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RAMWALL

DESIGN METHODOLOGY

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CONTENTS

1. INTRODUCTION

These calculations (RAMW/001 Rev.0) present a design methodology / theory and numerical design calculations for a new retaining wall system, RAMWALL.

RAMWALL comprises a gravity retaining wall constructed from bent welded wire fabric grid filled with crushed aggregate. The calculates will present basic gravity retaining wall stability charts for various configurations and heights of wall, slope angles and ground conditions, foundation bearing capacity calculations and internal wall stresses.

Finally an investigation and testing program will be recommended to verify the theories given in these calculations.

2. REFERENCED DOCUMENTS & ABBREVIATIONS

Standards and Codes of Practice

BS 8002:1994 Design of Earth-retaining structures
BS 8004 Foundations
BS 8006:1995 Strengthened/Reinforced Soils
EN 1997-1:2004 - Eurocode 7: Geotechnical design
BS 1052 Welded Wire Fabric
BS 443 and BS 729 - Galvanising
BS 4102 - PVC Coating
BS 5390 - Backfill

Abbreviations used in the text and formulae, with typical values used in the illustrations and worked example:

$kN := 1000\,newton$	$\beta := 10 \cdot rad$	$\delta := \phi$	$B := 3.5m$
$kPa := 1 \cdot kN \cdot m^{-2}$	$\alpha := 80 \cdot rad$	$H := 6 \cdot m$	$c := 0 \cdot kPa$
$MPa := 1000\,kPa$	$\psi := 30 \cdot rad$	$\gamma := 20 \cdot kN \cdot m^{-3}$	$N := 100 \cdot kN \cdot m^{-1}$
$rad := \frac{\pi}{180}$	$\phi := 30 \cdot rad$	$q := 10 \cdot kPa$	

3 DESIGN METHODOLOGY / THEORY

3.1 General

Internal forces in the wall can be calculated using standard soil mechanics theory as follows.

Assuming a cohesionless fill material (ϕ = Angle of friction of the soil); the vertical stress in a block of soil at a depth h is given by: $\sigma_v = \gamma.h$

At rest lateral stress in the soil is given by: $\sigma_h = k_o.\gamma.h$

where $k_o = 1 - \sin\phi$

As the soil expands laterally the soil lateral stress reduces to the limiting value, $k_a.\gamma.h$ where $k_a = \tan^2(45^o - \phi/2)$ this is represented graphically below using a Mohr circle of stress diagram, Figure 3.1.

