Concrete Retaining Structures

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Reinforced Concrete Masonry Cantilever Retaining Walls

Design and Construction Guide

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REINFORCED CONCRETE MASONRY CANTILEVER RETAINING WALLS

DESIGN AND CONSTRUCTION GUIDE

Edition E1, December 2008

Supersedes all previous editions

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PREFACE

Standards Australia has published AS 4678:2002 for the design of earth retaining structures, including reinforced concrete masonry cantilever retaining walls. It encompasses the following features:

- Limit state design
- Partial loading and material factors
- Compatibility with the general approach taken in AS 1170 *Structural design actions*(Note 1)
- Compatibility with the structures standards such as AS 3600 *Concrete structures*(Note 2) and AS 3700 *Masonry structures*.

This guide provides Australian designers and contractors with a comprehensive approach to the design and construction of reinforced concrete masonry cantilever retaining walls based on:

- The design and construction rules set out in AS 4678:2002
- An analysis method developed by the Concrete Masonry Association of Australia (CMAA) to fit Australian experience.

This guide describes the design and construction of gravity earth retaining structures, consisting of a reinforced concrete footing and a reinforced concrete masonry cantilever stem. It includes:

- A description of the principal features of the Australian Standard
- A description of the analysis method
- Design tables for a limited range of soil conditions and wall geometry
- A design example which demonstrates the use of the Australian Standard and analysis method
- Analysis of cohesive soils
- A site investigation check list
- A detailed construction specification
- A study of the reliability of AS 4678.

NOTES:

1 When published in early 2002, AS 4678 included load factors which were compatible with the load factors on the version of AS 1170 that was then current. However, changes to AS 1170 in late 2002 have meant that exact similarity of load factors no longer exists.

2 Design of the concrete base is based on Cement Concrete and Aggregates Australia and Standards Australia *Reinforced Concrete Design Handbook*, HB71–2002.

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1 INTRODUCTION

1.1 GENERAL

For many years, reinforced concrete masonry gravity retaining walls, relying on gravity loads to resist the overturning forces due to soil pressure, have been constructed using a reinforced concrete masonry stem (steel reinforcement grouted into hollow concrete blockwork), which is built on a reinforced concrete footing.

In 1990 the Concrete Masonry Association of Australia (CMAA) published Masonry Walling Guide No 4: *Design For Earth Loads - Retaining Walls*, which set out a design methodology and safe load tables for these structures. It included:

- Ultimate load design with material factors based on characteristic soil properties, partial load factors consistent with AS 1170.1 and structure designs to AS 3700 and AS 3600.
- Coulomb analysis of the back-fill.
- Bearing analysis using the Meyerhoff approach (including tilt and inclined load factors).
- Sliding analyses that account for friction, passive pressure and (if appropriate) base adhesion.

These design and analysis features were considerable improvement on the working stress/assumed bearing capacity/Rankine analysis that was then in common use.

Standards Australia AS 4678:2002 is generally consistent with the CMAA Guide No 4 approach (with some modifications to factors), and applies to reinforced masonry gravity retaining walls, dry-stacked masonry gravity retaining structures and dry-stacked masonry reinforced soil structures.

This guide describes the design and construction of gravity earth retaining structures, consisting of a reinforced concrete footing and a reinforced concrete masonry cantilever stem.

1.2 GLOSSARY

Loads and limit states:

Design life The time over which the structure is required to fulfil its function and remain serviceable.

Dead load(Note 1) The self-weight of the structure and the retained soil or rock.

Live load(Note 1) Loads that arise from the intended use of the structure, including distributed, concentrated, impact and inertia loads. It includes construction loads, but excludes wind and earthquake loads.

Wind load The force exerted on the structure by wind, acting on either or both the face of the retaining wall and any other structure supported by the retaining wall.

Earthquake load The force exerted on the structure by earthquake action, acting on either or both the face of the retaining wall and any other structure supported by the retaining wall.

Stability limit state A limit state of loss of static equilibrium of a structure or part thereof, when considered as a rigid body.

Strength limit state A limit state of collapse or loss of structural integrity of the components of the retaining wall.

Serviceability limit state A limit state for acceptable in-service conditions. The most common serviceability states are excessive differential settlement and forward movement of the retaining wall.

Components:

Concrete masonry units Concrete blocks manufactured to provide an attractive, durable, stable face to a retaining wall. They are commonly "H" or "Double U" configuration.

Geotextile A permeable, polymeric material, which may be woven, non-woven or knitted. It is commonly used to separate drainage material from other soil.

Retained material The natural soil or rock, intended to be retained by a retaining wall.

Foundation material The natural soil or rock material under a retaining wall.

Infill material The soil material placed behind the retaining wall facing. Often retained soil is used for this purpose.

Drainage material The crushed rock, gravel or similar material placed behind a retaining wall to convey ground water away from the wall and foundations. It is commonly used in conjunction with other drainage media, such as agricultural pipes.

Soil types:

Cohesive fill Naturally-occurring or processed materials with greater than 50% passing the 75 µm Australian standard sieve, a plasticity index of less than 30% and a liquid limit of less than 45%.

NOTES:

1 This Guide uses the terminology "dead load" to indicate permanent actions and "live load" to indicate imposed actions. This terminology is consistent with the convention adopted in AS 4678:2002.

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. For cohesionless soils, material compacted to at least 75% Density index is satisfactory.

Controlled fill Class II Soil, rock or other inert material that has been placed in specified layers and in a controlled fashion to ensure 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. For cohesionless soils, material compacted to at least 75% Density index is satisfactory. Generally the layer thickness is specified as a maximum of 300 mm.

Uncontrolled fill Soil, rock or other inert material that has been placed at a site and does not satisfy the materials included above.

Insitu material Natural soil, weathered rock and rock materials.

GW Well-graded gravel as defined by the Cassegrande extended classification system. Generally in the range of 2 mm to 60 mm, and graded such that the smaller particles pack into the spaces between the larger ones, giving a dense mass of interlocking particles with a high shear strength and low compressibility.

SW Well-graded sand as defined by the Cassegrande extended classification system. Generally in the range of 0.6 mm to 2 mm, and graded such that the smaller particles pack into the spaces between the larger ones, giving a dense mass of interlocking particles with a high shear strength and low compressibility.

GP Poorly-graded gravel as defined by the Cassegrande extended classification system. Generally in the range of 2 mm to 60 mm, and of a single size. This material has good drainage properties provided it is protected from infiltration by silts and clays.

1.3 BEHAVIOUR OF REINFORCED CONCRETE MASONRY CANTILEVER RETAINING WALLS

If unrestrained, a soil embankment will slump to its angle of repose. Some soils, such as clays, have cohesion that enables vertical and near-vertical faces to remain partially intact, but even these may slump under the softening influence of ground water. When an earth-retaining structure is constructed, it restricts this slumping. The soil exerts an active pressure on the structure, which deflects a little and is then restrained by the friction and adhesion between the base and soil beneath, passive soil pressures in front of the structure and the bearing capacity of the soil beneath the toe of the structure.

If water is trapped behind the retaining structure, it exerts an additional hydraulic pressure. This ground water also reduces the adhesion and bearing resistance. If massive rock formations are present immediately behind the structure, these will restrict the volume of soil which can be mobilised and thus reduce the pressure.

The walls described in this guide are gravity earth-retaining structures, consisting of a reinforced concrete footing and a reinforced concrete masonry cantilever stem (**Figure 1.1**).

The retained soil exerts an active pressure on the infill material above the heel of the base (in *Type 1*) and this, in turn, exerts an active force on the stem of the wall. In *Type 2*, the retained soil exerts an active pressure directly on the stem. Overturning is resisted by the vertical load of the structure and, where applicable,the soil above the heel. It is usual to disregard any resistance to overturning provided by live loads.

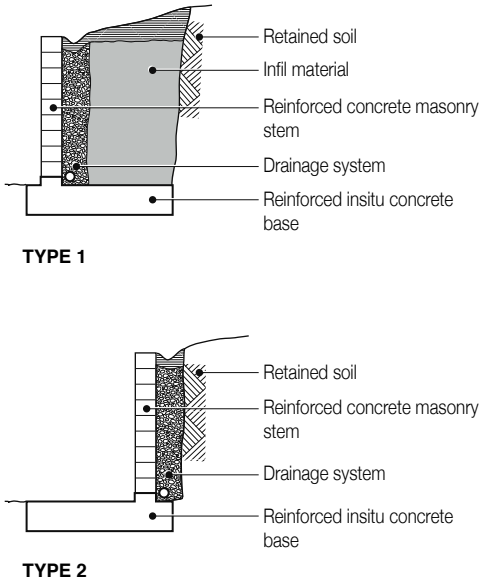


Figure 1.1 *Typical Arrangements of Reinforced Concrete Masonry Cantilever Retaining Walls*

1.4 IMPORTANCE OF A GEOTECHNICAL REPORT

The design of a retaining wall includes two essential parts:

- Analysis of the adjacent ground for global slip, settlement, drainage and similar global considerations; and
- Analysis and design of retaining wall structure for strength.

These analyses must be based on an accurate and complete knowledge of the soil properties, slope stability, potential slip problems and groundwater. A geotechnical report by a qualified and experienced geotechnical engineer should be obtained.

Such a report must address the following considerations, as well as any other pertinent points not listed.

- Soil properties;
- Extent and quality of any rock, including floaters and bedrock;
- Global slip and other stability problems;
- Bedding plane slope, particularly if they slope towards the cut;
- Effect of prolonged wet weather and the consequence of the excavation remaining open for extended periods;
- Effect of ground water;
- Steep back slopes and the effect of terracing;
- Effect of any structures founded within a zone of influence.

1.5 SAFETY AND PROTECTION OF EXISTING STRUCTURES

Whenever soil is excavated or embankments are constructed, there is a danger of collapse. This may occur through movement of the soil and any associated structures by:

- rotation around an external failure plane that encompasses the structure,
- slipping down an inclined plane,
- sliding forward, or
- local bearing failure or settlement.

These problems may be exacerbated by the intrusion of surface water or disruption of the water table, which increase pore water pressures and thus diminish the soil's ability to stand without collapse.

The safety of workers and protection of existing structures during construction must be of prime concern and should be considered by both designers and constructors. All excavations should be carried out in a safe manner in accordance with the relevant regulations, to prevent collapse that may endanger life or property. Adjacent structures must be founded either beyond or below the zone of influence of the excavation. Where there is risk of global slip, for example around a slip plane encompassing the proposed retaining wall or other structures, or where there is risk of inundation by ground water or surface water, construction should not proceed until the advice of a properly-qualified and experienced Geotechnical Engineer has been obtained and remedial action has been carried out.

1.6 GLOBAL SLIP FAILURE

Soil retaining structures must be checked for global slip failure around all potential slip surfaces or circles (**Figure 1.2**).

Designers often reduce the heights of retaining walls by splitting a single wall into two (or more) walls, thus terracing the site. Whilst this may assist in the design of the individual walls, it will not necessarily reduce the tendency for global slip failure around surfaces encompassing all or some of the retaining walls.

The designer should also take into account the effects of rock below or behind the structure in resisting slip failure.

Analysis for global slip is not included in this guide and it is recommended that designers carry out a separate check using commercially available software.

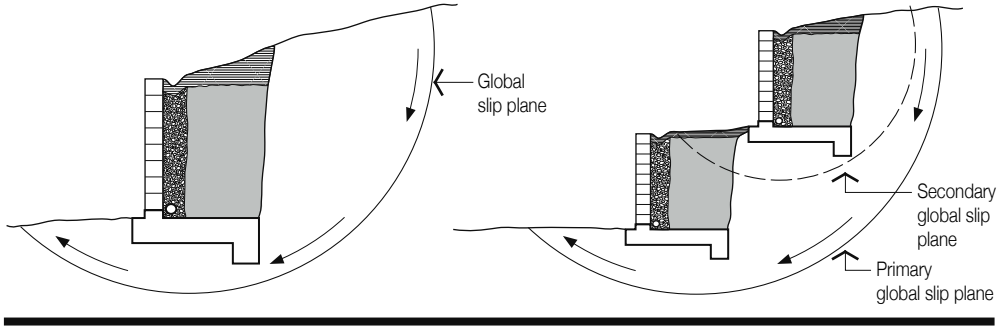


Figure 1.2 *Global Slip Failure*

1.7 DIFFERENTIAL SETTLEMENT

Techniques to reduce or control the effects of differential settlement and the possibility of cracking include:

- Articulation of the wall (by discontinuing the normal stretcher bond) at convenient intervals along the length.
- Excavating, replacing and compacting areas of soft soil.
- Limiting the stepping of the base to a maximum of 200 mm.

1.8 IMPORTANCE OF DRAINAGE

This guide assumes that a properly-functioning drainage system is effective in removing hydraulic pressure. If this is not the case, the designer will be required to design for an appropriate hydraulic load.

Based on an effective drainage system, it is common to use drained soil properties. For other situations, the designer must determine whether drained or undrained properties are appropriate. In particular, sea walls that may be subject to rapid draw-down (not covered in this guide) require design using undrained soil properties.

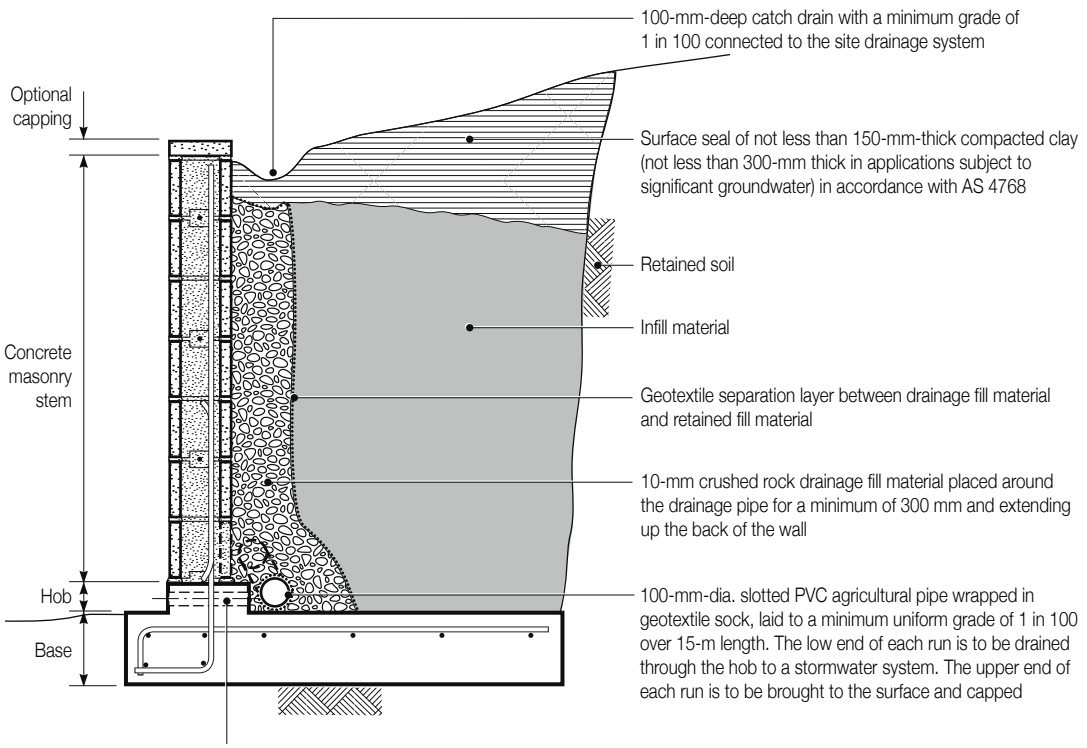


Figure 1.3 *Typical Drainage System*

2 DESIGN CONSIDERATIONS

2.1 SCOPE

This guide considers retaining walls founded on undisturbed material that is firm and dry and achieves the friction angle and cohesion noted for each particular soil type. It does not cover foundations exhibiting any of the following characteristics:

- Softness
- Poor drainage
- Fill
- Organic matter
- Variable conditions
- Heavily-cracked rock
- Aggressive soils.

If these conditions are present, they must be considered by the designer.

2.2 LIMIT STATE DESIGN

The design limit states considered are:

- strengths of the various components subject to ultimate factored loads;
- stability of the structure as a whole subject to ultimate factored loads; and
- serviceability of the structure and its components subject to service loads.

2.3 PARTIAL LOADING AND MATERIAL FACTORS

Partial-loading and partial-material factors enable the designer to assign various levels of confidence to assumed or measured soil strengths, material strengths and resistance to deterioration, predictability of loads and consequence of failure of various structures.

There are several reasons for compatibility of loading factors between AS 4678:2002 and AS 1170 *Structural design actions*, which applies to buildings(Note 1).

- Buildings are often constructed close to retaining walls, and therefore apply loads on them.
- Parts of buildings such as basement walls are often required to withstand loads imposed by earth and soil.
- The adoption of common load factors assists the rational comparison of the levels of safety and probability of failure of retaining walls and other structures.
- The design of concrete, masonry, steel and timber components of earth-retaining structures is determined using Australian Standards which are based on limit state concepts and loading factors from AS 1170.
- Most structural engineers are familiar with the loading factors of AS 1170.

2.4 LOAD COMBINATIONS AND FACTORS FOR STABILITY

The following load combinations and factors should be applied when checking the stability of the structure. This includes analysis for:

- Global slip
- Overturning
- Bearing capacity of the foundation under the toe of the base
- Sliding resistance of the foundation under the base(Note 2).

(i) $1.25\,G^C + 1.5\,Q^C < 0.8\,G^R + (\Phi\,R)$

(ii) $1.25\,G^C + \psi_c\,Q^C + W^C_u < 0.8\,G^R + (\Phi\,R)$

(iii) $1.25\,G^C + \psi_c\,Q^C + 1.0\,F^C_{eq} < 0.8(G + \psi_c\,Q)^R + (\Phi\,R)$

Where:

G^C = parts of the dead load tending to cause instability.

This includes: the weight of the retained soil, which causes horizontal pressures on the stem, thus tending to cause forward sliding, bearing failure or overturning, or the weight of the infill soil, which causes horizontal pressures on the facing, thus tending to cause stem rupture.

Q^C = parts of the live load tending to cause instability.

This includes all removable loads such as temporary loadings, live loadings applied from adjacent buildings, construction traffic and soil compaction loads and an allowance for the temporary stacking of soil of not less than 5 kPa, except for Structure Classification 3.

W^C_u = parts of the wind load tending to cause instability.

The factors are such that load combination (ii) involving wind loading, will not be the governing case when the effect due to wind, W^C_u is less than $(1.5 - \psi_c)$ times the effect due to live load, Q^C. For example, for a wall that does not support another exposed structure and for a minimum live load surcharge of $Q^C = 5$ kPa, an active pressure coefficient of $K_a = 0.3$ and a live load combination factor of $\psi_c = 0.6$, a wind load on the face of the retaining wall less than 1.35 kPa will not be the governing case. However, if the wind load is applied to some supported structure such as a building or a fence, the effect would be more pronounced.

NOTES:

1 When published in early 2002, AS 4678 included load factors which were compatible with the load factors on the version of AS 1170 that was then current. However, changes to AS 1170 in late 2002 have meant that exact similarity of load factors no longer exists.

2 Design for bearing capacity and external sliding resistance, involve the factoring-down of the soil properties (density, friction angle and/or cohesion) which are providing the resistance to instability.

F^{C}_{eq} = parts of the earthquake load tending to cause instability.
For earthquake categories A_e and B_e, design for static loads without further specific analysis is deemed adequate. For earthquake category C_e, a dead load factor of 1.5 (instead of 1.25) should be used and specific design for earthquake may be neglected. For earthquake categories D_e and E_e, the structures should be designed and analysed in accordance with the detailed method set out in AS 4678, Appendix I.

G^{R} = parts of the dead load tending to resist instability.
This includes the self-weight of the structure and the weight of soil in front of the structure.

ΦR = the factored design capacity of the structural component.
This includes calculated bearing capacity, sliding resistance, calculated pull-out strength, etc.

ψ_c = live load combination factor.
This is taken as 0.4 for parking or storage and 0.6 for other common applications on retaining walls.

$(G + \psi_c Q)^{R}$ = those components of dead and live load which can not be removed from the structure, which are resisting instability.

2.5 LOAD COMBINATIONS AND FACTORS FOR STRENGTH OF COMPONENTS

The following load combinations and factors should be applied when checking the strength of the structure components, including strength of any associated concrete, masonry and reinforcement.

(i) $1.25G + 1.5Q$

(ii) $1.25G + W_u + \psi_c Q$

(iii) $1.25G + 1.0F_{eq} + \psi_c Q$

(iv) $0.8G + 1.5Q$

(v) $0.8G + W_u$

(vi) $0.8(G + \psi_c Q) + 1.0F_{eq}$

Where:
G = dead load

Q = live load

W_u = wind load

F_{eq} = earthquake load

ψ_c = live load combination factor taken as 0.4 for parking or storage and 0.6 for other common applications on retaining walls.

2.6 LIVE LOADS

The appropriate values for live load must be determined by the design engineer. AS 4678:2002 specifies a minimum live loading of 5 kPa for walls of any height of Structure Classifications 1 and 2.

For walls under 1.5 metres high which are of Structure Classification 3, the following minimum live loads are applicable.

Slope of retained soil ≤ 1:4	2.5 kPa
Slope of retained soil >1:4	1.5 kPa

2.7 EARTHQUAKE LOADS

The appropriate earthquake loads must be determined by the designer. If earthquake load acts on some supported structure such as a building or a fence, the effect must be considered.

2.8 WIND LOADS

The load factors are such that load combination (ii) involving wind loading, will not be the governing case when the effect due to wind, W^{C}_{u} is less than $(1.5 - \psi_c)$ times the effect due to live load, Q^{C}.

For example, for a wall that does not support another exposed structure and for a minimum live load surcharge of Q^{C} = 5 kPa, an active pressure coefficient of K_a = 0.3 and a live load combination factor of ψ_c = 0.6, a wind load on the face of the retaining wall less than 1.35 kPa will not be the governing case. However, if the wind load is applied to some supported structure such as a building or a fence, the effect must be considered.

2.9 HYDRAULIC LOADS

The design example is based on the assumption that a properly-functioning drainage system is effective in removing hydraulic pressure.

2.10 DRAINED V UNDRAINED PARAMETERS

Based on an effective drainage system, the design example uses drained soil properties. For other situations, the designer must determine whether drained or undrained properties are appropriate.

2.11 CAPACITY REDUCTION FACTORS

The material strength factors from AS 4678 Table 5.1 have been used.

2.12 SOIL ANALYSIS MODEL

AS 4678 does not specify an analysis method. This guide uses the Coulomb Method to analyse the structure.

2.13 ACTIVE PRESSURE

In response to soil pressure, the wall will move away from the soil, thus partially relieving the pressure. This reduced pressure is the active pressure. The Coulomb equation for active pressure coefficient (K_a) can account for slope of the wall and slope of the backfill. The slope of the wall should be restricted to less than external angle of friction (δ) to ensure that there is no upward component of earth pressure which would reduce sliding resistance (ie the equation applies when wall slope is less than 15° for good quality granular backfills in contact with concrete).

p_a = active pressure on the wall at depth of H

$= K_a \gamma H$

Where:

K_a = active pressure coefficient

$$= \frac{\cos^2(\phi + \omega)}{\cos^2\omega \cos(\omega - \delta)\left[1+\sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \beta)}{\cos(\omega - \delta)\cos(\omega + \beta)}}\right]^2}$$

ϕ = factored value of internal friction angle (degrees)

δ = external friction angle (degrees)

$= \frac{2\phi}{3}$

where ϕ is the smaller of the friction angles at the particular interface

At any interface with a geotextile, the external friction angle should be taken from test data. If no data is available, it should be assumed to be zero.

ω = slope of the wall (degrees)

β = slope of the backfill (degrees)

γ = factored value of soil density (kN/m^3)

H = height of soil behind the wall (m)

2.14 PRESSURE AT REST

If the wall is unable to move away from the soil embankment, as may be the case for a propped cantilever basement wall, there will be no relief of the pressure and the soil will exert the full pressure at rest.

p_o = soil pressure at rest

$= K_o \gamma H$

Where:

K_o = coefficient for soil at rest

= 1.0

γ = factored value of soil density (kN/m^3)

H = height of soil behind the wall (m)

2.15 PASSIVE PRESSURE

If the structure pushes into the soil, as is the case at the toe of a retaining wall, the resistance by the soil is greater than the pressure at rest. This is the passive pressure, given by the following equation. If the soil in front of the toe is disturbed or loose, the full passive pressure may not be mobilised.

p_p = passive soil pressure (kPa)

$= K_p \gamma H_e$

Where:

K_p = passive pressure coefficient

$= \frac{(1 + \sin\phi)}{(1 - \sin\phi)}$

ϕ = factored value of internal friction angle (degrees)

γ = factored value of soil density (kN/m^3)

H_e = depth of undisturbed soil to the underside of the base, key or bearing pad as appropriate (m)

2.16 BEARING FAILURE

As soil and water pressure are applied to the rear face of the structure, it will tilt forward and the soil under the toe is subjected to high bearing pressures. Bearing is often the critical mode of failure. The following theoretical approach is used to analyse this region for bearing pressure failure and is based on the Meyerhof method. This gives consideration to footing width, footing tilt and angle of applied load and is explained in a paper by Vesic titled *Bearing Capacity of Shallow Footings* in the Foundation Engineering Handbook.

Q = Bearing capacity of foundation (kN)
$= q_{av} L_B$

Where:

q_{av} = average bearing capacity based on factored soil properties (kPa)
$= c N_c \zeta_c \zeta_{ci} \zeta_{ct} + \gamma H_e N_q \zeta_q \zeta_{qi} \zeta_{qt} + 0.5 \gamma B N_\gamma \zeta_\gamma \zeta_{\gamma i} \zeta_{\gamma t}$

B = actual base width (m)

L_B = effective width of base (m)

c = factored value of drained cohesion (kPa)

ϕ = factored value of friction angle (radians)

γ = factored value of soil density (kN/m^3)

H_e = depth of undisturbed soil to the underside of the base, key or bearing pad as appropriate (m)

$N_c = (N_q - 1)\cot \phi$

$N_q = e^{\pi \tan \phi} \tan^2[\pi/4 + \phi/2]$

$N_\gamma = 2(N_q + 1)\tan \phi$

Shape factors:
$\zeta_c = 1.0 \qquad \zeta_q = 1.0 \qquad \zeta_\gamma = 1.0$

Factors for inclined load:
$\zeta_{ci} = \zeta_{qi} - (1 - \zeta_{qi})/(N_c \tan \phi)$
$\zeta_{qi} = [1 - P^*/(Q^* + L_B c \cot \phi)]^2$
$\zeta_{\gamma i} = [1 - P^*/(Q^* + L_B c \cot \phi)]^3$

Factors for sloping bases (all = 1.0 for level bases):
$\zeta_{ct} = \zeta_{qt} - (1 - \zeta_{qt})/(N_c \tan \phi)$
$\zeta_{qt} = (1 - \alpha \tan \phi)^2$
$\zeta_{\gamma t} = (1 - \alpha \tan \phi)^2$

Q^* = vertical load based on factored loads and soil properties

P^* = horizontal load based on factored loads and soil properties

α = angle of base in radians

2.17 SLIDING FAILURE

As soil and water pressure are applied to the rear face of the structure, the footing may slide forward. Such sliding action is resisted by the friction and adhesion between the foundation material and the footing, and the passive resistance of any soil in front of the toe.

When considering passive resistance, note that material can be inadvertently removed from the toe of the wall.

F = Sliding resistance based on factored characteristic soil properties
= Friction + adhesion + passive resistance
$= Q^* \tan \delta + c B + K_p 0.5 \gamma H_e^2$

Where:

Q^* = vertical load based on factored loads and soil properties

δ = external friction angle of the soil calculated from the factored internal friction angle, assuming a smooth base-to-soil interface (if a rough base-to-soil interface is present, a friction angle of ϕ may be used)

B = actual base width (m)

c = factored value of adhesion (kPa)

K_p = passive pressure coefficient

γ = factored value of soil density (kN/m^3)

H_e = depth of undisturbed soil to the underside of the base, key or bearing pad as appropriate (m)

2.18 OVERTURNING

AS 4678:2002 does not specify an analysis method. This guide considers overturning about a point level with the underside of the key and a nominated distance behind the toe of the structure. If this nominated distance is one third of the base width and the factor against overturning is calculated as 1.0, this corresponds to the reaction being situated within the middle third of the base at ultimate loads.

2.19 GLOBAL SLIP

AS 4678:2002 Clause 3.2 requires stability (including rotation) to be checked.

The design example and design tables do not include analysis for global slip.

3 DESIGN TABLES

3.1 GENERAL

This section describes the design parameters covered by the *Design Tables* set out in **Appendix A**. The Tables apply to Structure Classification B, and for retaining walls under 1.5 m high, Structure Classification A (see *Site Investigation*, **Appendix D**).

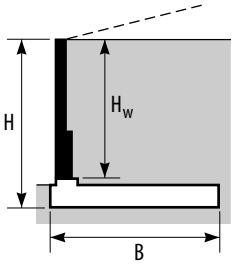
This Guide provides tables for suitable combinations of loads, geometry and soil properties, for six arrangements of Reinforced Concrete Masonry Cantilever Retaining Walls.

TYPE 1:

H_w = Masonry stem height

H = Total wall height

B = Total base width



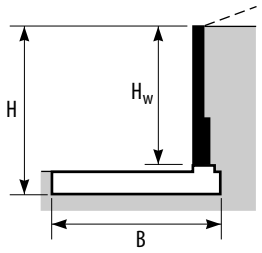
- Base width is 0.7 times the wall total height
- Base width is 1.0 times the wall total height
- Base width is 1.3 times the wall total height

TYPE 2:

H_w = Masonry stem height

H = Total wall height

B = Total base width



- Base width is 0.7 times the total wall height
- Base width is 1.0 times the total wall height
- Base width is 1.3 times the total wall height

It is suggested that the designer carry out the following steps:

- Determine which of these six types of retaining wall geometry most likely represents the intended earth retaining system.
- Read from the Tables the suitable combinations of loads, geometry and soil properties for the selected type.
- Determine whether actual combinations of loads, geometry and soil properties, existing in practice, correspond to these suitable combinations.
- Carry out a detailed design check against AS 4678, using proprietary software.

3.2 CONCRETE AND MASONRY PROPERTIES

The Design Tables are based on:

- Hollow concrete blocks with characteristic compressive strength, f'_{uc}, of at least 15 MPa;
- Mortar Type M3;
- Reinforcement grade 500 MPa;
- Concrete with characteristic compressive strength, f'_c, of at least 20 MPa.

3.3 LEAN-BACK

Consistent with AS 4678, this Guide does not cover the design of revetments with a lean-back of 20° or more from vertical. The tabulated typical wall details are applicable for "vertical" walls, with a maximum lean-back of 1 in 40 (1.4°).

3.4 BACKFILL SLOPE

The Tables in this Guide have been calculated for retained soil and infill soil, which is either level (0°) or 1 in 4 slope (14°). For other cases, the designer must perform calculations similar to those shown in the Design Example **Appendix B**.

3.5 LIVE LOADS

The Tables in this Guide have been calculated for a live loading of 2.5 kPa on walls up to 1.5 metres high and 5 kPa on other tabulated walls. A live load of 10 kPa has also been tabulated for all walls. The case of 10 kPa on a 1 in 4 slope (14°) is generally not practical, but has been included to permit interpolation. For other cases of live loads including Structure Classification C, traffic loading and construction loading, the appropriate values must be determined by the designer.

3.6 EARTHQUAKE LOADS

The Tables in this Guide have been calculated for AS 4678 earthquake categories Ae or Be and therefore are based on design for static loads without further specific analysis. For other cases, the appropriate earthquake loads must be determined by the designer. If earthquake load acts on some supported structure such as a building or a fence, the effect must be considered.

3.7 POSITION OF KEY

The Tables in this Guide have been based on placing the key (if required) at the rear of the base. This ensures that the bearing pad, or soil under the base and in front of the key, is able to resist forward sliding. It also simplifies excavation and simplifies the reinforcement arrangement. Other key positions may be more appropriate in particular applications. If other locations are adopted, calculations will be required to check the stability.

3.8 STEM DIMENSIONS

The Tables in this Guide include the following stem types:

- 140 mm hollow block
- 190 mm hollow block
- 290 mm hollow block
- Two leaves of 190 mm hollow block, separated by a cavity of 80 mm and joined by steel ties to prevent spreading during the grouting process, or peeling of the thin stem away form the thick stem.This arrangement gives a total width of 460 mm.

The stem width may be progressively increased down the wall to cater for increasing loads.

3.9 CONTROL JOINTS

Control joints should be included in the stem at centres up to 16.0 m, depending on the soil type and quantity of horizontal reinforcement that is incorporated.

3.10 HOB

Reinforced concrete footings for retaining walls should include a means of positively locating the steel starter bars accurately and a means of providing drainage through the wall at the level of the base. Both requirements may be achieved by including a concrete hob (or up-stand), through which vertical starter bars are placed and on which the masonry is built. Horizontal 50-mm diameter weep holes may pass through the hob at 1.2 m maximum centres.

