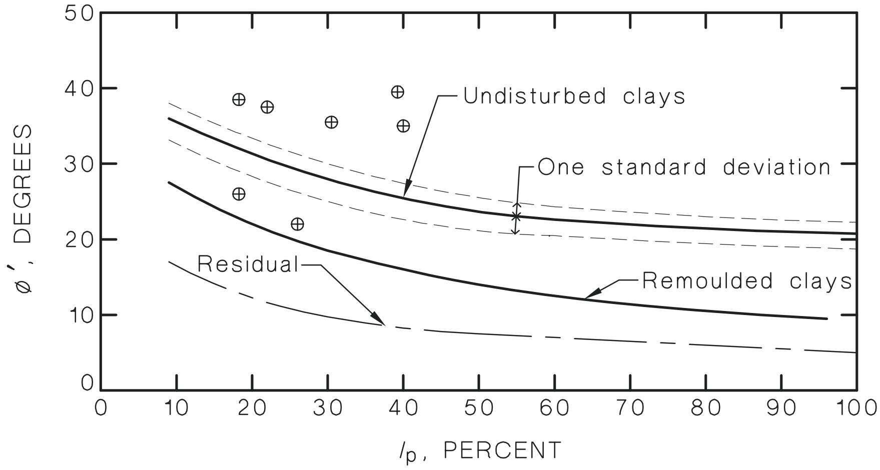

NOTE: Approximately 80% of data falls within one standard deviation. Only a few extreme scatter values are shown (Data from several sources: Ladd et al. (1977), Bjerrum and Simons (1960), Kanja and Wolle (1977), Olsen et al. (1986).)

FIGURE D1 CORRELATION BETWEEN ϕ' AND PLASTICITY INDEX I_p FOR NORMALLY CONSOLIDATED (INCLUDING MARINE) CLAYS

D2.2.3 *Cohesionless soils*

The strength and stiffness of cohesionless soils vary with respect to density, angularity and grading of particles. An estimation for characteristic peak effective internal friction angle ϕ' can be given by—

$$\phi' = 30 + k_A + k_B + k_C \qquad \text{. . . D1}$$

where the parameters k_A, k_B and k_C relate to the angularity, grading and density of the particles. Some conservative values of these parameters are set out in Table D2.

TABLE D2

ϕ' FOR SILICEOUS SANDS AND GRAVELS

Angularity (see Note 1)		**(k_A) (degrees)**
	Rounded	0
	Sub-angular	2
	Angular	4
Grading of soil (see Note 2 and Note 3		**(k_B) (degrees)**
	Uniform	0
	Moderate grading	2
	Well graded	4
***N'* (below 300 mm) (see Note 4)**		**(k_C) (degrees)**
	<10	0
	20	2
	40	6
	60	9

NOTES:

1 Angularity is estimated from visual description of soil.

2 Grading may be determined from grading curve by the use of—

coefficient of uniformity = D_{60}/D_{10}

where D_{10} and D_{60} and 60% are particle sizes such that, in the sample, 10% of the material is finer

than D_{10} and D_{60} and 60% is finer than D_{60}.

Grading	*Uniformity*
Uniform	< 2
Moderate grading	2 to 6
Well graded	6

3 A step-graded soil should be treated as uniform or moderately graded soil according to the grading of the finer fraction.

4 *N'* from results of standard penetration test modified where necessary.

5 Intermediate values of k_A, k_B and k_C are given by interpolation.

D2.2.4 *Rock materials*

The engineering properties of rock, relative to the design of an earth-retaining structure, is usually controlled by the extent and orientation of bedding planes and joints within the rock mass, together with any water pressures on discontinuity planes.

Whilst site investigation processes should normally determine the appropriate friction angle to be adopted, some conservative values of ϕ' are set out in Table D3.

D2.2.5 *Fill materials*

Fills have been classified in this Standard as being Class I or Class II controlled fill, uncontrolled fill and other fill. Whilst a wide range of fills may be used as backfill behind retaining walls, selected cohesionless granular fill placed in a controlled manner behind the wall is usually the most desirable.

'Other fill' should not be used as fill under, within or behind retaining structures unless specific investigations show that it is suitable; as such, no recommendations for 'other fill' are made in the Tables in this Standard.

Where plastic cohesive fills are used behind walls, the same can cause problems during both the design and the construction phases; this is because of aspects such as shrink/swell of the clays, softening of the clays with saturation and so on. Consequently, where clays of higher than low-to-moderate plasticity (viz. a PI of greater than 20) are used, then special attention should be paid to items such as shrink/swell and softening.