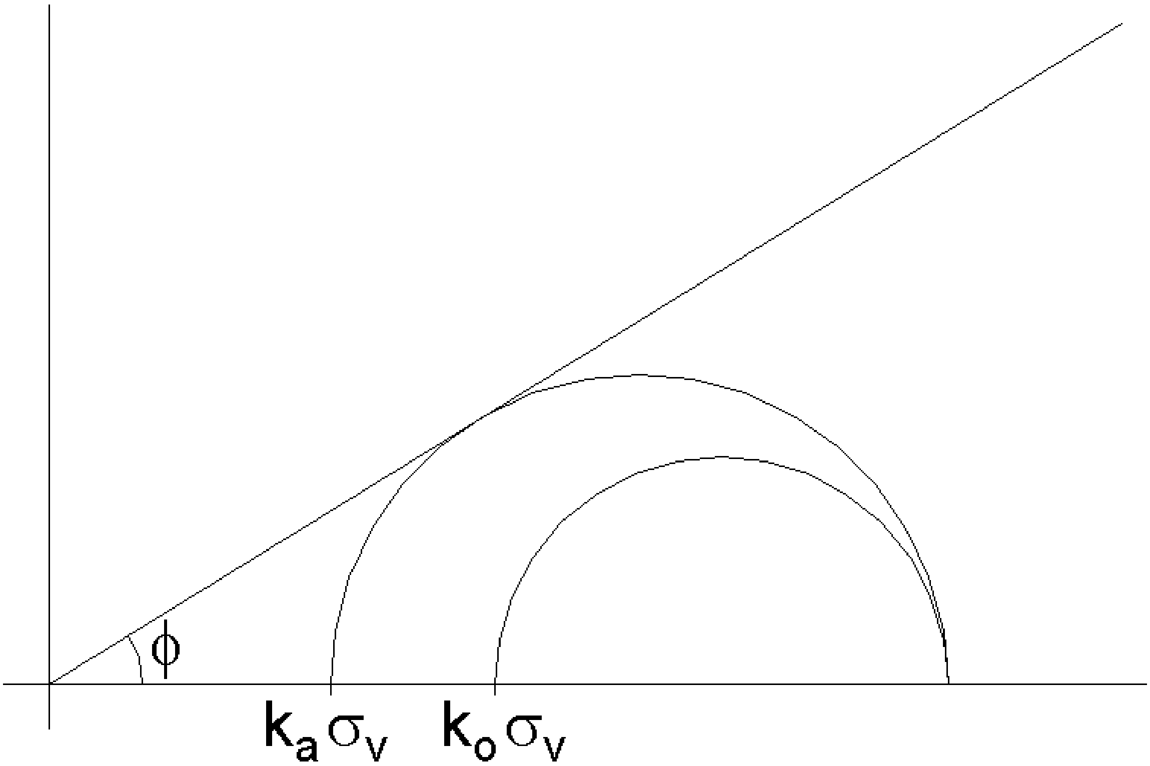

Figure 3.1

The reinforcement in the RAMWALL can be represented by considering a block of soil, Figure 3.2. Applying a vertical load to the soil, the block will strain laterally, δ_h, as well as compress axially, δ_v. The reinforcement grids in the RAMWALL will restrain the soil, provided there is adhesion or interlock between the soil and the reinforcement and the reinforcement is stiff. The force transferred by the soil into the reinforcement is equivalent to the at rest lateral stress, $\sigma_h = k_o.\sigma_v$.

This general condition is valid for any value of vertical stress. Reference to Figure 3.1 shows that the reinforced condition always lies below the rupture line.

From Figure 3.2, the tensile stress in any unit of reinforcement = $k_o.\sigma_v/a_r$,
where a_r = cross sectional area of the reinforcement.

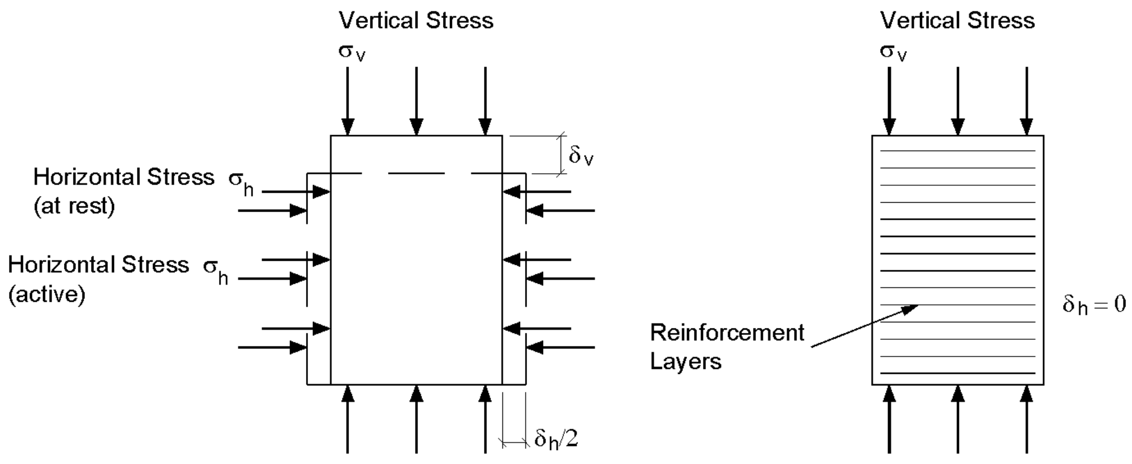

Figure 3.2

Therefore, the strain in the reinforcement equals $\delta r = k_o.\sigma_v/a_r.E_r$, where E_r = elastic modulus of steel. This equates to the lateral strain in the soil (ε_r) in the direction of the reinforcement.

