CONCRETE RETAINING BLOCK WALLS

Design of Reinforced CRB Walls

Existing applications are still performing well after 30 years

CONCRETE MANUFACTURERS ASSOCIATION

Quality cast in concrete

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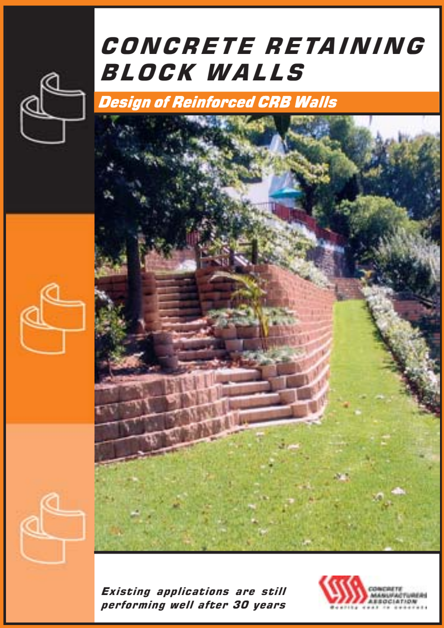

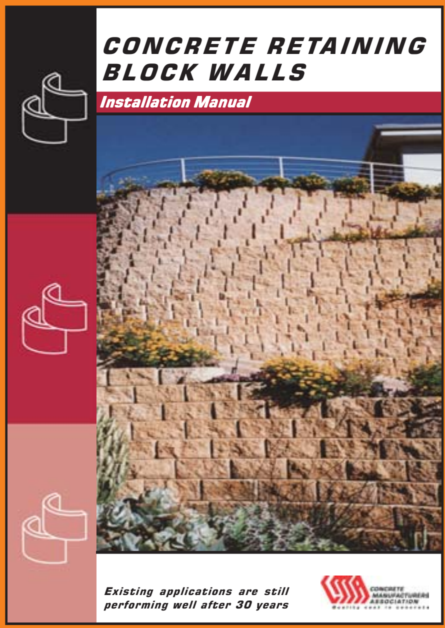

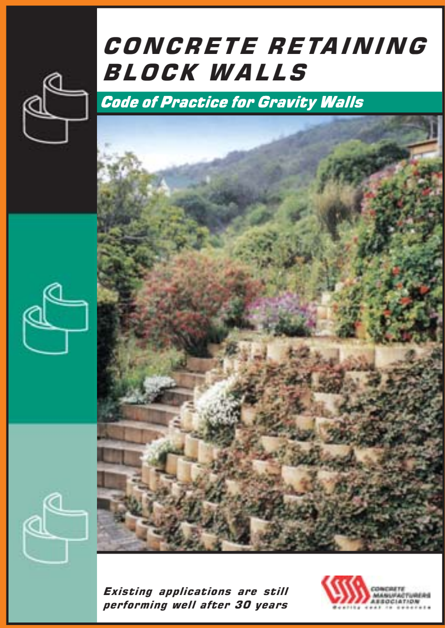

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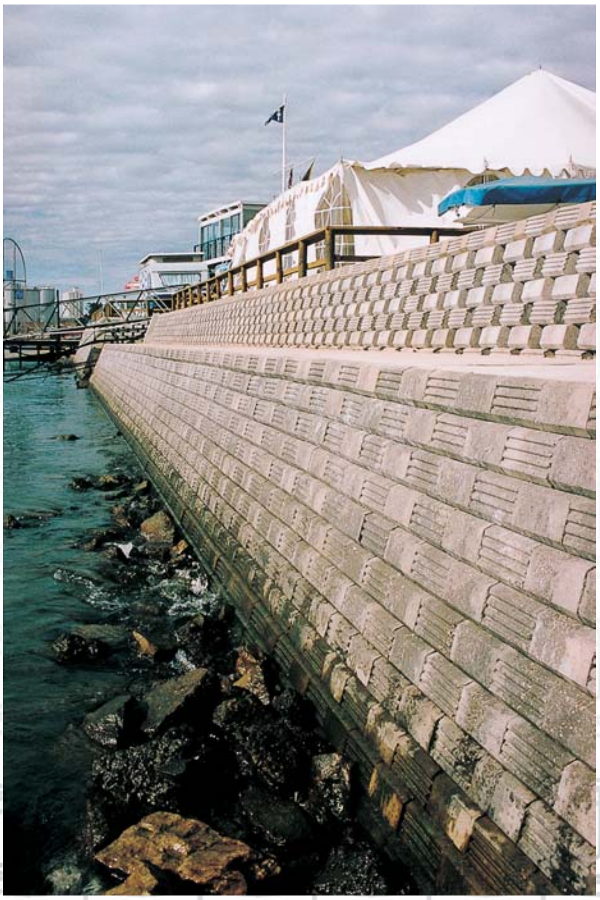
CONCRETE RETAINING BLOCK WALLS

