loadings on structures, taking into account—
 - (i) structure classification and related importance factor;
 - (ii) acceleration coefficient (a); and
 - (iii) site factor (S).

For the purpose of global stability analysis, the horizontal and vertical distribution of earthquake-induced forces on the structure may be calculated in accordance with AS 1170.4 and Appendix I, using a static analysis approach, or using a dynamic analysis.

For the purpose of internal stability analysis, the designer should determine the load distribution and structure resistance behaviour from properly identified dynamic response characteristics of similar structural systems. Characteristics of structures that need to be taken into account to differentiate behaviour include facing systems (flexible or stiff) and type of soil reinforcement (extensible or inextensible).

- 7 The loads applied by water forces should be taken into account in the design of the structure. Allowance for the effects of water pressure and buoyancy effects should be made where the structure is subject to immersion.
- 8 The design of the structure should allow for the proper drainage of seepage from behind the structure.
- 9 This Standard has been drafted with reference to AS 1170.1—1989 for combinations. The intention is to revise this Standard to be fully consistent with AS/NZS 1170.0.

SECTION 5 MATERIAL DESIGN FACTORS

5.1 GENERAL

This Section sets out the determination and combination of partial material strength design factors for earth-retaining structures.

Partial design factors for earth-retaining structures are grouped by subscripts as follows:

- (a) r —the reduction group of factors (Φ_r) that cover the effect of identified causes of decrease in strength and which are drawn from test data.
- (b) u —the uncertainty group of factors (Φ_u) that cover unknowns and uncertainties.
- (c) n —the structure classification group of factors (Φ_n) that cover the consequences of failure of the particular structure.

For each distinct soil stratum, backfill material or structural component, the design resistance effect (R^*) shall be determined by calculating the material strengths and resistances based on the characteristic strengths for the material multiplied by Φ_r , Φ_u and Φ_n .

Soil strengths shall be factored in accordance with Clause 5.2, except where unfactored values lead to greater critical limit states.

Material strength of structural components shall be factored in accordance with Clause 5.3.

Tensile strength of soil reinforcement shall be factored in accordance with Clause 5.4.

Partial material strength factors shall account for the following:

- (i) Variability in the manufactured strengths of the materials.
- (ii) Time-dependent stress/strain behaviour.
- (iii) Uncertainty of extrapolation of test data.
- (iv) Effect of construction-induced damage.
- (v) Uncertainties of environmental degradation.
- (vi) Time dependent material and strength loss.

An overall structure classification factor shall be applied in accordance with Clause 5.5.

5.2 MATERIAL STRENGTH FACTORS FOR SOIL SHEAR STRENGTH

5.2.1 Cohesion

The partial design factor for the cohesion of the soils and other backfill materials is Φ_{uc} (see Table 5.1(A) and Table 5.1(B)). It shall be applied to c , so that the design cohesion value c^* is given by the following equation:

$$c^* = \Phi_{uc} c \quad \dots 5.2(1)$$

5.2.2 Internal friction angle

The partial design factor for the internal friction angle of the soils and other backfill materials is $\Phi_{u\phi}$ (see Table 5.1(A) and Table 5.1(B)). It shall be applied to $(\tan \phi)$, so that the design internal friction angle ϕ^* is given by the following equation:

$$\phi^* = \tan^{-1} (\Phi_{u\phi} (\tan \phi)) \quad \dots 5.2(2)$$

TABLE 5.1(A)

**MATERIAL STRENGTH AND SERVICEABILITY UNCERTAINTY FACTORS FOR
SOIL (based on peak values of c' and ϕ')**

Soil or material uncertainty factor		Soil or fill conditions			
		Controlled fill		Uncontrolled fill	In situ material
		Class I	Class II		
Strength	$\Phi_{u\phi}$	0.95	0.90	0.75	0.85
	Φ_{uc}	0.90	0.75	0.50	0.70
Serviceability	$\Phi_{u\phi}$	1.0	0.95	0.90	1.00
	Φ_{uc}	1.0	0.85	0.65	0.85

NOTES:

- Where fill materials defined by the term 'other fill' are used, then the partial factors to be used will depend on the type and quality of the fill materials. In no case shall the partial factor be greater than the partial factors for Class 1 'controlled fill'.
- The soil strength parameters c' and ϕ' are effective strength parameters. Appendix D gives information on constant volume and residual strength parameters.

