AN OVERVIEW OF AS 4678 – EARTH RETAINING STRUCTURES

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SUMMARY

This paper describes the genesis of the Australian Standard on Earth Retaining Structures [known as AS 4678-2002], outlines & explains the various sections of the Standard and its implications for structural engineers. In addition, the paper presents a discussion of some of the more important aspects of the Standard, including the evaluation of earth pressures, design parameters, drainage and various ground support & anchor issues. The paper also explains the reasoning behind some of the recommendations included in the Standard, as well as highlighting the need for close interaction between geotechnical and structural engineers in retaining wall design.

INTRODUCTION

In December 1991 Standards Australia issued, as a draft for an Australian Standard on retaining walls, the British Standard on reinforced soils. However, because this Standard was a voluminous document and disputed by many groups in Australia, a committee was formed in 1992 to develop an Australian Standard for Earth Retaining Structures. The first meeting of the committee took place in September 1993, with the committee being chaired by Manfred Haussmann until the Standard's publication. The committee was made up of a range of persons drawn from government, industry associations and private consulting firms. After publication of the Standard, the committee has been chaired by Gary Mostyn.

At the outset, the committee decided that it was important that the proposed Australian Standard should be a relatively 'brief' document, and not adopt the 'textbook' approach that had been used by the British. In essence, the committee felt that the prime purpose of the Standard should be to define the important issues to which designers and constructors must pay careful attention, and leave most of the detailed design to an individual designer.

It was also thought important that the Standard should include a reasonably extensive series of appendices to explain, and add additional information to the Standard itself.

The committee processes for development of a draft of the Standard took over 5 years, and several committee members spoke at meetings of some engineers on the content of the proposed Standard. After the draft of the Standard was published in 1998, a series of workshops was held in the various states of Australia, and extensive public comment was received.

Finally, the Standard was published in February 2002 and was amended in a minor way in July 2003; another minor amendment is due later this year. Whilst the July 2003 amendments were fairly significant, the 2007 amendment is very minor and corrects a small typographic error.

THE STANDARD ITSELF

The Standard itself is divided into seven sections which are described as:

Section 1	Scope and General	Section 5	Material Design Factors
Section 2	Investigation and Testing	Section 6	Construction
Section 3	Design Requirements	Section 7	Performance Monitoring
Section 4	Design Loads		

Whilst in this paper, a detailed discussion of the various sections of the Standard will not be provided, some of the more important aspects of the Standard to structural engineers are described. It is also important to note that the Standard:

1. Does not apply to 'revetment type' structures.
2. Is limited to structures of less than 15 m high.
3. Should not be directly applied to sites where there are unusual ground conditions or structures subject to sustained cyclic loading.

Notes:

a) Limitations 2 & 3 are in reality an 'alert' to a designer to take very special care with high structures, and where the ground conditions are difficult.

b) Most of the technical information in the Standard is applicable to high structures and difficult ground conditions.

The reason the Standard specifically excludes revetment structures is that the common earth pressure theories [viz: Rankin and Coulomb Wedge] are not applicable to a slope flatter than 70° to the horizontal. Also, as revetment structures are normally analysed by 'slip circle' methods and have a slope of between 45° & 60/65°, the committee considered that inclusion of revetments in the Standard would unnecessarily complicate the proposed Standard.

This restriction on application of the Standard is illustrated in Figure 1.1.

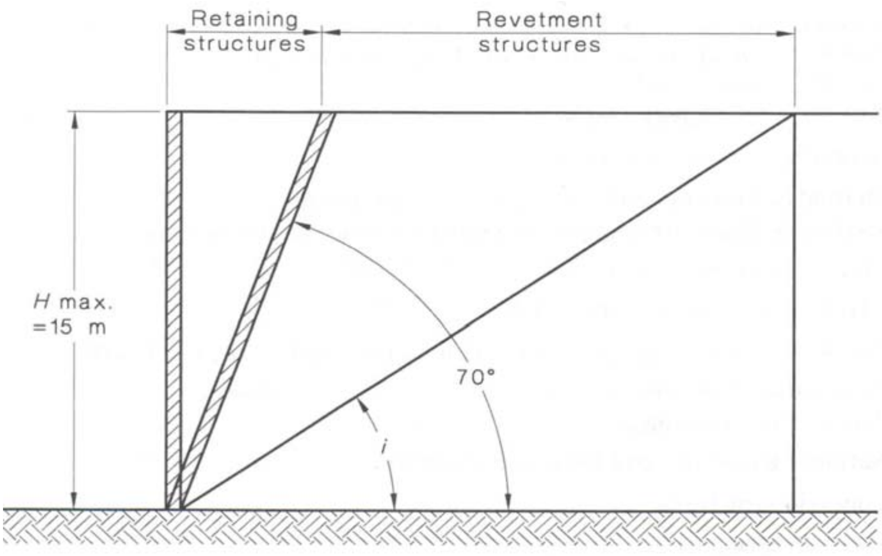


FIGURE 1.1 RETAINING AND REVETMENT STRUCTURES

THE APPENDICES TO THE STANDARD

The informative appendices to the Standard are as follows:

A	Structure Classification	**F**	Material Selection and Durability
B	Ground Anchors	**G**	Drainage of Earth Retaining Structures
C	Soil Nailing for Earth Retaining Structures	**H**	Reinforced Soil Facing System Connection Loads
D	Soil and Material Properties	**I**	Earthquake Design
E	Design Models and Methods	**J**	Load Combinations
		K	Partial Material Strength Factor Determination for Soil Reinforcement

Of these appendices, those that are of particular importance to structural engineers are the sections on structure classification, design models, drainage and ground anchors.

The Standard also has extensive appendices on the design of reinforced soil structures including soil nailed structures; whilst these sections are very informative, structural engineers need to recognise that the design of a reinforced soil structure requires considerable expertise in civil & geotechnical engineering, rather than structural expertise.

As such, if a structural engineer has a project where there are reinforced soil structures, then it would be prudent to work in close collaboration with a suitably experienced civil & geotechnical engineer.

IMPORTANT ASPECTS OF THE STANDARD

Prior to providing particular comment on the various sections of the Standard and its appendices, some general comments are provided below:

1. As the Standard is written in limit state format, it is very important for a designer to consider the various partial load factors and partial material factors when producing a design.

2. The Standard does not refer to the common earth pressure coefficients, K_a, K_p & K_o and uses the 'characteristic' parameters c' & φ' to describe a soil or weathered rock. Thus, if an engineer does not have sufficient knowledge to relate these parameters to earth pressure calculations, then the engineer should seek appropriate advice before designing a wall.

   Note: As there are a range of professional persons providing geotechnical advice, it would be prudent for a structural engineer to only rely on advice from properly qualified geotechnical engineers for recommendations on earth pressure coefficients.

3. Whilst the Standard is not specifically applicable to walls less than 800 mm high, it would normally be prudent for designers and builders of these small walls to comply with the Standard.

4. The Standard introduces two important elements into the wall design process, viz:

   - the need to consider the effect of the proposed construction on the adjoining ground;
   - the requirement for a retaining wall designer to design the drainage system associated with the wall.

   These elements were introduced because the committee considered that many engineers were not considering sufficiently the effects of the proposed wall construction on nearby properties, and only providing minimal detail of the drainage systems required.

Thus, as many wall failures are occasioned by faulty drainage systems, the committee considered it necessary to require that the subsoil drainage systems associated with retaining walls be placed in the hands of the wall designer.

1. Section 1 : Scope & General

Whilst this section of the Standard principally covers the various definitions used in the Standard, a very important section is the 'Structure Classification', which is elaborated on in Appendix A. In this regard, the following is noted:

a) The concept of structure classification was discussed extensively within the committee.

b) The committee decided that it was important to include in the partial safety factors, a factor that would consider the consequences of wall failure.

c) The 'risk' partial factor should apply the material design parameters.

The consequence of the above is that where the failure of a structure poses a significant risk to life, or has the potential to cause considerable damage, the earth retaining structure is designed more conservatively, than one where its failure would have minimal consequences.

Also, whilst the current table classification of A, B and C may appear to be 'out of order', the table was originally established for a Class 1, Class 2 and Class 3 structures, with a Class 1 structure being the most critical.

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:

1 Classification B includes structures not covered by Classifications A or C.

2 For more information on structure classification, see Appendix A.

2. Section 3 : Design Requirements

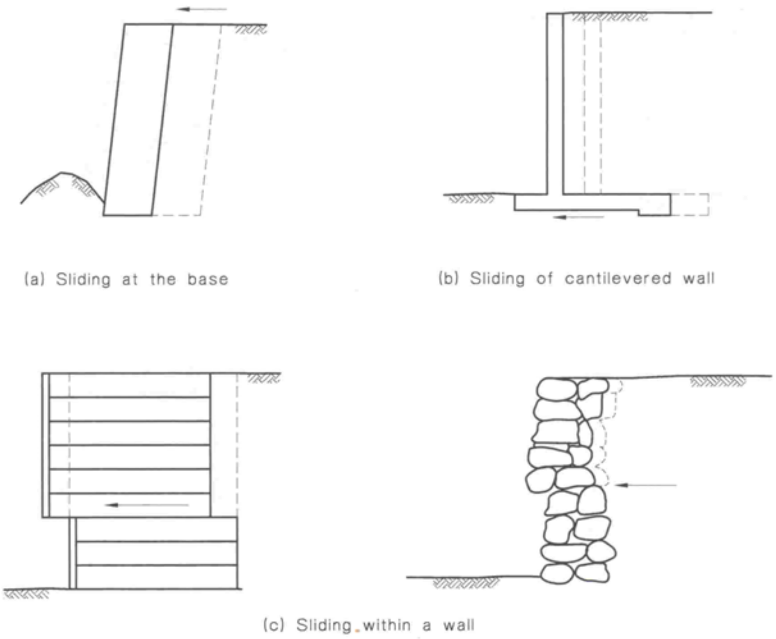
Section 3 of the Standard covers the various design requirements, and sets out the various ultimate & serviceability limit states for various types of retaining walls. This section of the Standard also covers issues such as design life, durability, drainage and the influence of construction on adjacent ground.

a) Design Models

Of particular importance to structural engineers are the various diagrams that illustrate the many of the 'limit modes' [or potential failure mechanisms] for both conventional and reinforced soil walls. These diagrams [Figures 3.1 & 3.2 in the Standard] illustrate the ways in which wall failures can occur, and provide a rational basis for a designer's assessment of the most critical form of failure that should be considered in wall design.

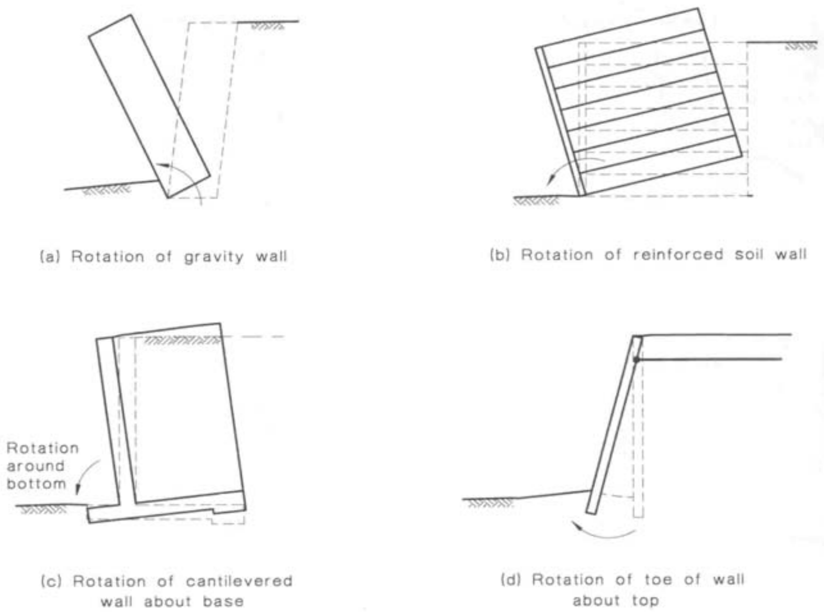
It is important to note that the diagrams presented in the Standard are only 'illustrative' of the possible limit / failure modes, with the wall designer being responsible for considering all possible failure modes.

Illustrated below are some of the limit modes included in the Standard that might have particular relevance to structural engineers.



NOTE: These diagrams are illustrative of the failure mode.

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



NOTE: These diagrams are illustrative of the failure mode.

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

Experience has also indicated that many retaining wall failures can be principally attributed to the wall designer not considering the various possible modes of failure in the design process, and only focussing on one failure mode. Further, as the actual earth pressure distribution is considerably affected by the way in which a wall can fail [viz: its critical limit mode], wall designers need to pay very careful attention to a wall's restraint conditions, and all the possible failure modes.

In view of the above, it would be prudent for an engineer who intends to design a retaining wall to consider carefully the various limit modes presented in the Standard.

It is also noted that whilst the Standard provides information on various design models and analysis methods in Appendix E, the Standard itself is silent on the particular theory / analysis method that should be used in wall design. This is because modern methods of calculation, combined with the continuing development in understanding of the way in which soils behave, suggested that a designer should be free to choose the most appropriate method of analysis.

b) Earth pressures

As many structural engineers apparently do not appreciate that the pressures upon a retaining wall are a function of the 'restraint' conditions, as well as the material parameters, the Standard includes a number of diagrams in Appendix E [Diagrams E1 to E5] to illustrate the variation in distribution of earth pressures as a result of the wall's restraint conditions & critical limit mode.