DESIGN OF REINFORCED CRB WALLS

Editor Fred Gassner

SCOPE OF DOCUMENT

This document provides the general principles of design of Reinforced Concrete Retaining Block (CRB) Walls. Guidelines related to construction and serviceability issues are also provided.



GENERAL PRINCIPLES

The approach requires a sound understanding of geotechnical behaviour of the soil, both during construction and during the service life of the structure. The behaviour of the structures comprises an interaction between the retained soil, the backfill of the wall, the reinforcement elements, the foundation and the facing or wall structure.

There are two fundamental conditions that should be assessed prior to the design of a retaining wall. A retaining wall can fulfil two functions, either "stabilisation" or "retaining". "Retaining" assumes that the final geometry of the local structure is stable, i.e. a potential failure plane around the outside of the structure is stable. This guideline addresses the "retaining" function. "Stabilisation" is required where the final structure is required to improve the stability of a slope. Stabilisation often includes deeper anchors or soil nails, deep embedment of the retaining structure, or other forms of soil improvement. These issues are not addressed by this document.

REINFORCED CRB WALLS:

These structures are based on the backfill and the reinforcement within the backfill resisting most of the loads. The facing structure is usually lightly loaded and is usually of flexible construction. The reinforcement units are placed during the construction of the backfill, and are loaded by the incremental loads induced during placing of backfill and compaction. The load induced in the reinforcement varies along the length, with the peak load being located near the Coulomb surface projected from the toe of the fill. The load in the reinforcement rapidly drops off to less than 20% of the peak value that occurs at the Coulomb surface. For a vertical face with a flat backfill and dry granular backfill, the location of the peak load in the reinforcement occurs along a line approximately at an angle of (45+ø'/2) up from the horizontal, starting at the toe of the fill. The ø' is the drained shear strength of the fill. For the presently available polymer based reinforcement materials, the bottom-up construction techniques employed for these walls results in the reinforcement acting as extensible materials, which results in the development of active soil forces in the reinforcement layers.

The load at the connection to the facing of the wall varies over the height of the wall. The highest load applied to the connection occurs near the bottom of the wall, with the load reducing towards the top. The loads near the top of the wall are usually controlled by loads transferred to the connection by imposed loads near the crest of the wall, such as light poles, crash barriers, or shallow foundations for structures.

The foundation for the facing of the wall provides support and vertical stability to the facing. The reinforcement of the backfill provides horizontal stability to the system. Loads developed in the facing are usually higher than the self-weight of the facing. Provision is usually made for a full vertical component of the active force from the backfill, in addition to the self-weight of the facing. For the assessment of the settlement of the facing foundation, allowance should be made for the combined effects from the bearing pressures of the facing and bearing pressures from the reinforced backfill.

Deflection and settlement of these structures are influenced primarily by the stiffness of the backfill material around the reinforcement, and by the stiffness of the reinforcement over the stress range induced in the layers for the service loads of the structures. The type of backfill and the time over which the loads are applied influences the deformation of the structure. The types of reinforcement being considered in this document are polymer-based materials, which have substantially higher strengths for short-term loads, and are subject to creep if stressed above certain levels for longer periods. Geosynthetic reinforced structures are therefore ideally suited to resist dynamic loads, such as impact and earthquake loads. For long-term loads such as dead load, the reinforcement materials are usually factored down to ensure that the materials function below their creep limits. These limits are established from long-term tests which have been shown to provide deflections of structures which are similar to other engineering structures.