TABLE 5.1(B)

**MATERIAL STRENGTH AND SERVICEABILITY UNCERTAINTY FACTORS FOR
SOILS (based on c_u and Φ_u)**

Soil or material uncertainty factor		Soil or fill conditions			
		Controlled fill		Uncontrolled fill	In situ material
		Class I	Class II		
Strength	$\Phi_{u\phi}$	0.0	0.0	0.0	0.0
	Φ_{uc}	0.6	0.5	0.3	0.5
Serviceability	$\Phi_{u\phi}$	0.0	0.0	0.0	0.0
	Φ_{uc}	0.9	0.8	0.5	0.75

5.2.3 Determination of c and ϕ

The characteristic values of c and ϕ shall be determined by a combination of the following:

- Laboratory or field testing or both.
- Knowledge of the geological conditions of the site, its stress history and the likely soil behaviour.
- Engineering judgement.

5.3 MATERIAL FACTORS FOR STRUCTURAL COMPONENTS

The structural components of retaining walls, including their connections, shall be designed in accordance with AS 3600, AS 3700, AS 4100 or AS 1720, as appropriate.

5.4 STRUCTURE CLASSIFICATION FACTOR

The partial design factor to account for structure classification, as defined in Clause 1.2, Φ_n , shall be as defined in Table 5.2.

TABLE 5.2
STRUCTURE CLASSIFICATION DESIGN FACTOR (ϕ_n)

Structure classification	Design factor, (ϕ_n)	
	Ultimate limit state	Serviceability limit state
C	0.9	1.0
B	1.0	1.0
A	1.1	1.0

NOTE: Depending on the structure classification (see Table 1.1), the consequences of the failure and the cost of stabilization, it may be necessary to adopt different partial factors to arrive at a practical and economic solution. Each case has to be assessed on its merits and the assignment of reduced partial factors, whilst likely to be necessary in some cases, should be carefully judged with respect to the type of structure and expected performance.

5.5 STRENGTH FACTORS FOR SOIL REINFORCEMENT

5.5.1 Tensile strength of soil reinforcement

5.5.1.1 General

Material strength factors shall be applied to the short-term ultimate tensile capacity of all soil reinforcement. These factors are related to the properties of the material itself as well as to construction and environmental effects and are either reduction or uncertainty factors.

Material property factors take into account manufacturing variations and time-dependent stress/strain behaviour (creep, rupture and extrapolation).

Construction and environmental factors take into account construction damage and environmental degradation (material loss and strength loss).

The partial material reduction and uncertainty factors are classified in Table 5.3 and described in this Section.

NOTE: Recommendations for the determination of partial material reduction and uncertainty factors are set out in Appendix K. The designer should nominate the appropriate factors and their basis for selection. The determination of reduction factors should be based on adequate test results. In the absence of test results, the values for reduction factors given in Appendix J should be used.

TABLE 5.3
MATERIAL REDUCTION AND UNCERTAINTY FACTORS

Factors	Manufacturing	Time-dependent stress/strain behaviour	Installation (construction)	Environmental
Material reduction factors	—	Creep rupture (ϕ_{rc})	Installation damage (ϕ_{ri})	Thickness (ϕ_{rt}) Strength (ϕ_{rs}) Temperature (ϕ_{rst})
Material uncertainty factors	Product manufacture (ϕ_{up})	Extrapolation (ϕ_{ue})	—	Degradation (ϕ_{ud})

5.5.1.2 Manufacturing variation factor

The short-term ultimate tensile strength (T_u) shall be multiplied by an uncertainty factor (product) (ϕ_{up}) which depends on the degree of quality control and whether it is a minimum or some other characteristic value.

5.5.1.3 Time-dependent stress/strain behaviour factors

The creep rupture strength is derived from the time at which samples of the reinforcing product are expected to fail when constantly loaded at a certain percentage of their initial resistance. The creep rupture strength corresponding to the required minimum service life shall be the appropriate reference as far as tensile strength is concerned.