3.11 FOUNDATION MATERIAL

The properties of foundation soils vary widely, with combinations of internal friction, external friction and cohesion. It is a common design practice to ignore cohesion, although this should be done in the context of close consideration of the corresponding friction angles. See *Analysis of Cohesive Soils* **Appendix C**.

The Tables are based on two types of foundation soil (**Figure 3.1**):

- Cohesionless foundation soil, where the cohesion is assumed to be zero and the required internal friction angle is tabulated.
- Cohesive foundation soil, where the internal friction angle is assumed to be 25° and the required cohesion is tabulated. In those cases where cohesion in excess of 10 kPa is required, the table is left blank.

Important Note
The tabulated values are intended to demonstrate some possible combinations of suitable soil properties, but the list is neither comprehensive nor intended to serve as recommendations.

In some cases, foundations with low friction angles require either wide bases or deep keys. To avoid this situation, one design option is to remove any material with a low friction angle and replace it with a more suitable material with a characteristic internal friction angle of at least 35°. Typically, compacted road base would be suitable in such an application. The foundation soil should be excavated and replaced with compacted road base to a depth such that sliding and bearing resistance can be achieved. In all cases, an experienced civil or geotechnical engineer should be engaged to determine the appropriate soil properties.

The Tables are based on a rough interface between the base and the foundation, such that the internal angle of friction, ϕ, is applicable.

3.12 RETAINED SOILS AND INFILL MATERIAL

The properties of retained soils vary widely, with combinations of internal friction, external friction and cohesion. It is a common design practice to ignore cohesion. See *Analysis of Cohesive Soils* **Appendix C**.

In the Tables, it is assumed that any infill soil (between the wall and the retained soil) is the same as the retained soil; and that both are the same as the foundation soil. The designer must consider the validity of both assumptions during the design process.

The tables provide for (see **Figure 3.1**):

- Cohesionless retained soil, where the cohesion is assumed to be zero and the required internal friction angle is tabulated.
- Cohesive retained soil, where the internal friction angle is assumed to be 25°. In this case the active soil pressure is based on the Coulomb formula, with the cohesion assumed to be zero.

Important Note
The tabulated values are intended to demonstrate some possible combinations of suitable soil properties, but the list is neither comprehensive nor intended to serve as recommendations.

The *Design Example* **Appendix B** indicates how to design for different retained soils and infill material.

Exposed stem height, H_w (mm)	800							
Total height, H (mm)	1150							
Total width, B (mm)	1150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	20	20	25	26	25	26	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	20	20	25	26	25	26	–	31
Foundation cohesion, c_f (kPa)	0	0	1	0	1	0	–	0
Columns:	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*

KEY
Columns 1 = Cohesive soils
Columns 2 = Cohesionless soils

Where it is demonstrated that a soil with a low friction angle (below 25°) is suitable, that minimum value for friction angle has been tabulated for both cohesive and cohesionless soils.

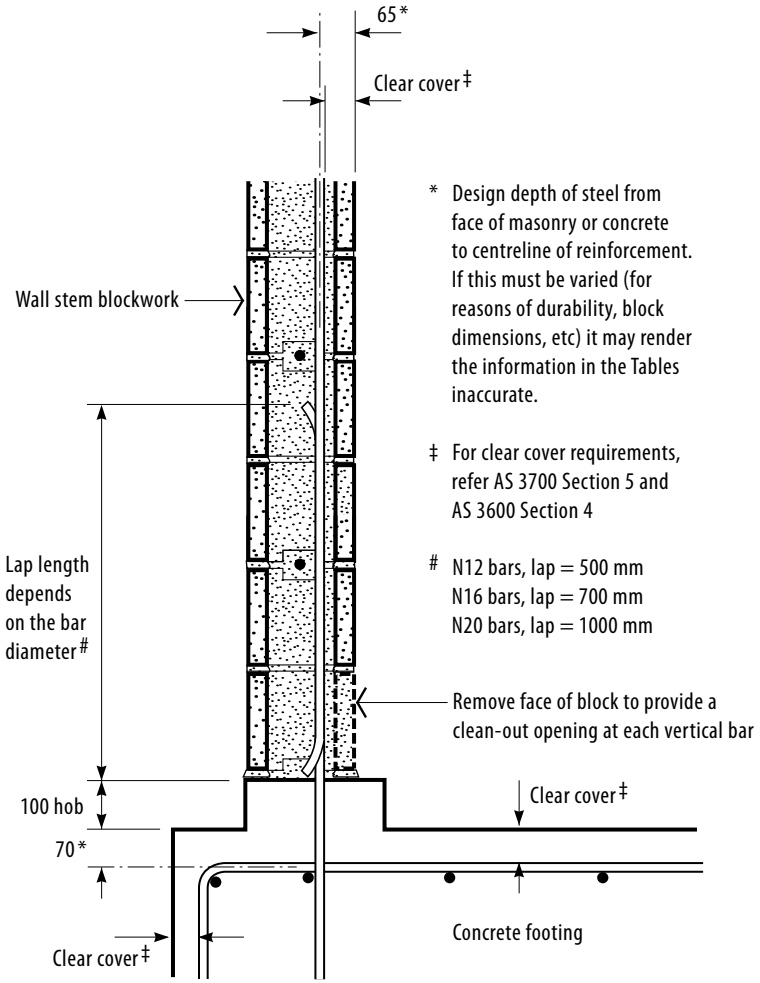
Suitable cohesive soil values for system

Suitable cohesionless soil values for system

This indicates the system will not work for this combination.

Figure 3.1 *Sample of Design Tables and their Interpretation*

COMMON DETAILS FOR **TYPE 1** AND **TYPE 2** CANTILEVER RETAINING WALLS



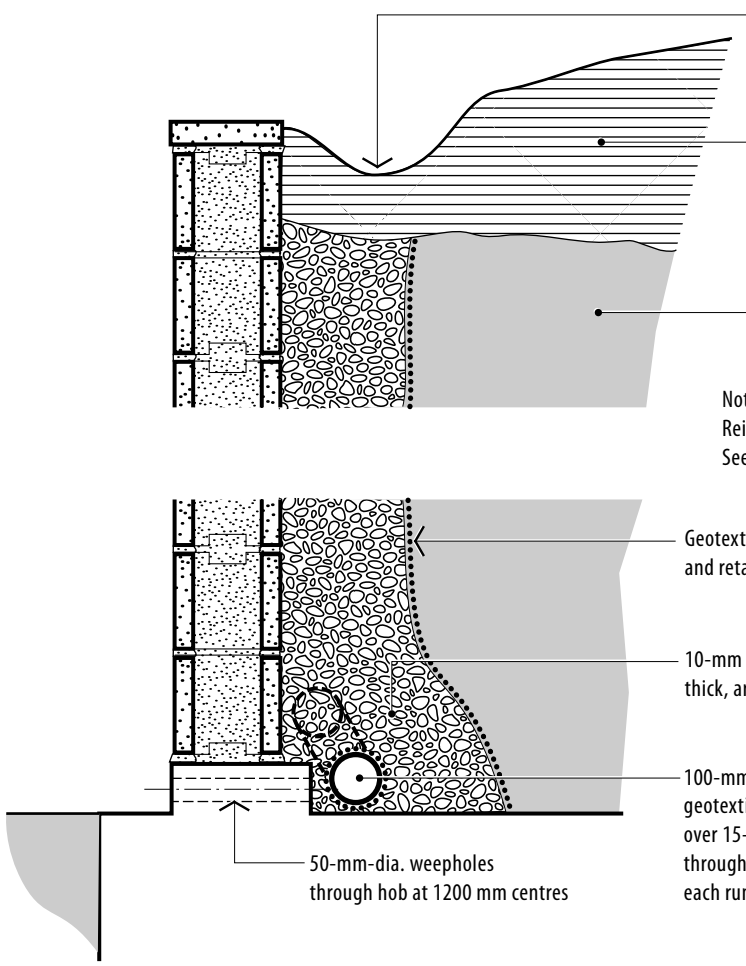
* Design depth of steel from face of masonry or concrete to centreline of reinforcement. If this must be varied (for reasons of durability, block dimensions, etc) it may render the information in the Tables inaccurate.

‡ For clear cover requirements, refer AS 3700 Section 5 and AS 3600 Section 4

\# N12 bars, lap = 500 mm
N16 bars, lap = 700 mm
N20 bars, lap = 1000 mm

Remove face of block to provide a clean-out opening at each vertical bar

PLACING OF REINFORCEMENT



Note:
Reinforcement not shown for clarity.
See '*Placing of Reinforcement*' for details

DRAINAGE REQUIREMENTS

Appendix A – DESIGN TABLES FOR REINFORCED CONCRETE MASONRY CANTILEVER RETAINING WALLS

INSTRUCTIONS FOR USE

1 Determine the type of retaining wall geometry that most likely represents the intended earth retaining system.
   - **Click** on appropriate exposed **stem height** for the wall Type you require.
   - You will be presented with a **suitably-detailed wall** and a set of variables
   - The primary set of variables is the overall **height-to-base ratio** (three options are given)
   - The next set of variables is **loading** in the form of slope of retained fill and live load surcharges
   - Finally, there are the required **soil properties** to make the selection work
   - The details should be read in conjunction with the **Common Details** and the **Construction Specification**

2 Read from the Tables (see sample below) the suitable combinations of loads, geometry and soil properties for the selected type.

3 Determine whether actual combinations of loads, geometry and soil properties, existing in practice, correspond to these suitable combinations.

4 Carry out a detailed design check against AS 4678, using proprietary software.

Exposed stem height, H_w (mm)	800							
Total height, H (mm)	1150							
Total width, B (mm)	1150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	20	20	25	26	25	26	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	20	20	25	26	25	26	–	31
Foundation cohesion, c_f (kPa)	0	0	1	0	1	0	–	0
Columns:	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*

KEY

Columns 1 = Cohesive soils

Columns 2 = Cohesionless soils

Where it is demonstrated that a soil with a low friction angle (below 25°) is suitable, that minimum value for friction angle has been tabulated for both cohesive and cohesionless soils.

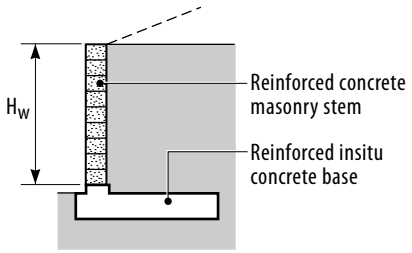
Suitable cohesive soil values for system

Suitable cohesionless soil values for system

This indicates the system will not work for this combination.

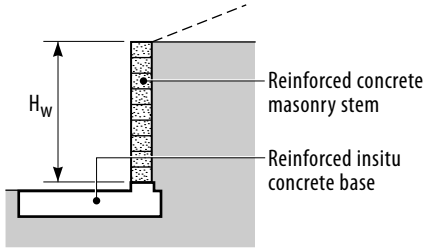
READING THE TABLES

TYPE 1 WALLS



Exposed stem height, H_w (mm)
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600

TYPE 2 WALLS

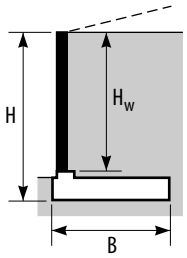


Exposed stem height, H_w (mm)
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **800** mm

General arrangement

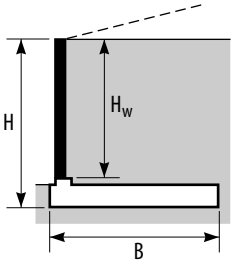
B = 0.7H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	805							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	25	25	31	25	30	–	36
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	25	25	31	25	30	–	36
Foundation cohesion, c_f (kPa)	0	0	10	0	9	0	–	0

General arrangement

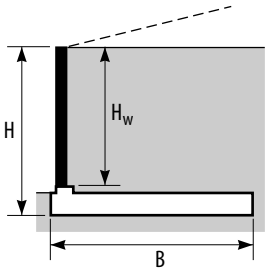
B = 1.0H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	1150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	20	20	25	26	25	26	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	20	20	25	26	25	26	–	31
Foundation cohesion, c_f (kPa)	0	0	1	0	1	0	–	0

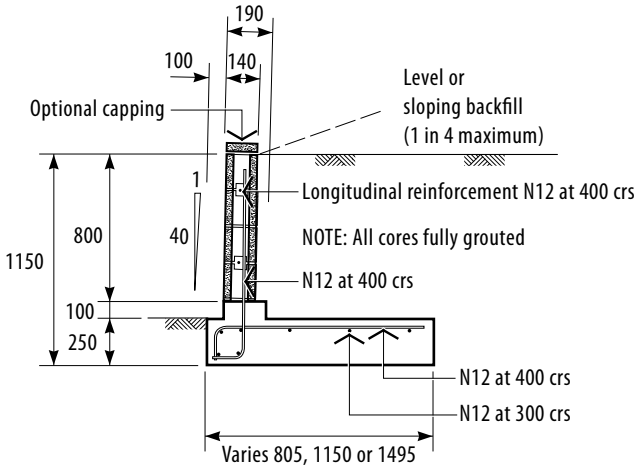
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	1495							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	18	18	23	23	24	24	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	18	18	23	23	24	24	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	0	0	5	0

General details



NOTES:

All cores to be fully grouted.

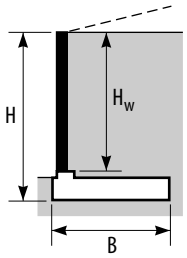
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1000** mm

General arrangement

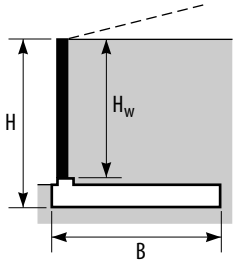
B = 0.7H



Exposed stem height, H_w (mm)	1000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	945							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	25	25	31	25	31	–	35
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	25	25	31	25	31	–	35
Foundation cohesion, c_f (kPa)	0	0	10	0	10	0	–	0

General arrangement

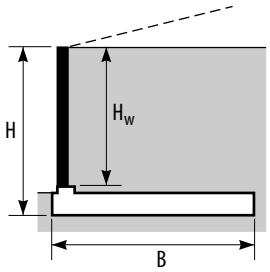
B = 1.0H



Exposed stem height, H_w (mm)	21000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	1350							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	20	20	25	25	25	27	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	20	20	25	25	25	27	–	31
Foundation cohesion, c_f (kPa)	0	0	0	0	2	0	–	0

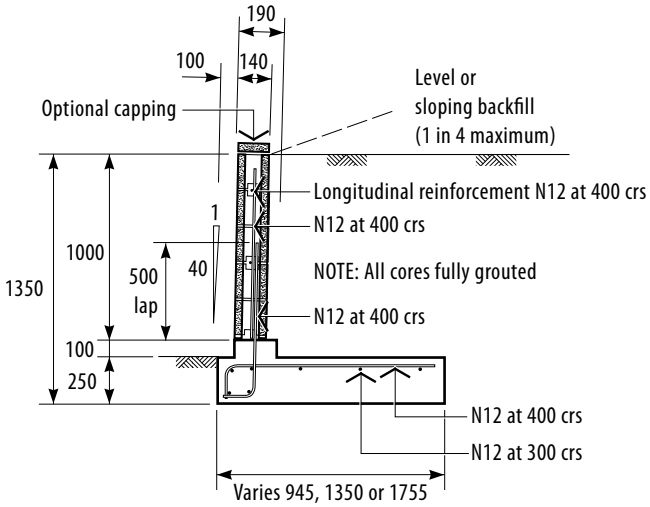
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	1755							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	19	19	22	22	25	25	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	19	19	22	22	25	25	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	0	0	6	0

General details



NOTES:

All cores to be fully grouted.

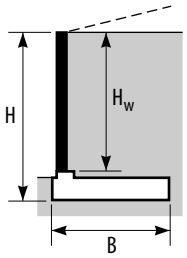
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1200** mm

General arrangement

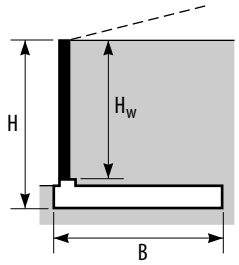
B = 0.7H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	1085							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	26	25	30	–	31	–	35
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	26	25	30	–	31	–	35
Foundation cohesion, c_f (kPa)	1	0	9	0	–	0	–	0

General arrangement

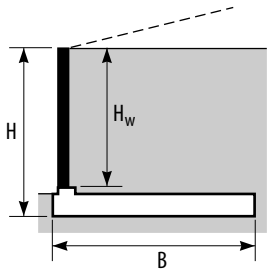
B = 1.0H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	1550							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	20	20	25	25	25	27	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	20	20	25	25	25	27	–	31
Foundation cohesion, c_f (kPa)	0	0	0	0	2	0	–	0

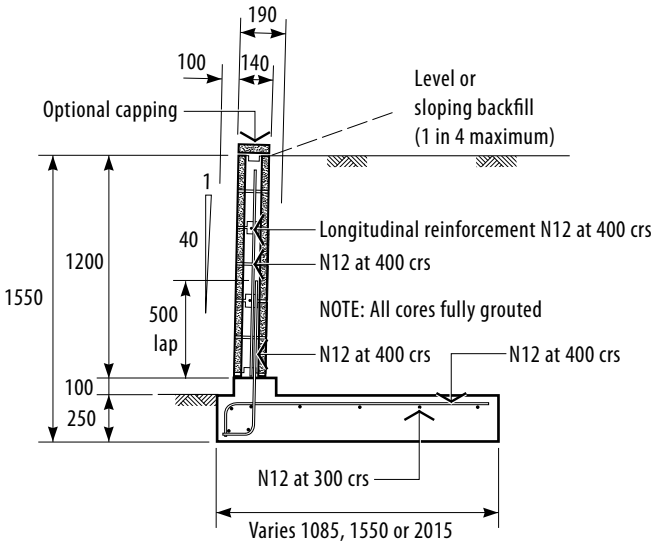
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	2015							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	19	19	25	25	25	25	25	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	19	19	25	25	25	25	25	30
Foundation cohesion, c_f (kPa)	0	0	0	0	0	0	6	0

General details



NOTES:

All cores to be fully grouted.

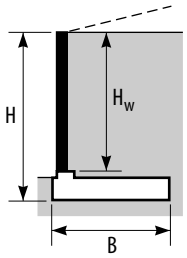
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1400** mm

General arrangement

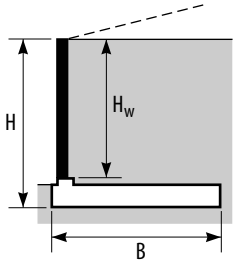
B = 0.7H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	1225							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	26	25	30	–	31	–	35
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	26	25	30	–	31	–	35
Foundation cohesion, c_f (kPa)	1	0	9	0	–	0	–	0

General arrangement

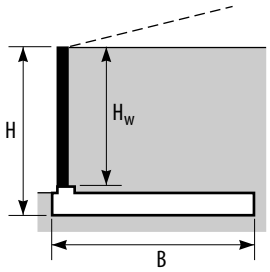
B = 1.0H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	1750							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	21	21	25	25	25	27	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	21	21	25	25	25	27	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	3	0	–	0

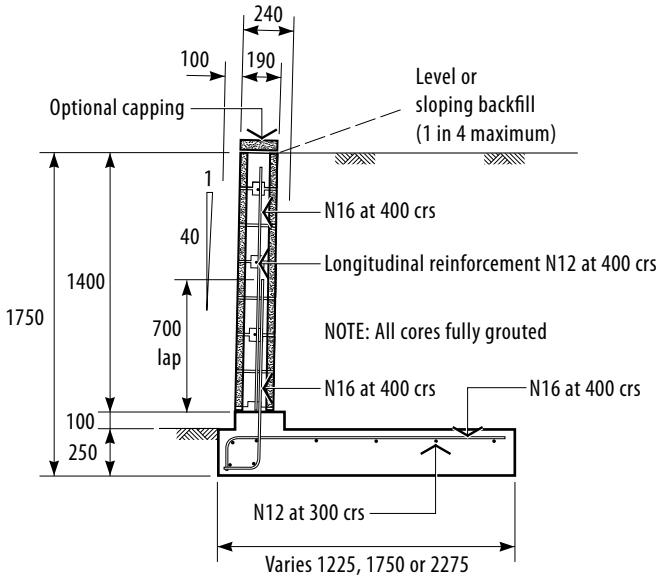
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	2275							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	19	19	22	22	25	25	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	19	19	22	22	25	25	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	0	0	6	0

General details



NOTES:

All cores to be fully grouted.

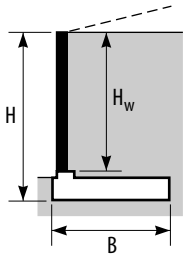
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1600** mm

General arrangement

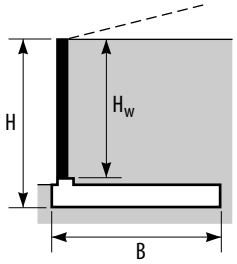
B = 0.7H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	1365							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	31	–	33	–	35
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	31	–	33	–	35
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

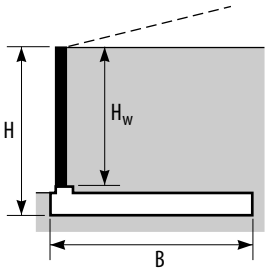
B = 1.0H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	1950							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	25	25	25	29	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	25	25	25	29	–	31
Foundation cohesion, c_f (kPa)	0	0	0	0	8	0	–	0

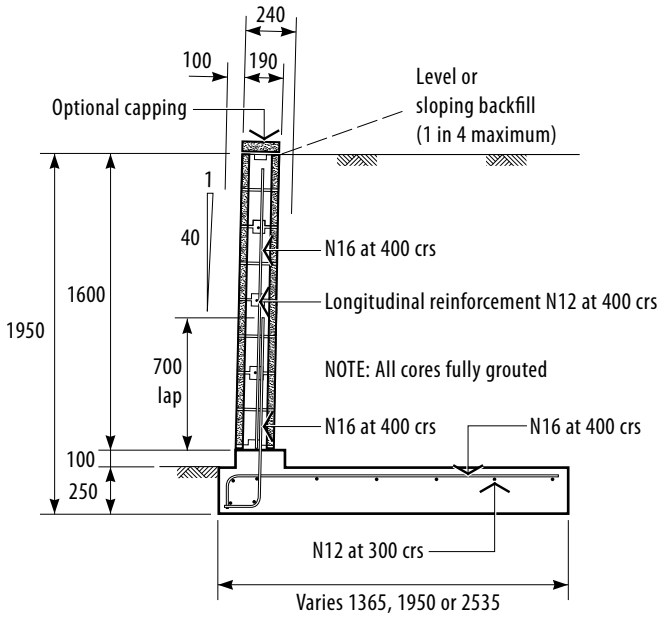
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	2535							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	23	23	25	27	25	29
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	23	23	25	27	25	29
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	8	0

General details



NOTES:

All cores to be fully grouted.

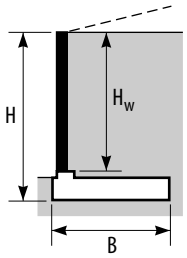
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1800** mm

General arrangement

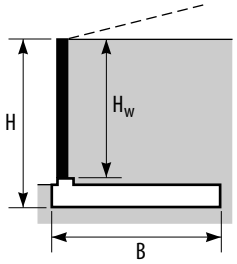
B = 0.7H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	1505							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	30	–	33	–	35
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	30	–	33	–	35
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

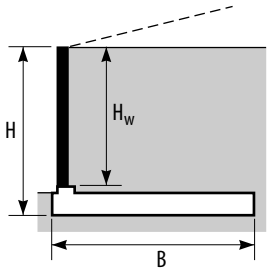
B = 1.0H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	2150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	25	25	25	29	–	31
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	25	25	25	29	–	31
Foundation cohesion, c_f (kPa)	0	0	0	0	9	0	–	0

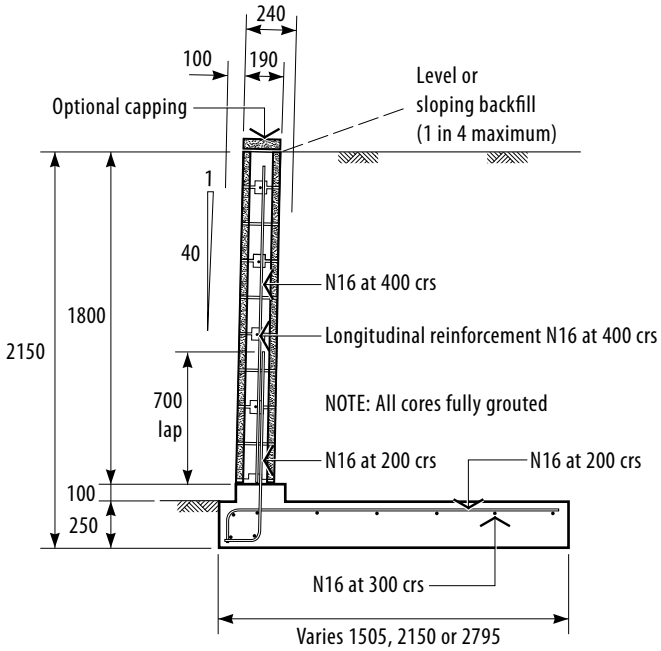
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	2795							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	22	22	25	27	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	22	22	25	27	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	9	0

General details



NOTES:

All cores to be fully grouted.

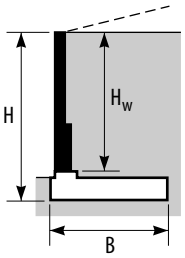
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2000** mm

General arrangement

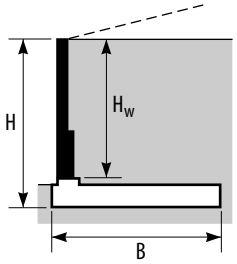
B = 0.7H



Exposed stem height, H_w (mm)	2000							
Total height, **H** (mm)	2450							
Total width, **B** (mm)	1715							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	30	–	32	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	30	–	32	–	34
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

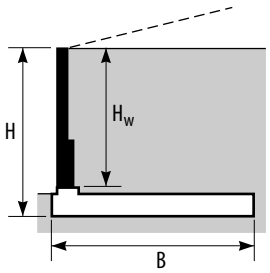
B = 1.0H



Exposed stem height, H_w (mm)	2000							
Total height, **H** (mm)	2450							
Total width, **B** (mm)	2450							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	22	22	24	24	25	28	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	22	22	24	24	25	28	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	9	0	–	0

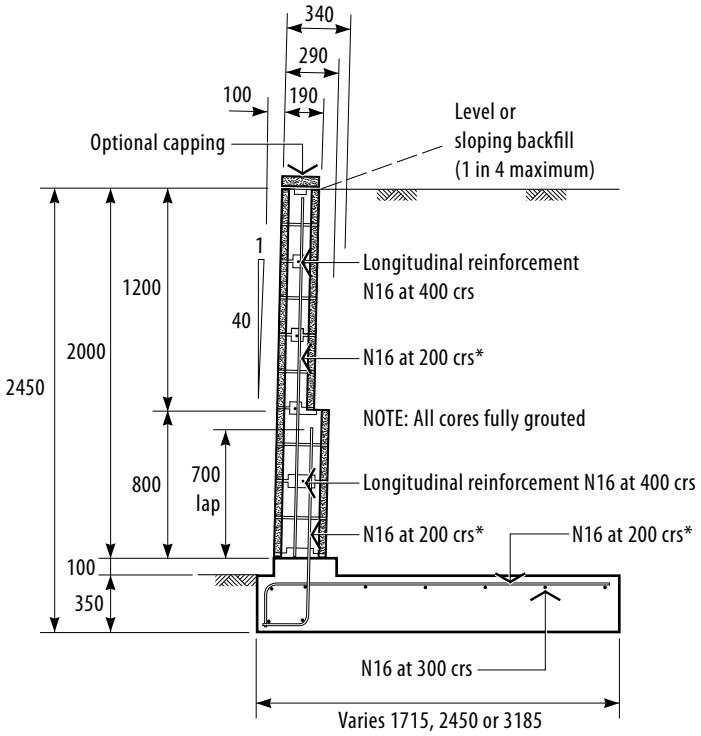
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2000							
Total height, **H** (mm)	2450							
Total width, **B** (mm)	3185							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	21	22	25	26	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	21	22	25	26	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	3	0	8	0

General details



* N16 at 400 crs for B = 0.7 H

NOTES:

All cores to be fully grouted.

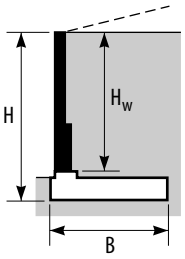
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2200** mm

General arrangement

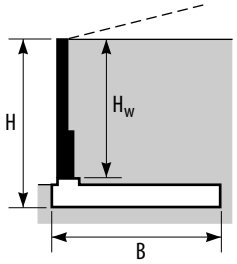
B = 0.7H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	1855							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	30	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	30	–	33	–	34
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

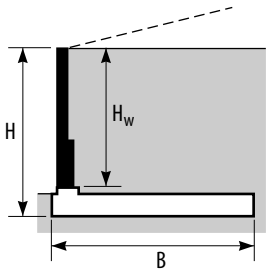
B = 1.0H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	2650							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	24	24	25	28	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	24	24	25	28	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	9	0	–	0

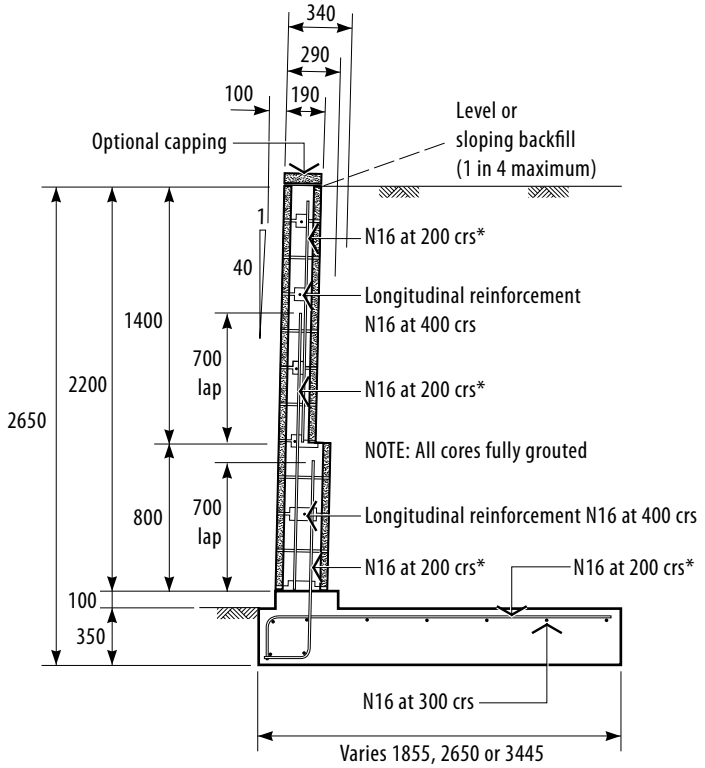
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	3445							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	22	22	25	26	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	22	22	25	26	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	3	0	8	0

General details



* N16 at 400 crs for B = 0.7 H

NOTES:

All cores to be fully grouted.

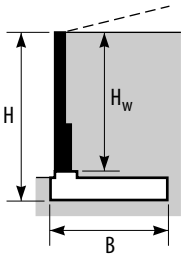
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2400** mm

General arrangement

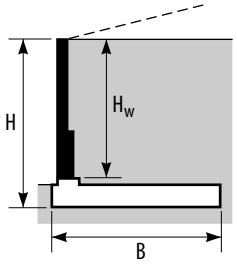
B = 0.7H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	1995							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

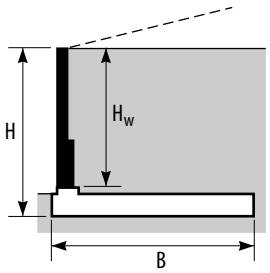
B = 1.0H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	2850							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	24	24	25	28	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	24	24	25	28	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	10	0	–	0

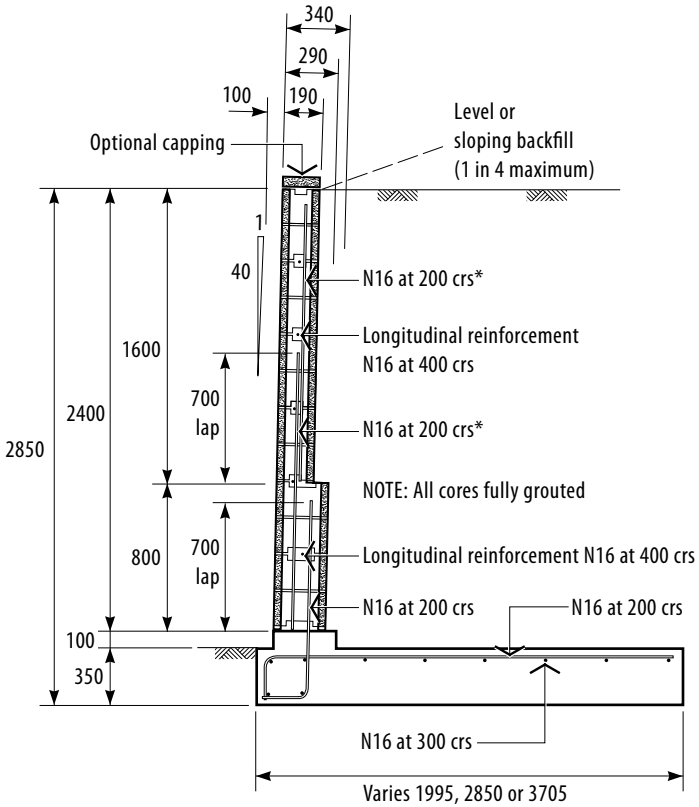
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	3705							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	22	22	25	26	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	22	22	25	26	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	3	0	8	0

General details



NOTES:

All cores to be fully grouted.