DESIGN PROCEDURE OF REINFORCED CRB WALL:

The following points should be assessed as part of the design of Reinforced CRB Wall, which are listed in a preferred sequence:

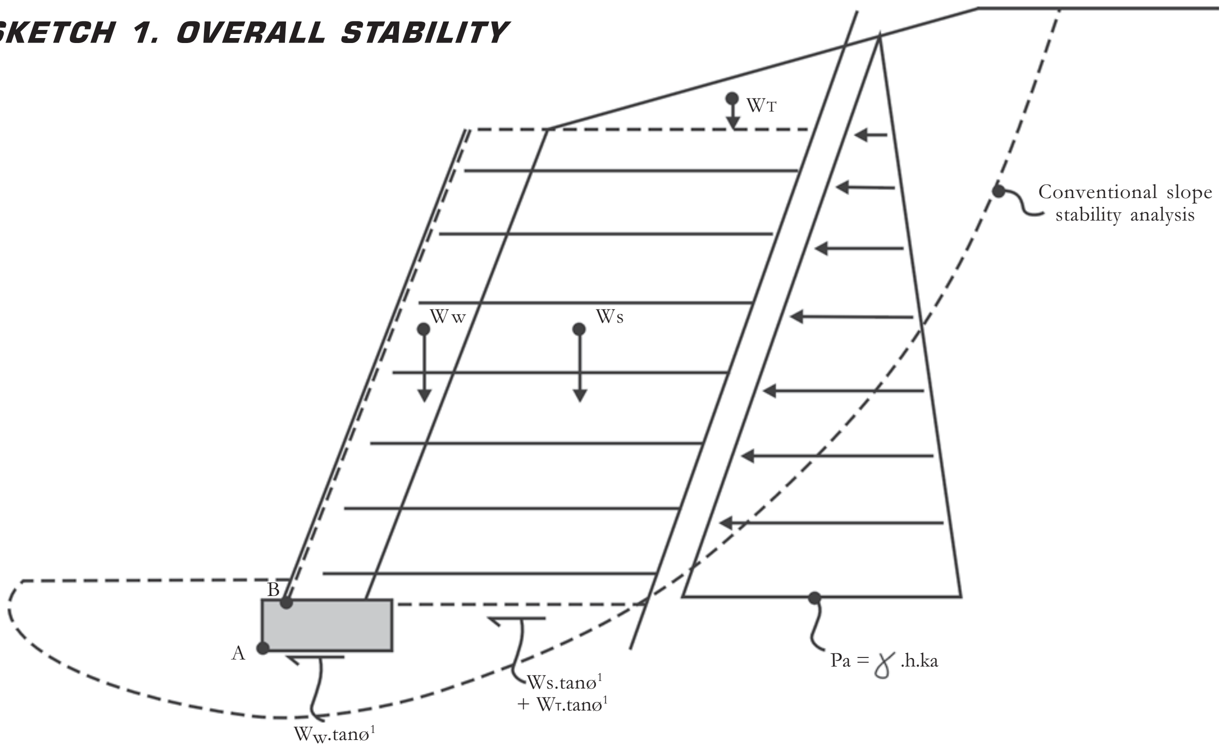
- External Stability
- Bearing Capacity and Settlement
- Internal Stability and Creep
- Facing

To assess the **external stability**, the Reinforced CRB Wall is treated as an inert stable block. The external stability is checked using conventional slope methods, which would result in the minimum base width and embedment depth required for the Reinforced CRB Wall to maintain overall stability of the slope or structure being retained. For simple geometric conditions with stable foundation conditions, a simplified overall stability analysis may be considered. This simplified analysis would include calculating the active soil pressure behind the Reinforced CRB Wall, and checking the Reinforced CRB Wall for sliding and overturning stability. This method is considered suitable for granular soils with no groundwater conditions.

The minimum factor of safety of overall stability, considered suitable for normal applications = 1,5.

The applied **bearing pressure** on the foundation soils below the Reinforced CRB Wall should be assessed by again treating the Reinforced CRB Wall as a stable rigid block. The bearing pressure should be assessed for a number of load combinations to predict the highest likely load on the foundation soils. Under simple loading conditions the highest foundation pressure usually occurs when all the dead and live loads associated with the Reinforced CRB Wall block are combined with the maximum overturning loads applied to the Reinforced CRB Wall from loads behind the Reinforced CRB Wall. The Meyerhof method to calculate foundation pressures is considered appropriate for Reinforced CRB Wall. The ultimate bearing capacity of the foundation soils should be assessed using the methods proposed by Terzaghi, etc. Alternatively, the foundation pressure calculated below the Reinforced CRB Wall should be compared to the allowable bearing pressure for the foundation soils recommended by a suitably qualified geotechnical engineer.