In the case of reinforced soil structures, it is usually necessary to be very specific about the fill material to be used in the reinforced soil block. Some suggestions on the various types of fill for reinforced soil structures are provided in subsequent Paragraphs of this Appendix.

TABLE D3

ϕ' FOR ROCK

Stratum	ϕ' (degrees)
Chalk	35
Weathered granite	33
Fresh basalt	37
Weak sandstone	42
Weak siltstone	35
Weak mudstone	28

NOTES:

1 The presence of a preferred orientation of joints, bedding or cleavage in a direction near that of a possible failure plane may require a reduction in the above values, especially if the discontinuities are filled with weaker materials.

2 Chalk is defined here as unweathered medium to hard, rubbly to blocky chalk.

3 Weathered basalt may have very low values of ϕ'.

D3 TYPICAL SOILS

Whilst the variety of soils encountered in practice is very large, the usual range of soils can be classified as set out in Table D4.

TABLE D4

SOIL CLASSIFICATION

Soil group	Typical soils in group	Soil parameters	
		c' (kPa)	ϕ' (degrees)
Poor	Soft and firm clay of medium to high plasticity, silty clays, loose variable clayey fill, loose sandy silts	0 to 5	17 to 25
Average	Stiff sandy clays, gravelly clays, compact clayey sands and sandy silts, compacted clay fill (Class II)	0 to 10	26 to 32
Good	Gravelly sands, compacted sands, controlled crushed sandstone and gravel fills (Class I), dense well-graded sands	0 to 5	32 to 37
Very good	Weak weathered rock, controlled fills (Class I) of roadbase, gravel and recycled concrete	0 to 25	36 to 43

D4 FILL MATERIALS FOR REINFORCED SOIL STRUCTURES

D4.1 General

Fill materials for reinforced soil structures should be free from any organic, plastic, metal, rubber or any other synthetic material, inorganic contaminants, dangerous or toxic material or material susceptible to combustion. Fill materials should consist of naturally occurring or processed materials that are capable of being compacted in accordance with the specified requirements, to form a stable mass of fill.

Where reinforced soil structures are used to retain highly plastic or reactive soil materials, then the impact of the shrink/swell movements of such soils on the reinforced soil structures, embedded services and associated structures should be considered in the design.

Fill materials should have values of shear strength and soil/reinforcement friction consistent with the design parameters. The reinforced soils design should specify physical, chemical and electrochemical properties.

Select or other fill materials may be used for reinforced soil structures as defined in Paragraphs D4.2.2 and D4.2.3.

D4.2 Select fill for reinforced soil structures

D4.2.1 *General*

Select fill material for reinforced soil structures should be a frictional, non-aggressive material of either natural or industrial origin, free of organic material, meeting the physical, chemical and electrochemical criteria defined in Paragraph D4.2.

The use of select fill material as defined in Paragraphs D4.2.2 and D4.2.3 will allow appropriate design parameters to be adopted as defined in Paragraphs D4.2.4 and D4.2.5, provided that it is constructed as defined in Paragraph D4.2.6. This material will result in a sound, durable structure whose design and construction performance will be predictable over a wide range of construction and service conditions.

D4.2.2 *Physical properties*

Select frictional fill material should be defined based on the physical (size) properties of the fill material in place (after compaction) as follows:

(a) Grading as determined by AS 1289.3.6.3 should be within the limits defined in Table D5 below:

(b) If more than 15% of the material passes the 75 μm sieve, then not more than 10% of the material should have a diameter less than 20 μm.

(c) Coefficient of uniformity should be greater than 2.

(d) Plasticity index should be less than 12.

D4.2.3 *Chemical and electrochemical properties*

Select non-aggressive fill material may be defined based on the chemical and electrochemical properties described in Table D6.

TABLE D5

PARTICLE GRADING

A2

Particle size	Percent passing
150 mm	100
9.5 mm	25–100
2.36 mm	15–100
600 µm	10–100
75 µm	0–15

NOTE: For geosynthetic reinforcement, use of larger particle sizes may require a decrease in the damage factor.

TABLE D6

BASIC SOIL PROPERTIES FOR NON-AGGRESSIVE SELECTED BACKFILL

Classification	S1	S2
Resistivity (ohm, cm)	>5000	>1000
pH (min.)	>5	>5
pH (polyester, galvanized steel only)	<10	<10
Chlorides (mg/kg)	—	<200
Sulfates (mg/kg)	—	<1000

D4.2.4 *Design parameters, physical*

The soil shear strength parameters (required by Section 5), for select fill material as defined in this Appendix, should be taken as follows:

(a) Characteristic friction angle .... $\phi' = 36°$.

(b) Characteristic drained cohesion .... $c' = 0$.