For a required service life in excess of the limit of test data, it shall be necessary to carry out an extrapolation, which is valid only if there is no risk of a transition or 'knee' in the rupture mechanism, knowing that in a log-normal scale diagram the decrease of the creep rupture strength is represented by a straight line.

The short-term ultimate strength (T_u), shall be multiplied by the following factors:

- (a) A partial material creep reduction factor (creep) (Φ_{rc}), which is based on test data conducted at the average estimated in-service temperature.
- (b) A partial design uncertainty factor for cohesion of the soil and back fill material (extrapolation) (Φ_{ue}), which covers the uncertainties of the extrapolation.

5.5.1.4 Construction damage factor

From manufacture to installation, the strength of the reinforcing product may be reduced due to—

- (a) weathering during the storage period; and
- (b) damage due to backfilling and compaction.

The amount of damage depends on the material and structure of the product as well as the nature of backfill, assuming reasonable compactive effort.

The short-term ultimate tensile strength (T_u) shall be multiplied by a reduction factor (construction or installation) (Φ_{ri}), which is based on test data.

5.5.1.5 Environmental degradation factor

All types of reinforcing materials are potentially affected by chemical, biological or physical actions due to the soil, its constituents, the air and water.

The short-term ultimate tensile strength (T_u) shall be multiplied by the following factors:

- (a) A thickness reduction factor (Φ_{rt}), which accounts for the diminishing average thickness or section area of the material and which depends on the required service life. It typically concerns metallic corrosion, but may also be applied to the superficial erosion of polymers.
- (b) A strength reduction factor (Φ_{rs}), which accounts for the loss of strength and which depends on the required service life. It covers the internal alterations of the material itself as well as the superficial unevenness, which makes strength decrease more than the average section area of the material, typically in the case of metals.
- (c) A temperature reduction factor (Φ_{rst}), which accounts for the loss of strength and which depends on the temperature of the material during the life of the structure.
- (d) An uncertainty factor (overall degradation) (Φ_{ud}), which depends on the limitation of knowledge or experience and which covers the unknowns regarding long-term behaviour.

For strength calculations, a combined reduction factor ($\Phi_{rt} \Phi_{rs}$) may be calculated from a nominal structural corrosion allowance, normally specified for metals.

5.5.1.6 Design tensile strength of the soil reinforcement

The design tensile strength of the soil reinforcements shall be determined from the following equation:

$$T_d^* = T_u(\Phi_{up})(\Phi_{rc} \Phi_{ue})(\Phi_{ri})(\Phi_{rt} \Phi_{rs} \Phi_{rst} \Phi_{ud})(\Phi_n) \quad \dots 5.5(1)$$

where

T_d = design tensile strength

T_u = short-term tensile strength

Φ_{up} = uncertainty factor (product)

Φ_{rc} = reduction factor (creep)

Φ_{ue} = uncertainty factor (creeptime extrapolation)

Φ_{ri} = reduction factor (installation)

Φ_{rt} = reduction factor (thickness)

Φ_{rs} = reduction factor (strength)

Φ_{rst} = reduction factor (temperature)

Φ_{ud} = uncertainty factor (degradation)

Φ_n = structure classification factor (see Table 5.2)

A1 | The maximum tensile force to be carried by the j^{th} layer of reinforcement shall not exceed the design strength of the reinforcement, i.e.

$$T_j^* \leq T_d^*$$

where

A1 | T_j^* = design maximum tensile force in the j^{th} layer

5.5.2 Soil/reinforcement interaction strength

5.5.2.1 General

A material strength factor shall be applied to the soil/reinforcement interaction strength. This factor shall be assessed by the designer for relevance to the subject soil characteristics and reinforcement configuration and is an uncertainty factor.

The uncertainty factor for soil/reinforcement interaction shall be Φ_u .

The appropriate range of values is given in Table 5.4.

TABLE 5.4
MATERIAL STRENGTH FACTORS FOR SOIL/REINFORCEMENT INTERACTION

Soil reinforcement interaction factors	Soil or fill conditions	Strength and stability load cases	Serviceability load case
Φ_u (Sliding resistance across reinforcement surface)	Controlled fill (Class I or II)	0.8	1
Φ_u (Pull out resistance)	Controlled fill (Class I or II)	0.8	1
	Natural or in situ soil	0.75	1