SKETCH 1. OVERALL STABILITY

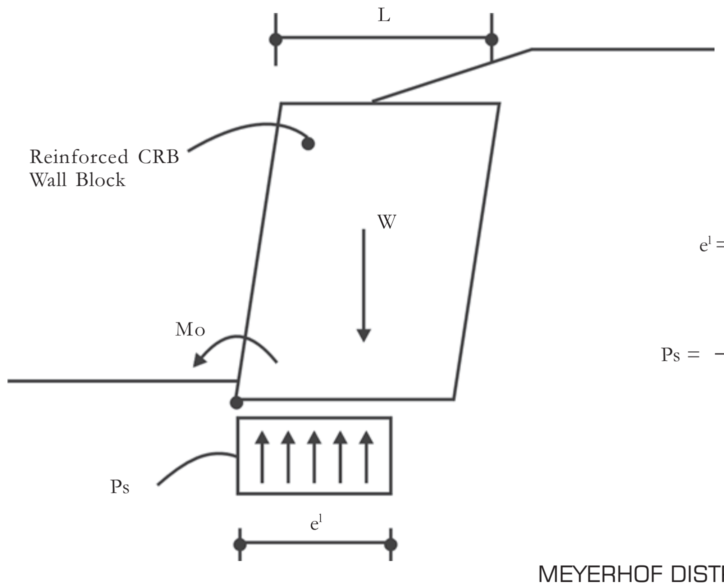


$$\text{F of S (Sliding)} = \frac{W_s.\tan ø^1 + W_T.\tan ø^1 + W_W.\tan ø^1}{\frac{1}{2}\gamma.h^2.ka} \geqslant 1,5$$

$$\text{F of S (Overturning)} = \frac{\text{Weight x lever arm about A or B}}{\text{Active soil force x lever arm about A or B}} \geqslant 1,5$$

Moments should be checked at A and B, to assess worst condition.

SKETCH 2. BEARING PRESSURE



$$e^{l} = \frac{Mo}{W}$$

$$Ps = \frac{W}{e^{l}} = \text{Foundation Pressure}$$

Mo = Nett Moment of loads about A

MEYERHOF DISTRIBUTION

The minimum factor of safety compared to the ultimate bearing capacity that is considered suitable for normal applications = 3,0. The factor of safety of 3,0 is based on limiting the total settlement to approximately 20 mm. For structures that are not sensitive to movement, consideration may be given to reducing the factor of safety with respect to the ultimate bearing capacity. However, this should be considered only in consultation with a suitably qualified geotechnical engineer.

The consistency and type of soil below the Reinforced CRB Wall determine the settlement of the structure. The zone of influence below a Reinforced CRB Wall normally extends to a depth of approximately 1,5 times the base width of the Reinforced CRB Wall with the greatest influence occurring over a depth of one times the base width of the Reinforced CRB Wall.

Settlement of the foundation soils usually results in a tilt of the Reinforced CRB Wall, as higher bearing pressures normally occur near the toe of the wall, with subsequent higher settlements near the toe. Excessive tilting of the structure usually results in a tension crack occurring near the back or just beyond the Reinforced CRB Wall. For settlement sensitive structures, in granular soils, simple loading and no groundwater, where more sophisticated analyses are not considered appropriate, the width of the Reinforced CRB Wall should not be less than 80% of the height of the wall.

Considerations such as collapse settlement and shrink/swell of the soil require an assessment from a suitably qualified geotechnical engineer. Where a significant or settlement sensitive Reinforced CRB Wall is to be constructed, consideration should be given to employing the services of a suitably qualified geotechnical engineer.

The **internal stability** analysis of the Reinforced CRB Wall results in the spacing and strength of reinforcement required. For walls with a facing slope between 70º and 90º the single-wedge method is considered suitable. For flatter sloped walls the two-wedge method is considered appropriate. These two methods are analytical methods, which mean they require the spacing and strength of the reinforcement layers to analyse the stability of the structure.