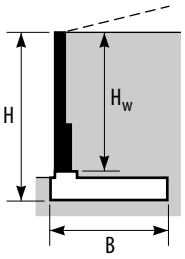
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2600** mm

General arrangement

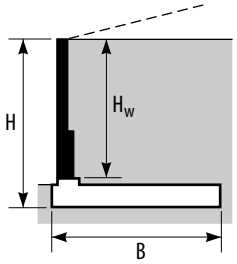
B = 0.7H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	2135							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	6	0	–	0	–	0	–	0

General arrangement

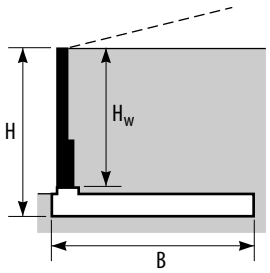
B = 1.0H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	3050							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	24	24	25	28	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	24	24	25	28	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	10	0	–	0

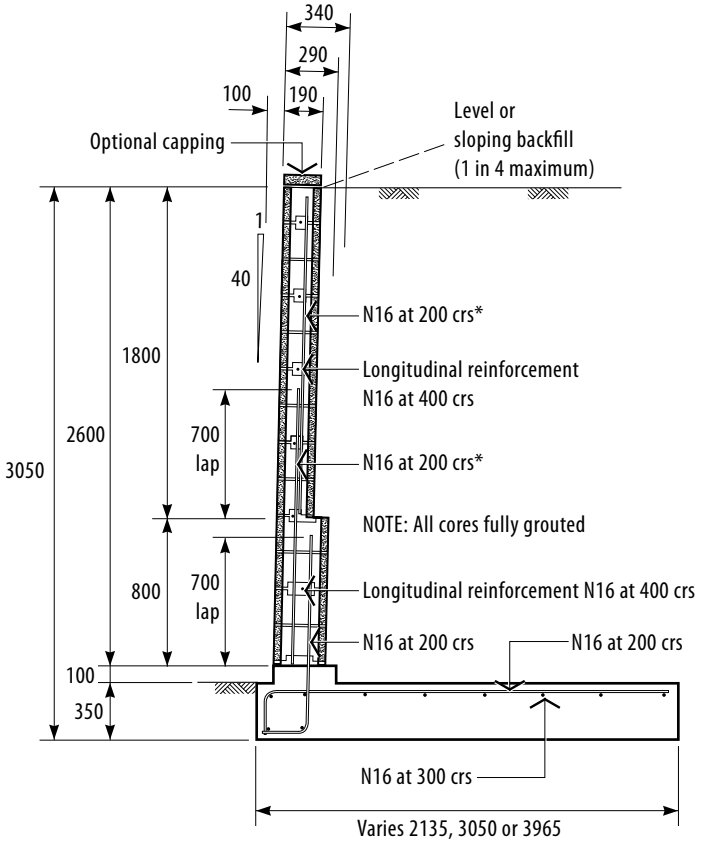
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	3965							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	22	22	25	26	25	28
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	22	22	25	26	25	28
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	8	0

General details



NOTES:

All cores to be fully grouted.

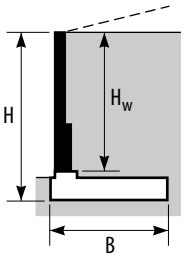
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2800** mm

General arrangement

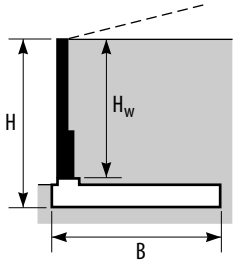
B = 0.7H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	2275							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	6	0	–	0	–	0	–	0

General arrangement

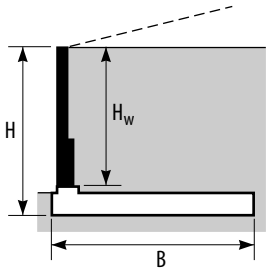
B = 1.0H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	3250							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	23	23	24	24	–	28	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	23	23	24	24	–	28	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	–	0	–	0

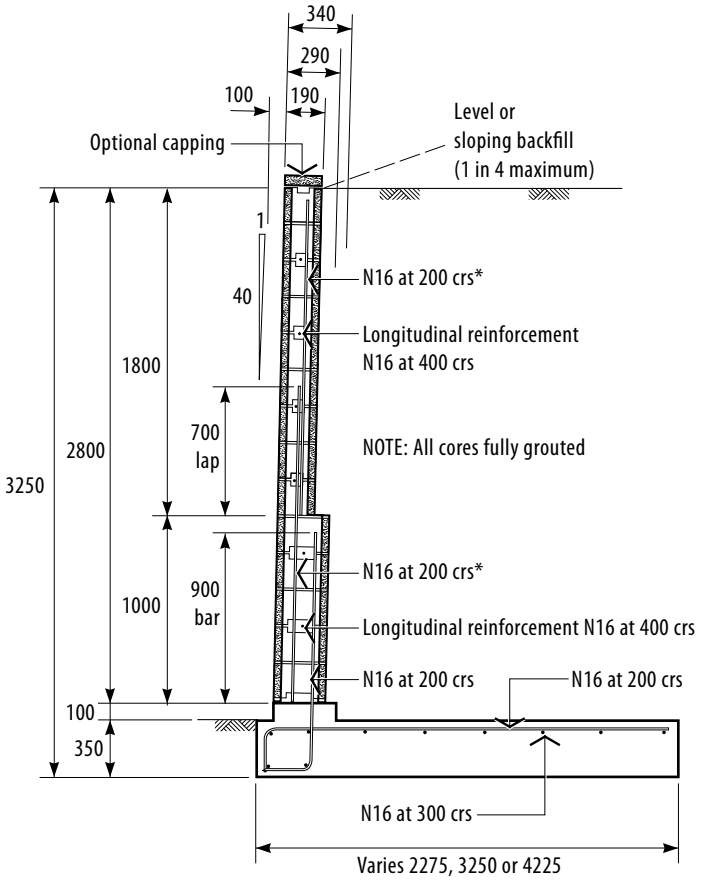
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	4225							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	23	23	25	26	25	29
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	23	23	25	26	25	29
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	8	0

General details



* N16 at 400 crs for B = 0.7H

NOTES:

All cores to be fully grouted.

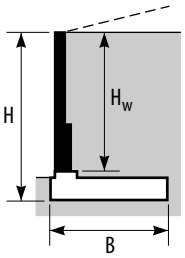
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3000** mm

General arrangement

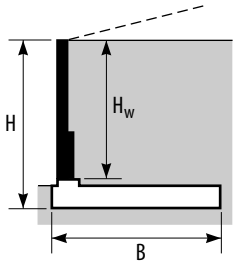
B = 0.7H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	2415							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	6	0	–	0	–	0	–	0

General arrangement

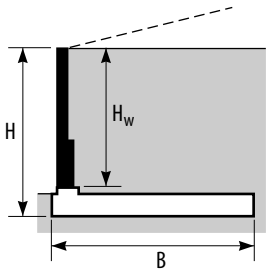
B = 1.0H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	3450							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	24	24	25	25	–	29	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	24	24	25	25	–	29	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	–	0	–	0

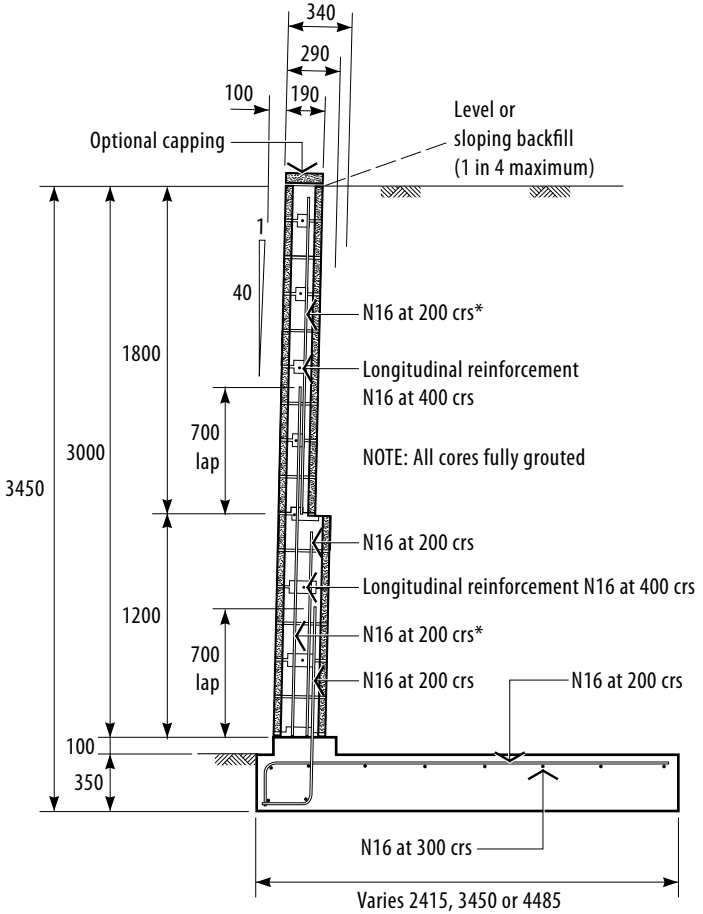
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	4485							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	22	22	25	27	25	28	25	32
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	22	22	25	27	25	28	25	32
Foundation cohesion, c_f (kPa)	0	0	1	0	4	0	9	0

General details



* N16 at 400 crs for B = 0.7 H

NOTES:

All cores to be fully grouted.

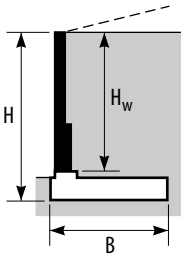
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3200** mm

General arrangement

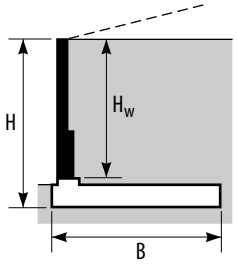
B = 0.7H



Exposed stem height, H_w (mm)	3200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	2555							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	7	0	–	0	–	0	–	0

General arrangement

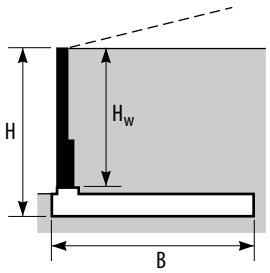
B = 1.0H



Exposed stem height, H_w (mm)	3.200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	3650							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	24	24	25	25	–	29	–	30
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	24	24	25	25	–	29	–	30
Foundation cohesion, c_f (kPa)	0	0	0	0	–	0	–	0

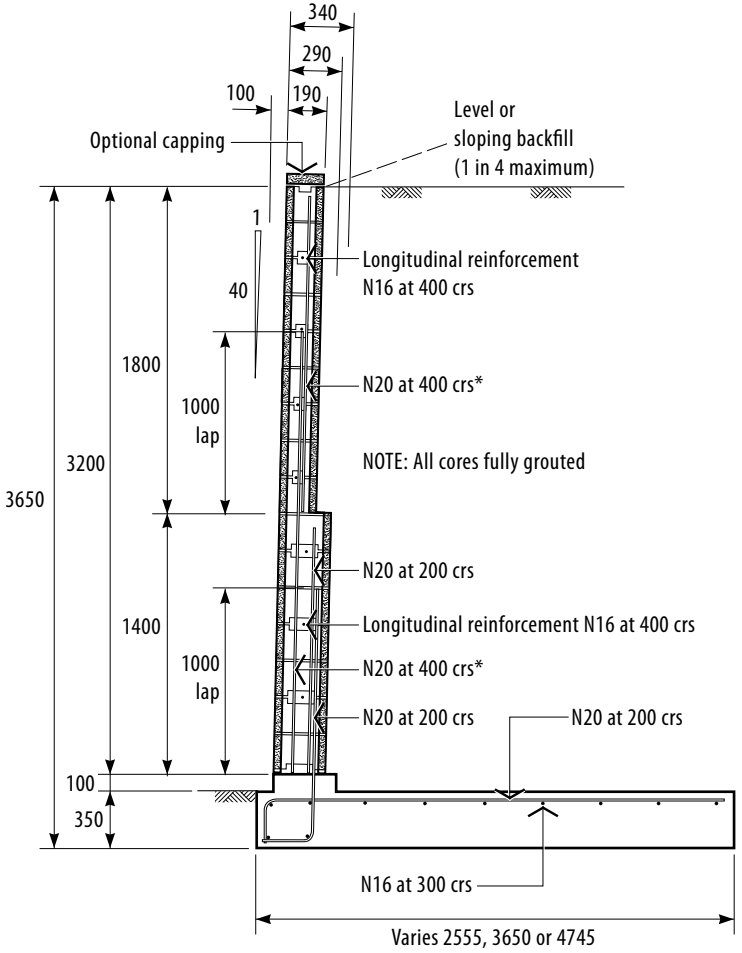
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	4745							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	23	23	25	26	25	29
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	23	23	25	26	25	29
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	8	0

General details



* N20 at 200 crs for B = 1.3 H

NOTES:

All cores to be fully grouted.

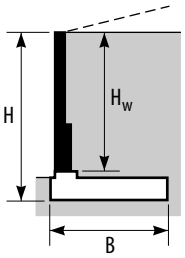
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3400** mm

General arrangement

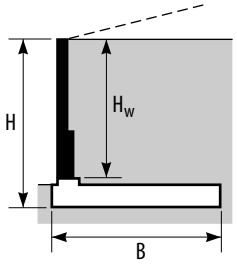
B = 0.7H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	2695							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	28	–	29	–	33	–	34
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	–	29	–	33	–	34
Foundation cohesion, c_f (kPa)	7	0	–	0	–	0	–	0

General arrangement

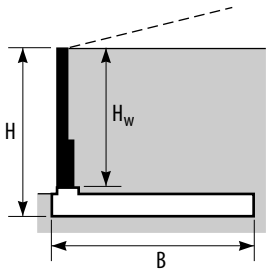
B = 1.0H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	3850							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	24	24	25	25	–	29	–	32
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	24	24	25	25	–	29	–	32
Foundation cohesion, c_f (kPa)	0	0	0	0	–	0	–	0

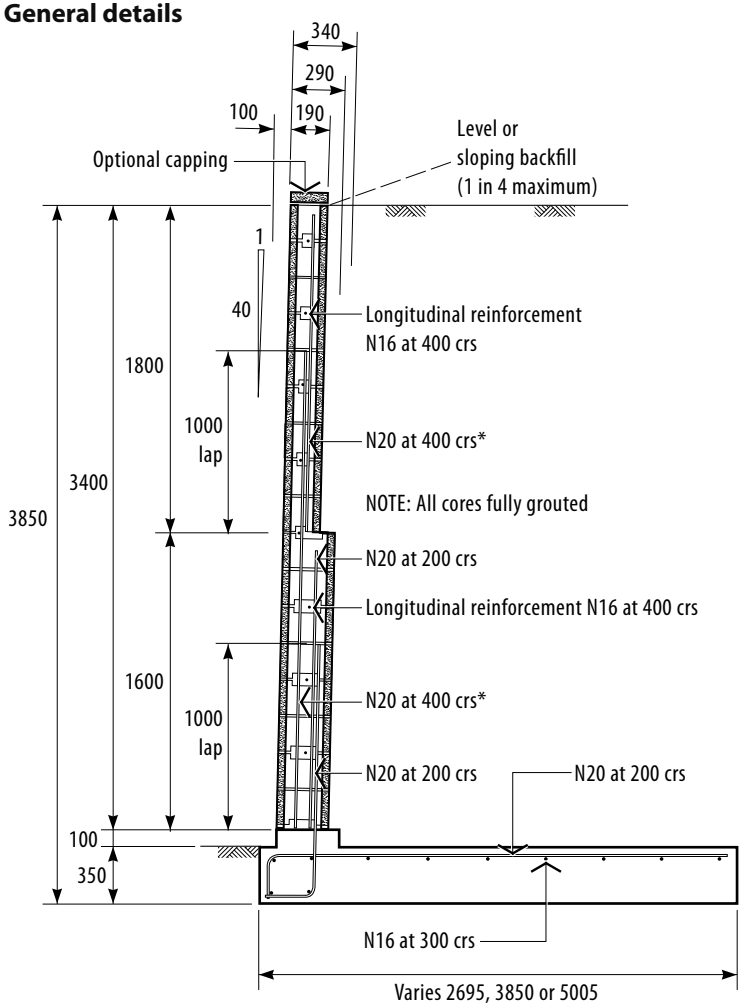
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	5005							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	22	22	25	25	25	28	25	32
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	22	22	25	25	25	28	25	32
Foundation cohesion, c_f (kPa)	0	0	0	0	4	0	9	0

General details



* N20 at 200 crs for B = 1.3 H

NOTES:

All cores to be fully grouted.

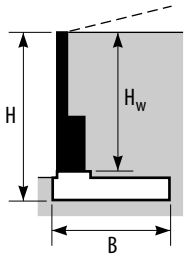
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 1** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3600** mm

General arrangement

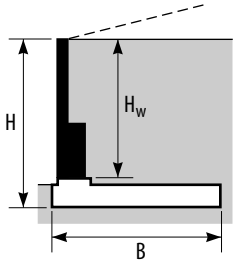
B = 0.7H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	2940							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	27	–	29	–	32	–	33
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	27	–	29	–	32	–	33
Foundation cohesion, c_f (kPa)	6	0	–	0	–	0	–	0

General arrangement

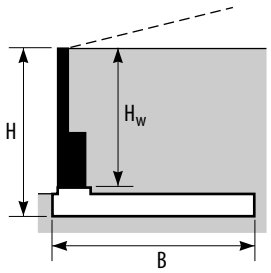
B = 1.0H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	4200							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	24	24	24	24	–	28	–	29
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	24	24	24	24	–	28	–	29
Foundation cohesion, c_f (kPa)	0	0	0	0	–	0	–	0

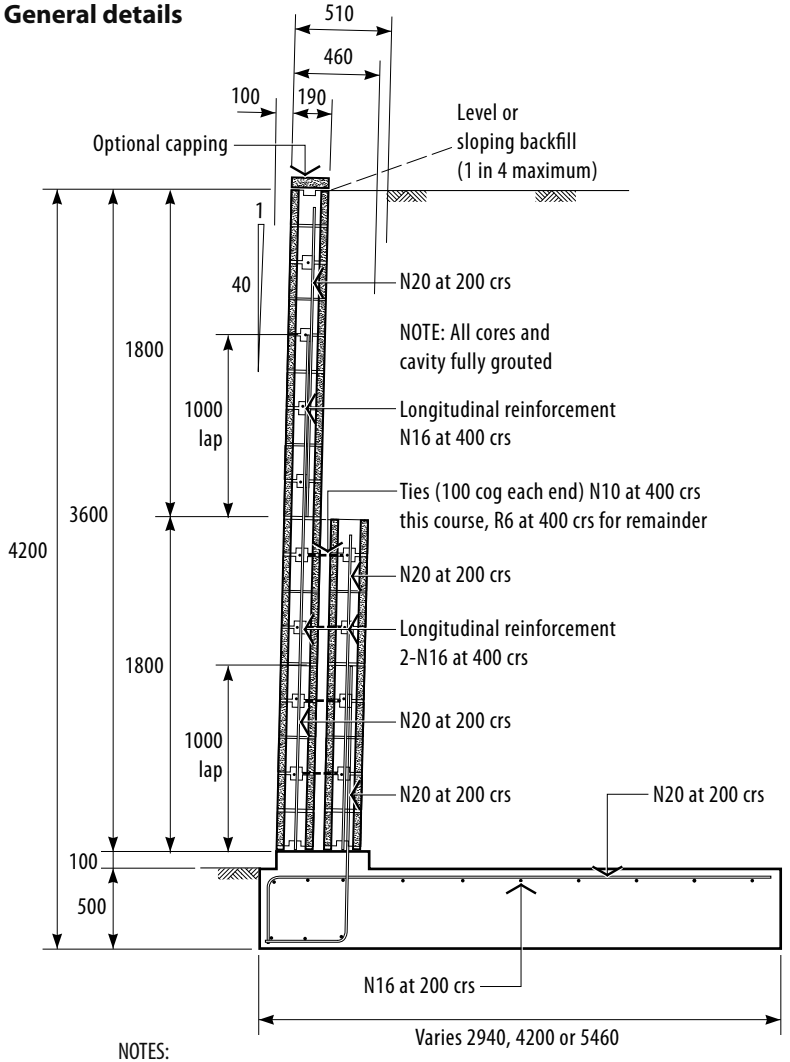
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	5460							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	21	21	22	22	25	26	25	27
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	21	21	22	22	25	26	25	27
Foundation cohesion, c_f (kPa)	0	0	0	0	3	0	8	0

General details



NOTES:

All cores to be fully grouted.

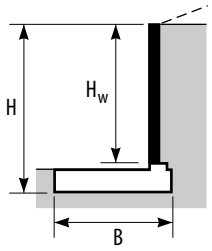
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **800** mm

General arrangement

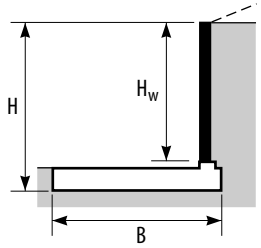
B = 0.7H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	805							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	30	–	37	25	33	–	39
Retained soil cohesion, c_r (kPa)	0	0	–	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	30	–	37	25	33	–	39
Foundation cohesion, c_f (kPa)	3	0	–	0	10	0	–	0

General arrangement

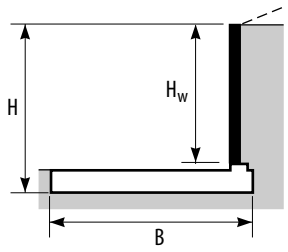
B = 1.0H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	1150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	26	25	33	25	30	–	36
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	26	25	33	25	30	–	36
Foundation cohesion, c_f (kPa)	1	0	6	0	4	0	–	0

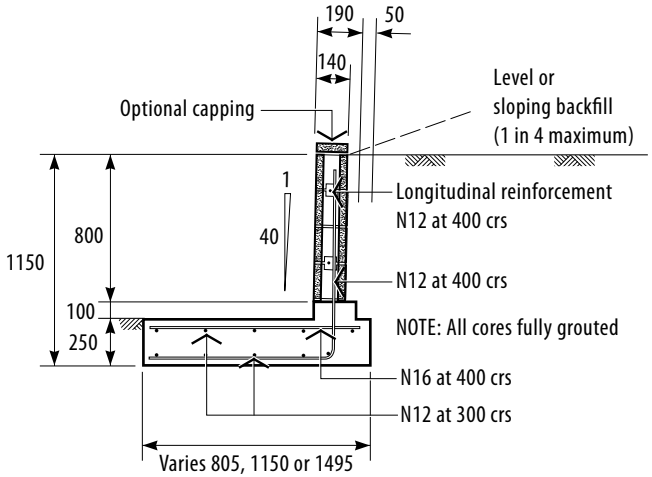
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	800							
Total height, **H** (mm)	1150							
Total width, **B** (mm)	1495							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	25	25	30	25	28	25	33
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	25	25	25	30	25	28	25	33
Foundation cohesion, c_f (kPa)	0	0	4	0	2	0	8	0

General details



NOTES:

All cores to be fully grouted.

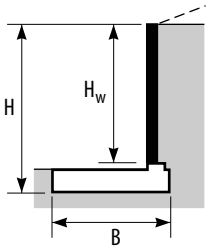
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1000** mm

General arrangement

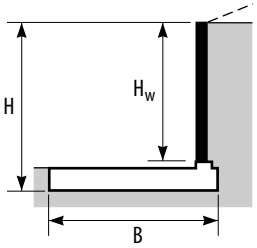
B = 0.7H



Exposed stem height, H_w (mm)	1000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	945							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	31	–	37	–	34	–	40
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	31	–	37	–	34	–	40
Foundation cohesion, c_f (kPa)	5	0	–	0	–	0	–	0

General arrangement

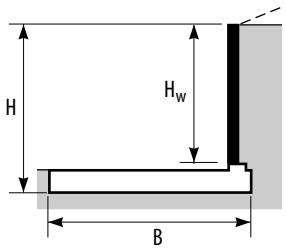
B = 1.0H



Exposed stem height, H_w (mm)	1000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	1350							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	28	25	34	25	31	–	37
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	28	25	34	25	31	–	37
Foundation cohesion, c_f (kPa)	2	0	7	0	6	0	–	0

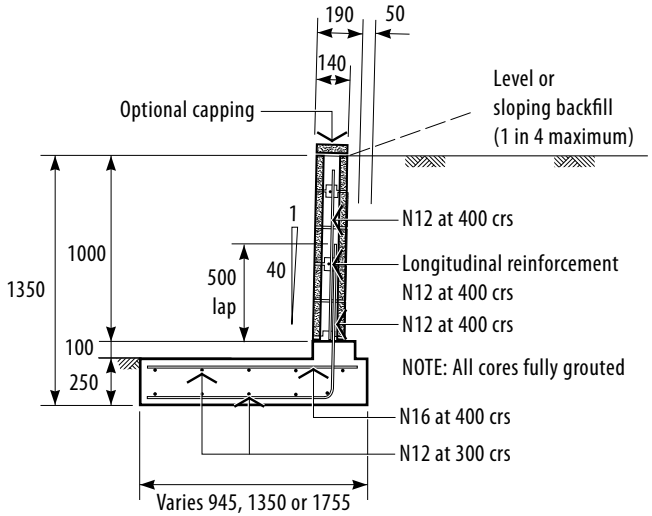
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1000							
Total height, **H** (mm)	1350							
Total width, **B** (mm)	1755							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	27	25	31	25	30	25	34
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	25	27	25	31	25	30	25	34
Foundation cohesion, c_f (kPa)	1	0	5	0	4	0	9	0

General details



NOTES:

All cores to be fully grouted.

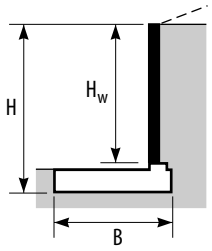
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1200** mm

General arrangement

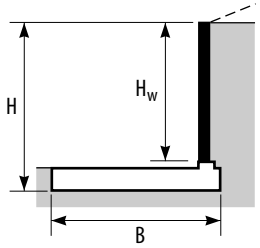
B = 0.7H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	1085							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	32	–	38	–	35	–	40
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	32	–	38	–	35	–	40
Foundation cohesion, c_f (kPa)	7	0	–	0	–	0	–	0

General arrangement

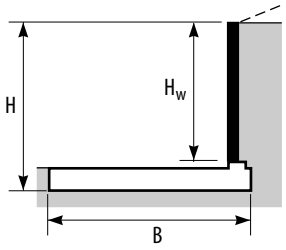
B = 1.0H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	1550							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	30	25	34	25	32	–	37
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	30	25	34	25	32	–	37
Foundation cohesion, c_f (kPa)	4	0	8	0	7	0	–	0

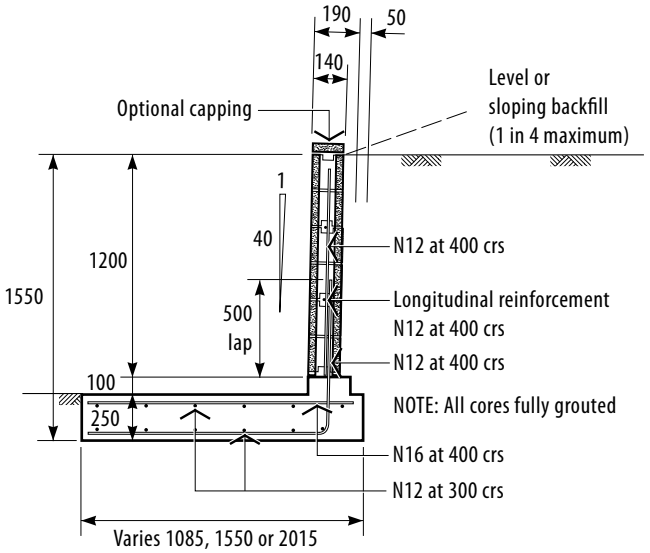
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1200							
Total height, **H** (mm)	1550							
Total width, **B** (mm)	2015							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	28	25	33	25	31	25	35
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	0	0
Foundation internal friction, ϕ_f (°)	25	28	25	33	25	31	25	35
Foundation cohesion, c_f (kPa)	2	0	6	0	5	0	10	0

General details



NOTES:

All cores to be fully grouted.

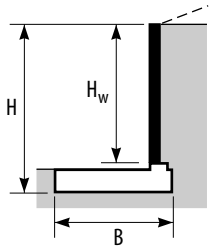
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1400** mm

General arrangement

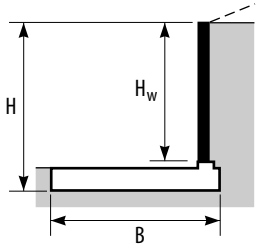
B = 0.7H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	1225							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	32	–	37	–	35	–	40
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	32	–	37	–	35	–	40
Foundation cohesion, c_f (kPa)	7	0	–	0	–	0	–	0

General arrangement

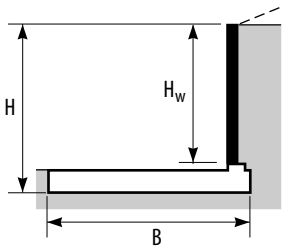
B = 1.0H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	1750							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	30	25	34	25	33	–	37
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	30	25	34	25	33	–	37
Foundation cohesion, c_f (kPa)	4	0	9	0	8	0	–	0

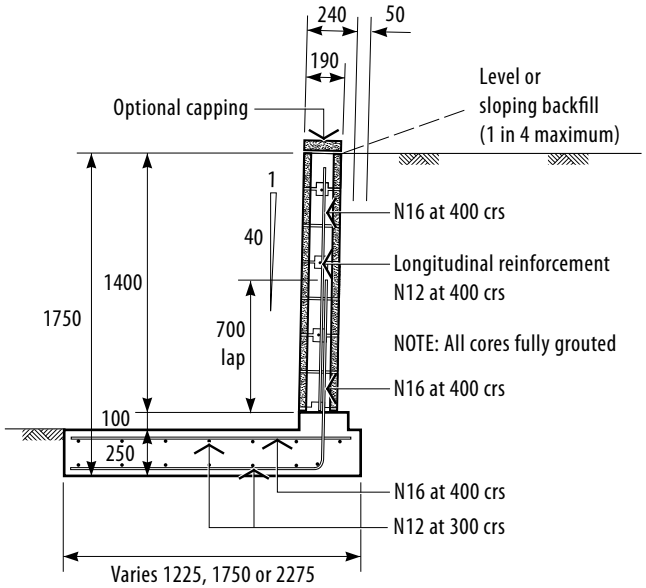
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1400							
Total height, **H** (mm)	1750							
Total width, **B** (mm)	2275							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	2.5		10		2.5		10	
Retained soil internal friction, ϕ_r (°)	25	29	25	33	25	32	–	35
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	29	25	33	25	32	–	35
Foundation cohesion, c_f (kPa)	3	0	7	0	6	0	–	0

General details



NOTES:

All cores to be fully grouted.

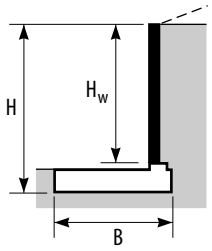
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1600** mm

General arrangement

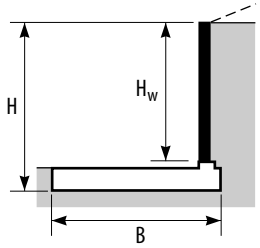
B = 0.7H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	1365							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	39	–	38	–	41
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	39	–	38	–	41
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

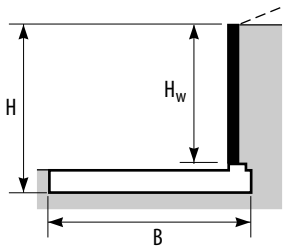
B = 1.0H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	1950							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	34	–	36	–	36	–	38
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	34	–	36	–	36	–	38
Foundation cohesion, c_f (kPa)	9	0	–	0	–	0	–	0

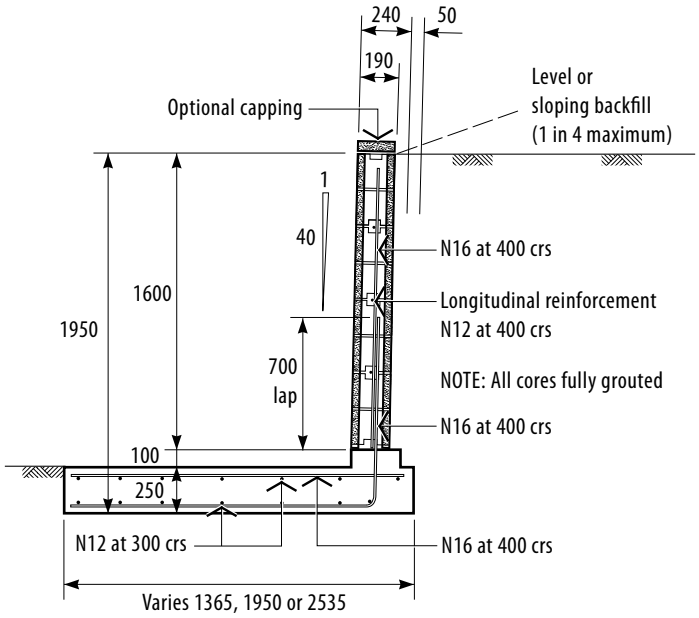
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1600							
Total height, **H** (mm)	1950							
Total width, **B** (mm)	2535							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	33	25	35	25	35	–	37
Retained soil cohesion, c_r (kPa)	0	0	0	0	0	0	–	0
Foundation internal friction, ϕ_f (°)	25	33	25	35	25	35	–	37
Foundation cohesion, c_f (kPa)	6	0	9	0	10	0	–	0

General details



NOTES:

All cores to be fully grouted.