This argument is only valid if the effective stiffness ($a_r.E_r$) of the reinforcement is high so that ε_r tends to zero.

This is the case with RAMWALL as the reinforcement panels are made out of closely spaced high tensile welded wire fabric bent into a series of zig-zag panels stacked on top of each other. Combined with a suitable sized and graded fill material they will form a fully interlocked mass where the forces in the soil will be restrained by the reinforcement grid.

Grids are effective reinforcement because of the increased resistance to pullout formed by the longitudinal bars and the bent shape. However, as the mechanism of pullout resistance is not fully understood it is recommended that tests are carried out to validate the assumptions made.

Internal Analysis:- concerns all areas relating to internal behaviour mechanisms, stress within the structure, arrangement and durability of reinforcement and backfill properties.

External Stability:- check stability against sliding, overturning, bearing capacity failure and overall slope stability failure.

3.2 Internal Analysis

Unlike a standard gabion where part of the gabion's strength relies on the placement of the backfill material, the presence of the grids in the RAMWALL act as internal strips of reinforcement to the backfill. The overall pattern of a constructed RAMWALL has been designed to form a solid interlocked reinforced mass gravity retaining wall with nominal compaction of the infill material.

Initial trials have shown that with a suitably graded fill the RAMWALL can be backfilled simply by tipping and requires no additional compaction. These initial trials require laboratory confirmation with grading tests on the backfill and tests to confirm the mass density of a constructed wall for use in design. The tests will also trial different grades and types of backfill material.

Initial designs can be carried out using a porosity, η_r, of 0.35 and the density, γ_r, of the fill material. For designs to BS8004:1994 a porosity of 0.4 should be used.

In 3.1 above it was shown that the internal forces in the RAMWALL backfill are transferred directly in to the reinforcement either by friction or more likely interlock between the reinforcement grid and the angular backfill material.

Therefore, stresses in the reinforcement can be calculated from the known forces acting within the RAMWALL as the reinforcement is considered to be axially stiff and capable of absorbing tensile, shear and bending forces. The maximum tensile stress in the reinforcement can be determined from:

$$\sigma_r := k_o \cdot \frac{\sigma_{max} \cdot H_u}{a_r}$$

Where σ_{max} is the maximum stress developed in the wall, taking into consideration the forces acting on the RAMWALL can be obtained assuming a Meyerhof distribution:

$$\sigma_{max} := \frac{N_v}{(B - 2 \cdot e)}$$

where Nv is the vertical resultant load, B is the width of the RAMWALL and e is the eccentricity of the resultant load about the centre-line of the base width B equal to M/N; a_r is the area of reinforcement, which is equal to $1.4e10^{-3}$ m^2 for a H_u = 0.9m high RAMWALL unit when 6mm diameter welded wire fabric is used.

For stability, $\sigma_r <= \sigma_t / \gamma_m$ where σ_t is the ultimate tensile strength of the reinforcement and γ_m is a partial material factor. The partial material factor is dependent on the reliability of the tensile strength values, manufacturing quality, the backfill material, levels of installation damage and the design life. For short-term design life conditions a value equal to 1.05 could be used. For long term design life conditions a value of 1.5 may be more appropriate. Reference could be made to BS8006 with adoption of the partial factor used for metallic soil reinforcement.

The average shear stress in the wall can be taken as $\tau = P_{AH}/B$ where P_{AH} is the resultant horizontal force acting on the RAMWALL. Without test results it is difficult to quantify the allowable shear fore of a RAMWALL unit but provided the RAMWALL passes the overall check in sliding the shear force within the wall should be within allowable limits. This assumption will be reviewed following full scale testing of the product.

3.3 External Stability

Coulomb analysis: General Assumptions

The RAMWALL is a permeable structure so porewater pressures at the back face of the wall will be zero. Section 5 gives further information on design, wall layout and where it may be necessary to install filter layers to prevent loss of fines through the wall.