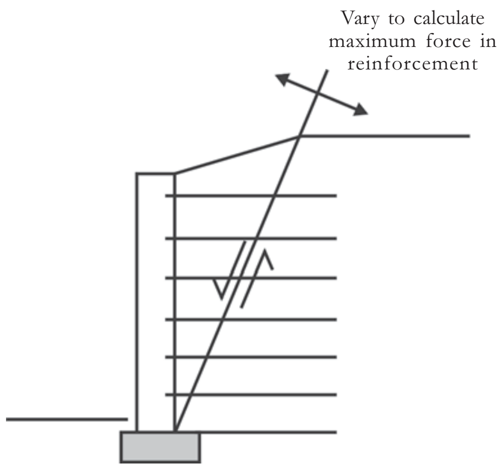
To obtain a preliminary layout and strength of the reinforcement consideration may be given to using the Rankine soil pressure coefficient method. The active soil pressure coefficient, ka should be used to calculate the horizontal pressure at the back of the wall facing. The pressure should then be split into layers with a vertical spacing suitable for the proposed facing. A preliminary vertical spacing of 0,3 times the length of the reinforcement layer may be considered. The length of the reinforcement layer has been previously calculated based on the criteria of overall stability, bearing capacity and settlement. The preliminary load in the reinforcement layers would be the calculated horizontal pressure at the level of the reinforcement multiplied by the vertical spacing.

The preliminary layout and force in the reinforcement layers is then used to calculate the internal stability using one of the two wedge methods. The length and load in the reinforcement layers may be adjusted to refine the design, using the wedge methods to check stability. Both the wedge methods must consider trial wedges that extend outside the Reinforced CRB Wall block, to check the stability of compound failure surfaces, which are failure surfaces that are part in the Reinforced CRB Wall and part outside.

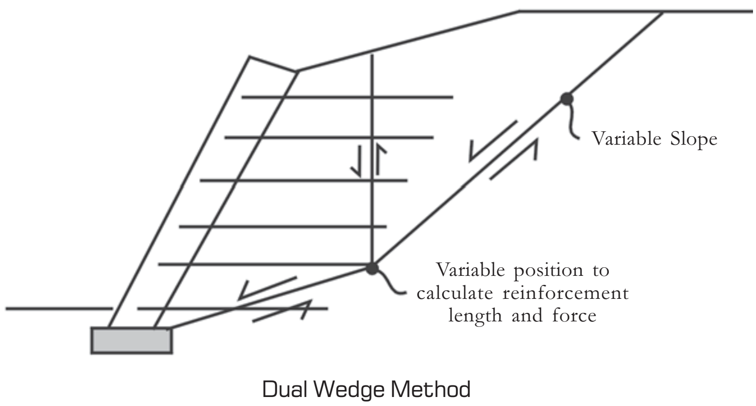
The minimum factor of safety of internal stability, considered suitable for normal applications = 1,5.

The **pullout resistance** of the reinforcement layers should be checked for every layer. The resistance should be checked on both sides of the failure surface being considered, to check that the layer of reinforcement can provide the assumed restraining force at the failure surface.