D4.2.5 *Design parameters, chemical and electrochemical*

The corrosion allowances defined in Table D7 should be adopted to assess the combined reduction factors for strength and thickness (required by Section 5), for steel reinforcements buried in selected fill material.

TABLE D7

CORROSION ALLOWANCES (mm)

Design life (years)		5	30	100
Land based	Plain	0.5	1.5	4.0
	Galvanized	0	0.5	1.5
Freshwater	Plain	0.5	2.0	5.0
	Galvanized	0	1.0	2.0
Marine	Plain	1.0	3.0	7.0

NOTE: The corrosion allowance is the total effective loss of thickness in a section from which is determined the residual tensile strength.

D4.2.6 *Construction*

The select fill in the reinforced soil structure should be placed and compacted in layers of thickness appropriate to the compaction methods to be used and so that each layer of fill is completed at the connection to the facing panel.

The select fill placement should closely follow the erection of each course of facing panels and should be placed and spread in a direction parallel to the face of the structure. Plant with an equivalent static weight of more than 10 kN should be excluded from a zone extending to 1.5 m from the facing panels of the structure. Compaction of the select fill in this zone should be carried out using hand-operated equipment with an equivalent static weight of less than 10 kN, to achieve the equivalent density to that achieved in the main body of the reinforced soil structure.

The select fill should meet the requirements of a controlled fill (Class I) and compacted to provide a uniform density over the full width of the reinforced fill structure.

A minimum of 1 in situ density test to verify compaction should be carried out per layer, as follows, except in the case of structure classification 3:

(a) For plan areas of filling less than 1000 m^2, one test every 200 m^3.

(b) For plan areas of filling greater than 1000 m^2, one test every 500 m^3.

D4.3 Other fill for reinforced soil structures

D4.3.1 *General*

Fill for reinforced soil structures may be outside the criteria for select fill defined in Paragraph D4.2 provided that the design and construction of the structure takes into account the performance characteristics of the material, both in the short and long term, and appropriate controls are provided.

The use of highly plastic or expansive clays is not recommended for reinforced soil structures, because of the potential for movement due to changes in moisture content.

D4.3.2 *Physical properties*

The maximum particle size should be limited by the needs of the earthworks placement and compaction. As a guide, the maximum particle size should be limited to two-thirds the compacted layer thickness and should be consistent with the design criteria used to take into account construction damage.

The minimum particle size should be limited by the need to control plasticity and to achieve consistent shear strength and frictional resistance with the reinforcement under construction and in-service conditions. A minimum particle size limit of not more than 20% smaller than 20 μm is recommended, with up to 40% smaller than 20 μm being possible, subject to detailed testing and performance evaluation.

D4.3.3 *Chemical and electrochemical properties*

The chemical and electrochemical properties of the fill should be appropriate to the material and the service life of the structure, based on relevant test data.

D4.3.4 *Design parameters, physical*

The design soil shear strength and the friction coefficient should be assessed based on the soil fill and the reinforcement material to be used. Fill that exhibits a friction angle (ϕ) less than 24° should not be used, and a maximum cohesion value (c) of 5 kPa should be used in the calculation.

D4.3.5 *Design parameters, chemical and electrochemical*

Material reduction factors should be based on appropriate test data for the soil and environmental conditions expected in the design.

D4.3.6 *Construction*

The placement and compaction of fill in a reinforced soil structure should meet the recommendations of Paragraph D4.2.6.

The fill should be compacted to provide a uniform density over the full width of the reinforced soil structure. The minimum density should be consistent with the design of the soil and the reinforcement, and strength and performance criteria of the structure.

APPENDIX E

DESIGN MODELS AND METHODS

(Informative)

E1 DESIGN MODELS

There are various methods of calculation of earth pressures on retaining walls and some methods of calculation are only appropriate in very particular circumstances (for example, the Rankine theory is only applicable to vertical walls). Further, the effect of the 'restraint' conditions on the wall can vary enormously the distribution of the earth pressures behind a wall.

Therefore, it is very important to select—

(a) the appropriate method analysis; and

(b) the wall restraint conditions.

A guide as to the applicable earth pressure theories is given in Table E1, whilst the various restraint conditions are illustrated in Figures E1 to E5.

In addition, as an individual earth pressure theory may only inadequately describe the likely forces on the wall, the designer should consider the degree to which the design model is applicable to a particular site and include an appropriate 'partial factor', if required.

As the analysis of structures that slope backwards at an angle that approximates the typical 'Coulomb Wedge' (see Figures E3 and E4) requires a consideration of the overall stability of the slope using slope stability analysis methods, this Standard does not provide the recommendations or requirements for the design of this form of structure, which is usually termed a 'revetment structure' (see Figure 1.1).