Note: Some of these diagrams were developed from the textbook by Wayne Teng [Ref. 3], and illustrate the way in which the distribution of earth pressures varies with a wall's restraint conditions.

It was also this considerable difference in magnitude & distribution of earth pressures on a wall with different restraint conditions, that led the committee to decide that rather than recommending an 'earth pressure coefficient' approach to wall design, the Standard should base its design recommendations [viz: partial & uncertainty factors] on the 'characteristic' material parameters of soils / weathered rock [viz: c' and φ'].

One of the diagrams included in the Standard is as follows:

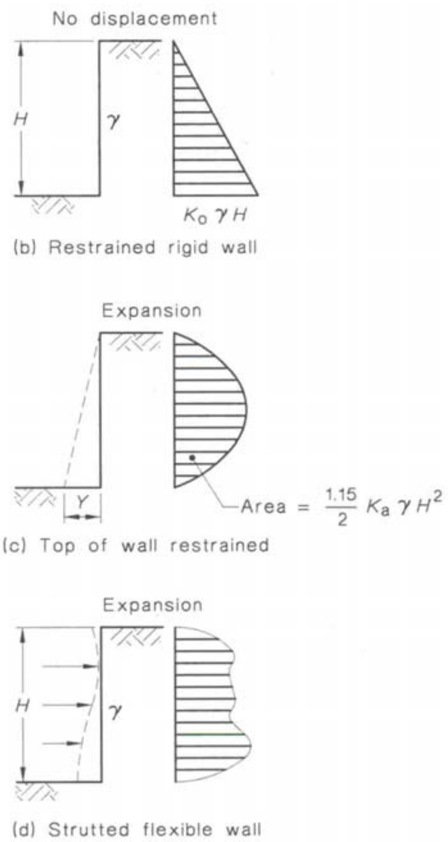


FIGURE E5 EFFECT OF RESTRAINT CONDITIONS ON EARTH PRESSURES

c) Drainage

Engineers have long recognised that the provision of effective drainage behind a retaining wall is very important to the stability of the wall. However, because the detailing of this drainage by wall designers and engineers was generally minimal, faulty drainage systems have often been installed with consequent problems / wall failure.

As such, the committee decided that the Standard should include the following clause **to require** a wall designer to 'design' the drainage associated with a retaining wall.

Clause 3.6.2

Design considerations

…. 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 -

- *the subsurface drainage system, including pipe drains and subsoil drains;*
- *weep holes;*
- *filters and geotextiles;*
- *fill materials;*
- *other drainage details; and*
- *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.

Thus, as the Standard now requires a wall designer to also design the drainage system associated with the wall, should there be any fault with the design of the drainage system, then it will be clear as to the person / organisation that is responsible for the fault.

Note: Additional remarks on wall drainage are provided in Section 5 of this paper.

3. Section 5 – Material Design Factors

Section 5 of the Standard covers the various partial factors to be applied to various materials and the various 'uncertainty factors' to be applied to the characteristic soil / weathered rock material parameters.

Whilst the various 'characteristic' material parameters for soils / weathered rock will normally be selected on the basis of advice from geotechnical engineers, the Standard includes some guidance on typical values in Appendix D.

If a designer wants to use an 'earth pressure coefficient' to design a wall, then the following is to be especially noted:

a) To accurately determine the appropriate earth pressure coefficient, it will be necessary to consider the material design parameters, the structure restraint conditions and a variety of limit [failure] modes.

b) The 'earth pressure coefficient' approach usually ignores soil / structure interaction and can lead to a design which incorrectly locates the reinforcement within a wall.

c) Whilst more substantial walls are preferably designed using 'finite element type' computer programs, it is very important that the various input parameters are carefully selected and relevant to the site conditions. Thus, it is usually necessary for a structural engineer to obtain specific advice on the various material design parameters from a suitably experienced geotechnical engineer.

4. Appendix B – Ground Anchors

Prior to the publication of the Standard, there was only minimal information available in Australia on the design of ground anchors and the required specifications for contract purposes. Even today, many engineers still specify ground anchors as having a particular load carrying capacity, without proper consideration of:

- the depth to which the anchor should be installed;
- the test [proof] load;
- the working load;

of the required anchor.

Thus, as ground anchors are often used in combination with an earth retaining structure, the committee felt it appropriate to provide guidance on ground anchors in an appendix to the Standard.

An important feature of Appendix B is Clause B4.4 Anchorage Loads, wherein it is suggested that the designer should specify the following:

1. The required anchor working load.
2. The anchor proof (or test) load.
3. The anchor 'lock off' load.
4. The long-term design load in the ground anchor.