SKETCH 3. INTERNAL STABILITY



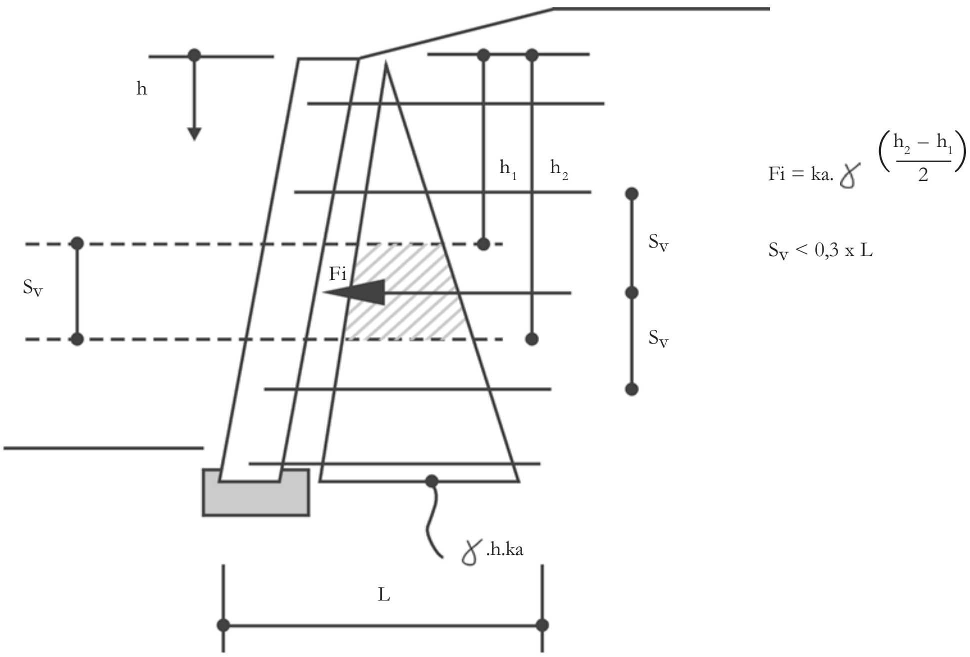
Single Wedge Method
70° to 90° Wall



Dual Wedge Method
< 70° Slopes

(Resistance of facing blocks may be included in analysis)

SKETCH 4. PRELIMINARY LOAD ASSESSMENT



The assessment of the pullout resistance requires that the type of reinforcement be selected. Most types of reinforcement have specific friction and /or interlock properties, which result in large differences in the pullout resistance in different soils. This information is normally available from the manufacturers of geosynthetics. The pullout resistance of a layer of geosynthetic is a function of the vertical stress applied to the geosynthetic over the anchorage length. The anchorage length is defined in the sketch below. The pullout resistance is compared to the load required at the failure surface to obtain the factor of safety against pullout.

The minimum factor of safety against pullout considered suitable for normal applications = 1,5.

The **strength of geosynthetic** required at each level of the Reinforced CRB Wall has been calculated from the above. Now the geosynthetic should be selected. Most geosynthetics have a threshold stress level, at which the material continues to strain without additional load being applied, until the material ruptures. This threshold level is specific to the material and manufacture process used for the geosynthetic, and is sometimes referred to as the plastic flow stress. Typically this stress is between 50% and 30% of the ultimate strength of the geosynthetic.

The installation of most geosynthetics results in damage to the fibres. Further damage to the geosynthetic may occur due to environmental damage, such as chemical attack, temperature or biological influence. Again, this is specific to each type of geosynthetic. To make allowance for the anticipated damage to the geosynthetic due to these influences, the ultimate strength of the geosynthetic is factored down by a series of reduction factors. These reduction factors would be dependent on the type of fill being used for the Reinforced CRB Wall, the likely long-term environment of the geosynthetic, and the type of material of the geosynthetic. These factors are combined in the formula below to determine the design strength of the geosynthetic.

F (design) = F (plastic flow) / (factor 1* factor 2* … factor n)

Where factor 1 = construction damage

factor 2 = chemical attack

factor 3 = creep reduction factor, etc.

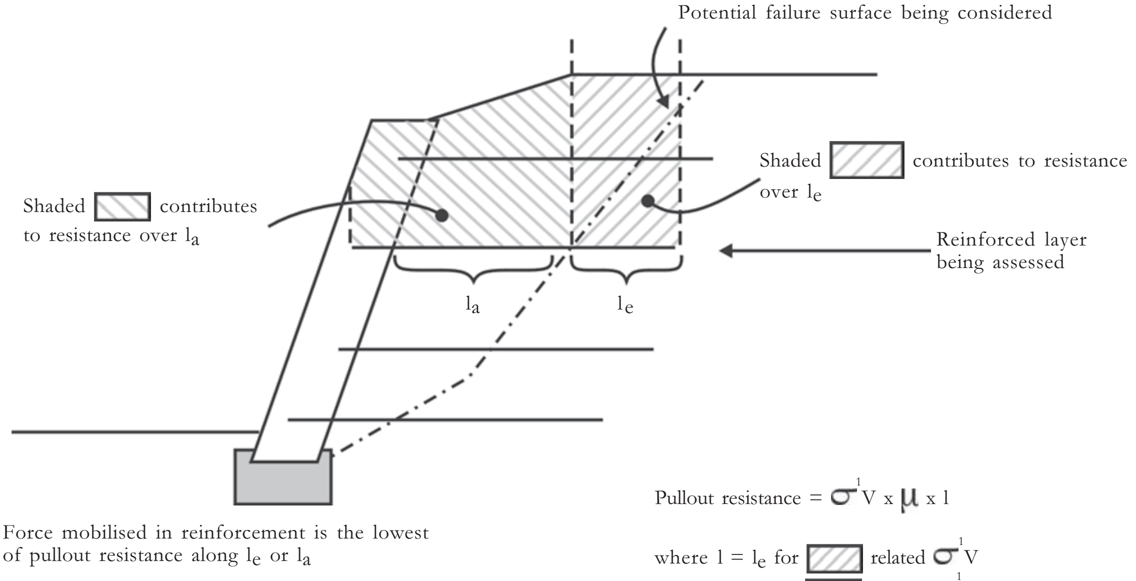
The number of factors is normally dependent on the type of geosynthetic and should be provided by the manufacturer of the geosynthetic.