Where retaining walls using 'embedded piles' are adopted at a site, the design of such structures should be carried out as suggested in AS 2159 for laterally loaded piles.

E2 DESIGN METHODS

E2.1 Safety in design

According to this Standard, safety is incorporated in the design process by the following:

(a) Using conservative soil properties in the analysis of stability, deformation, seepage or other ground engineering problems. This Standard prescribes or recommends factors by which characteristic material properties are multiplied in order to lead to a safe design (Section 5).

(b) Factoring up loads where they contribute to ground failure or excessive deformation, and factoring down loads that resist failure or reduce deformations (Section 4).

(c) The designer should be aware that additional safety in design may result from—

   (i) performing laboratory or field tests that tend to underestimate strength or overestimate deformation of soils;

   (ii) sampling and testing soils with a bias towards finding the most unfavourable result;

   (iii) using methods of analysis that are known to give conservative results; and

   (iv) using empirical correlations that tend to err on the safe side.

Conversely, safety may be reduced where the above techniques are deemed to yield non-conservative results.

NOTE: The following alternative design approaches to retaining walls may be used, provided the same design considerations and performance criteria as outlined in this Standard are satisfied:

(a) For walls other than reinforced soil walls, a global (lumped) geotechnical resistance factor may be used, rather than partial material design factors. No guidance is given in this Standard for the choice of global factors.

(b) A safe design of conventional retaining structures can also be achieved by analysing limit equilibrium conditions using the worst credible soil parameters. A factor of safety just exceeding 1 would be sufficient to prevent failure. However, if the chosen safety factor is also intended to limit displacements to a tolerable maximum, the lowest credible soil strength will need to be further reduced by dividing it by a partial factor. This approach is referred to as the Direct Assessment (Worst Credible Scenario) method. No guidance for this approach is given in this Standard.

E2.2 Representative material properties

E2.2.1 *General*

In this Standard, representative material properties are called characteristic values. The meaning of characteristic value may vary depending on the particular material involved and conventions in the relevant industry.

Material design factors (Section 5) are thus applied to characteristic values (refer Clause 1.4.1.4).

E2.2.2 *Soil shear strength parameters*

The Mohr-Coulomb failure criteria contains two parameters, c' and ϕ' commonly referred to as the cohesion and the friction angle respectively, regardless of their true physical interpretation. Different sets of strength parameters are defined depending on loading and drainage conditions or the stress-strain characteristics as follows:

(a) Peak values are strength parameters determined from the highest strength value recorded during the test. Peak values are traditionally used in the analysis of bearing capacity and the determination of earth pressures.

(b) Effective strength parameters c' and ϕ' as obtained from a drained shear test or an undrained shear test with pore pressure measurements. These parameters are used for the analysis of free-draining granular soils and the long-term stability of clays.

(c) Undrained strength parameters c_u and ϕ_u as obtained from an undrained shear test. These parameters are used for the analysis of short-term stability, or stability under sudden loading of clays.

(d) Ultimate, constant volume or critical values (ϕ_{cr} or ϕ_{cv}) are derived from measurements where the sheared specimen has reached constant volume conditions (usually at a strain of say 10%). These values are used in analyses based on the concept of critical state soil mechanics.

(e) Residual values (ϕ_r) are determined at very large strains (say 100%). They may be relevant for the analysis of the global stability of a wall in a slope with a history of instability.

For any analysis involving soil shear strength, an appropriate set of shear strength parameters has to be chosen.

For retaining structures with controlled backfill, analysis with effective strength parameters is usually critical. Partial factors given in Section 5 are applied to strength components based on effective strength parameters.

For retaining structures supporting excavations in saturated clay and possible for other soil or loading conditions, undrained analysis may be more critical than an analysis using effective strength parameters. For some problems, it may be appropriate to analyse both, undrained and drained (effective stress) conditions. Undrained strength of clays is referred to in Paragraph D2.2.2 of Appendix D.

E2.3 Notation

For the purpose of this Appendix, the following notation applies:

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

c' = characteristic effective cohesion of a soil

c_u = characteristic undrained cohesion of a soil

A1 c^* = design cohesion of a soil

ϕ = characteristic angle of shearing resistance 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' = characteristic effective internal friction angle of a soil

ϕ_u = characteristic undrained internal friction angle resistance of a soil

ϕ_{cv} = critical or constant-volume internal friction angle of a soil under effective stress conditions

ϕ_r = residual internal friction angle of a soil under effective stress conditions

ϕ^* = design internal friction angle of a soil