The reason for the Standard suggesting that a designer to state these items, is to foster more careful consideration of the behaviour of a ground anchor in the design process. The committee also considered that if a designer carefully thought through these requirements, then anchor failure incidents would be greatly reduced.

5. Appendix G - Drainage

In Appendix G, extensive information is provided on the drainage systems for various forms of earth retaining structures. A common theme of the drainage details provided is the use of geotextiles and geocomposites within the drainage system, as these materials have greatly improved the constructability of effective drainage behind a retaining wall. However, traditional materials [viz: free draining sands and gravels] have also been included to provide the greatest flexibility in design.

The details provided also highlight a number of items not often appreciated in the design of subsoil systems, including:

a) The need to separate subsoil systems from surface drainage systems.

b) The importance of locating the subsoil pipe at the bottom of the subsoil drain so that the seepage water flows through the pipe rather than in the underlying gravel / soil surround.

c) The specification and use of appropriate free draining materials, rather than the commonly used brick bats and general fill.

d) The need to correctly locate the filters and geotextiles, with there being no point in providing a geotextile between a subsoil pipe and a gravel surround. In fact, the use of a geotextile 'sock' to surround a subsoil pipe set in gravel can adversely affect the drainage system as such 'socks' can be rendered impervious by the crusher dust on the typical gravel.

The Appendix also provides much useful information on the maintenance of subsoil drainage systems and the way in which the subsoil drainage systems can fail by blockage and bacterial growth. As such, it would be prudent for a retaining wall designer to give careful consideration to the required maintenance of the subsoil system. In this regard, experience has also shown that maintenance details are best provided by long-lasting signs attached to the structure, rather than by written documents and / or plans.

6. Appendices C & H – Soil Nailing & Reinforced Earth Structures

In Appendices C & H extensive comment and advice is provided on the two major groups of reinforced soil structures, viz:

1. Soil Nailed Structures.

2. Reinforced Earth Structures / Embankments.

These appendices also suggest that different forms of analyses should be used for steel reinforced structures, as compared to plastic reinforced structures. This is because reinforced soil structures created using steel reinforcement behave in a different way to those structures that are created using plastic materials.

Typically, a steel reinforced soil structure is analysed using the 'Coherent Gravity' method, whereas a plastic reinforced soil structure is analysed by the conventional ‘Coulomb Wedge’ methods.

It is also important to note that although steel rusts and corrodes with time, the various plastic and geosynthetic materials also deteriorate with time and are subject to long-term creep. Thus, it is important for a designer to carefully consider the properties of the soil, its chemical properties and the environment into which the reinforcement is to be installed as a part of the design process.

It is also necessary for a designer of a reinforced soil structure to have:

- a good understanding of the behaviour of the site soils and rocks, including the site geology & geotechnical constraints;
- the impact of soil behaviour on the reinforcing elements and structure drainage;
- the chemical properties of soils & groundwater;
- the behaviour of steel and plastics.

As such, the design of reinforced soil structures is a very specialised discipline, and should be only undertaken by engineers who have appropriate experience in all the above.

Note: Appendix C, Clause C8 provides a number of references intended to assist designers of reinforced soil structures.

CONCLUSION

The Australian Standard on Earth Retaining Structures has represented a major step in the development of the engineering design of retaining walls; as such, most civil and structural engineers would greatly benefit by studying, in detail, the various parts of the Standard.

In particular, it would be prudent for structural engineers to carefully consider the following in undertaking earth retaining structure design:

1. The failure of a small retaining wall can have very serious consequences.
2. The consequences of failure of the structure and / or its drainage systems.
3. The various 'limit modes' of failure suggested in the Standard.
4. The magnitude and distribution of earth pressures on the retaining structure, bearing in mind the wall's restraint conditions, as well as the various material parameters.
5. The details of the proposed drainage behind the wall, connection to an appropriate point of efflux and need for maintenance.

Engineers also need to appreciate that:

a) Whilst the Standard is a relatively short document, it contains a large amount of detail that needs to be fully understood by persons undertaking the design of an earth retaining structure. As such, wall designers need to be wary of undertaking retaining wall design without a full understanding of the Standard's requirements, information & implications.

b) The Standard is a 'work in progress', and it may well be that in the future the Standard will need further amplification and modification.

REFERENCES

1. AS 4678-2002 [Amended July 2003] : Earth Retaining Structures - Standards Australia
2. New Draft AS - Earth Retaining Structures (including Reinforced Soils). M R Haussmann, A F Shirley & M Boyd : Proceedings of 7th ANZ Conference on Geomechanics July, 1996.
3. Foundation Design - Wayne C Teng : Prentice Hall 1978.