Lastly, creep should be considered. Creep continues to occur in most geosynthetic after installation in the Reinforcement CRB Wall. The amount of creep that occurs is dependent on the stress in the geosynthetic, with the general trend being the lower the stress the lower the creep, with the rate of creep reducing on a log scale if the stress is well below the plastic flow stress level. The percentage of on-going creep is specific to the type of geosynthetic, and is usually presented as a function of the long-term stress in the geosynthetic. This creep value should **not** be multiplied by the length of geosynthetic reinforcement to calculate the amount of lateral deflection that may be expected at the face of the Reinforced CRB Wall. In the absence of more detailed analysis, the general guide provide below, which is based on experience may be adopted. If the lateral deflection at the face of the Reinforced CRB Wall needs to be assessed in more detail, the services of a specialist geotechnical engineer should be sought.

- 0,5% creep limit based on permanent loads for Reinforced CRB Wall steeper than 70°
- 1,0% creep limit based on permanent loads for Reinforced CRB Wall flatter than 70°

All of the above properties of the geosynthetic being considered should be obtained from the suppliers of the geosynthetic. The methods to test and determine

SKETCH 5. PULLOUT RESISTANCE



Pullout resistance = $\sigma^1 V \times \mu \times l$

where $l = l_e$ for [shaded] related $\sigma^1 V$

$= l_a$ for [shaded] related $\sigma^1 V$

and μ = friction and interlock factors for top plus bottom of reinforcement l_a

the properties discussed above are all documented in international standards for testing, e.g., BS, ASTM, DIN and SABS.

The **type of facing being selected usually governs the facing connection.** The force applied to the facing connection is generally less than the load applied to the layer of reinforcement. In the absence of more detailed analysis the following guide may be adopted for walls sloping at 70° or steeper.

For continuous layers of reinforcement, which are continuously connected to the facing:

- 50% of the load in the reinforcement layer over the top 2/3 of height
- 100% of the load in the reinforcement layer over the bottom 1/3 of height.

For strip reinforcement:

- 50% of the load in the reinforcement layer over the top half of height
- 100% of the load in the reinforcement layer over the bottom half of height.

The pullout strength of facing connections that rely on gravity is usually specific for the geosynthetic and facing. If laboratory pullout tests are not available, the target factor of safety for this component of the Reinforced CRB Wall should be suitably increased to reflect the uncertainty.

For Reinforced CRB Wall flatter than 70°, the force likely to be transferred to the facing through the connection is considered to be lower than specified above, and consideration may be given to a lower factor of safety of 1,30, where the Reinforced CRB Wall is not subject to pore pressures due to inundation or seepage.

The minimum factor of safety for the facing connection for steep walls is considered = 1,5.

SERVICEABILITY CONSIDERATIONS:

The following points usually have a significant impact on the performance of the Reinforced CRB Wall:

- Saturation of the fill:
- Moisture sensitive soils:
- Development of phreatic surface:
- Stiffness profile of the geosynthetic.

The **saturation of the fill** would typically result in a change of weight of the Reinforced CRB Wall, which results in a change in the load in the reinforcement layers. This change in load should be assessed in terms of the change in strain and how this impacts on the structure.