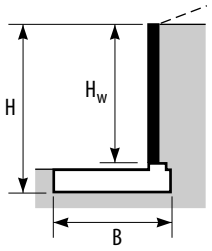
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **1800** mm

General arrangement

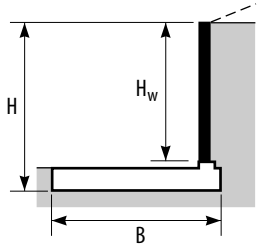
B = 0.7H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	1505							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	39	–	39	–	41
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	39	–	39	–	41
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

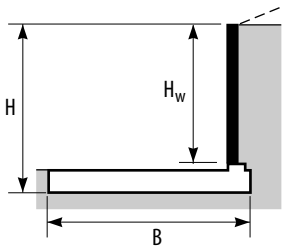
B = 1.0H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	2150							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	35	–	37	–	37	–	39
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	35	–	37	–	37	–	39
Foundation cohesion, c_f (kPa)	10	0	–	0	–	0	–	0

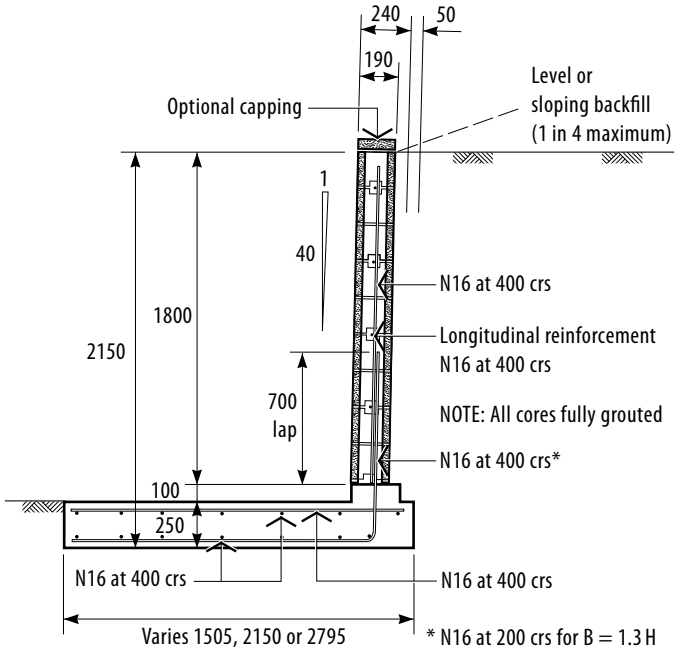
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	1800							
Total height, **H** (mm)	2150							
Total width, **B** (mm)	2795							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	34	25	36	–	36	–	38
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	34	25	36	–	36	–	38
Foundation cohesion, c_f (kPa)	7	0	10	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

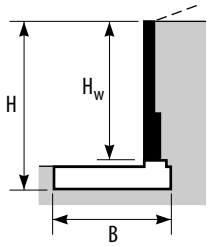
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2000** mm

General arrangement

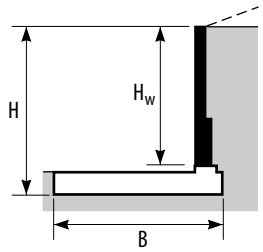
B = 0.7H



		Level				1 in 4			
Exposed stem height, H_w (mm)	2000								
Total height, **H** (mm)	2450								
Total width, **B** (mm)	1715								
Retained soil slope, β		Level				1 in 4			
Live load surcharge, q_l (kPa)		5		10		5		10	
Retained soil internal friction, ϕ_r (°)		–	34	–	37	–	37	–	39
Retained soil cohesion, c_r (kPa)		–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)		–	34	–	37	–	37	–	39
Foundation cohesion, c_f (kPa)		–	0	–	0	–	0	–	0

General arrangement

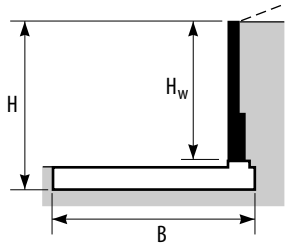
B = 1.0H



		Level				1 in 4			
Exposed stem height, H_w (mm)	2000								
Total height, **H** (mm)	2450								
Total width, **B** (mm)	2450								
Retained soil slope, β		Level				1 in 4			
Live load surcharge, q_l (kPa)		5		10		5		10	
Retained soil internal friction, ϕ_r (°)		25	33	–	35	–	35	–	37
Retained soil cohesion, c_r (kPa)		0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)		25	33	–	35	–	35	–	37
Foundation cohesion, c_f (kPa)		9	0	–	0	–	0	–	0

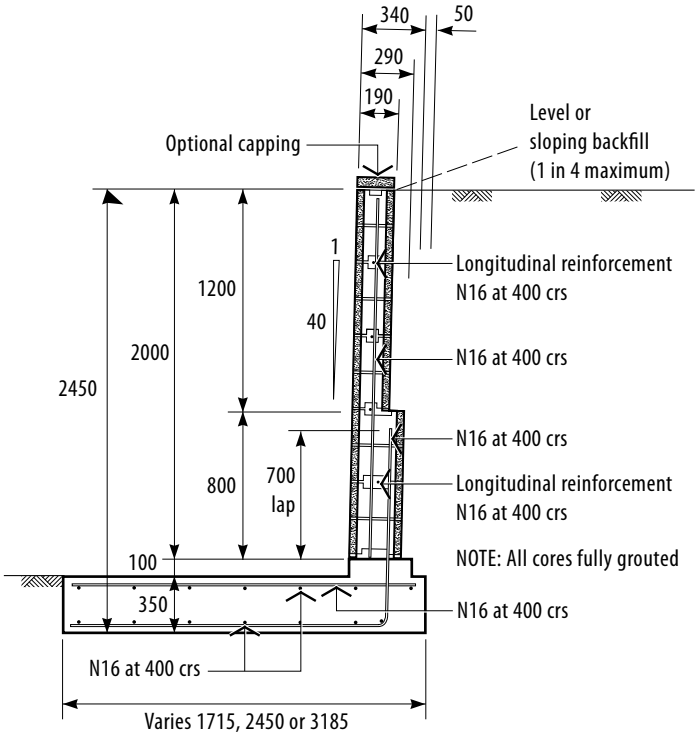
General arrangement

B = 1.3H



		Level				1 in 4			
Exposed stem height, H_w (mm)	2000								
Total height, **H** (mm)	2450								
Total width, **B** (mm)	3185								
Retained soil slope, β		Level				1 in 4			
Live load surcharge, q_l (kPa)		5		10		5		10	
Retained soil internal friction, ϕ_r (°)		25	31	25	33	–	34	–	36
Retained soil cohesion, c_r (kPa)		0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)		25	31	25	33	–	34	–	36
Foundation cohesion, c_f (kPa)		6	0	9	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

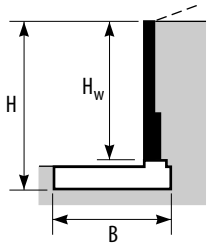
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2200** mm

General arrangement

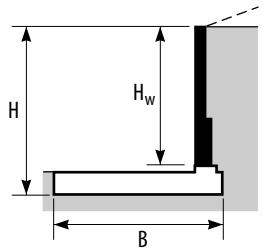
B = 0.7H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	1855							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	35	–	37	–	38	–	40
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	35	–	37	–	38	–	40
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

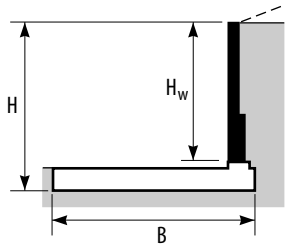
B = 1.0H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	2650							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	33	–	35	–	36	–	37
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	33	–	35	–	36	–	37
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

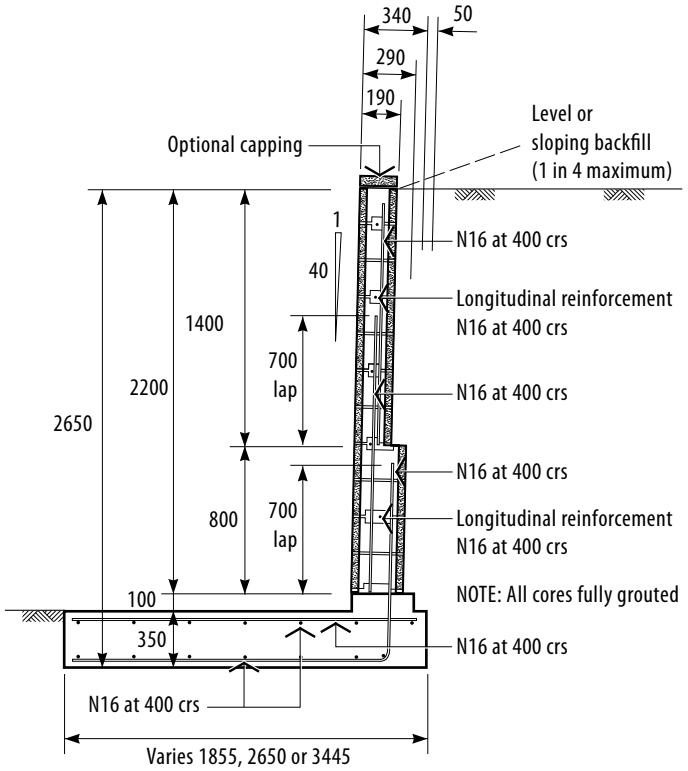
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2200							
Total height, **H** (mm)	2650							
Total width, **B** (mm)	3445							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	32	25	34	–	35	–	36
Retained soil cohesion, c_r (kPa)	0	0	0	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	32	25	34	–	35	–	36
Foundation cohesion, c_f (kPa)	7	0	10	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

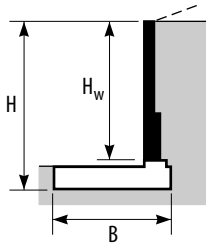
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2400** mm

General arrangement

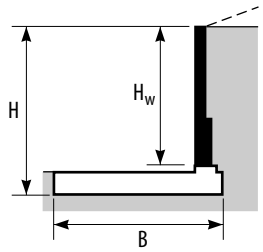
B = 0.7H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	1995							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	38	–	38	–	40
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	38	–	38	–	40
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

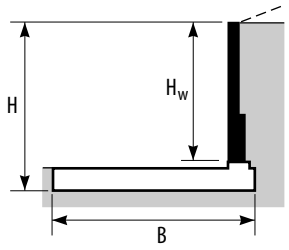
B = 1.0H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	2850							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	34	–	36	–	36	–	38
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	34	–	36	–	36	–	38
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

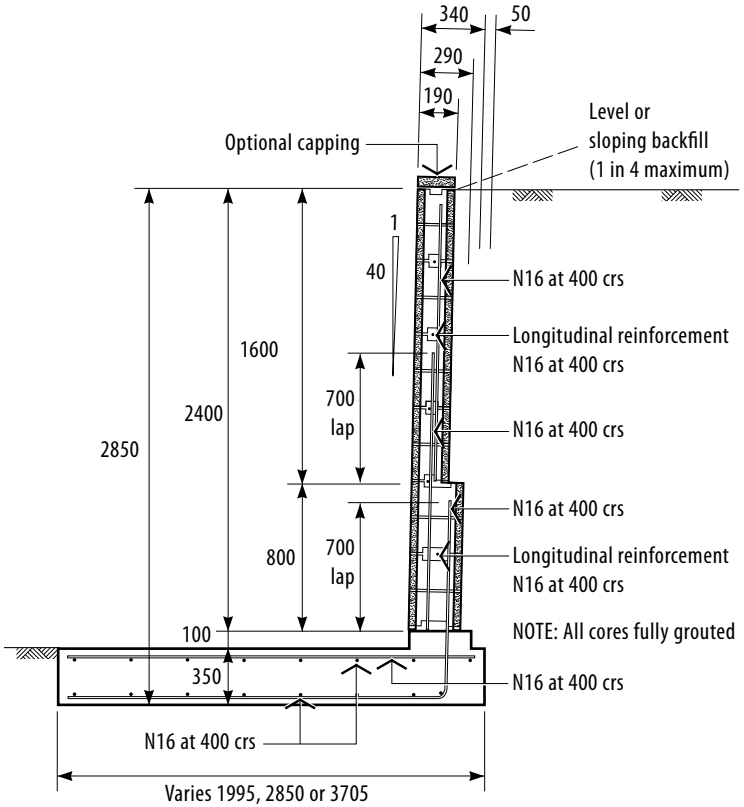
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2400							
Total height, **H** (mm)	2850							
Total width, **B** (mm)	3705							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	33	–	35	–	35	–	37
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	33	–	35	–	35	–	37
Foundation cohesion, c_f (kPa)	8	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

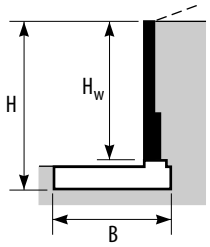
This detail to be read in conjunction with ***Common Details*** regarding reinforcement placement and drainage design.

See also, ***Construction Specification*** for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2600** mm

General arrangement

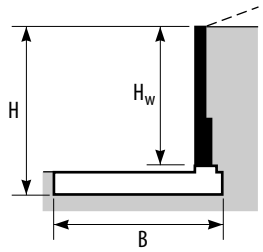
B = 0.7H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	2135							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	38	–	39	–	41
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	38	–	39	–	41
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

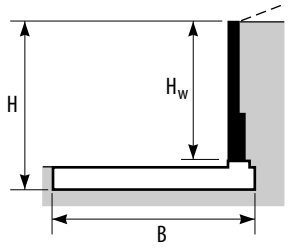
B = 1.0H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	3050							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	35	–	36	–	37	–	38
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	35	–	36	–	37	–	38
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

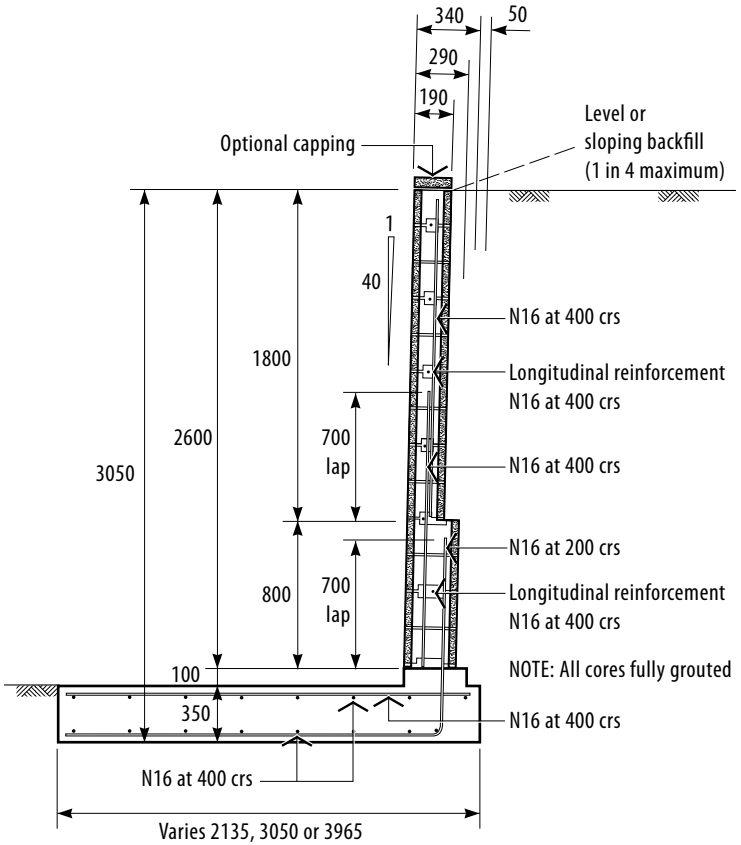
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2600							
Total height, **H** (mm)	3050							
Total width, **B** (mm)	3965							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	34	–	35	–	36	–	37
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	34	–	35	–	36	–	37
Foundation cohesion, c_f (kPa)	9	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

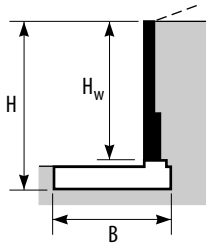
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **2800** mm

General arrangement

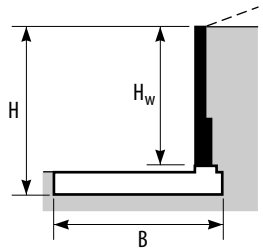
B = 0.7H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	2275							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	37	–	39	–	39	–	41
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	37	–	39	–	39	–	41
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

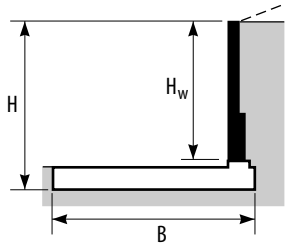
B = 1.0H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	3250							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	35	–	37	–	38	–	39
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	35	–	37	–	38	–	39
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

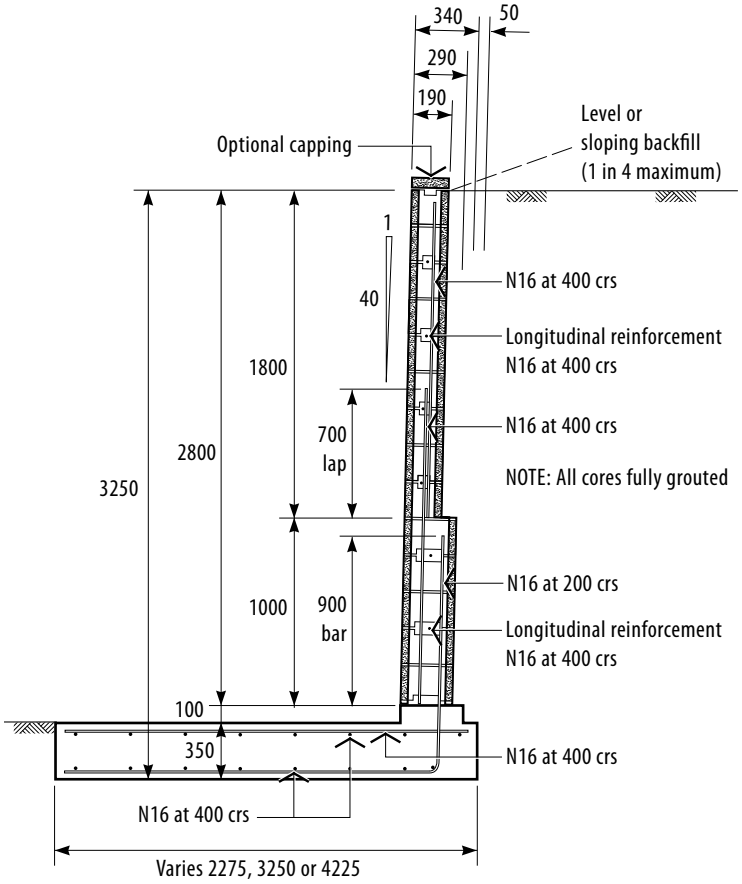
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	2800							
Total height, **H** (mm)	3250							
Total width, **B** (mm)	4225							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	25	34	–	36	–	36	–	38
Retained soil cohesion, c_r (kPa)	0	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	25	34	–	36	–	36	–	38
Foundation cohesion, c_f (kPa)	10	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

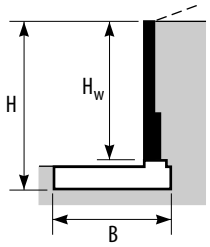
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3000** mm

General arrangement

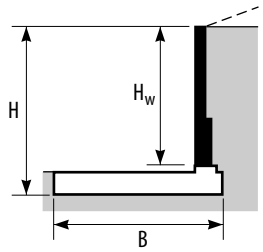
B = 0.7H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	2415							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	37	–	39	–	40	–	41
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	37	–	39	–	40	–	41
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

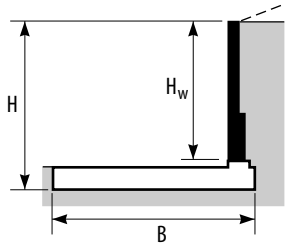
B = 1.0H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	3450							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	37	–	38	–	39
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	37	–	38	–	39
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

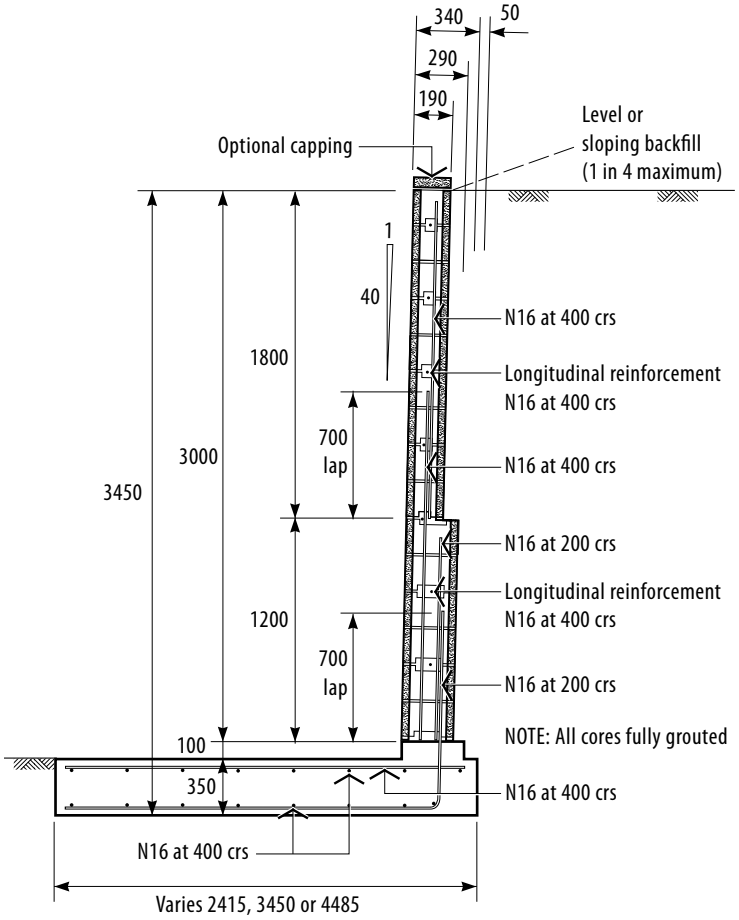
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3000							
Total height, **H** (mm)	3450							
Total width, **B** (mm)	4485							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	35	–	36	–	37	–	38
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	35	–	36	–	37	–	38
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

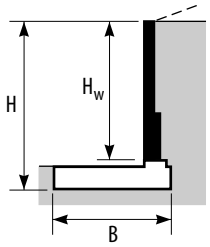
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3200** mm

General arrangement

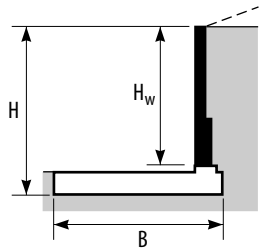
B = 0.7H



Exposed stem height, H_w (mm)	3200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	2555							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	38	–	39	–	40	–	42
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	38	–	39	–	40	–	42
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

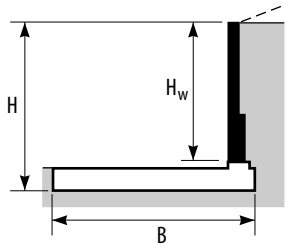
B = 1.0H



Exposed stem height, H_w (mm)	3200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	3650							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	38	–	38	–	40
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	38	–	38	–	40
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

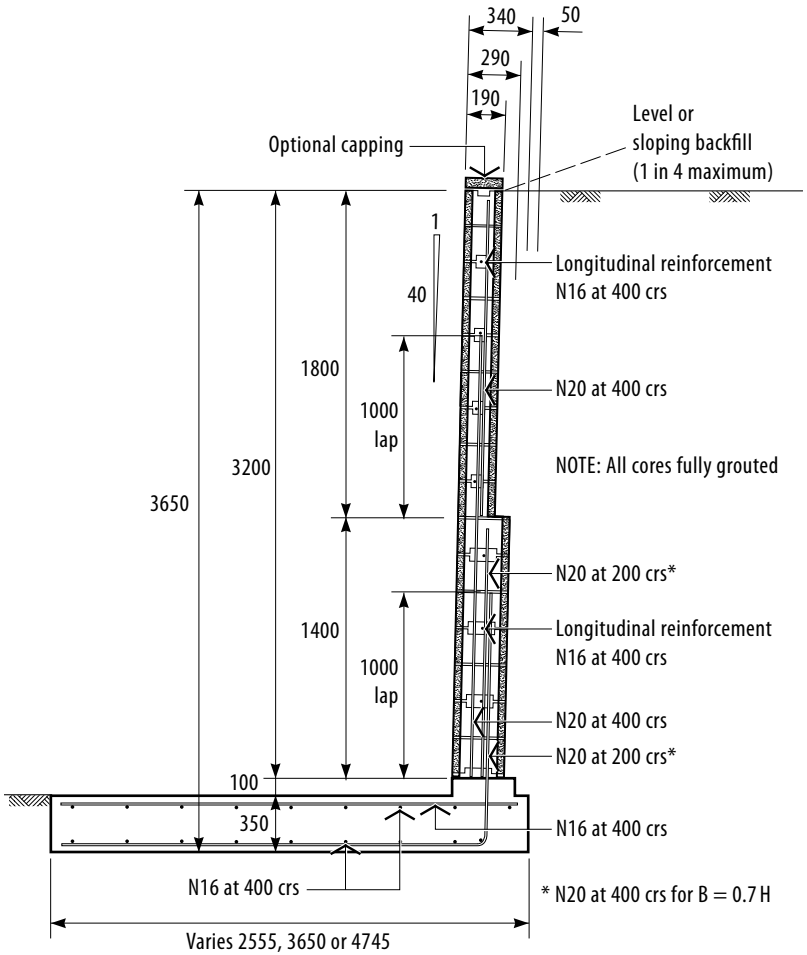
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3200							
Total height, **H** (mm)	3650							
Total width, **B** (mm)	4745							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	35	–	37	–	37	–	39
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	35	–	37	–	37	–	39
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

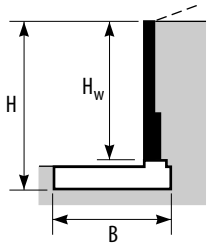
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR TYPE 2 CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF 3400 mm

General arrangement

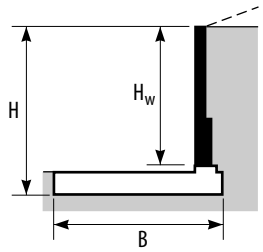
B = 0.7H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	2695							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	38	–	40	–	40	–	42
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	38	–	40	–	40	–	42
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

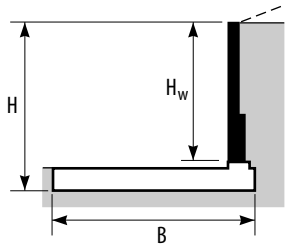
B = 1.0H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	3850							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	37	–	38	–	39	–	40
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	37	–	38	–	39	–	40
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

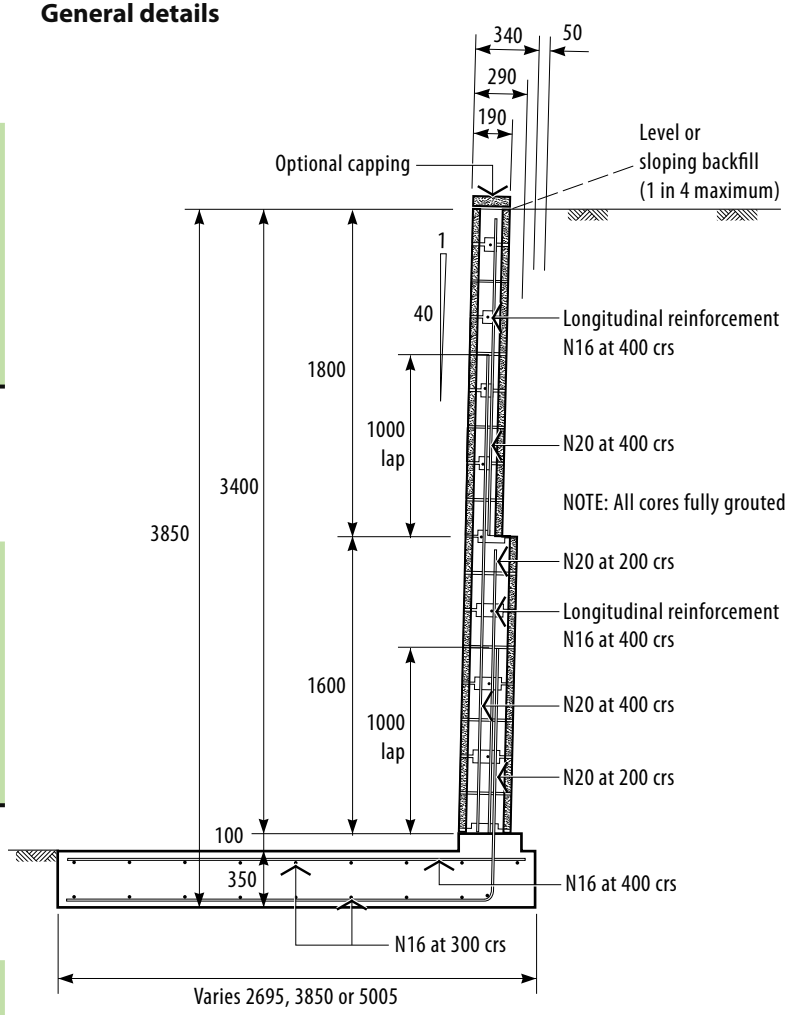
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3400							
Total height, **H** (mm)	3850							
Total width, **B** (mm)	5005							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	37	–	38	–	39
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	37	–	38	–	39
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General details



NOTES:

All cores to be fully grouted.

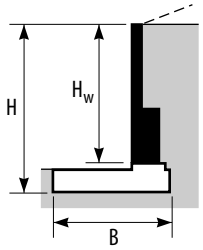
This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

DESIGN DATA FOR **TYPE 2** CANTILEVER RETAINING WALL WITH EXPOSED STEM HEIGHT, H_w, OF **3600** mm

General arrangement

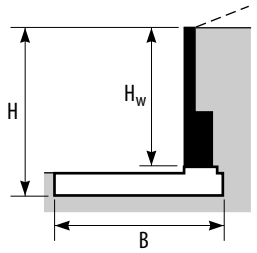
B = 0.7H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	2940							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	36	–	37	–	38	–	39
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	36	–	37	–	38	–	39
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General arrangement

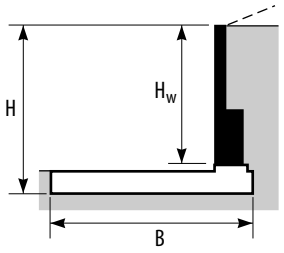
B = 1.0H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	4200							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	34	–	35	–	36	–	38
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	34	–	35	–	36	–	38
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

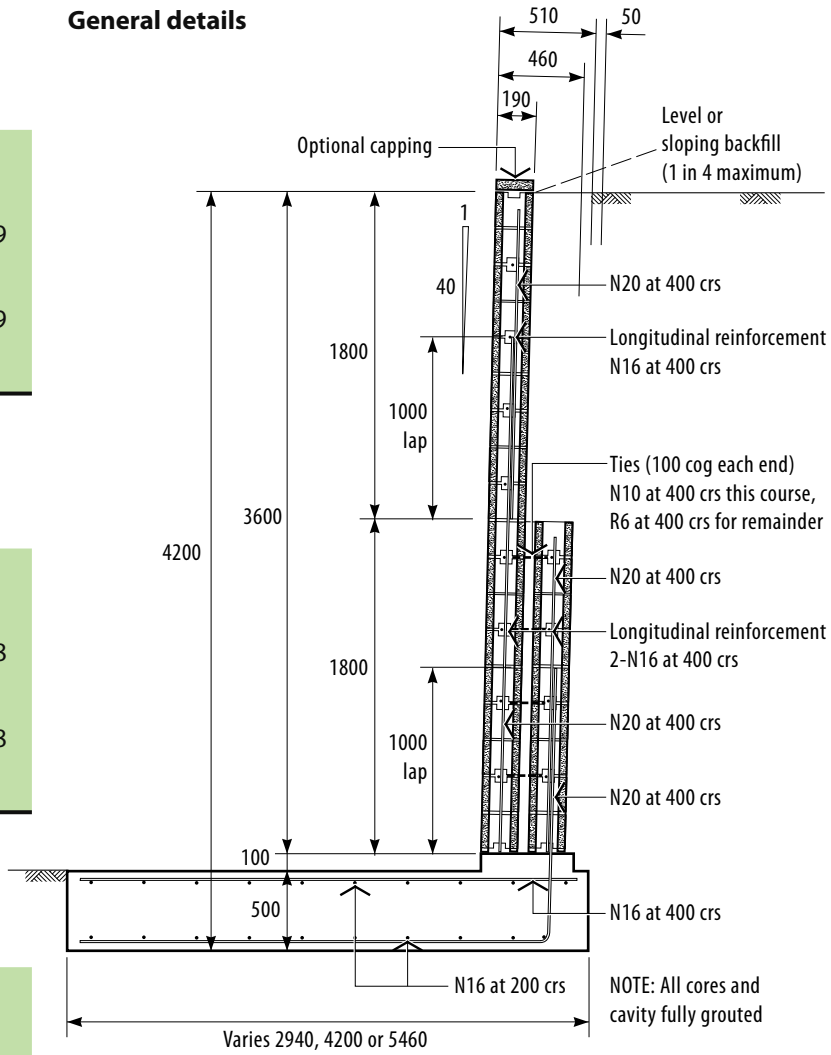
General arrangement

B = 1.3H



Exposed stem height, H_w (mm)	3600							
Total height, **H** (mm)	4200							
Total width, **B** (mm)	5460							
Retained soil slope, β	Level				1 in 4			
Live load surcharge, q_l (kPa)	5		10		5		10	
Retained soil internal friction, ϕ_r (°)	–	33	–	34	–	35	–	36
Retained soil cohesion, c_r (kPa)	–	0	–	0	–	0	–	0
Foundation internal friction, ϕ_f (°)	–	33	–	34	–	35	–	36
Foundation cohesion, c_f (kPa)	–	0	–	0	–	0	–	0

General details



NOTES:

All cores and cavity to be fully grouted.