Coulomb analysis: Theory c = 0 ϕ' soil

Figure 3.3(a) shows a theoretical layout of a wall with a failure surface extending from the rear toe of the wall to the ground surface behind the wall. This failed wedge of soil exerts horizontal and vertical thrusts on the wall, which tend to push the wall forwards away from the retained soil slope.

The known forces acting on the wedge are:

i) Unknown frictional force R acting on the failure plane in a direction ϕ to the normal and opposing the downward movement of the wedge caused by the wall moving away from the retained soil.

ii) The active thrust P_A inclined at an assumed angle δ to the normal and in the direction opposing the downward movement of the wedge.

iii) The total weight of the wedge W

$$W := \frac{1}{2}\gamma \cdot H^2 \cdot \left[\frac{(\sin(\alpha + \beta)\cdot\sin(\psi))}{\left(\sin(\alpha)^2\cdot\sin(\alpha + \beta + \psi)\right)}\right]$$

iv) The known surcharge forces Q and q.

By force equilibrium the unknown forces P_A and R can be determined. From the polygon of forces, Figure 3.3(b), it can be seen that the vector W plus the surcharge is statically equivalent to P_A and R. Since the absolute direction of these forces are known the triangle of forces can be computed. Repeating this procedure for different failure surfaces the maximum value of P_A can be determined.