Where **moisture sensitive soils** are being considered in conjunction or as part of the Reinforced CRB Wall, care should be taken to assess the impact of water ingress into the system. Moisture sensitive soils have a significant reduction in both strength and stiffness when changing from a partially saturated to a saturated state. Structures constructed with these soils would typically deform substantially upon wetting-up of the soil. This deflection is a combination of larger loads transferred to the reinforcement layers, due to an increase in weight of the fill and a reduction in the strength of the fill. In addition the stiffness of the fill itself is also reduced, which adds more deformation to the structure. When moisture sensitive soils are being considered, effective seepage and surface water management structures should be considered to reduce the risk of inundation.

The **development of a phreatic surface** in the fill is of no concern if the Reinforced CRB Wall has been designed for it. However, if a phreatic surface develops in a structure due to unforeseen circumstances, then large deformations and possibly failure may be expected. Reinforced CRB Walls have substantial excess capacity in the short-term strength of the reinforcement, and hence can resist significantly larger loads for short periods of time, as long as the pullout resistance is not exceeded. When a phreatic surface develops in the Reinforced CRB Wall block, the load in the structure is increased, and the pullout resistance is reduced. This could lead to a pullout failure and subsequent collapse of the Reinforced CRB Wall.

Where the phreatic surface is located in the soil behind the Reinforced CRB Wall block, the load on the Reinforced CRB Wall block increases, but the pullout resistance of the reinforced layers is usually not reduced. Under these circumstances the Reinforced CRB Wall is not likely to collapse, but may deform excessively or slide near the foundation level of the Reinforced CRB Wall.

Hence, it is more effective to locate a subsoil drain, if required, behind the Reinforced CRB Wall, or across the bottom of the Reinforced CRB Wall block.

The **stiffness of the geosynthetic** determines how much strain occurs upon loading the material. Some geosynthetics have a more non-linear stress-strain response than others. For a geosynthetic with an approximately constant stiffness over the stress range being considered there is no special consideration related to changes in stiffness of the geosynthetic. However, for the geosynthetic where the stiffness changes significantly over the stress range being considered, care should be taken to ensure that the change in geosynthetic strain does not result in excessive deflection of the structure. In the absence of more detailed assessment it is considered good practice to limit the change in stress in the geotextile due to changes in the loads applied to the Reinforced CRB Wall during normal operations to a stress range of approximate constant stiffness. The stiffness of a geosynthetic is defined as:

E_{geo} = Force (per m width) / deformation (m) = kN/m^2

The test results from standard wide width tensile tests for geosynthetics should be used to assess the stiffness of the geostynthetic.

RECOMMENDED STANDARD BILL OF QUANTITIES

Item	Description	Unit	Quantity	Rate	Amount
1	Preliminary and General	Sum			
2	Trimming of batter faces to correct angle	m^3			
3	Embankment preparation work	m^2			
4	Trenching for foundations	m			
5	Clearing and grubbing	m^2			
6	Excavate for foundations	m^3			
7	20 MPa concrete to foundations				
	a) Type 1	m^3			
	b) Type 2	m^3			
	c) Type 3	m^3			
8	Reinforcing steel to foundations	ton			
9	Supply and install Concrete Retaining Blocks (CRB's) including placing of fill material in the blocks for a minimum mass of kg/m^2 of wall, to curves and angles as per drawings, including backfill to 250 mm behind blocks. Approved fill to be supplied to workface by others.	m^2			
10	Ditto above, but minimum mass to be kg/m^2 of wall.	m^2			
11	Ditto above, but minimum mass to be kg/m^2 of wall.	m^2			
12	Supply and place specified fill material in layers not exceeding block height, compact to 90% Mod. AASHTO.	m^3			
	Or				
	Place only of fill supplied by others, layers not exceeding block height, compact to 90% Mod. AASHTO	m^3			
13	Supply and place geotextile to machine/warp direction before placing fill on top				
	1) U24 Kaymat	m^2			
	2) Kaytape S120 or S210 or S270	m^2			
	3) Restrain 50 or 75 or 100	m^2			
	4) Geogrid 110 or Fortac 35/20-20, etc.	m^2			
14	Supply and install perforated 100 Ø pipe encased in 19 mm stone, wrapped in U24 Kaymat	m			
15	Supply and install wickdrains to seepage areas as indicated on site by engineer	m^2			
16	Supply and place 19 mm stone infill to blocks at or just below pebble marker	m^3			
17	Engineers design fees				
	a) Full design indemnity	%			
	b) Ditto with drawings	Sum			