This detail to be read in conjunction with *Common Details* regarding reinforcement placement and drainage design.

See also, *Construction Specification* for further details.

APPENDIX B – DESIGN EXAMPLE

INTRODUCTION

The following example demonstrates the method used by the CMAA to design retaining walls in accordance with AS 4678.

External Design. The external design (for sliding, bearing and overturning) is applicable to:

- Segmental Concrete Gravity Retaining Walls
- Segmental Concrete Reinforced Soils Retaining Walls
- Reinforced Concrete Masonry Cantilever Retaining Walls

Internal Design. The internal design is specific to Reinforced Concrete Masonry Cantilever Retaining Walls

DESIGN BRIEF

Geometric Data

Exposed height of retaining wall
H_1 = 3.000 m

Slope of retaining wall (measured from vertical)
ω = 1.43° (1 in 40 from vertical)

Slope of retained soil close to retaining wall (measured from horizontal)
β_1 = 14.04° (1 in 4 from horizontal)

Length of slope at wall
$L_{slope\ 1}$ = 3.000 m

Slope of retained soil at distance from retaining wall (measured from horizontal)
β_2 = 1.43° (1 in 40 from horizontal)

Length of slope at distance from wal
$L_{slope\ 2}$ = 1.000 m

Location, Service and Environmental Conditions

Service life
Y_{serv} = 60 years

Ambient temperature at surface
T = 30° C

Location
Sydney

Underlying soil
Not more than 30 m of stiff hard clay

Wind load
q_w = 0.9 kPa Determined from AS/NZS 1170.2

Groundwater

Allow for partial inadequacy of drainage system during rapid drawdown of water in front of wall.

Height of water table in front of wall (from soil surface at toe)
$H_{w\ front}$ = 0.100 m

Height of water table behind wall (from soil surface at toe)
$H_{w\ rear}$ = 0.400 m

Supported Structures

Barrier is 140 mm reinforced concrete blockwork on 450 mm x 300 mm reinforced concrete footing

Height of barrier
$H_{barrier}$ = 1.800 m

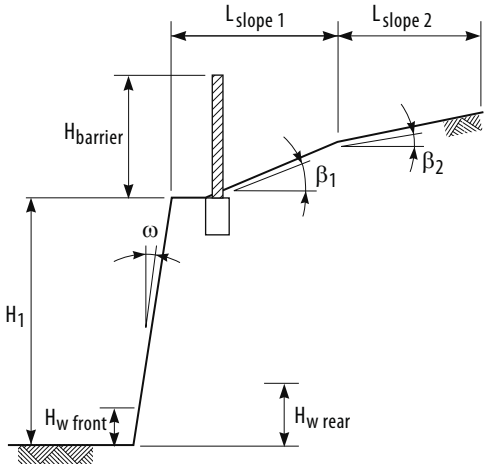


Figure B1 *Profile and Supported Structure*

Loads

Dead load vertical surcharge
q_d = 2.5 kPa

Live load vertical surcharge
q_l = 5.0 kPa

Wind vertical surcharge
q_w = 0.1 kPa

Earthquake vertical surcharge
q_e = 0.1 kPa

Dead vertical line load

$$D_v = H_{barrier}\, T_{barrier}\, \gamma_{barrier} + H_{footing}\, T_{footing}\, (\gamma_{footing} - \gamma_{soil})$$

$$= (1.80 \times 0.14 \times 22) + (0.45 \times 0.30) \times (24 - 20)$$

$$= 6.0 \text{ kN/m}$$

Live vertical line load
L_v = 0.1 kN/m

Dead horizontal line load
D_H = 0.1 kN/m

Live horizontal line load
L_H = 0.1 kN/m

Wind horizontal line load

$$W_H = q_w (H_{barrier} + H)$$

$$= 0.9(1.80 + 3.0)$$

$$= 4.3 \text{ kN/m}$$

Earthquake horizontal line load
E_H = 0.6 kN/m

Position of Line Loads

(Measured from ground level in front of embankment. See **Figure B2**)

Height of horizontal line dead load
y_{DH} = 3.900 m (At top of barrier)

Height of horizontal line live load
y_{EH} = 3.900 m (At top of barrier)

Height of horizontal line wind load
y_{WH} = 2.400 m (At mid-height of combined barrier and retaining wall)

Height of horizontal line earthquake load
y_{EH} = 3.900 m (At top of barrier)

Horizontal lever arm to vertical line dead load
x_{DV} = 0.400 m (Constructed behind the retaining wall facing)

Horizontal lever arm of vertical line live load
x_{LV} = 0.400 m (Constructed behind the retaining wall facing)

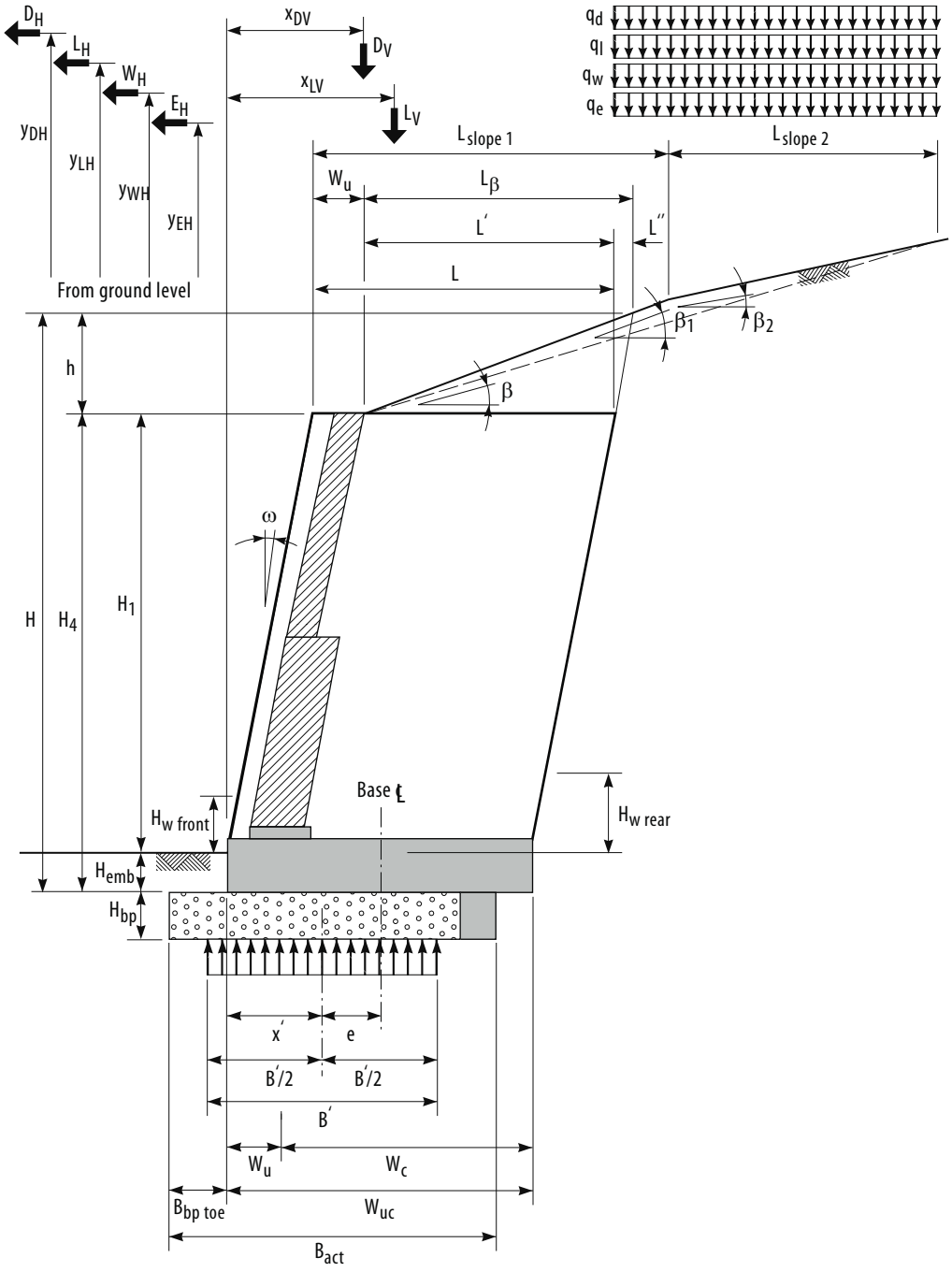


Figure B2 *Dimensions for External Design*

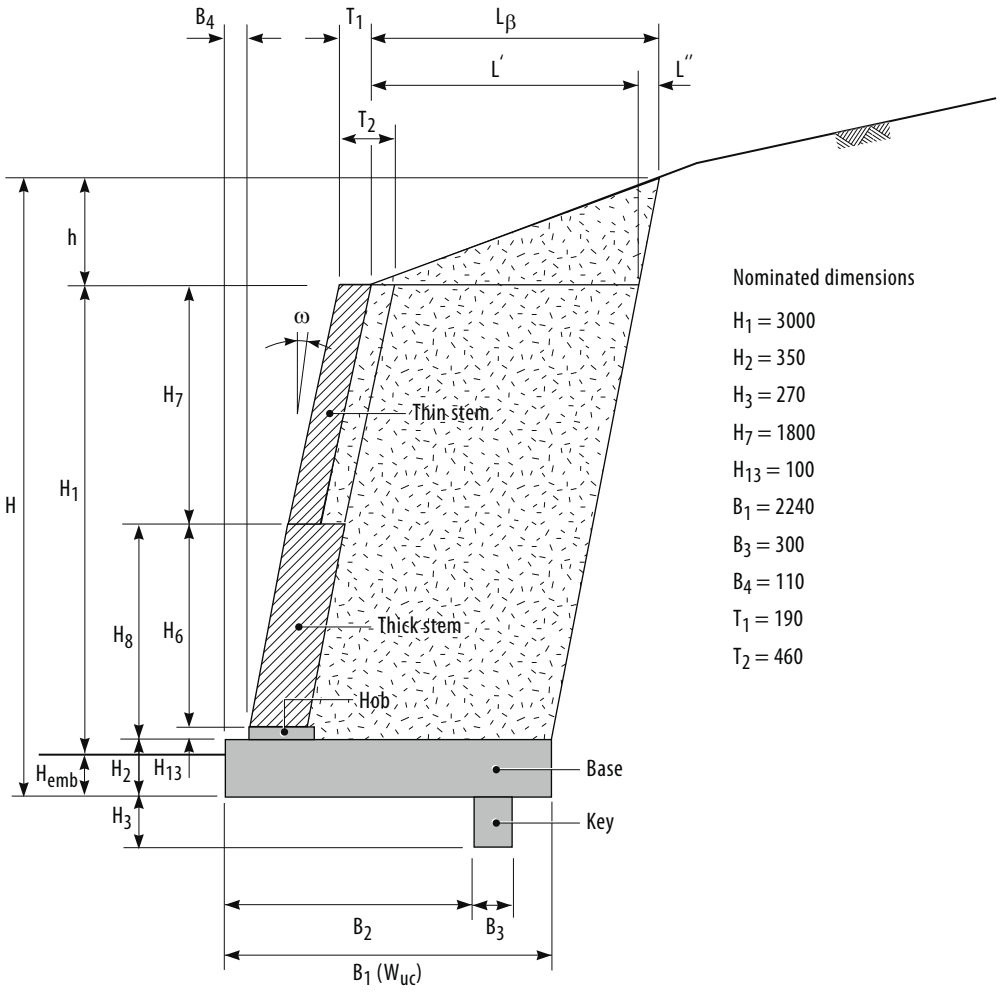


Figure B3 *Dimensions for Internal Design*

Retained Soil Properties

The retained soil is an Insitu soil of one of the following types:

Stiff sandy clays, gravelly clays, compact clayey sands and sandy silts, compact clay fill (Class 2)

Retained soil density

γ_r = 20 kN/m^3

Retained soil conservative estimate of the mean internal friction angle

ϕ_r = 30°

Retained soil conservative estimate of the mean cohesion

c_r = 5.0 kPa

Except in those cases of relatively low retaining walls where the Rankine-Bell method is used, cohesion of the retained soil will be assumed to be zero.

Foundation Soil Properties

The foundation soil is an Insitu soil of one of the following types:

Stiff sandy clays, gravelly clays, compact clayey sands and sandy silts, compact clay fill (Class 2)

Foundation soil density

γ_f = 20 kN/m^3

Foundation soil conservative estimate of the mean internal friction angle

ϕ_f = 30°

Foundation soil conservative estimate of the mean cohesion

c_f = 5.0 kPa

Designer must determine whether this value should be used.

Properties of Earth Retaining Structure

Gravity wall density

γ_i = 20.0 kN/m^3 (ie, facing and any confined soil)

In order to simplify the comparison of the three alternative retaining wall systems, an average density 20.0 kN/m^3 has been adopted in this worked example, for both the retaining wall facing and the infill material, including no-fines concrete.

More common values are:

- *Dense concrete footings* ***24.0*** *kN/m^3*
- *Dense concrete masonry* ***22.0*** *kN/m^3 (This should be reduced to allow for voids in the facing that cannot be filled)*
- *Compacted soil infill* ***20.0*** *kN/m^3*
- *No-fines concrete infill* ***18.0*** *kN/m^3*

Infill soil density

γ_i = 20 kN/m^3

See note above.

GEOMETRY OF THE RETAINING STRUCTURE

System is a gravity wall, of one of the following types:

- Segmental Concrete Gravity Retaining Wall
- Segmental Concrete Reinforced Soils Retaining Wall
- Type 1(Note 1) Reinforced Concrete Masonry Cantilever Retaining Wall.

NOTES:

1 Type 1 structures have an elongated heel extending behind the wall under the infill soil, which contributes to the weight of the total structure.
Type 2 has an elongated toe extending in front of the wall, but not supporting any soil. Because the total weight of Type 2 structures (including the infill soil) is less than Type 1 structures of similar dimensions, the resistance to sliding and overturning is lower. Type 2 structures must be designed for this reduced resistance.

Retaining Structure Dimensions

Total width of retaining structure (at the base) selected by trial and error based on approximately 0.7 times the exposed height (see **Figures B2** and **B3**).

$W_{uc} = 0.7(H_1 + H_{emb})$
$= 0.7 \times (3.0 + 0.2)$
$= 2.240$ m

Width of infill behind facing at the base of the retaining structure

$W_c = W_{uc} - W_u$
$= 2.240 - 0.3$
$= 1.940$ m

Length of infill behind facing at the base of the retaining structure

L′ = 1.940 m

L′ is commonly the same as W_c (i.e. the depth into the embankment of the retaining structure is the same at the top as at the bottom). However, this is not necessarily always the case.

Width increase due to backfill slope

$L'' = [L' \tan(\beta_1) \tan(\omega)]/[1 - \tan(\beta_1).\tan(\omega)]$
$= [1.940 \times \tan(14.04°) \tan(1.43°)] / [1 - \tan(14.04°) \tan(1.43°)]$
$= 0.012$ m

Width at top of backfill slope

$L_\beta = L' + L''$
$= 1.940 + 0.012$
$= 1.952$ m

Height from top of wall to top of slope

$h = L_\beta \tan(\beta_1)$
$= 1.952 \times \tan(14.04°)$
$= 0.488$ m

Embedment (including footings, if applicable, but excluding bearing pad

H_{emb} = 0.200 m

In the case of a reinforced concrete masonry cantilever gravity retaining wall of this height, the thickness of the reinforced concrete base would be of the order of 0.350 m. However, a value of 0.200 m has been adopted to maintain consistency between the worked examples for varoius systems of retaining wall.

Height of wall (including embedment)

$H = H_1 + h + H_{emb}$
$= 3.000 + 0.488 + 0.200$
$= 3.688$ m

Effective slope of retained soil (measured from horizontal)

$\beta = \tan^{-1}[\{L_{slope\ 1} \tan(\beta_1) + L_{slope\ 2} \tan(\beta_2)\}/(L_{slope\ 1} + L_{slope\ 2})]$
$= \tan^{-1}[\{3.0 \times \tan(14.04°) + 1.0 \times \tan(1.43°)\}/(3.0 + 1.0)]$
$= 11.0°$

Angle of underside of base (measured from horizontal)

α = 0° Horizontal

Bearing Pad Dimensions

The actual width of the bearing pad should be selected to be just greater than that required by the analysis below.

Bearing pad thickness

H_{bp} = 270 mm

Factor for the spread of load through the bearing pad.
The following assumptions are made to determine how effective the bearing pad is in spreading load down to the foundation.

K_{bp} = 2 for compacted road base
= 4 for cement-stabilised compacted road base
= 8 for reinforced concrete.

Actual width of bearing pad

B_{act} = 3.400 m

Depth of bearing pad

H_{bp} = 0.270 m

Maximum potential effective width of a bearing pad

$B = \min [B_{act}, (W_{uc} + K_{bp} H_{bp})]$
$= \min [3.400, (2.240 + 4 \times 0.270)]$
$= 3.320$ m

This is the width of bearing pad into which the vertical load (without lateral load) could be distributed, if it were central under the retaining structure, giving consideration to the particular material, its strength and stiffness.

Facing/Stem

In order to simplify the comparison of the three alternative retaining wall systems, an average density 20.0 kN/m^3 has been adopted in this worked example, for both the retaining wall facing and the infill material, including no-fines concrete.

Earthquake Considerations

Acceleration coefficient

a = 0.08

Site factor

S = 1.0

Local acceleration

$aS = a\ S$
$= 0.08 \times 1.0$
$= 0.08$

Earthquake design category

$C_{eq} = B_{er}$

There is no need to use increased factors or particular analysis for earthquake.

If a Mononobe-Okabe Pseudo-Static Analysis for earthquake loads were to be carried out, the following factors would be applicable.

Nominal horizontal acceleration

a_h = 0.04 m/s

Nominal vertical acceleration

a_v = 0.00 m/s

Average amplified horizontal acceleration within the retained soil

$a_{mh} = \text{If } [a_h < 0.45, (1.45 - a_h)a_h, a_h]$
$= 0.056$ m/s

Average amplified vertical acceleration within the retained soil

$a_{mv} = \text{If } [a_v < 0.45, (1.45 - a_v)\ av, a_v)$
$= 0.00$ m/s

Horizontal seismic coefficient

k_h = 0.056

Vertical seismic coefficient

k_v = 0.0

Earthquake factors

$\theta_{eq} = \text{Max } [\tan^{-1}(k_h/(1 - k_v)), \tan^{-1}(k_h/(1 + k_v)]$
$= \text{Max } [\tan^{-1}(0.056/(1 - 0)), \tan^{-1}(0.056/(1 + 0)]$
$= 3.2°$

ULTIMATE LOAD (LIMIT STATE) CALCULATIONS IN ACCORDANCE AS 4678:2002

Partial Load Factors and Material Factors

This design is based on AS 4678.

Table B1 sets out the load combinations that should be checked, together with the corresponding load and materials factors. In this worked example, only the Ultimate Case, U (i) has been checked.

Table B1 *Partial Load Factors and Material Factors*

		Ultimate			Short-term serviceability					Long-term serviceability
Load case		U (i)	U (ii)	U (iii)	SS (i)	SS (ii)	SS (iii)	SS (iv)	SS (v)	LS (i)
Overturning (active) soil loads	G_{dos}	1.25	1.25	1.25	NA	NA	1.00	1.00	1.00	1.00
Overturning dead loads	G_{do}	1.25	1.25	1.25	NA	NA	1.00	1.00	1.00	1.00
Overturning live loads	G_{lo}	1.50	0.60	0.60	NA	NA	0.00	0.60	0.60	0.00
Overturning wind loads	G_{wo}	0.00	1.00	0.00	NA	NA	1.00	0.00	1.00	0.00
Overturning earthquake loads	G_{eo}	0.00	0.00	1.00	NA	NA	0.00	0.00	0.00	0.00
Resisting dead loads	G_{dr}	0.80	0.80	0.80	NA	NA	1.00	1.00	1.00	1.00
Resisting live loads (eg over infill material)	G_{lr}	0.00	0.00	0.00	NA	NA	0.00	0.00	0.00	0.00
Water in tension cracks and groundwater	G_{v}	1.00	1.00	1.00	NA	NA	1.00	1.00	1.00	1.00
Partial factors on tan(phi)	$\Phi_{tan(q)}$									
Class 1 controlled fill		0.95	0.95	0.95	NA	NA	1.00	1.00	1.00	1.00
Class 2 controlled fill		0.90	0.90	0.90	NA	NA	0.95	0.95	0.95	0.95
Uncontrolled fill		0.75	0.75	0.75	NA	NA	0.90	0.90	0.90	0.90
Insitu natural soil		0.85	0.85	0.85	NA	NA	1.00	1.00	1.00	1.00
Partial factors on cohesion	Φ_{c}									
Class 1 controlled fill		0.90	0.90	0.90	NA	NA	1.00	1.00	1.00	1.00
Class 2 controlled fill		0.75	0.75	0.75	NA	NA	0.85	0.85	0.85	0.85
Uncontrolled fill		0.50	0.50	0.50	NA	NA	0.65	0.65	0.65	0.65
Insitu natural soil		0.70	0.70	0.70	NA	NA	0.85	0.85	0.85	0.85
Structure classification factor	Φ_{n}	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Soil Design Properties

Retained soil

In this case, the retained soil is "insitu" material.
Any gap between the retaining structure and the retained soil should be filled with compacted infill-material. However, because failure planes may still form in the insitu material, the design in this example will be based on the retained soil.
Alternatively, the insitu material could be excavated and replaced to such a depth that any failure planes are forced to form in the infill material.

Retained soil partial factor on tan(ϕ)

$\Phi_{\tan(\phi_r)} = 0.85$

Retained soil partial factor on cohesion

$\Phi_{cr} = 0.70$

Retained soil design internal friction angle

$\phi_r^* = \tan^{-1}[\Phi_{\tan(\phi_r)}.\tan(\phi_r)]$
$= \tan^{-1}[0.85 \times \tan(30°)]$
$= 26.1°$

Retained soil design external friction angle

$\delta_r^* = 0.667\phi_r^*$
$= 0.667 \times 26.1°$
$= 17.4°$
against relatively smooth concrete

$= 1.0\phi_r^*$
$= 1.0 \times 26.1°$
$= 26.1°$
against no-fines concrete

$= 1.0\phi_r^*$
$= 1.0 \times 26.1°$
$= 26.1°$
against compacted infill soil

Allowance should be made for the effect of any geotextile or geocomposite that is incorporated into the structure.

Retained soil design cohesion

$c_r^* = \Phi_{cr}.c_r$
$= 0.70 \times 5.0$
$= 3.5$ kPa

Except in those cases of relatively low retaining walls where the Rankine-Bell method is used, cohesion of the retained soil will be assumed to be zero.

Orientation of failure plane

$$\alpha_{ir} = \phi_r^* + \tan^{-1}\left[\frac{-\tan(\phi_r^* - \beta) + \sqrt{\tan(\phi_r^* - \beta)\,[\tan(\phi_r^* - \beta) + \cot(\phi_r^* + \omega)].[1 + \tan(\delta_r^* - \omega)\cot(\phi_r^* + \omega)]}}{1 + \tan(\delta_r^* - \omega)\,.\,\tan(\phi_r^* - \beta) + \cot(\phi_r^* + \omega)}\right]$$

$= 47.5°$

Active pressure coefficient

$$K_{ar} = \frac{\cos^2(\phi_r^* + \omega)}{\cos^2(\omega)\cos(\omega - \delta_r^*)\left[1 + \sqrt{\frac{\sin(\phi_r^* + \delta_r^*)\sin(\phi_r^* - \beta)}{\cos(\omega - \delta_r^*)\cos(\omega + \beta)}}\right]^2}$$

$$= \frac{\cos^2(26.1° + 1.43°)}{\cos^2(1.43°)\cos(1.43° - 26.1°)\left[1 + \sqrt{\frac{\sin(26.1° + 26.1°)\sin(26.1° - 11°)}{\cos(1.43° - 26.1°)\cos(1.43° + 11°)}}\right]^2}$$

$= 0.394$

Foundation Soil

In this case, the retained soil is "insitu" material.
Any over-excavation should be filled with compacted cement-stabilised road base.

Foundation soil partial factor on tan(ϕ)

$\Phi_{\tan(\phi_r)} = 0.85$

Foundation soil partial factor on cohesion

$\Phi_{cf} = 0.70$

Foundation soil design internal friction angle

$\phi^*_f = \tan^{-1}[\Phi_{\tan(\phi_f)}.\tan(\phi_f)]$
$= \tan^{-1}[0.85 \times \tan(30°)]$
$= 26.1°$

Foundation soil design cohesion

$c^*_f = \Phi_{cf}.c_f$
$= 0.70 \times 5.0$
$= 3.5$ kPa

Foundation soil design external friction angle

$\delta^*_f = 0.667\phi^*_f$
$= 0.667 \times 26.1°$
$= 17.4°$
against relatively smooth concrete
$= 1.0\phi^*_f$
$= 1.0 \times 26.1°$
$= 26.1°$
against no-fines concrete
$= 1.0\phi^*_f$
$= 1.0 \times 26.1°$
$= 26.1°$
against compacted infill soil

Allowance should be made for the effect of any geotextile or geocomposite that is incorporated into the structure.

Active pressure coefficient of foundation soil

$$K_{af} = \frac{\cos^2(\phi + \omega)}{\cos^2\omega \cos(\omega - \delta)\left[1+\sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \beta)}{\cos(\omega - \delta)\cos(\omega + \beta)}}\right]^2}$$

$$= \frac{\cos^2(26.1° + 1.43°)}{\cos^2 1.43° \cos(1.43° - 26.1°)\left[1+\sqrt{\frac{\sin(26.1° + 26.1°)\sin(26.1° - 11.0°)}{\cos(1.43° - 26.1°)\cos(1.43° + 11.0°)}}\right]^2}$$

$$= 0.394$$

This is assumed to be the same as the active pressure coefficient for the retained soil, including:

- *soil to rough surface or soil to soil*
- *consideration of lay-back*
- *consideration of slope of retained soil.*

Passive pressure coefficient of foundation soil

$$K_{pf} = \frac{1 + \sin(\phi^*_f)}{1 - \sin(\phi^*_f)}$$

$$= \frac{1 + \sin(26.1°)}{1 - \sin(26.1°)}$$

$$= 2.58$$

Infill Soil

Depending on the type of earth retaining structure and the profile of the existing embankment to be retained, it may be necessary to place infill soil between the embankment and the structure. In this case, the infill soil will be specified as one of the following:

gravelly and compacted sands,
controlled crushed sandstone and
gravel fills (Class 1),
dense well graded sands.

The infill material will be compacted to Class C2 (Refer AS 4678 for definition of the compaction).

Infill soil density

$\gamma_i = 20$ kN/m^3

Infill soil conservative estimate of the mean internal friction angle

$\phi_i = 32°$

Infill soil conservative estimate of the mean cohesion

$c_i = 3.0$ kPa

Infill soil partial factor on tan(ϕ)

$\Phi_{\tan(\phi_i)} = 0.90$

Infill soil partial factor on cohesion

$\Phi_{ci} = 0.75$

Infill soil design internal friction angle

$\phi_i^* = \tan^{-1}[\Phi_{\tan(\phi_i)}.\tan(\phi_i)]$
$= \tan^{-1}[0.90 \times \tan(32°)]$
$= 29.4°$

Infill soil design cohesion

$c_i^* = \Phi_{ci}.c_i$
$= 0.75 \times 3.0$
$= 2.3$ kPa

A value of zero will be used in the design.

Infill soil design external friction angle

$\delta_i^* = 0.667\phi_i^*$
$= 0.667 \times 29.4°$
$= 19.6°$
against relatively smooth concrete

$= 1.0\phi_i^*$
$= 1.0 \times 29.4°$
$= 29.4°$
against no-fines concrete

$= 1.0\phi_i^*$
$= 1.0 \times 29.4°$
$= 29.4°$
against compacted infill soil

Allowance should be made for the effect of any geotextile or geocomposite that is incorporated into the structure.

Orientation of failure plane

$$\alpha_{ii} = \phi_i^* + \tan^{-1}\left[\frac{-\tan(\phi_i^* - \beta) + \sqrt{\tan(\phi_i^* - \beta)\,[\tan(\phi_i^* - \beta) + \cot(\phi_i^* + \omega)].[1 + \tan(\delta_i^* - \omega)\cot(\phi_i^* + \omega)]}}{1 + \tan(\delta_i^* - \omega)\,.\,\tan(\phi_i^* - \beta) + \cot(\phi_i^* + \omega)}\right]$$

$= 50.6°$

Active pressure coefficient

$$K_{ai} = \frac{\cos^2(\phi_i^* + \omega)}{\cos^2(\omega)\cos(\omega - \delta_i^*)\left[1 + \sqrt{\frac{\sin(\phi_i^* + \delta_i^*)\sin(\phi_i^* - \beta)}{\cos(\omega - \delta_i^*)\cos(\omega + \beta)}}\right]^2}$$

$$= \frac{\cos^2(29.4° + 1.43°)}{\cos^2(1.43°)\cos(1.43° - 19.6°)\left[1 + \sqrt{\frac{\sin(29.4° + 19.6°)\sin(29.4° - 14.04°)}{\cos(1.43° - 19.6°)\cos(1.43° + 14.04°)}}\right]^2}$$

$= 0.362$

Bearing Pad

In this case, the bearing pad shall consist of compacted controlled fill, with 5% cement-stabilised crushed rock, WET when base is laid.

Specified compressive strength

$f'_c = 5.0$ MPa

Bearing pad density

$\gamma_b = 20$ kN/m3

Bearing pad conservative estimate of the mean internal friction angle

$\phi_b = 40°$

Bearing pad conservative estimate of the mean cohesion

$c_b = 0.1$ kPa

For a granular base, the cohesion is normally zero, and the adhesion is therefore also zero. In this example, a small nominal value of 0.1 kPa has been assumed for both adhesion and cohesion to demonstrate the method. In practice, it is common for a designer to ignore this value.