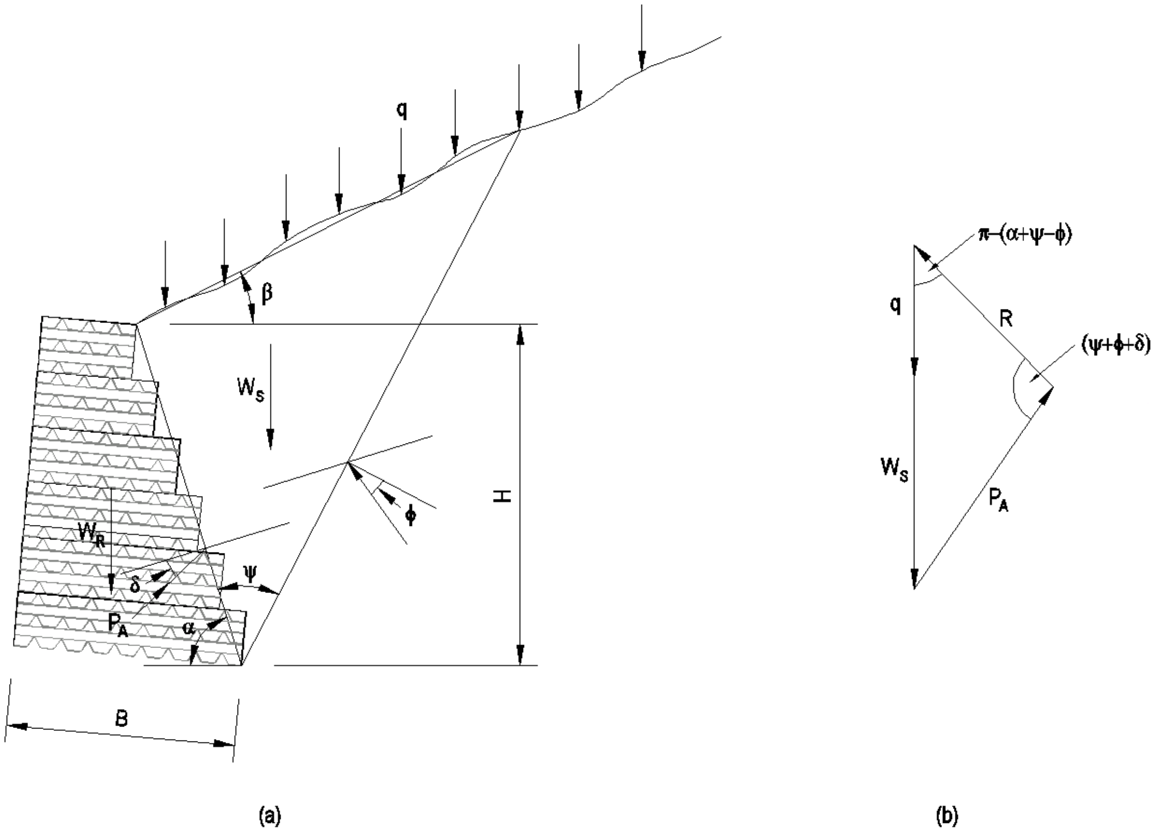

Figure 3.3

The horizontal component of the resultant thrust can be expressed as,

$$K_{HA} := \left[\frac{\csc(\alpha)\cdot\sin(\alpha + \phi)}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{(\sin(\phi + \delta)\cdot\sin(\phi - \beta))}{\sin(\alpha + \beta)}}} \right]^2 \cdot\sin(\alpha - \delta)$$

$$P_{HA} := \frac{1}{2}\cdot\gamma\cdot H^2\cdot K_{HA}$$

where:

$$K_{HA} := \left[\frac{\csc(\alpha)\cdot\sin(\alpha + \phi)}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{(\sin(\phi + \delta)\cdot\sin(\phi - \beta))}{\sin(\alpha + \beta)}}} \right]^2 \cdot\sin(\alpha - \delta)$$

$$K_{HA} = 0.346$$

$$N_{\gamma HA} := \frac{K_{HA}}{2}$$

$$N_{\gamma HA} = 0.173$$

(for $\alpha = 80^o$, $\beta = 10^o$, $\phi = \delta = 30^o$).

Adopting the notation that the vertical component P_{AV} is positive when it is acting downwards on the wall,

$$N_{\gamma VA} := N_{\gamma HA} \cdot \cot(\alpha - \delta)$$

$$N_{\gamma VA} = 0.145$$

(for $\alpha = 80^o$, $\beta = 10^o$, $\phi = \delta = 30^o$).

Where a surcharge q is applied over the upper surface, the orientation of the failure plane corresponding to the maximum thrust is not affected. The surcharge component of horizontal thrust is

$$P_{qH} := q \cdot H \cdot \frac{(2 \cdot \sin(\alpha))}{\sin(\alpha + \beta)} \cdot N_{\gamma HA}$$

and so,

$$N_{qHA} := \frac{(2 \cdot \sin(\alpha))}{\sin(\alpha + \beta)} \cdot N_{\gamma HA}$$

hence, the value of N_{qHA} can be readily obtained from the numerical values of K_{HA} quoted on Figure 3.5a-e.

Furthermore,

$$N_{qVA} := N_{qHA} \cdot \cot(\alpha - \delta)$$

It is a reasonable assumption for RAMWALL that the angle of friction δ between the line of thrust and the back of the wall is equal to ϕ.

The resultant thrust along the soil-wall interface, P_A, is given by;

$$P_A := P_{HA} \cdot \csc(\alpha - \delta)$$

$$P_A := \frac{1}{2} \cdot \gamma \cdot H^2 \left[\frac{(\csc(\alpha) \cdot \sin(\alpha + \phi))}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta)}{\sin(\alpha + \beta)}}} \right]^2$$

and

$$K_A := \left[\frac{(\csc(\alpha) \cdot \sin(\alpha + \phi))}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta)}{\sin(\alpha + \beta)}}} \right]^2,$$

The force acts at the third height of the wall above the rear toe. Graphs given in Figure 3.5a-e can be used to obtain the thrust coefficient K_{HA} for various combinations of slope backfill angle, β, wall angle, α, and soil friction angle, ϕ. Or alternatively the equations quoted above can be used to obtain the values of P_{AH} and P_{AV} for use in the stability analysis.