Bearing pad partial factor on tan(ϕ)

$\Phi_{\tan(\phi_b)} = 0.95$

Bearing pad partial factor on cohesion

$\Phi_{cb} = 0.90$

Bearing pad design internal friction angle

$\phi^*_b = \tan^{-1}[\Phi_{\tan(\phi_b)}.\tan(\phi_b)]$
$= \tan^{-1}[0.95 \times \tan(40°)]$
$= 38.6°$

Bearing pad design external friction angle(Note 1)

$\delta^*_b = 0.667\phi^*_b$
$= 0.667 \times 38.6$
$= 25.7°$
against relatively smooth concrete

$= 1.0\ \phi^*_b$
$= 1.0 \times 38.6°$
$= 38.6°$
against no-fines concrete

$= 1.0\ \phi^*_f$
$= 1.0 \times 26.1°$
$= 26.1°$
against compacted foundation soil (foundation soil governs)

Bearing pad design cohesion

$c^*_b = \Phi_{cb}.c_b$
$= 0.90 \times 0.1$
$= 0.09$ kPa

NOTES

1 The values above are reasonably consistent with the NCMA approach, which uses the following:

Sliding resistance coefficient of levelling pad to other soil, $C_{ds\ b} = 1.0$

Sliding resistance coefficient of levelling pad to smooth masonry, $\mu_b = 0.68$

EXTERNAL STABILITY AT ULTIMATE LOADS AND RESISTANCES

Horizontal Forces

Horizontal active force due to surcharge

$P_{q\,H} = K_{ar} [G_{do}\, q_d + G_{lo}\, q_l + G_{wo}\, q_w + G_{eo}\, q_e] H \cos(\delta^*_r - \omega)$
$= 0.394 [(1.25 \times 2.5) + (1.5 \times 5.0) + (0 \times 0.1) + (0 \times 0.1)] 3.688 \times \cos(26.1° - 1.43°)$
$= 14.0$ kN/m

Horizontal active force due to soil

$P_{s\,H} = K_{ar}\, 0.5\, (G_{do}\, \gamma^*_r)\, H^2 \cos(\delta^*_r - \omega)$
$= 0.394 \times 0.5\, (1.25 \times 20.0)\, 3.6882 \times \cos(26.1° - 1.43°)$
$= 60.8$ kN/m

Horizontal force due to water in front of wall

$P_{w\,front} = - [0.5\, \gamma^*_w\, (H_{w\,front} + H_{emb})^2]$
$= - [0.5 \times 9.81 \times (0.100 + 0.200)^2]$
$= -0.44$ kN/m

Horizontal force due to water behind infill

$P_{w\,rear} = 0.5\, \gamma^*_w\, (H_{w\,rear} + H_{emb})^2$
$= 0.5 \times 9.81 \times (0.400 + 0.200)^2$
$= 1.77$ kN/m

Horizontal force due to dead line load

$P_{D\,H} = G_{do}\, D_H$
$= 1.25 \times 0.1$
$= 0.13$ kN/m

Horizontal force due to live line load at top

$P_{L\,H} = G_{lo}\, L_H$
$= 1.\ 5 \times 0.1$
$= 0.15$ kN/m

Horizontal force due to wind line load at top

$P_{W\,H} = G_{wo}\, W_H$
$= 0 \times 4.3$
$= 0.0$ kN/m

Horizontal force due to earthquake line load at top

$P_{E\,H} = G_{eo}\, E_H$
$= 0 \times 0.6$
$= 0.0$ kN/m

Horizontal active force due to water in tension cracks

$P_{wc\,H} = 0.0$ kN/m

This force will only apply in some cases of cohesive soil (when using Rankine-Bell method), where the fill is not protected against ingress of water.

Total horizontal forces causing forward movement (at the interface between the retaining structure and bearing pad)

$P_{b\,H} = P_{q\,H} + P_{s\,H} + P_{w\,front} + P_{w\,rear} + P_{D\,H} + P_{L\,H} + P_{W\,H} + P_{E\,H} + P_{wc\,H}$
$= 14.0 + 60.8 - 0.44 + 1.77 + 0.13 + 0.15 + 0.0 + 0.0 + 0.0$
$= 76.4$ kN/m

Horizontal active force due to surcharge on bearing pad

$P_{bpq\,H} = K_{ar} [G_{do}\, q_d + G_{lo}\, q_l + G_{wo}\, q_w + G_{eo}\, q_e] H_{bp} \cos(\delta^*_r)$
$= 0.394 [(1.25 \times 2.5) + (1.5 \times 5.0) + (0 \times 0.1) + (0 \times 0.1)] 0.270 \times \cos(26.1°)$
$= 1.0$ kN/m

The same active pressure coefficent as is applicable for the upper part of the retaining structure, K_{ar}, has been used. This is based on:

- *The internal friction angle for retained soil (acting against bearing pad granular material)*
- *The layback of the upper structure, ω. (Slightly non-conservative assumption)*

Horizontal active force due to soil on bearing pad

$P_{bps\,H} = K_{ar}\, G_{dos}\, \gamma_b\, 0.5\, [(H + H_{bp})^2 - H^2] \cos(\delta^*_r)$
$= 0.394 \times 1.25 \times 20.0 \times 0.5 \times [(3.688 + 0.270)^2 - 3.688^2] \times \cos(26.1°)$
$= 9.1$ kN/m

The average pressure, acting on the thickness of bearing pad, H_{bp}, is at a depth of $0.5\, [H + (H + H_{bp})]$

The same active pressure coefficent as is applicable for the upper part of the retaining structure, K_{ar}, has been used. See comment above.

Horizontal force due to water in front of bearing pad

$P_{bw\,front} = - 0.5\, \gamma^* w\, [(Hw\ front + Hemb + Hbp)2 - [(Hw\ front + Hemb)2]$
$= - [0.5 \times 9.81 \times [(0.100 + 0.200 + 0.270)2 - [(100 + 200)2]\ ]$
$= -1.15$ kN/m

Horizontal force due to water behind bearing pad

$P_{bw\,rear} = 0.5\, \gamma^*_w\, [(H_{w\,rear} + H_{emb} + H_{bp})^2 - (H_{w\,rear} + H_{emb})^2]$
$= 0.5 \times 9.81 \times [(0.400 + 0.200 + 0.270)^2 - (0.400 + 0.200)^2]$
$= 1.95$ kN/m

Total horizontal forces causing forward movement (at the interface between the bearing pad and foundation)

$P_{f\,H} = P_{b\,H} + P_{bpq\,H} + P_{bps\,H} + P_{bw\,front} + P_{bw\,rear}$
$= 76.4 + 1.0 + 9.1 - 1.15 + 1.95$
$= 87.3$ kN/m

Vertical Forces

Weight of thin stem

$P_{1\,V} = G_{dr\ gmasonry}\ H_7\ T_1$
$= 0.8 \times 22.7 \times 1.800 \times 0.190$
$= 6.21$ kN/m

Weight of thick stem (including hob)

$P_{2\,V} = G_{dr\ gmasonry}\ H_8\ T_2$
$= 0.8 \times 22.7 \times 1.050 \times 0.460$
$= 8.77$ kN/m

Weight of soil above thick stem

$P_{3\,V} = G_{dr}\ \gamma^*_i\ H_7\ (T_2 - T_1)$
$= 0.8 \times 20.0 \times 1.800 \times (0.460 - 0.190)$
$= 7.78$ kN/m

Weight of soil block

$P_{5\,V} = G_{dr}\ \gamma^*_i\ (B_1 - B_4 - T_2) H_{soil}$
$= 0.8 \times 20.0 \times (2.240 - 0.110 - 0.460) \times 2.850$
$= 76.15$ kN/m

Weight of base

$P_{6\,V} = G_{dr}\ \gamma^*_c\ B_1\ H_2$
$= 0.8 \times 25.0 \times 2.240 \times 0.350$
$= 15.68$ kN/m

Check:

Vertical weight of the gravity structure

$P_{f\,V} = P_{1\,V} + P_{2\,V} + P_{3\,V} + P_{5\,V} + P_{6\,V}$
$= 6.21 + 8.77 + 7.78 + 76.15 + 15.68$
$= 114.6$ kN/m

Vertical load due to sloping soil above the structure

$P_{f\ slope V} = G_{dr}\ \gamma_{su}\ 0.5\ L_\beta\ h$
$= 0.8 \times 20 \times 0.5 \times (2.240 - 0.300) \times 0.488$
$= 7.62$ kN/m

Vertical friction component of active surcharge load acting on the retained soil behind the structure

$P_{q\,V} = K_{ar}[G_{do}\ q_d + G_{lo}\ q_l + G_{wo}\ q_w + G_{eo}\ q_e]\ H \sin(\gamma^*_r - \omega)$
$= 0.394\ [(1.25 \times 2.5) + (1.5 \times 5.0) + (0 \times 0.1) + (0 \times 0.1)]\ 3.688 \times \sin(26.1° - 1.43°)$
$= 6.45$ kN/m

Vertical friction component of active soil load behind the structure

$P_{s\,V} = K_{ar}\ 0.5\ (G_{do}\ \gamma^*_r)\ H^2 \sin(\gamma^*_r - \omega)$
$= 0.394 \times 0.5\ (1.25 \times 20.0)\ 3.6882 \times \sin(26.1° - 1.43°)$
$= 27.97$ kN/m

Vertical line dead load (on wall stem and infill)

$P_{D\,V} = G_{dr}\ D_v$
$= 0.8 \times 6.0$
$= 4.80$ kN/m

Vertical line live load (on wall stem and infill)

$P_{L\,V} = G_{lr}\ L_v$
$= 0.0 \times 0.1$
$= 0.00$ kN/m

Vertical uplift force of ground-water displaced by the retaining structure

$P_{w\,V} = -\gamma^*_w\ [0.5\ (H_{w\ front} + H_{w\ rear}) + H_{emb}]\ W_{uc}$
$= -9.81 \times [0.5 \times (0.100 + 0.400) + 0.200] \times 2.240$
$= -9.89$ kN/m

It is assumed that the water table varies linearly from the rear of the retaining structure to the front

Total vertical force at the interface of the retaining structure and bearing pad

$P_V = P_{f\,V} + P_{f\ slope\,V} + P_{q\,V} + P_{s\,V} + P_{D\,V} + P_{L\,V} + P_{w\,V}$
$= 114.1 + 7.62 + 6.45 + 27.97 + 4.80 + 0.00 - 9.89$
$= 151.1$ kN/m

Weight of bearing pad

$P_{bp\,V} = G_{dr}\ \gamma^*_b\ H_{bp}\ (B - B_k)$
$= 0.80 \times 20.0 \times 0.270 \times (3.320 - 0.300)$
$= 13.05$ kN/m

The weight of the bearing pad has been calculated on the following basis.

- *The effective width of the bearing pad, B, with includes allowance for the spread of load from the underside of the retaining structure, down through the bearing pad.*
- *For reinforced concrete masonry cantilever gravity retaining walls, which include a key (positioned at the rear of the base), the width of the bearing pad is the total width, B, less the width of the key, B_k.*
- *The effective width of the bearing pad, B, can not exceed the actual width of the bearing pad, B_{act}.*
- *Weights and reactions outside the extent of the effective width of the bearing pad, B, are considered to balance each other and are disregarded in the calculations.*
- *Provided that the effective width of the bearing pad, B, does not extend behind the rear of the structure, the assumptions above will be valid.*

Weight of key

$P_{k\,V}$ = $G_{dr}\,\gamma^*_c\,H_3\,B_3$
= 0.80 x 25.0 x 0.270 x 0.300
= 1.62 kN/m

Vertical uplift force of ground-water displaced by the bearing pad

$P_{bp\,w\,V}$ = $-[\gamma^*_w\,H_{bp}\,B]$
= -[9.81 x 0.270 x 3.320]
= -8.79 kN/m

It is assumed that:

- *The water table varies linearly from the rear of the retaining structure to the front*
- *The volume of water is that which is displaced by the part of the bearing pad which participates in supporting the loads of the structure, ie, depth of bearing pad submerged x effective width under bearing pad, B.*

Vertical friction component of active surcharge force acting on the bearing pad

$P_{bp\,q\,V}$ = $K_{ar}\,[G_{do}\,q_d + G_{lo}\,q_l + G_{wo}\,q_w + G_{eo}\,q_e]\,H_{bp}\,\sin(\gamma^*_r)$
= 0.394 [(1.25 x 2.5) + (1.5 x 5.0) + (0 x 0.1) + (0 x 0.1)] 0.27 x sin (26.1°)
= 0.5 kN/m

Vertical friction component of active soil load acting on the bearing pad

$P_{bp\,s\,V}$ = $0.5\,K_{ar}\,(G_{dos}\,\gamma_b)\,(2\,H + H_{bp})\,H_{bp}\,\sin(\delta^*_r)$
= 0.5 x 0.394 x 1.25 x 20.0 x [(2 x 3.688) + 0.270] x 0.270 x sin (26.1°)
= 4.5 kN/m

Total vertical forces at the interface between the bearing pad and foundation

$P_{f\,V}$ = $P_V + P_{bp\,V} + P_{k\,V} + P_{bp\,w\,V} + P_{bp\,q\,V} + P_{bp\,s\,V}$
= 151.1 + 13.05 + 1.62 - 8.79 + 0.5 + 4.5
= 162.0 kN/m

Vertical Lever Arms

Vertical lever arm of horizontal surcharge load above toe

y_{qh} = 0.5 H
= 0.5 x 3.688
= 1.844 m

Vertical lever arm of horizontal soil load above toe

y_{sh} = 0.333 H
= 0.333 x 3.688
= 1.229 m

Vertical lever arm of horizontal force due to water in front of wall

y_{wf} = $0.333\,(H_{w\,front} + H_{emb})$
= 0.333 x (0.100 + 0.200)
= 0.100 m

Vertical lever arm of horizontal force due to water behind infill

y_{wb} = $0.333\,(H_{w\,rear} + H_{emb})$
= 0.333 x (0.400 + 0.200)
= 0.200 m

Vertical lever arm of dead line loads above toe

y_{Dh} = $y_{DH} + H_{emb}$
= 3.900 + 0.200
= 4.100 m

Vertical lever arm of live line loads above toe

y_{Lh} = $y_{LH} + H_{emb}$
= 3.900 + 0.200
= 4.100 m

Vertical lever arm of wind line loads above toe

y_{Wh} = $y_{WH} + H_{emb}$
= $0.5\,(H_1 + H_{barrier}) + H_{emb}$
= 0.5 x (3.000 + 1.800) + 0.200
= 2.600 m

Vertical lever arm of earthquake line loads above toe

y_{Eh} = $y_{LH} + H_{emb}$
= 3.900 + 0.200
= 4.100 m

Vertical lever arm on passive pressure in front of embedment

y_p = $0.333\,H_{emb}$
= 0.333 x 0.200
= 0.067 m

Depth of tension cracks in fissured cohesive soil
The following approach is applicable to the application of water in tension cracks in cohesive soils.

$$H_c = \frac{2\,c'}{\frac{(g\,K_{ar}\,0.5) - (G_{do}\,q_d + G_{lo}\,q_l)}{G_{do}\,g}}$$

$= 0$ m

Vertical lever arm of horizontal water in tension cracks

$y_{qh} = H_1 - 0.667\,H_c$
$= 0$ m

Horizontal Lever Arms
Horizontal lever arms may be calculated from any point, and the toe is commonly selected as the reference point. A check of overturning about the centroid of reaction will be carried out later, but at this stage in the calculations, the eccentricity is unknown.

Horizontal lever arm of thin stem
$X_{1v} = B_4 + T_1/2$
$= 0.110 + 0.190/2$
$= 0.205$ m

Horizontal lever arm of thick stem
$X_{2v} = B_4 + T_2/2$
$= 0.110 + 0.460/2$
$= 0.340$ m

Horizontal lever arm of soil above thick stem
$X_{3v} = B_4 + T_1 + (T_2 - T_1)/2$
$= 0.110 + 0.190 + (0.460 - 0.190)/2$
$= 0.435$ m

Horizontal lever arm of soil above heel
$X_{5v} = B_4 + T_2 + (B_1 - B_4 - T_2)/2$
$= 0.110 + 0.460 + (2.240 - 0.110 - 0.460)/2$
$= 1.405$ m

Horizontal lever arm of sloping soil
$x_{f\ slope\ v} = W_u + 0.667\,L' + (H_1 + H_{emb} + 0.5\,h)\tan\omega$
$= 0.3 + (0.667 \times 1.940) + [(3.000 + 0.200 + (0.5 \times 0.488)]\tan(1.43°)$
$= 1.679$ m

Horizontal lever arm for vertical surcharge load
$x_{qv} = W_u + B + 0.5\,H\tan\omega$
$= 0.300 + 1.940 + [0.5 \times 3.688 \times \tan(1.43°)]$
$= 2.286$ m

Horizontal lever arm for vertical soil load
$x_{sv} = W_u + B + 0.333\,H\tan\omega$
$= 0.300 + 1.940 + [0.333 \times 3.688 \times \tan(1.43°)]$
$= 2.271$ m

Horizontal lever arm to vertical line dead load
$x_{DV} = 0.400$ m
Nominated in design brief

Horizontal lever arm of vertical line live load
$x_{LV} = 0.400$ m
Nominated in design brief

Horizontal lever arm from toe for water uplift
$x_{fv\ wu} = 0.5\,W_{uc}$
$= 0.5 \times 2.240$
$= 1.120$ m

Sliding Resistance of Structure on Bearing Pad
Friction resistance of structure on bearing pad
$P_{bf} = P_v \tan(\phi^*_b)\,\Phi_n$
$= 151.6 \times \tan(38.6°) \times 1.0$
$= 120.8$ KN/m

The vertical load, P_v, is the sum of vertical loads that have already been factored by the relevant load factor for resisting loads, G_{drs}.

In this case, the key at the back of the footing "captures" the bearing pad material, mobilising the internal friction of the bearing pad material to resist forward sliding.

In other retaining systems (eg reinforced soils) it is assumed that the interface between the retaining structure (granular soil fill in hollow concrete facing units plus either compacted infill soil of no-fines concrete) is rough. Therefore the appropriate external friction angle is the minimum of the internal friction angles of the structure and the bearing pad.

If the retaining structure surface had been substantially smooth concrete and no key, the appropriate external friction angle would be some lesser value, approximately two thirds of the internal friction angle.

Base adhesion of structure on bearing pad
$P_{ba} = (G_{drs}\,c^*_{bv}\,W_{uc}\,\Phi_n$
$= (0.80 \times 0.09) \times 2.24 \times 1.0$
$= 0.16$ KN/m

The adhesion of a retaining structure on a bearing pad is the minimum of the adhesion (stickiness) of the interface and the cohesion of the bearing pad material. For a granular base, the cohesion

is normally zero, and the adhesion is therefore also zero. For a cement-stabilized material where the units are laid before the cement has hydrated, there may be some small value of adhesion. In this example, a small nominal value has been assumed to demonstrate the method. In practice, it is common for a designer to ignore this value.

The components of base adhesion have not already been factored by the relevant load factor for resisting loads, G_{drs} , which should be included in this formula.

Resisting passive earth pressure on structure

$P_{bp} = 0.5\ K_{pb}\ (G_{drs}\ \gamma_b)\ H_{emb}^2\ \Phi_n$
$= 0.5 \times 2.58 \times 0.80 \times 20.0 \times 0.200^2 \times 1.0$
$= 0.82$ KN/m

It is the designer's choice of whether or not to use passive resistance, giving consideration to issues of disturbance, erosion and poor compaction of the material in front of the structure. It is common practice to ignore passive resistance.

The components of passive resistance have not already been factored by the relevant load factor for resisting loads, G_{drs}, which should be included in this formula.

Total sliding resistance of facing on bearing pad

$R_b = P_{bf} + P_{ba} + P_{bp}$
$= 120.8 + 0.16 + 0.82$
$= 121.8$ kN/m

$> P_{b\,H} = 76.4$ kN/m OK

Factor against sliding $= R_b/P_{b\,H}$
$= 121.8/76.4$
$= 1.59$

Sliding Resistance of Bearing Pad on Foundation

Friction resistance of bearing pad on foundation

$P_{ff} = P_{f\,V} \tan(\phi^*_b)\ \Phi_n$
$= 162.0 \times \tan(26.1°) \times 1.0$
$= 79.6$ KN/m

The appropriate external friction angle is the lesser of the values for the bearing pad and the foundation.

Base adhesion of structure on bearing pad

$P_{fa} = (G_{drs}\ c^*_{bv}\ W_{uc}\ \Phi_n$
$= (0.80 \times 3.5) \times 2.24 \times 1.0$
$= 6.27$ KN/m

The adhesion of a bearing pad on the foundation approximates the cohesion of the foundation. In this example, a small nominal value has been assumed to demonstrate the method. In practice, it is common for a designer to ignore this value.
The components of foundation adhesion have not already been factored by the relevant load factor for resisting loads, G_{drs}, which should be included in this formula.

Resisting passive earth pressure on structure

$P_{fp} = 0.5\ K_{pb}(G_{drs}\ \gamma_b)(H_{emb} + H_{bp})^2\ \Phi_n$
$= 0.5 \times 2.58 \times 0.80 \times 20.0 \times (0.200 + 0.270)^2 \times 1.0$
$= 4.55$ KN/m

It is the designer's choice of whether or not to use passive resistance, giving consideration to issues of disturbance, erosion and poor compaction of the material in front of the structure. It is common practice to ignore passive resistance.
The components of passive resistance have not already been factored by the relevant load factor for resisting loads, G_{drs}, which should be included in this formula.

Total sliding resistance of facing on bearing pad

$R_f = P_{ff} + P_{fa} + P_{fp}$
$= 79.6 + 6.27 + 4.55$
$= 90.4$ kN/m

$> P_{f\,H} = 87.3$ kN/m OK

Factor against sliding $= R_f/P_{f\,H}$
$= 90.4/87.3$
$= 1.04$

Eccentricity of Reaction

Take moments about the toe

Overturning moment about the toe

$M_o = P_{q\,H}\,y_{qh} + P_{s\,H}\,y_{sh} + P_{w\,front}\,y_{wf} + P_{w\,rear}\,y_{wb} + P_{D\,H}\,y_{Dh} + P_{L\,H}\,y_{Lh} + P_{W\,H}\,y_{Wh} + P_{E\,H}\,y_{Eh} + P_{wc\,H}\,y_{qh}$

$= (14.0 \times 1.844) + (60.8 \times 1.229) + (-0.44 \times 0.100) + (1.77 \times 0.200) + (0.13 \times 4.100) + (0.15 \times 4.100) + (0.0 \times 2.600) + (0.0 \times 4.100) + (0.00 \times 0.0)$

$= 101.9$ kN.m/m

Restoring moment about the toe

$M_r = P_{1V}\,x_{1V} + P_{2V}\,x_{2V} + P_{3V}\,x_{3V} + P_{5V}\,x_{5V} + P_{6V}\,x_{6V} + P_{f\,slope\,V}\,x_{f\,slope\,V} + P_{q\,V}\,x_{qv} + P_{s\,V}\,x_{sv} + P_{DV}\,x_{DV} + P_{Lv}\,x_{LV} + P_{w\,V}\,x_{fv\,wu}$

$= (6.21 \times 0.205) + (8.77 \times 0.255) + (7.78 \times 0.350) + (76.15 \times 1.485) + (15.68 \times 1.120) + (7.58 \times 1.679) + (6.45 \times 2.286) + (28.0 \times 2.271) + (4.80 \times 0.400) + (0.00 \times 0.400) + (-9.89 \times 1.120)$

$= 218.6$ kNm/m

Vertical weight of the gravity structure

$P_{f\,V} = P_{1V} + P_{2V} + P_{3V} + P_{5V} + P_{6V}$

$= 6.21 + 8.77 + 7.78 + 76.15 + 15.68$

$= 114.6$ kN/m

Eccentricity of reaction (measured from toe)

$x' = (M_r - M_o)/P_v$

$= (218.6 - 101.9)/151.6$

$= 0.770$ m

$> 0.333\,W_{uc}$

$= 0.333 \times 2.240$

$= 0.746$ mm OK The reaction is in the middle third.

Eccentricity of reaction (measured from centreline)

$e = 0.5\,W_{uc} - x'$

$= (0.5 \times 2.240) - 0.770$

$= 0.350$ m

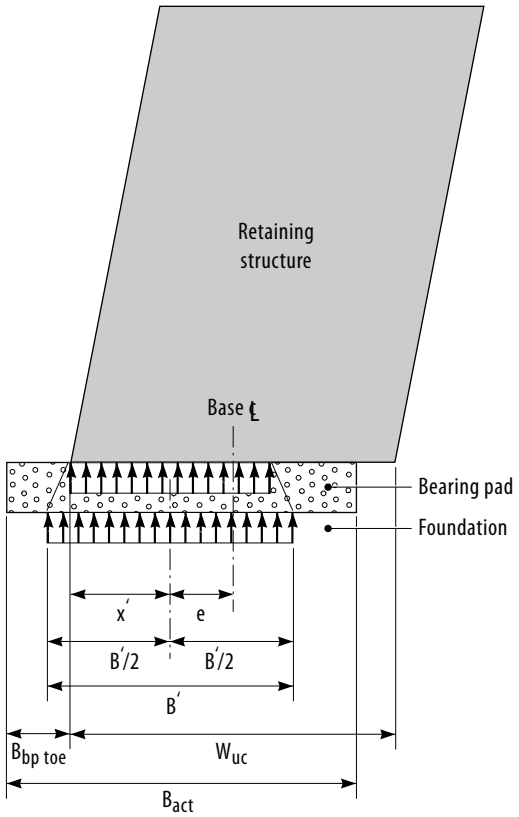


Figure B4 *Bearing Pad Details*

Bearing Capacity at the Interface between the Bearing Pad and the Foundation

The bearing capacity at the interface between the bearing pad and the foundation is determined by Terzaghi analysis, modified by Vesic factors inclined load etc.

Effective width of bearing pad

$B' = B - 2e$

$= 3.320 - (2 \times 0.350)$

$= 2.620$ m

This is the width of bearing pad into which the vertical load is distributed, giving consideration to the effect of the lateral load and the particular material, its strength and stiffness.

$N_q = e^{\pi \tan \phi^*_f} \tan^2[\pi/4 + \phi^*_f/2]$

$= e^{3.14\tan(26.1)} \tan^2[(3.14/4) + (26.1°/2)]$

$= 12.0$

$N_c = (N_q - 1) \cot \phi^*_f$

$= (12.0 - 1) \cot (26.1°)$

$= 22.5$

$N_g = 2(Nq + 1) \tan \phi^*_f$

$= 2\,(12.0 + 1) \tan (26.1°)$

$= 12.8$

Shape factors

$\xi_c = 1.0$

$\xi_q = 1.0$

$\xi_g = 1.0$

Factors for inclined load

$\xi_{qi} = [1 - P_H/(P_v + B' c^*_f \cot \phi^*_f)]^2$
$= [1 - 76.4/\{151.5 + 2.620 \times 3.5 \times \cot (26.1°)\}]^2$
$= 0.304$

$\xi_{ci} = \xi_{qi} - (1 - \xi_{qi})/(N_c \tan \phi^*_f)$
$= 0.295 - [(1 - 0.304)/(22.5 \times \tan (26.1°)]$
$= 0.241$

$\xi_{gi} = [1 - P_H/(P_v + B' c \cot \phi^*_f)]^3$
$= [1 - 76.4/\{151.5 + 2.620 \times 3.5 \times \cot (26.1°)\}]^3$
$= 0.167$

Factors for sloping bases

$\xi_{qt} = (1 - \alpha \tan \phi^*_f)^2$
$= 1.0$ for level base

$\xi_{ct} = \xi_{qt} - (1 - \xi_{qt})/(N_c \tan \phi^*_f)$
$= 1.0$ for level base

$\xi_{gt} = (1 - \alpha \tan \phi^*_f)^2$
$= 1.0$ for level base

Average bearing capacity based on factored soil properties

$q_{av} = c\, N_c\, \xi_c\, \xi_{ci}\, \xi_{ct} + \gamma\, (H_{emb} + H_{bp})\, N_q\, \xi_q\, \xi_{qi}\, \xi_{qt} + 0.5\, \gamma\, B\, N_\gamma\, \xi_\gamma\, \xi_{\gamma i}\, \xi_{\gamma t}$
$= (3.5 \times 22.5 \times 1.0 \times 0.241 \times 1.0) + (20.0 \times [0.200 + 0.270) \times 12.0 \times 1.0 \times 0.304 \times 1.0) +$
$(0.5 \times 20.0 \times 3.320 \times 12.8 \times 1.0 \times 0.167 \times 1.0)$
$= 101.1$ kPa

Bearing capacity of the foundation

$P_{v\,cap} = q_{av} B'$
$= 101.1 \times 2.620$
$= 320.1$ kN

> 161.8 kN OK

Factor of Safety against bearing failure

$F_{bearing} = P_{v\,cap}/P_v$
$= 320.1/161.8$
$= 1.98$

INTERNAL DESIGN

Masonry Properties

Block height
$h_u = 190$ mm

Mortar joint thickness
$t_j = 10$ mm

Height ratio
$h_u/t_j = 190/10$
$= 19.0$

Compressive strength factor
$k_h = 1.3$ *AS 3700 Table 3.2*

Masonry factor for face-shell-bedded concrete units
$k_m = 1.6$ *AS 3700 Table 3.1*

Mortar type
M3 (1:5 + water thickener)

Characteristic unconfined unit strength
$f'_{uc} = 15$ MPa

Characteristic masonry strength for 76-mm-high units
$f'_{mb} = k_m (f'_{uc})^{0.5}$ *AS 3700 Clause 3.3.2(a)(i)*
$= 1.6 (15.0)^{0.5}$
$= 6.20$ MPa

Characteristic unconfined compressive masonry strength
$f'_m = k_h f'_{mb}$ *AS 3700 Clause 3.3.2(a)(i)*
$= 1.3 \times 6.20$
$= 8.06$ MPa

Characteristic shear strength
$f'_{ms} = 0.35$ MPa (at interface) *AS 3700 Cl 3.3.4(d)*
$f'_{vm} = 0.35$ MPa *AS 3700 Cl 8.6.3*

Reinforcement strength
$f_{sy} = 500$ MPa *AS 3700 Table 3.7*

Design shear strength
$f_{vs} = 17.5$ MPa *AS 3700 Cl 8.6.3*

Required clear cover to steel from face shell
$c_{c.req}$ = Max (20 mm aggregate, 15 mm cover)
$= 20$ mm *AS 3700 Clause 10.7.2.5 Table 5.1*

Width of web
$b_w = 1000$ mm

Capacity reduction factor
$\phi = 0.75$ *AS 3700 Table 4.1*

Thin-Stem Strengths

Blockwork width
$T_1 = 190$ mm

Face-shell thickness
$t_{s1} = 30$ mm

Block core taper
$t_{t1} = 3$ mm

Steel reinforcement N16 bars at 400-mm centres
Diameter of reinforcement
$R_{dia\ 1} = 16$ mm

Required cover to steel centreline
$c_{req\ 1} = c_{c.req} + R_{dia\ 1}/2 + t_{t1} + t_{s1}$
$= 20 + 16/2 + 3 + 30$
$= 61$ mm

Specify cover to steel centreline
$c = 65$ mm (ie from rear face of block)
> 61 mm OK

Effective depth
$d_1 = T_1 - c_1$
$= 190 - 65$
$= 125$ mm

Cross-sectional area of reinforcement 1000

$A_{st\ 1}$ = 200 x 1000/400
= 500 mm^2/m

< 0.02 b_w d *AS 3700 Cl 8.6.3*
= 0.02 x 1000 x 125
= 2500 mm^2 OK

Cross-sectional area of shear reinforcement

$A_{sv\ 1}$ = 0 (no stirrups)

Spacing of shear reinforcement

S_1 = NA (no stirrups)

Out-of-plane shear capacity *AS 3700 Cl 8.6.3*

$\phi V_1 = \min [\phi\{f'_{vm}\ b_w\ d_1 + f_{vs}\ A_{st} + f_{sy}\ A_{sv}\ d_1\}$ or min $(S, 4\ \phi\ f'_{vm}\ b_w\ d_1)]$
= 0.75{0.35 x 1000 x 125) + (17.5 x 500) + 0} or (1000) or (4 x 0.75 x 0.35 x 1000 x 125)
= 39.4 kN/m

Design area of reinforcement

$A_{sd\ 1} = A_{st\ 1}$
= 500 mm^2/m

< (0.29) 1.3 f'_m b d_1/f'_{sy} *AS 3700 Cl 8.3.5*
= 0.29 x 1.3 x 8.06 x 1000 x 125/500
= 759 mm^2 OK

> 0.0013 b d *AS 3700 Cl 8.5*
= 0.0013 x 1000 x 125
= 162 mm^2 OK

$\phi M_1 = \phi\ f_{sy}\ A_{sd1}\ d_1[1 - 0.6\ f_{sy}\ A_{sd\ 1}\ d_1/(1.3\ f'_m\ b\ d_1)]$
= 0.75 x 500 x 500 x 125 [1 - (0.6 x 500 x 500)/(1.3 x 8.06 x 125 x 1000)]/10^6
= 20.8 kN.m/m

Thick-Stem Strengths

Blockwork width

T_2 = 460 mm

Face-shell thickness

t_{s2} = 30 mm

Block core taper

t_{t2} = 3 mm

Steel reinforcement - N20 bars at 400-mm centres
Diameter of reinforcement

$R_{dia\ 2}$ = 20 mm

Required cover to steel centreline

$c_{req\ 2} = c_{c.req} + R_{dia\ 2}/2 + t_{t1} + t_{s1}$
= 20 + 20/2 + 3 + 30
= 62 mm

Specify cover to steel centreline

c = 95 mm (ie in centre of rear block)
> 63 mm OK

Effective depth

$d_2 = T_2 - c_2$
= 460 - 95
= 365 mm

Cross-sectional area of reinforcement 1000

$A_{st\ 2}$ = 310 x 1000 / 400
= 775 mm^2/m

< 0.02 b_w d *AS 3700 Cl 8.6.3*
= 0.02 x 1000 x 365
= 7300 mm^2 OK

Cross-sectional area of shear reinforcement

$A_{sv\ 2}$ = 0 (no stirrups)

Spacing of shear reinforcement

S_2 = NA (no stirrups)

Out-of-plane shear capacity AS 3700 Cl 8.6.3

$\phi V_2 = \min [\phi\{f'_{vm}\ b_w\ d_2 + f_{vs}\ A_{st} + f_{sy}\ A_{sv}\ d_2\}$ or min $(S, 4\ \phi\ f'_{vm}\ b_w\ d_2)]$
= 0.75{0.35 x 1000 x 365) + (17.5 x 775) + 0} or (1000) or (4 x 0.75 x 0.35 x 1000 x 365)
= 106.0 kN/m

Design area of reinforcement

$A_{sd\,2} = A_{st\,2}$
$= 775\ mm^2/m$
$< (0.29)\ 1.3\ f'_m\ b\ d_2/f'_{sy}$ *AS 3700 Cl 8.3.5*
$= 0.29 \times 1.3 \times 8.06 \times 1000 \times 365/500$
$= 2218\ mm^2$ OK

$> 0.0013\ b\ d$ *AS 3700 Cl 8.5*
$= 0.0013 \times 1000 \times 365$
$= 475\ mm^2$ OK

$\phi M_2 = \phi\ f_{sy}\ A_{sd2}\ d_2[1 - 0.6\ f_{sy}\ A_{sd\,1}\ d_2/(1.3\ f'_m\ b\ d_2)]$
$= 0.75 \times 500 \times 775 \times 365\ [1 - (0.6 \times 500 \times 775)/(1.3 \times 8.06 \times 365 \times 1000)]/10^6$
$= 99.6\ kN.m/m$

Thick-stem/Thin-stem Connection

At the connection of the thick stem to the thin stem, there exists the possibility that the thin stem could shear away from the thick stem. To prevent this, use 1-N10 tie at 400-mm centres, with sufficient strength to transfer the load from the top part of the wall to the bottom part.

Reinforcement strength
$f_{sy} = 500\ MPa$

Diameter of reinforcement
$R_{tie} = 10\ mm$

Cross-sectional area of tie
$A_{tie} = (3.14 \times 102/4) \times 78.5 \times 1{,}000/400$
$= 196\ mm^2/m$

Capacity reduction factor
$\phi = 0.75$

Capacity of tie
$\phi\ V_{tie} = \phi\ f_{sy}\ A_{tie}$
$0.75 \times 500 \times 196/1{,}000$
$= 74\ kN/m$

Base Strengths

Satisfactory shear and bending moment capacity can be achieved by using the same reinforcement in the base as is required in the stem and ensuring the depth of the section of the base is greater than the thicknes of the stem, provided reinforcement limits are observed. The capacity can be checked as follows.

Base depth
$H_2 = 350\ mm$
$< 460\ mm$ (thick stem)

It is normally good practice to make the base slightly thicker than the bottom part of the stem (thick stem). In this example, this has not been achieved, and could indicate a potential problem. However, this example demonstrates that the adoption of an unusually wide thick stem (for reasons of block availability etc) should not necessarily force the adoption of an abnormally thick stem.

Steel reinforcement
N20 bars at 400-mm centres

Reinforcement strength
$f_{sy} = 500\ MPa$

Diameter of reinforcement
$R_b = 20\ mm$

Surface of member in contact with non-aggressive soil
Exposure classification
A2 *AS 3600 Table 4.3*

Concrete strength grade
$f'_c = 25\ MPa$ *AS 3600 Clause 4.4*

Characteristic flexural tensile strength
$f'_{cf} = 0.6\ (f'_c)0.5$ *AS 3600 Clause 6.1.1.3*
$= 0.6 \times 250.5$
$= 3.0\ MPa$

Footing will be cast against ground without membrane.
Required clear cover to steel from face of concrete
$c_{c.req} = 30 + 20$ *AS 3600 Tables 4.10.3.2, 4.10.3.3*
$= 50\ mm$

Required cover to steel centreline
$c_{req} = c_{c.req} + R_b/2$
$= 50 + 20/2$
$= 60\ mm$

Specified cover to steel centreline
$c = 80\ mm$ (Allows for some variation in placing)

$> 60\ mm$ OK

Effective depth
$d = H_2 - c$
$= 350 - 80$
$= 270\ mm$

Capacity-reduction factor for bending
$\phi_b = 0.8$ *AS 3600 Table 2.3*

Capacity-reduction factor for shear
$\phi_v = 0.7$ *AS 3600 Table 2.3*

Area of tensile steel
$A_{st} = 310 \times 1000/400$
$= 775\ mm^2/m$

Tensile steel ratio
$A_{st}/bd = 775/(1{,}000 \times 270)$
$= 0.00287$
$\geq 0.22\ (D/d)^2\ f'_{cf}/f_{sy}$
$= 0.22\ (350/430)^2\ 3/500$
$= 0.000875$ OK

Shear reinforcement

$A_{sv} = 0$

Shear coefficients

$\beta_1 = 1.1(1.6 - d_o/1{,}000)$ *AS 3600 Clause 8.2.7.1*

$= 1.1(1.6 - 270/1{,}000)$

$= 1.46$

≥ 1.1 OK

$\beta_2 = 1.0$ *AS 3600 Clause 8.2.7.1*

$\beta_3 = 1.0$ *AS 3600 Clause 8.2.7.1*

Ultimate shear strength excluding reinforcement

$V_{uc} = \beta_1 \beta_2 \beta_3 b_v d_o [A_{st} f'_c / b_v d_o]^{0.333}$ *AS 3600 Clause 8.2.7.1*

$= 1.46 \times 1.0 \times 1.0 \times 1000 \times 270 \times [775 \times 25 / (1{,}000 \times 270)]^{0.333}$

$= 162$ kN

$V_{us} = 0$ *AS 3600 Clause 8.2.10*

Shear capacity

$\phi V_u = \phi(V_{uc} + V_{us})$ *AS 3600 Clause 8.2.2*

$= 0.7(162 + 0)$

$= 113$ kN/m

Ratio of depth of assumed compression block

$\gamma = 0.85 - 0.007(f'_c - 28)$ *AS 3600 Clause 8.1.2.2*

$= 0.85 - 0.007(25 - 28)$

$= 0.87$

> 0.65 OK Use moment capacity formula based on 0.85

Bending ratio

$q = A_{st} f_{sy} / b d f'_c$ *AS 3600 Clause 8.1.2.2*

$= 775 \times 500 / (1000 \times 270 \times 25)$

$= 0.0574$

Bending capacity *RC Design Handbook Clause 4.2.2**

$\phi M = \phi_b f'_c q(1 - q/1.7) b d^2$

$= 0.8 \times 25 \times 0.0574(1 - 0.0574/1.7) \times 1{,}000 \times 270^2 / 10^6$

$= 80.8$ kNm/m

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Thin Stem Design

Height of thin stem

$H7 = 1.8$ m

Horizontal active force due to surcharge

$P_{q\,H\,thin} = K_{ar}[G_{do}\, q_d + G_{lo}\, q_l + G_{wo}\, q_w + G_{eo}\, q_e) H_7 \cos(\delta^*_i - \omega)$

$= 0.362[(1.25 \times 2.5) + (1.5 \times 5.0) + (0 \times 0.1) + (0 \times 0.1)] 1.8 \times \cos(19.4° - 1.43°)$

$= 6.58$ kN/m

Horizontal active force due to soil

$P_{s\,H\,thin} = K_{ar}\, 0.5\, (G_{do}\, \gamma^*_i) H_7^2 \cos(\delta^*_i - \omega)$

$= 0.362 \times 0.5\, (1.25 \times 20.0)\, 1.82 \times \cos(19.4° - 1.43°)$

$= 13.91$ kN/m

Horizontal force due to dead line load

$P_{D\,H\,thin} = G_{do}\, D_H$

$= 1.25 \times 0.1$

$= 0.13$ kN/m

Horizontal force due to live line load at top

$P_{L\,H\,thin} = G_{lo}\, L_H$

$= 1.5 \times 0.1$

$= 0.15$ kN/m

Horizontal force due to wind line load at top

$P_{W\,H} = G_{wo}\, W_H$

$= 0 \times 4.3$

$= 0.0$ kN/m

Horizontal force due to earthquake line load at top

$P_{E\,H} = G_{eo}\, E_H$

$= 0 \times 0.6$

$= 0.0$ kN/m

Total horizontal forces on thin stem

$P_{H\,thin} = P_{q\,H\,thin} + P_{s\,H\,thin} + P_{D\,H\,thin} + P_{L\,H\,thin} + P_{W\,H\,thin} + P_{E\,H\,thin}$

$= 6.58 + 13.91 + 0.13 + 0.15 + 0.0 + 0.0$

$= 20.8$ kN/m

< 39.4 kN/m (reinforced blockwork) OK

< 74.0 kN/m (tie to thick stem) OK

Vertical lever arm of horizontal active force due to surcharge

$\gamma_{q\ H\ thin}$ = 0.5 H_7
= 0.5 x 1.800
= 0.900 m

Vertical lever arm of horizontal active force due to soil

$\gamma_{s\ H\ thin}$ = 0.333 H_7
= 0.333 x 1.800
= 0.600 m

Vertical lever arm of horizontal force due to dead line load

$\gamma_{D\ H\ thin}$ = γ_{DH} – H_1 + H_7
= 3.900 – 3.000 +1.800
= 2.700 m

Vertical lever arm of horizontal force due to live line load at top

$\gamma_{L\ H\ thin}$ = γ_{LH} – H_1 + H_7
= 3.900 – 3.000 +1.800
= 2.700 m

Vertical lever arm of horizontal force due to wind line load at top

$\gamma_{W\ H\ thin}$ = γ_{WH} – H_1 + H_7
= 2.600 – 3.000 +1.800
= 1.400 m

Vertical lever arm of horizontal force due to earthquake line load at top

$\gamma_{E\ H\ thin}$ = γ_{DH} – H_1 + H_7
= 3.900 – 3.000 +1.800
= 2.700 m

Maximum bending moment at base of thin stem

$M^*_{H\ thin}$ = $P_{q\ H\ thin}\ \gamma_{q\ H\ thin}$ + $P_{s\ H\ thin}\ \gamma_{s\ H\ thin}$ + $P_{D\ H\ thin}\ \gamma_{D\ H\ thin}$ + $P_{L\ H\ thin}\ \gamma_{L\ H\ thin}$ + $P_{W\ H\ thin}\ \gamma_{W\ H\ thin}$ + $P_{E\ H\ thin}\ \gamma_{E\ H\ thin}$

= (6.58 x 0.900) + (13.91 x 0.600) + (0.13 x 2.700) + (0.15 x 2.700) + (0 x 1.400) + (0 x 2.700)

= 15.0 kN.m/m

< 20.8 kN.m/m OK

Thick Stem Design

Height of stem (including hob)

H_8 = 2.85 m

Horizontal active force due to surcharge

$P_{q\ H\ thick}$ = K_{ar} ($G_{do}\ q_d$ + $G_{lo}\ q_l$ + $G_{wo}\ q_w$ + $G_{eo}\ q_e$) H_8 cos (δ^*_i – ω)
= 0.362 [(1.25 x 2.5) + (1.5 x 5.0) + (0 x 0.1) + (0 x 0.1)] 2.850 x cos (19.4° – 1.43°)
= 10.43 kN/m

Horizontal active force due to soil

$P_{s\ H\ thick}$ = K_{ar} 0.5 ($G_{do}\ \gamma^*_i$) H_8^2 cos (δ^*_i – ω)
= 0.362 x 0.5 (1.25 x 20.0) 2.850^2 x cos (19.4° – 1.43°)
= 34.96 kN/m

Horizontal force due to dead line load

$P_{D\ H\ thick}$ = $G_{do}\ D_H$
= 1.25 x 0.1
= 0.13 kN/m

Horizontal force due to live line load at top

$P_{L\ H\ thick}$ = $G_{lo}\ L_H$
= 1. 5 x 0.1
= 0.15 kN/m

Horizontal force due to wind line load at top

$P_{W\ H\ thick}$ = $G_{wo}\ W_H$
= 0 x 4.3
= 0.0 kN/m

Horizontal force due to earthquake line load at top

$P_{E\ H\ thick}$ = $G_{eo}\ E_H$
= 0 x 0.6
= 0.0 kN/m

Total horizontal forces on thick stem

$P_{H\ thick}$ = $P_{q\ H\ thick}$ + $P_{s\ H\ thick}$ + $P_{D\ H\ thick}$ + $P_{L\ H\ thick}$ + $P_{W\ H\ thick}$ + $P_{E\ H\ thick}$
= 10.43 + 34.96 + 0.13 + 0.15 + 0.0 + 0.0
= 45.6 kN/m

< 106.0 kN/m (reinforced blockwork) OK

Vertical lever arm of horizontal active force due to surcharge

$\gamma_{q\ H\ thick} = 0.5\ H_8$
$= 0.5 \times 2.850$
$= 1.425$ m

Vertical lever arm of horizontal active force due to soil

$\gamma_{s\ H\ thick} = 0.333\ H_8$
$= 0.333 \times 2.850$
$= 0.949$ m

Vertical lever arm of horizontal force due to dead line load

$\gamma_{D\ H\ thick} = \gamma_{DH} - H_1 + H_8$
$= 3.900 - 3.000 + 2.850$
$= 3.750$ m

Vertical lever arm of horizontal force due to live line load at top

$\gamma_{L\ H\ thick} = \gamma_{LH} - H_1 + H_8$
$= 3.900 - 3.000 + 2.850$
$= 3.750$ m

Vertical lever arm of horizontal force due to wind line load at top

$\gamma_{W\ H\ thick} = \gamma_{WH} - H_1 + H_8$
$= 2.600 - 3.000 + 2.850$
$= 2.450$ m

Vertical lever arm of horizontal force due to earthquake line load at top

$\gamma_{E\ H\ thick} = \gamma_{DH} - H_1 + H_8$
$= 3.900 - 3.000 + 2.850$
$= 3.750$ m

Maximum bending moment at base of thick stem

$M^*_{thick} = P_{q\ H\ thick}\ \gamma_{q\ H\ thick} + P_{s\ H\ thick}\ \gamma_{s\ H\ thick} + P_{D\ H\ thick}\ \gamma_{D\ H\ thick} + P_{L\ H\ thick}\ \gamma_{L\ H\ thick} + P_{W\ H\ thick}\ \gamma_{W\ H\ thick} + P_{E\ H\ thick}\ \gamma_{E\ H\ thick}$

$= (10.42 \times 1.425) + (34.96 \times 0.949) + (0.13 \times 3.750) + (0.15 \times 3.750) + (0 \times 2.450) + (0 \times 3.750)$
$= 49.0$ kN.m/m

< 99.6 kN.m/m OK

Base Design

Upper-bound estimates of the shear force and bending moments in the heel of the base may be calculated as follows.

Upper-bound bending moment

$M^*_{base} = M^*_{thick}$
$= 49.0$ kNm/m

< 80.8 kNm/m OK

Upper-bound shear force

$V^*_{base} = M^*_{base}/(0.5\ B_1)$
$= 49.0/(0.5 \times 2.240)$
$= 43.8$ kN/m

< 113 kN/m OK

■ END

APPENDIX C – ANALYSIS OF COHESIVE SOILS

Soil Properties

The stability of an embankment is influenced by loading, ground water and soil properties. The most common soil properties used for design are:

- Density
- External friction
- Internal friction
- Cohesion.

The two common properties representing soil "strength" are internal friction and cohesion.

- A broad description of "internal friction" of a soil is its resistance to rupture, which is proportional to an applied external pressure. It is expressed as an angle, the tangent of which gives the increase in strength relative to a corresponding increase in applied pressure.
- "Cohesion" results for several diverse factors, but is a taken in this Guide to include the combined effect of all properties that resist soil rupture at zero internal friction.

Typical Soils

Most soils include both internal friction and cohesion, but in varying proportions.

- Sands, gravels and the like, which have low cohesion or no cohesion, are described as "cohesionless". Retaining structures in such soils are normally designed assuming cohesion of zero.
- Clays, silts and the like, which have low internal friction and substantial cohesion, are generally described as "cohesive".

Table C1, from AS 4678, describes the internal friction angle and cohesion for a range of typical soils.

Foundation Sliding Resistance and Bearing Capacity

The sliding resistance, applied by a foundation soil to a structure, results from a combination of external friction (closely related to internal friction), cohesion and (in some cases) passive resistance. The bearing capacity of a foundation soil results from a combination of internal friction, density and cohesion. In this Guide, cohesion is considered for both sliding resistance and bearing capacity, although its contribution has been capped at 10 kPa. This is to maintain consistency with AS 4678 Table D4 (see **Table C1**).

Table C1 *Soil Classification and their Properties* [After AS 4678]

Soil group	Typical soils in group	Soil parameters	
		Cohesion (kPa)	Internal friction (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

Horizontal Forces due to Retained Soil

- The Coulomb formula (used for the determination of lateral soil loads in the **Appendix A** *Design Tables* and in the **Appendix B** *Design Example*) does not consider cohesion. This is most appropriate for cohesionless soils, such as sands, gravels and the like.
- The Coulomb formula may also be used to determine lateral soil loads exerted on retaining walls by cohesive soils, such as clay, silt and the like, provided a sensible value for internal friction is assumed. (See further comment below)
- Alternatively, there are other approaches that could be used to account for cohesion, including Rankine-Bell Analysis and General Wedge Analysis. This Guide does not seek to differentiate between these methods, or to comment on their relative reliabilities. Caution is strongly recommended if a designer should choose to use either of the methods that consider cohesion.

Problems Associated with Design Based on Cohesion

There are practical limitations in respect of the use of cohesion, including its unpredictability, particularly when there is groundwater present or when water can fill tension cracks in fissured clay. Extreme caution should be exercised by the design engineer in these circumstances. Notwithstanding these limitations, it is instructive to consider the effect of cohesion in the case of relatively low retaining walls in some soils. If one describes the soil in an embankment in terms of both friction and cohesion (either based on test results and/or observation), and then ignores the cohesion component, the performance of the embankment will probably be underestimated.

Selection of the Appropriate Soil Properties for Design

Experience and desk research have shown that the selection of appropriate soil properties is critical to sensible design, particularly in the case of cohesive soils. Cohesion is often taken as the intercept on the vertical axis of a linear extrapolation of the plot of shear strength at a limited range of normal stress (**Figure C1**).

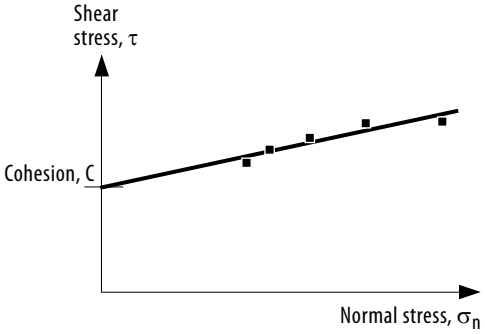

Figure C1 *Method for Determining Cohesion*

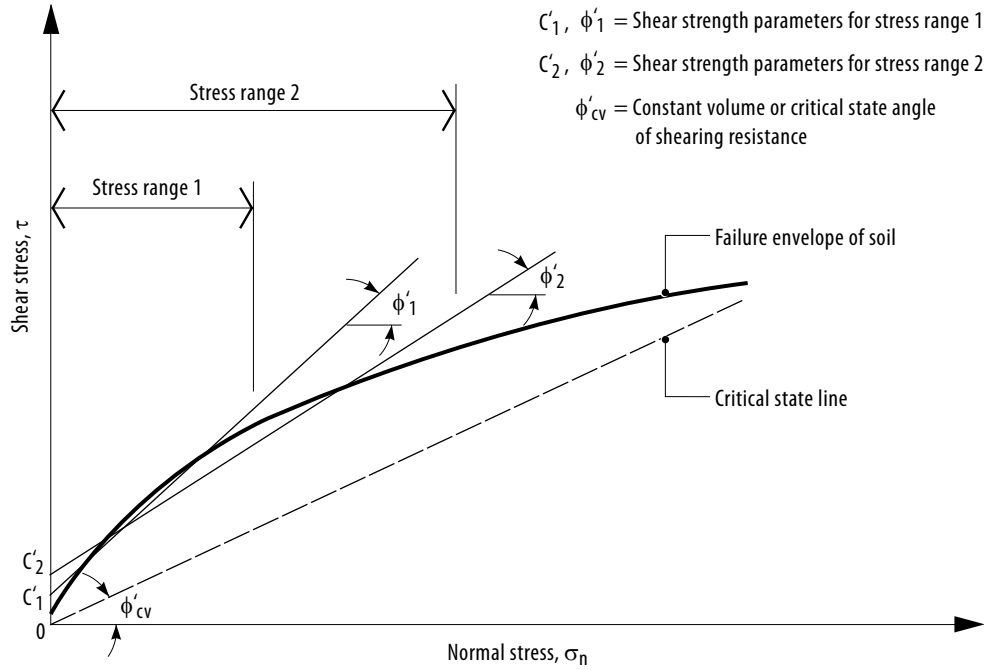

Figure C2 *Effect of Non-linear Soil Failure Envelope* [After Hong Kong Geoguide]

Having been so determined, the cohesion is often then assumed to be zero, and the internal friction angle is used alone in the design process. However, if the relationship is not linear, then the value of internal friction angle so determined would be incorrect. Caution should be exercised when making assumptions about the shear strength at low levels of normal stress. This point is demonstrated by the following diagram (**Figure C2**), reproduced from the *Hong Kong Geoguide*, in which the effective friction angle at low normal stresses (low retaining walls) is shown to be considerably higher than that at high normal stresses (high retaining walls).

Limitations on the use of Cohesion in Determining Lateral Loads

This Guide does not consider cohesion in determining lateral loads, as would be the case if the Rankine-Bell method, General Wedge theory or similar were used. However, if a designer does opt to consider cohesion, the following limitations (adapted from CMAA MA 53 Appendix D) should be applied.

- All retaining walls shall be designed to AS 4678 (Including Amendment 1).
- All retaining walls shall comply with AS 4678 Structure Classification A. The design shall be applicable for for a maximum imposed load of 2.5 kPa. If imposed loads greater than 2.5 kPa are expected, the design shall not be appropriate.
- Retaining soil heights shall be within the range 800 mm to 1200 mm.
- All retaining walls shall have level backfill. If the backfill has a slope greater than 1 in 8, the design shall not be applicable.
- The design shall be only applicable to retaining walls that incorporate an impermeable surface membrane and drainage system, such that there can be no ingress of any water into the soil behind the retaining wall. Structures that do not incorporate an impermeable surface membrane and drainage system, such that there can be no ingress of any water into the soil behind the retaining wall, are deemed to be outside the scope of the design.
- Retained soil shall have a Plasticity Index, PI, less than 20.
- The design shall be applicable to cuts in insitu soils. The design shall not be applicable to cohesive fill.
- The design shall be based on a 0.8 factor on the vertical component of soil friction, for both permanent and imposed soil and surcharge loads.

APPENDIX D – SITE INVESTIGATION

SITE INVESTIGATION

Date: .....

Report prepared by: .....

Client: .....

Project: .....

Location: .....

Use for which retaining wall is intended: .....

Proximity of other structures and loads to the face of the retaining wall:

	Structure or load	*Distance (m)*
Distance of live loads from top of wall		
Distance of dead loads from top of wall		
Distance of other structures from base of wall		

Structure classification: .....

For guidance refer AS 4678, Table 1.1

Structure Classification	*Examples*
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

Required design life: .....

For guidance refer AS 4678, Table 3.1

Type of Structure	*Design life (years)*
Temporary site works	5
Mine structures	10
Industrial structures	30
River and marine structures	60
Residential dwellings	60
Minor public works	90
Major public works	120

Required wall type: .....

Exposed height of retaining wall stem: ..... m

Slope of wall: ..... 1 horizontal in ..... vertical

Slope of backfill: ..... 1 vertical in ..... horizontal

Specified surcharge loading (if any) or other loads: ..... kPa

Soil Properties

Soil	Density (kg/m³)	Effective internal angle of friction (°)	Cohesion (kPa)	Soil type*
Insitu foundation				
Imported foundation material				
Insitu retained soil				
Infill soil				

* Please indicate the appropriate type(s) and add any other notes.

Hard rock, sandstone, gravel, sand, silty sand, clayey sand, stiff clay, weak clay, other

Are soil strength tests required? *(yes/no)* .....

Is there ground water seepage present? **Now** *(yes/no)* ..... **After heavy rain** *(yes/no)* .....

If yes, how much? .....

Is it practical to install subsurface drainage *(yes/no)* ..... **and surface drainage** *(yes/no)?* .....

How will the drainage system affect the site? .....

.....

What is the effect of excavation or filling? .....

.....

Are there obvious global stability problems? *(yes/no)* .....

What is the effect of ground movement? .....

.....

General description of site topography
(Sketch, site plan, and photographs where possible to be attached).

.....

.....

.....

.....

APPENDIX E – CONSTRUCTION SPECIFICATION

SUPERVISION

The Contractor shall ensure that the work is performed and directly supervised by appropriately-experienced personnel.

QUALITY ASSURANCE

Suppliers and contractors shall provide assurance of the quality of all goods, materials and services to be provided. The following are deemed to meet this requirement:

- a quality assurance system complying with AS/NZS ISO 9001, or
- a quality control system approved by the Builder.

BUILDING REGULATIONS AND STANDARDS

All materials and construction shall comply with the most recent version of:

- the relevant parts of the Building Regulations;
- the Standards referred to therein;
- other Standards nominated in this specification; and
- other relevant Regulations.

Relevant Standards

AS 4678 *Earth retaining structures*

AS 2758.1 *Aggregates and rock for engineering purposes - Concrete aggregates*

AS 3600 *Concrete Structures*

AS 3700 *Masonry structures*

AS 3798 *Guidelines on earthworks for commercial and residential developments*

AS/NZS 4671 *Steel reinforcing materials*

AS 3972 *Portland and blended cements*

AS 1672.1 *Limes and limestone - Limes for building*

AS 4455.1 *Masonry units*

AS 2001.2.3.1 *Methods of test for textiles - Determination of maximum force and elongation at maximum force using the strip method*

AS 3706.2 *Geotextiles - Methods of test - Determination of tensile properties – Wide strip method*

AS 3706.3 *Geotextiles - Methods of test - Determination of tearing strength - Trapezoidal method*

AS 3706.4 *Geotextiles - Methods of test - Determination of burst strength - California bearing ratio (CBR) - Plunger method*

AS 3706.7 *Geotextiles - Methods of test - Determination of pore size distribution - Dry sieving method*

AS 3706.9 *Geotextiles - Methods of test - Determination of permittivity, permeability and flow rate*

MATERIALS

Geocomposites

Geocomposites shall comply with the Drawings, Building Regulations and relevant Standard (AS 3706). Unless stated otherwise, geocomposites shall exhibit:

- Sufficient permeability to maximise the amount of water passing through the outer surface
- Sufficient void size, under load, to convey the required water flow to the stormwater system.
- Pore size small enough to block fine material from entering the drainage system, without compromising the permeability requirements
- Strength, toughness and abrasion resistance to resist damage during construction and service

Geocomposites shall comply with the specification "*Geotextiles for Filters and Drains*".

Notes:

Permeability, Permittivity and Flow

The permeability test measures the water flow through a sample of the subject geotextile under constant head

- *Thickness of the sample* t
- *Head during test* $h = 100$ mm
- *Flow rate under 100 mm of head* Q_{100}
- *Permittivity* $\psi = Q_{100}/h$
- *Permeability* $k = \psi t$

Flow may be unidirectional (only perpendicular to the geotextile) or may be multidirectional. This specification deals only with unidirectional flow and does not deal with problem soils. Several authors (Calhoun, Ogink, McKeand, Giroud, Schober and Teinol) provide recommendations for specifying the permeability, k, of a filter, ranging from 0.1 to 10 times the permeability of the soil.

This will depend in part, on whether the soil is particularly coarse or particularly fine. In this specification, a value permeability, k, of the geotextile not less than 1 times the permeability of the soil has been adopted. In the case of important structures, or those where the permeability of the geotextile is critical, more precise methods and different specifications should be employed. This specification is not suitable for fine clay, and may not match the flow of water through coarse sands and gravels. The designer must consider variations to this specification in these circumstances.

Opening Size

Several authors provide recommendations for determining the maximum opening size of a filter. To prevent piping (drawing of fine soil particles into the filter), Calhoun recommends that the O_{95} of the geotextile filter should be not more than the D_{15} of coarse soils and not more than 200 µm of cohesive soils. The general limits adopted in this specification are as follows:

- *For cohesive soil (D_{20} soil ≤ 75 µm), O_{95} geotextile should be between 150 µm and 250 µm.*
- *For non-cohesive soil (D_{20} soil > 75 µm), O_{95} geotextile should be between 80 µm and 250 µm.*

To minimize clogging of a geotextile filter, the O_{95} opening size should be not less than 3 times the D_{15} of the soil.

An alternative specification to minimize clogging is to require the Austroads G Rating (if available) to be less than 3.

Geotextiles for Filters and Drains

Geotextiles for filters and drains shall comply with the Drawings, Building Regulations and relevant Standard (AS 3706). Unless stated otherwise, geotextiles for filters and drains shall exhibit:

- Sufficient permeability to maximise the amount of water passing through the outer surface
- Sufficient void size, under load, to convey the required water flow to the stormwater system.
- Pore size small enough to block fine material from entering the drainage system, without compromising the permeability requirements
- Strength, toughness and abrasion resistance to resist damage during construction and service.

Geocomposites shall comply with the specification "*Geotextiles for Filters and Drains*".

Function	Filter and drainage	
Typical location	Drain soil behind retaining walls and structures	
Protection to geotextile	The geotextile shall be protected against tear or puncture. Note 2	
Soil Type[Note 1]	Cohesive and other fine grained soils such as silts and some clays[Note 3]	Cohesionless soils such as some sands[Note 3]
Where required by the Engineer: Minimum Wide Strip Tensile Strength shall be as high as practical, but not less than[Note 2]...	7.5 kN/m	7.5 kN/m
Minimum Trapezoidal Tear Strength shall be as high as practical, but not less than[Note 2]...	210 N	210 N
Where required by the Engineer: Minimum CBR Burst Strength shall be as high as practical, but not less than[Note 2]...	1,500 N	1,500 N
Pore Size O_{95} by dry sieving, shall be in the range...	150 µm to 250 µm	80 µm to 250 µm
Permittivity, shall be as high as practical, but not less than...	2.0 sec^{-1}	0.7 sec^{-1}
Flow Rate under 100 mm Head shall be as high as practical, but not less than...	100 $l/m^2/sec$	70 $l/m^2/sec$
Coefficient of Permeability shall be as high as practical, but not less than[Note 3]...	0.00001 m/sec (1 x 10^{-5} m/sec)	0.003 m/sec (3 x 10^{-4} m/sec)

Notes:

1. This specification does not apply to "problem soils", defined as exhibiting one or more of the following:
   - Silty soils with hydraulic gradients greater than 3
   - Widely-graded or gap-graded particle size distribution
   - Dispersive clays and silts
   - Uniform silts and sands with a coefficient of uniformity under 3.
2. The geotextile shall be protected against tear or puncture by either:
   - Avoiding fill with sharp angular aggregate, heavy compaction (over 95% standard) and fill depths over 3.0 m, or
   - Providing a protective layer of drainage aggregate not less than 50 mm thick.

   If these criteria are not met, the specified strength properties must be at least doubled.
3. In this specification, permeability, k, of the geotextile not less than 1 times the permeability of the soil has been adopted. In the case of important structures, or those where the permeability of the geotextile is critical, more precise methods and different specifications should be employed. This specification is not suitable for fine clay, and may not match the flow of water through coarse sands and gravels. The designer must consider variations to this specification in these circumstances.

Drainage Fill

Drainage fill material shall comply with the Drawings, Building Regulations and relevant Standard (AS 2758.1). Unless stated otherwise, drainage fill material shall be GP (poorly graded gravel) single-sized gravel of nominal size 10 mm to 20 mm complying with the following specification.

Sieve (mm)	Percent Passing
26.5	100
19.0	70 - 100
13.2	0 - 100
9.52	0 – 0

Concrete

Concrete shall comply with the Drawings, Building Regulations and relevant Standard (AS 3600). Unless stated otherwise, properties shall be not less than:

- Characteristic compressive strength of 20 MPa (Strength grade N20)
- Maximum aggregate size of 20 mm
- Of sufficient slump to facilitate the nominated means of placement
  Note: Superplasticied cohesive concrete with a slump of not less than 200 mm and a spread of 400 to 600 mm (using a slump cone) is considered suitable.
- Subject to plant control testing.

Reinforcement
Reinforcement shall comply with the Drawings, Building Regulations and relevant Standard (AS/NZS 4671). Unless stated otherwise, properties shall be not less than:

- Deformed bars - 500 MPa, normal ductility (N)
- Square fabric, rectangular fabric and trench mesh - 500 MPa, low (L) or normal (N) ductility ribbed wires
- Fitments - 500 MPa, low (L) or normal (N) ductility ribbed wires
- Round bar (eg R250 N10 for dowels) - 250 MPa round.

Bar Chairs
Bar chairs shall comply with the Drawings, Building Regulations and relevant Standard. Unless stated otherwise, properties shall such that:

- Reinforcement is positioned in the top half of the concrete slab
- Reinforcement in footings has 40 mm in concrete in contact with unprotected ground and 30 mm to a sealed vapour barrier.

Formwork
Formwork shall comply with the Drawings, Building Regulations and relevant Standard (AS 3610).