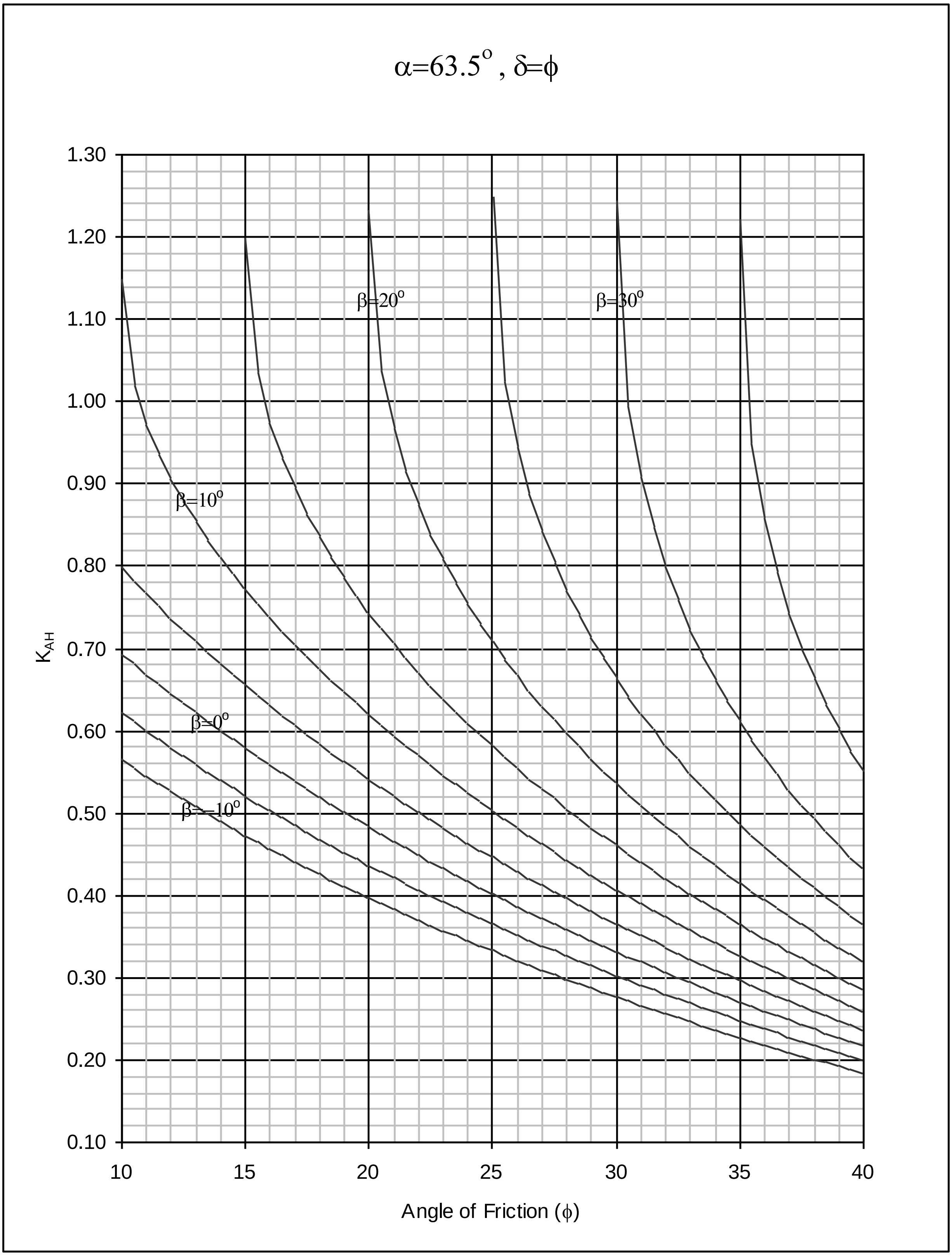
α=63.5°, δ=φ
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
K_AH
β=20°
β=30°
β=10°
β=0°
β=−10°
10
15
20
25
30
35
40
Angle of Friction (φ)