Curing Compounds
Curing compounds shall comply with the Drawings, Building Regulations and relevant Standards. Unless stated otherwise, curing compounds shall be hydrocarbon, solvent-based acrylic, water-based acrylic or wax-based acrylic. Wax-based compounds shall not be used in areas requiring the subsequent application of curing adhesives.

Joint Material
Joint material shall comply with the Drawings, Building Regulations and relevant Standard (AS 4678). Unless stated otherwise:

- Backing rod for control joints, expansion joints and articulation joints shall be expanded polystyrene tube or bead or, rigid steel backing profile with closed cell foam adhered to the metal profile face.
- Joint sealant shall be gun-grade multi-purpose polyurethane sealant.

Expansion Joints for Continuous Pours
Expansion joints for continuous pours shall comply with the Drawings, Building Regulations and relevant Standard (AS 4678). Unless stated otherwise, expansion joints in continuous pour applications shall provide a full depth straight joint and a purpose built dowelling system to provide positive load transfer across the finished slab.

Concrete Jointing Accessories
Concrete jointing accessories shall comply with the Drawings, Building Regulations and relevant Standard (AS 4678). Unless stated otherwise, concrete jointing accessories shall have appropriate properties to ensure they fulfil their intended function and can be accurately installed.

- Dowel Cradles shall provide accurate horizontal and vertical alignment of dowels.
- Crack Inducers shall provide an adequate crack to relieve contraction stresses.
- Rebate Moulds shall be constructed of a rigid PVC material and form a true square or rectangular rebate.
- Dowel Sleeves shall include provision for longitudinal expansion in the ends of all sleeves, stiffening ribs to minimise distortion, end clips to ensure correct alignment during pour and end closures to prevent entering of slurry.
- Expansion Caps shall fit a variety of dowel sizes and provide internal compression pins for longitudinal expansion.
- Permanent Flexible Plastic Capping shall be UV-treated PVC material and provide a bevelled edge to the joint.
- Removable Capping shall be PVC material and provide a bevelled edge to the joint.
- Foam Filler compression strips shall be closed-cell polyethylene foam.
- Key Joint Joiners shall provide accurate alignment of key joints in both horizontal and vertical directions without interrupting the capping line.

Concrete Blocks for Reinforced Masonry Applications
Concrete blocks for reinforced masonry applications shall comply with the Drawings, Building Regulations and relevant Standard (AS/NZS 4455.1). Unless stated otherwise, properties shall be not less than:

- Dimensional category DW4
- Salt attack resistance grade shall be:

  General Purpose except as listed below for Exposure Grade where the masonry is:

  - subject to saline wetting and drying; or
  - in aggressive soils; or
  - in a severe marine environment; or
  - subject to saline or contaminated water, including tidal spash zones; or
  - in especially aggressive environments. e.g. subject to attack by corrosive liquids or gasses, or within 1 km of industry in which chemical pollutants are produced.
- Minimum characteristic compressive strength shall be as nominated by the engineer and not less than 15 MPa. The required strength depends on the the particular application. Refer to the manufacturer's design literature for guidance.

- Dimensions and core configuration shall be such that:
  - If units are intended to incorporate both horizontal and vertical reinforcement and are not protected both sides by a waterproof membrane, they shall be:
    - "H" or "Double U" configuration with appropriate web rebates for horizontal reinforcement; or
    - if flush-ended, have web rebates not less than 35 mm deep and be constructed such that all horizontal reinformcement has at least 30 mm cover then units are laid with the rebates coinciding
  - Units may be fully grouted and may be reinforced both vertically and horizontally;
  - Grout must flow easily around and enclose the reinforcement in all cores; and
  - Cover is consistent with the requirements for durability, strength and fire resistance as appropriate.
- Mean Coefficient of Residual Drying Contraction shall be not more than 0.6 mm/m.
- If intended for face applications and exposed to the weather:
  - Permeability shall be not more than 2 mm/minute
  - Efflorescence Potential shall be Nil or Slight
  - Colour and texture shall be within an agreed range.

Definitions

Dimensional Category DW4 - For a sample of 20 units, the standard deviation of work sizes shall be not more than 2 mm, and the difference between the mean and the work size shall be not more than 3 mm. For split faces, the dimensional deviations shall not apply to the width of the unit, provided the average width is not less than 90% of the work size.

General Purpose Salt Attack Resistance Grade - Performance such that it is possible to demonstrate that the product has a history of surviving under non-saline environmental conditions similar to those existing at the site considered, but not expected to meet the mass loss criterion for Exposure Grade Salt Attack Resistance Grade.

Exposure Grade Salt Attack Resistance Grade - Performance such that it is possible to demonstrate that the product has a history of surviving under saline environmental conditions similar to those existing at the site considered; and less than 0.2 grams mass loss in 40 cycles in AS/NZS 4456.10, Method B test.

Cement

Cement shall be Type GP portland cement or GB blended cement complying with the relevant Standard (AS 3972).

Lime

Lime shall be hydrated building lime complying with complying with the relevant Standard (AS 1672).

Water Thickener

Water thickener shall be methyl-cellulose based.

Sand

Sand shall be well-graded and free from salts, vegetable matter and impurities. Sand shall not contain more than 10% of the material passing the 75 micron sieve. Sand within the following grading limits complies with this requirement and is deemed suitable for concrete masonry.

Sieve	Percent Passing
4.76 mm	100
2.36 mm	95–100
1.18 mm	60–100
600 µm	30–100
300 µm	10–50
150 µm	0–10
75 µm	0–4

Joint Material

Joint material shall comply with the Drawings, Building Regulations and relevant Standard (AS 3700). Unless stated otherwise:

- Backing rod for control joints, expansion joints and articulation joints shall be expanded polystyrene tube or bead or, rigid steel backing profile with closed-cell foam adhered to the metal profile face.
- Joint sealant shall be gun-grade multi-purpose polyurethane sealant.
- Control joints and articulation joints shall incorporate de-bonding tape.

Concrete Grout

Concrete grout shall comply with the Drawings, Building Regulations and relevant Standard (AS 3700). Unless stated otherwise, properties shall be:

- a minimum portland cement content of 300 kg/cubic metre;
- a maximum aggregate size of 10 mm;
- sufficient slump to completely fill the cores; and
- a minimum compressive cylinder strength of 20 MPa.

Surface Sealing Material

The material used to seal the surface of the fill shall be compacted clay.

Alternatively, a 0.2 mm thick PVC membrane or a needle-punched bentonite liner overlaid by at least 150 mm of bulk fill material may be used in lieu of the clay.

Bulk Fill Material

Bulk fill material shall be uniform and of maximum particle size of 100 mm.

CONSTRUCTION

Safety and Protection of Existing Structures

All excavations shall be carried out in a safe manner in accordance with the relevant regulations, to prevent collapse that may endanger life or property. Before major excavation and shoring is undertaken, a survey of cracks in adjacent building shall be undertaken and recorded. In the absence of regulations to the contrary, the following may be applied where

- Excavation is performed and remains open only in dry weather,
- There is no significant ground water seepage,
- The excavation remains open for no longer than two weeks,
- The back slope of the natural ground does not exceed 1 vertical in 6 horizontal,
- Bedding planes do not slope towards the cut, and
- There are no structures founded within a zone of influence defined by a line from the toe of the cut at 30 degrees for cohesionless material and 45 degrees for other material.

In all other cases, the advice of the Engineer shall be sought.

Adjacent structures must be founded either beyond or below the zone of influence. Where there is risk of global slip around a slip plane encompassing the proposed retaining wall or other structures, or where there is risk of inundation by ground water or surface water, retaining wall construction shall not proceed until remedial action has been carried out.

Natural material	Maximum height of cut (m)	Maximum permissible unpropped batter (Vertical : Horizontal)
Stable rock, sandstone, firm shale etc where bedding planes do not slope towards the excavation	0 to 3.2	1 : 0.4
	Over 3.2	Seek advice of Engineer
Materials with both significant cohesion and friction in its undisturbed natural compacted state	0 to 2.6	1 : 0.8
	Over 2.6	Seek advice of Engineer
Cohesive soils, e.g. clay, silts	0 to 2.0	1 : 1.2
	Over 2.0	Seek advice of Engineer
Cohesionless soils, e.g. Loose gravel, sand	0 to 1.4	1 : 1.6
	Over 1.4	Seek advice Engineer

Temporary Shoring of Excavations

All temporary shoring shall comply with drawings and specifications produced by a suitably-qualified and experienced Civil Engineer based on geotechnical advice. Consideration shall be given to the settlement effects from the removal of ground water by de-watering the site.

Foundation and Bearing Pad

A qualified and experienced Geotechnical or Civil Engineer shall determine the capacity of the foundation material to resist global slip and to simultaneously support the horizontal and vertical loads, noted in the design schedule annexed to this specification. This shall be assessed when the excavation has revealed the nature and extent of the foundation material.

If the existing foundation material does not have these properties or has insufficient friction angle and cohesion to provide the requisite sliding and bearing capacity, it shall be removed and be replaced with an enlarged bearing pad with the following properties.

Lean-mix concrete

Mass concrete with a compressive strength f'c of not less than15 MPa; or

Cement-Stabilized Crushed Rock

Crushed rock conforming with the specification below with an additional 5% by mass of GP Portland cement thoroughly mixed, moistened and compacted; or

Compacted Crushed Rock

- Compacted density such that a conservative estimate of the mean is at least 2000 kg/m^3
- Effective internal friction angle such that a conservative estimate of the mean is at least 35°
- Effective cohesion such that a conservative estimate of the mean is at least 3 kPa.

A well-graded, low-plasticity crushed rock complying with the following specification is deemed satisfactory for this application.

Nominal Size: 20 mm

AS Sieve	% Passing
26.5 mm	100
19.0 mm	95 -100
13.2 mm	78 - 92
9.5 mm	68 - 83
4.75 mm	44 - 64
2.36 mm	29 - 47
425 µm	12 - 20
75 µm	2 – 6

Liquid Limit not exceeding 20.

Plasticity Index not exceeding 6.

Compaction shall be by mechanical plate vibrator to a minimum of 100% Standard Compaction. Where there are significant variations of foundation material or compaction, soft spots, or where there is ponding of ground water, the material shall be removed, replaced and compacted in layers not exceeding 150 mm at a moisture content within 2% of Optimum Moisture Content (OMC) to achieve 100% Standard Compaction.

Trenches and footing excavations shall be dewatered and cleaned prior to placement of drainage material or footings such that no softened or loosened material remains. Place and compact the material in layers not exceeding 150 mm, to make up the levels. The levels beneath the wall shall not be made up with bedding sand or other poorly-graded granular material that may permit ground water to permeate under the base of the retaining wall, except where drainage material is specified and an adequate drainage system is designed.

Retained Soil
If the existing retained material, within an envelope at 45° (1 : 1 batter) from a point 300 mm behind proposed heel of the structure, does not have the properties specified in the design, or has insufficient friction angle and cohesion to remain stable at the design batter, it shall be removed and replaced with a material that is stable. These properties may be achieved by modification of suitable site materials (as advised by a suitably-qualified Geotechnical Engineer) provided the properties are not injurious to any of the other materials in the structure.

Drainage System
The drainage system shall comply with the Drawings, Building Regulations and relevant Standard (AS 4678). Unless stated otherwise, the drainage system shall consist of:

- Horizontal 50-mm diameter weep holes passing through a hob (or the reinforced masonry stem if appropriate) at 1.2 m maximum centres.
- A permeable drainage layer not less than 300 mm wide adjacent to the stem of the wall.
- A 100-mm slotted PVC agricultural pipe
- For applications with high water table, 200-mm wide geocomposite strips at 2.0 m centres at the existing 1 : 1 batter, connected to the agricultural pipe drainage system.

Constructing Drainage Fill
Drainage fill shall be:

- Placed and compacted, by mechanical plate vibrator, to a minimum of 95% Standard Compaction
- Above and beside the drainage pipe with a minimum cover of 150 mm
- Behind the wall to a minimum width of 300 mm to within 300 mm of the top
- Protected by a geotextile envelope that completely isolates the drainage fill from the retained fill
- Adequately drained away from the retaining structures by the drainage system.

Constructing the Drainage System
The drainage pipe shall be positioned in the drainage fill at a minimum uniform grade of 1 in 100 over a length not exceeding 15 metres. It shall be connected to the storm-water system at the lower end of each run and shall drain positively away from base of the retaining wall. The drainage pipe shall be brought to the surface at the upper end of each run to facilitate future flushing, capped and its positioned marked.

Sub-surface Drainage
Sub-surface drainage shall comply with the Drawings, Building Regulations and relevant Standard. Unless stated otherwise, sub-surface drainage shall consist of one of the following:

- Slotted PVC agricultural pipe, of diameter nominated on the drawings and not less than 100 mm; or
- Polypropylene drainage cell, of diameter nominated on the drawings and not less than 30 mm.

Depending on the volume of groundwater expected, assessed by the Engineer at the time of construction, a geotextile sock may be required. If required, geotextiles shall comply with the specification "*Geotextiles for Filters and Drains*".

Positioning Reinforcement
Starter bars shall be tied into position to provide the specified lap above the top surface of the footing. The starter bars shall be held in position by a timber hob form and controlled within a tolerance of ± 5 mm through the wall and ± 50 mm along the wall.

Bar chairs shall be placed at one metre centres both ways to give the following clear cover. Chair bases shall be used to prevent sinking of the chairs. Unless specified otherwise on the drawings, structural laps and cover shall be as follows.

Required Cover

- 40 mm in concrete in contact with unprotected ground
- 40 mm in concrete exposed externally
- 30 mm to a sealed vapour barrier
- 20 mm to the internal surface.

Reinforcement	Required Laps
Bars	500 mm
Fabric	2 cross wires overlapping
Trench mesh	500 mm

Two N12 corner bars 1.0 metre long shall be placed at all re-entrant corners.

Placing Concrete
Trenches and footing excavations shall be dewatered and cleaned prior to concrete placement so that no softened or loosened material remains.

All concrete shall be compacted by mechanical immersion vibrator.

Unless noted otherwise on the drawings, reinforced concrete footings for retaining walls shall include a level concrete hob (or up-stand), through which vertical starter bars are placed and on which the masonry is built. Horizontal 50 mm diameter weep holes shall pass through the hob at 1.2 m maximum centres. The top of the footing immediately behind the hob shall be sloped at 1 in 100 to provide for the drainage pipe.

Finishing Concrete
Concrete surfaces shall be finished as noted below unless specified otherwise in the Drawings.

- Floor slabs - Steel float
- External paths, driveways and parking areas at less than 10% slope - Fine broomed steel float
- External paths, driveways and parking areas at greater than 10% slope - Coarse broomed steel float
- Vertical surfaces exposed in the completed building – All voids filled and rubbed back to provide a smooth surface
- Vertical surfaces not exposed in the completed building - Off form finish.

Curing Concrete
All concrete shall be cured using a sprayed curing compound.

Wax-based compounds shall not be used in areas requiring the subsequent application of curing adhesives.

Stripping Formwork
Unless adverse weather or the use of retarders delays the hardening of concrete, the minimum stripping time for formwork shall be 3 days.

Mortar
For general applications (except as listed for M4), Type M3 mortar shall be used, and shall consist by volume of:

1 part GP or GB cement, 1 part lime, 6 parts sand (water thickener optional)

1 part GP or GB cement, 5 parts sand plus water thickener

1 part masonry cement, 4 parts sand

For the applications listed below, Type M4 mortar shall be used, and shall consist by volume of:

1 part GP or GB cement, 0.5 part lime, 4.5 parts sand (water thickener optional)

1 part GP or GB cement, 4 parts sand plus water thickener

1 part GP or GB cement, 0-0.25 parts lime, 3 parts sand (water thickener optional)

- Elements in interior environments subject to saline wetting and drying
- Elements below a damp-proof course or in contact with ground in aggressive soils
- Elements in severe marine environments
- Elements in saline or contaminated water including tidal splash zones
- Elements within 1 km of an industry producing chemical pollutants.

Constructing the Reinforced Masonry Stem
The first course of a reinforced masonry wall shall consist of clean-out blocks (with only one face shell) to permit the subsequent removal of debris and mortar fins. The opening of the clean-out blocks shall face the soil embankment, except where there is insufficient access. The blocks shall be positioned to provide 55-mm cover from the face of the bar to the rear face of the blockwork. (This will allow 35 mm for the face shells of upper courses and 20 mm of cover within the grout).

Provide drainage through the stem of the wall by;

- Horizontal 50-mm diameter weep holes at 1,200 mm maximum centres through a hob, or
- Horizontal 50-mm diameter weep holes at 1,200 mm maximum centres through the reinforced masonry stem.

Subsequent courses shall consist of H-Block or Double U-Block. Horizontal reinforcement shall be placed centrally on the webs during the laying of the blockwork. If blocks with webs flush with the ends are to be used, horizontal reinforcement shall be suspended above the webs on 30 mm mortar pack on the centre web only.

Mortar joints shall be 10-mm-thick and shall be face-shell-bedded and ironed (unless a flush joint is specified for aesthetic reasons). Control joints shall be built into the masonry at joints in the footing, at significant changes in wall profile or at centres not exceeding 16 metres.

If the retaining consists of two leaves of cavity construction, suitable cavity ties shall be built in at centres such that the wet grout pressure does not cause spreading of the cavity. Ties shall incorporate 100 cogs at each end that shall bear snugly against the rebate in the blocks and shall be securely fixed by embedment in mortar. The following combinations are deemed to meet this requirement:

Maximum grout height	Tie (Grade 250)	Maximum spacing (Vertical x Horizontal)
2.0 metres	R6	400 mm x 400 mm

Where a retaining wall consists of a single-leaf stem supported by a cavity stem, links shall be provided in the first joint below the junction of cavity stem and single leaf stem to prevent widening of the cavity. The following reinforcement is deemed to meet this requirement:

Maximum height	Shear reinforcement of single-leaf stem
2.0 metres	SL62 Fabric

Debris and mortar fins shall be removed by rodding and hosing out the cores.

Vertical steel reinforcement shall be positioned towards the rear of the cores to provide the cover noted above.

Vertical steel reinforcement shall be tied through clean-out openings with wire ties to the steel starter bars and fixed in position at the top of the wall by plastic clips before the placing of any grout.

When cleaning out and tying of steel are complete, the opening shall be blanked off with a timber form suitably propped to prevent movement. Alternatively blocks which incorporate purpose-designed blanks may be used.

Concrete grout shall be placed in the cores either by pumping or, for small projects, by bucket. Grout shall be compacted so that there are no voids, using either a high frequency pencil vibrator or by rodding. (The main vertical bars shall not be moved to compact the grout.)

On completion of the grouting, capping blocks shall be installed (if required) and any control joints finished.

Constructing Bulk Fill Material
Bulk fill material shall be uniform and of maximum particle size of 100 mm.

Bulk filling material shall be placed and in layers not exceeding 200 mm at a moisture content within 2% of Optimum Moisture Content (OMC) to achieve 85% Standard Compaction.

At the end of each day's construction, the infill material shall be sloped such that any rainwater is directed away from the face of the retaining wall and to a temporary (or permanent) drainage system.

Constructing Surface Sealing Material and Catch Drain
The whole of the disturbed fill surface shall be sealed and drained by compacting a layer of surface-sealing material of suficient thickness to ensure that groundwater does not seep into the fill material. It shall be not less than 150-mm thick and not less than 300-mm thick in applications subject to significant groundwater flow and shall be in accordance with the relevant Standard (or AS 4768).

The drainage shall shed water away from the retaining wall structure. This may be achieved by constructing a 100-mm deep catch drain to drain to the site drainage system at a minimum slope of 1 in 100.

Tolerances

Unless specified otherwise for reasons of aesthetics or by the client or architect, all construction shall be within the following tolerances:

Element	Vertical Position	Horizontal Position	Vertical Alignment	Horizontal Alignment
Soil surface	± 100 mm	-	-	-
Facings and wall structures	± 50 mm	± 50 mm	± 20 mm in 3 m	± 20 mm in 3 m
Footings and supports	± 50 mm	± 50 mm	± 20 mm in 3 m	± 20 mm in 3 m

Inspections and Tests

When work reaches a stage of requiring inspection, (eg footing reinforcement, geogrids and drainage) the Contractor shall advise the Engineer, before proceeding to cover, close or complete the work. The following inspections shall be performed.

Item or Product	Inspection Required	Accept Criteria	Hold or Witness
Drawings & Specifications	Inspect controlled documents	Controlled copy of latest issue on site	Hold
Foundation & retained soil			
Density	Density meter *		
Friction angle	Shear box *	As specified	Hold
Cohesion	Shear box *		
Levelling pad			
Width	Spot check	+ 10%, - 2%	Hold
Depth	Spot check	+ 10%, - 2%	Hold
Density	Density meter *	As specified	Hold
Friction angle	Shear box *	As specified	Hold
Cohesion	Shear box *	As specified	Hold
Footing dimensions			
Width	Spot check	+ 10%, - 2%	Hold
Length	Spot check	+ 10%, - 2%	Hold
Reinforcement cover	Check chair size	As specified	Hold
Edge forms	Check all edges	± 20 mm	Hold
Level on soil	Spot check levels	+ 10 mm, -50 mm	Hold
Footing Reinforcement			
Reinforcement grade	Spot check markings	As specified	Hold
Reinforcement diameter	Spot check diameter	As specified	Hold
Reinforcement spacing	Spot check	± 10%	Hold
Reinforcement laps	Spot check	± 10%	Hold
Reinforcement ligature spacing	Spot check	± 10%	Hold
Concrete strength	Spot check dockets	As specified	Witness
Concrete curing	Spot check	As specified	Witness
Masonry units			
Type	Spot check	As specified	Hold
Dimensions	Spot check	As specified	Witness
Strength	Spot check dockets	As specified	Witness
Mortar mix	Spot check	As specified	Witness
Weep holes	Spot check	As detailed	Hold
Cover	Spot check	As spec >15 mm	Hold
Wall Reinforcement			
Reinforcement grade	Spot check markings	As specified	Hold
Reinforcement diameter	Spot check markings	As specified	Hold
Reinforcement spacing	Spot check	± 10%	Hold
Reinforcement laps	Spot check	± 10%	Hold
Concrete grout strength	Spot check dockets	As specified	Witness
Cleaning	Visual	As per test panel	Witness
Drainage system	Flush pipes	Positive 1 in 100	Hold
Granular fill	Visual	Grading	Hold
Geotextile	Visual	As specified	Hold
Fill	Visual	Grading	Witness
Sealing and surface drains	Visual	Located to drawing	Witness

Notes:
All tolerances shall be as shown, except where overridden by architectural or regulatory requirements.
The Engineer may relax requirements marked *, if other satisfactory controls are in place.

Editable Specification

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APPENDIX F – RELIABILITY OF AS 4678

BACKGROUND

The design of gravity structures (including Concrete Segmental Reinforced Soil Structures, Segmental Concrete Gravity Retaining Walls and Reinforced Concrete Masonry Cantilever Retaining Walls) was previously governed principally by overturning about the toe. However, design for forward sliding or bearing now often governs the design process. This has major implications for the economy of all gravity structures. AS 4768 indicates that most structures in cohesive soils have difficulty in meeting the sliding (external design) limit state, for the types of soil parameters commonly assumed by Australian design engineers.

The Concrete Masonry Association of Australia has prepared a detailed study of the implications of external design for sliding, overturning and bearing, common to all gravity retaining wall systems.

1 The first step in the investigation was to create a spreadsheet that can handle all practical variables; ie structure density, wall slope, backfill slope, soil properties, bearing pad, distributed loads, line loads, water table, wind and earthquake.

2 The spreadsheet then was checked by worked example. To make this comparison meaningful for all three structures, an idealised structure has been selected that best mimics all three, and, most important, is able to be checked by working stress to *Code of Practice* CP2. This involves constant density (20 kN/m^3), idealised block (also 20 kN/m^3), level slope of retained soil, near vertical face, embedment of H/15, external friction 30 degrees, internal friction 30 degrees, and live load of 5.0 kPa.

3 The next step was to compare design to AS 4678 with design to *Code of Practice* CP2 for a series of idealised structures of different heights, soils, slopes, and water table.

4 The final step was to investigate any peculiarities related to any particular system, ie:

- Slope of RSS and Gravity Walls
- Toe in front for Type 2 Cantilever Walls
- Reduced density of no-fines segmental gravity walls
- Key in Type 1 and Type 2 Cantilever walls

BENCHMARK CONSTRUCTION

In order to calibrate AS 4678 and the CMAA Manuals, it iwas necessary to adopt benchmarks of acceptable designs that have a long history of satisfactory performance, which can be justified by a combination of theory and experience. The CMAA chose the working stress design method(Note 1) and soil properties set out in:

> Civil Engineering Code of Practice No 2 (1951) *Earth Retaining Structures,* The Institution of Structural Engineers (UK).

Code of Practice No 2 was published in 1951, reprinted in 1975 and the methods described therein remained in common use to the turn of the century. Thus, for over fifty years it has provided the basis of design of most retaining walls in the English speaking world, including Australia.

Whilst there are sound reasons to deviate from Code of Practice No 2 for uncommon consequence of failure or for uncommon levels of workmanship, it still remains an acceptable starting point for the benchmarking process for the most common situations.

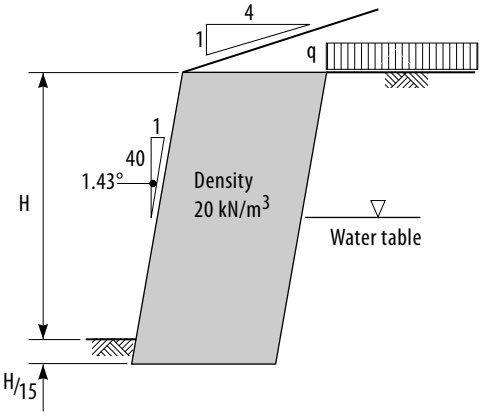
Notes:
1 The reasons for adopting a new approach (eg adopting a limit state standard instead of working stress standard) relate to flexibility and application, and are explained later in this paper.

RETAINING WALLS STUDIED

External design considerations are common to all types of gravity walls, including:

- Concrete Segmental Reinforced Soil Structures
- Concrete Segmental Gravity Retaining Walls (with or without no-fines concrete)
- Type 1 Reinforced Concrete Masonry Cantilever Retaining Walls.

The following idealised structure, which best fits all three types, has been analysed.



Case 1:
Level retained soil
q = minimum 1.5 kPa
No water table

Case 2:
1:4 slope of retained soil
q = minimum 1.5 kPa
No water table

Case 3:
Level retained soil
q = 10.0 kPa
No water table

Case 4:
Level retained soil
q = minimum 1.5 kPa
Water table at half wall height

Figure F1 *Idealised Structure and Cases used in the Analysis*

- The assumed shape of the gravity structure is a parallelogram, with horizontal base and horizontal top, with slightly sloping front face and parallel rear surface. Both front and rear faces are at 1.43° (I in 40) to vertical.
- Density of the gravity structure is a uniform value, approximating the average density of the soil and concrete, and taken as 20 kN/m^3 (Note 1)
- Embedment of the structure is taken as the exposed height divided by 15.(Note 2)
- Minimum imposed (live) load of 1.5 kPa, except in Load Case 3 (**Table F4**) where a minimum of 10 kPa is specified.(Note 3) In the case of walls designed to AS 4678, the minimum values of imposed (live) surcharge are given in **Table F1**.
- Because the purpose of the study was to determine the broad effects of the various design standards, possible pragmatic construction expedients to make the structures more economic were ignored. For example, the following expedients, although considered to be "good engineering" were not assumed:
  - Excavation and replacement of weak foundation material (Soil type 2 and 3).
  - Draining the water table (Load case 4).
  - Sloping the face more than the 1.43° (I in 40).

Table F1 *Minimum Uniform Imposed Load* (kPA)

		Backfill Slope (Horizontal : Vertical)	
Classification	**Height**	**Steeper than 4:1**	**4:1 of flatter**
B, C	Any	2.5 kPa	5.0 kPa
A	≤1.5 m[Note 1]	1.5 kPa	2.5 kPa

Notes
1 Classification 'A' retaining walls must be equal to or less than 1.5 m high.

Table F2 *Heights Analysed*

Exposed height (m)	Embedment depth (m)	Total height (m)
1.50	0.10	1.60
3.00	0.20	3.20
4.50	0.30	4.80
6.00	0.40	6.40

Table F3 *Structure Classification Analysed*

Consequence of failure	Structure Classification	Exposed heights assumed applicable (m)	Total heights assumed applicable (m)
Failure results in minimal damage and loss of access	A[Note 1]	1.50	1.60
Failure results in moderate damage and loss of service	B	3.00 & 4.50	3.20 & 4.80
Failure results in significant damage or risk to life	C	6.00	6.40

Notes
1 Definitions and height limit for A are taken from AS 4678.

Table F4 *Load Cases Analysed*

Load Case	Slope of retained soil	Imposed Load Surcharge (kPa)	Height of water table behind structure
1	Nil	1.5	Nil
2	1 in 4	1.5	Nil
3	Nil	10.0	Nil
4	Nil	1.5	Half wall height

Notes

1 If the face is vertical and density of gravity structure is assumed equal to the density of retained soil, the benchmark designs will be quite accurate for Concrete Segmental Reinforced Soil Structures, Concrete Segmental Gravity Walls (without no-fines concrete) and Type 1 Reinforced Concrete Cantilever Gravity Walls. However, the benchmark designs will be a little non-conservative for Concrete Segmental Gravity Walls (with no-fines concrete), and quite non-conservative for Type 2 Reinforced Concrete Cantilever Gravity Walls. These two cases should be considered independently.

2 Reinforced soils generally require total height/20. Low-height segmental gravity walls may be built with zero embedment. Type 1 cantilever walls often require 300 + mm depth to cover the footing. The selected compromise embedment is exposed height/15.

3 Although CP2 and the NCMA method do not specify a minimum imposed (live) load, it is impossible to have a "zero imposed load" case. There will always be at least some (perhaps unspecified) imposed (live) load that a designer must consider. Failure of a designer to formally assume at least some value for imposed (live) surcharge would leave the designer exposed in any potential litigation, and a competent designer using CP2 or the NCMA method would always adopt some value. The question is, "What is a reasonable minimum value?" AS 4678 assumes a general minimum of 5 kPa (except in low-risk walls). In this analysis, a much more optimistic minimum value of 1.5 kPa has been assumed.

Table F5 *Soil Types Analysed*

Soil Type	Soil Description	Effective angle of internal friction ϕ (degrees)	Effective angle of external friction δ (degrees)	Effective cohesion c_0 (kPa)
1	Cohesionless soil, moist backing	35	20	0.0
2	Cohesive soil, silt with both friction and cohesion	20	0	7.2
3	Cohesive soil, non-fissured clay	0	0	14.3

Note:
The soil properties and water table to be checked are from Appendix D of Code of Practice No 2.

ANALYSES UNDERTAKEN

It was necessary to determine whether or not there is any mandatory requirements in AS 4678, the CMAA Manuals (MA 51, MA 52 or MA 53), or the NCMA Method that lead to either unsafe or uneconomical design. The following steps were undertaken.

- For a range of heights and soil types (**Tables F2** and **F5**) determine the required width of gravity structure necessary to satisfy Code of Practice CP2, AS 4678 and NCMA Method.
- Calculate the Reliability Indices, β, for each of the preliminary designs for sliding, bearing and overturning (including premature bearing).(Note 1)
- Determine initial Target Reliability Indices, β_{target}, for particular applications, based on ISO 2394 Table E1.

Notes:
1 Sliding may occur independently of both overturning and bearing failure. Bearing failure may occur independently of both sliding and overturning. Overturning may occur about the toe under conditions of adequate bearing. However, if bearing failure occurs, it causes overturning failure. Therefore the Reliability Index for overturning is the minimum of the indices calculated for overturning about the toe and that calculated for bearing failure.

CONCLUSIONS

The study provided the following conclusions:

- The ultimate-load, limit-state method of AS 4678 generally yields a more liberal design than the historical working stress method of Code of Practice CP 2.
- The difference lies in the ability of AS 478 to take advantage of a stiff bearing pad to allow the point of rotation to approach the toe of the retaining wall and to spread the load deep into the foundation. The working stress method limits this reaction to within the middle third of the footing.
- Load Case 1. (cohesionless soil) is limited by overturning for both methods, although AS 4678 has an advantage.
- Load Case 2 (silt) shows close relationship between both methods, generally limited by forward sliding.
- Load Case 3 (non-fissured clay) can not be sensibly designed in either case, because the clay foundation can not prevent forward sliding. This leads to the logical conclusion that such foundations should replaced by material with high friction.
- These observations lead to the following broad conclusions:
  - AS 4678 is not conservative when compared to traditional working stress methods. To the contrary, it is consistently slightly more liberal.
  - Unlike traditional working stress methods, AS 4678 caters, to some extent, for the need for greater safety in structures with high consequence of failure and lower safety in structures with low consequence of failure.
  - There are some marginal savings in structure volume to be derived from using AS 4678, when compared to traditional working stress methods.
  - The difficulties in designing for cohesive soils derive not from AS 4678, but from the assumptions made in respect to soil properties.

The study is available on application from Concrete Masonry Association of Australia.

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For details of masonry manufacturers, see CMAA Web Site: *www.cmaa.com.au*