Figure 3.5a

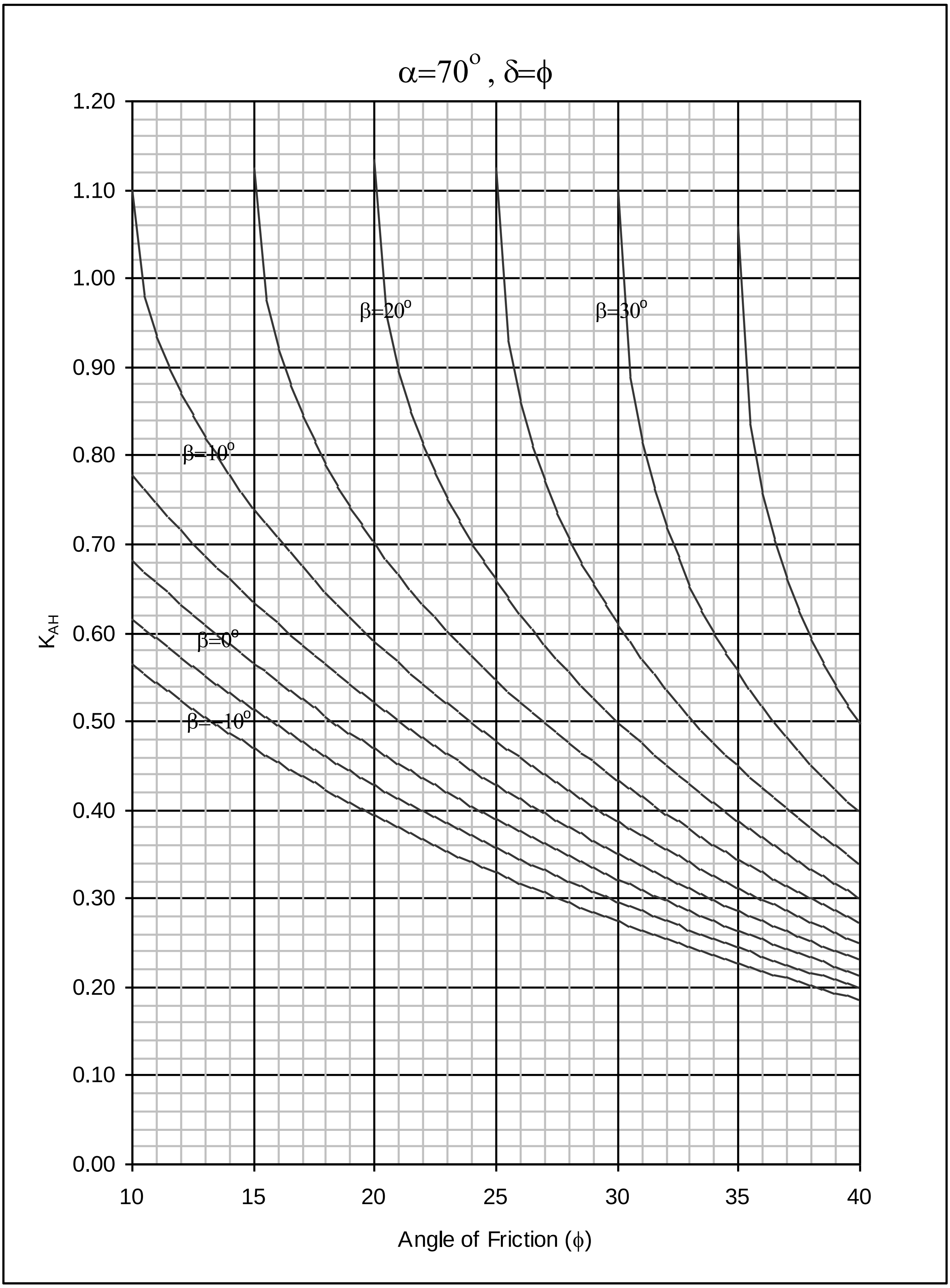
α=70°, δ=φ
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
K_AH
β=20°
β=30°
β=10°
β=0°
β=−10°
10
15
20
25
30
35
40
Angle of Friction (φ)

Figure 3.5b

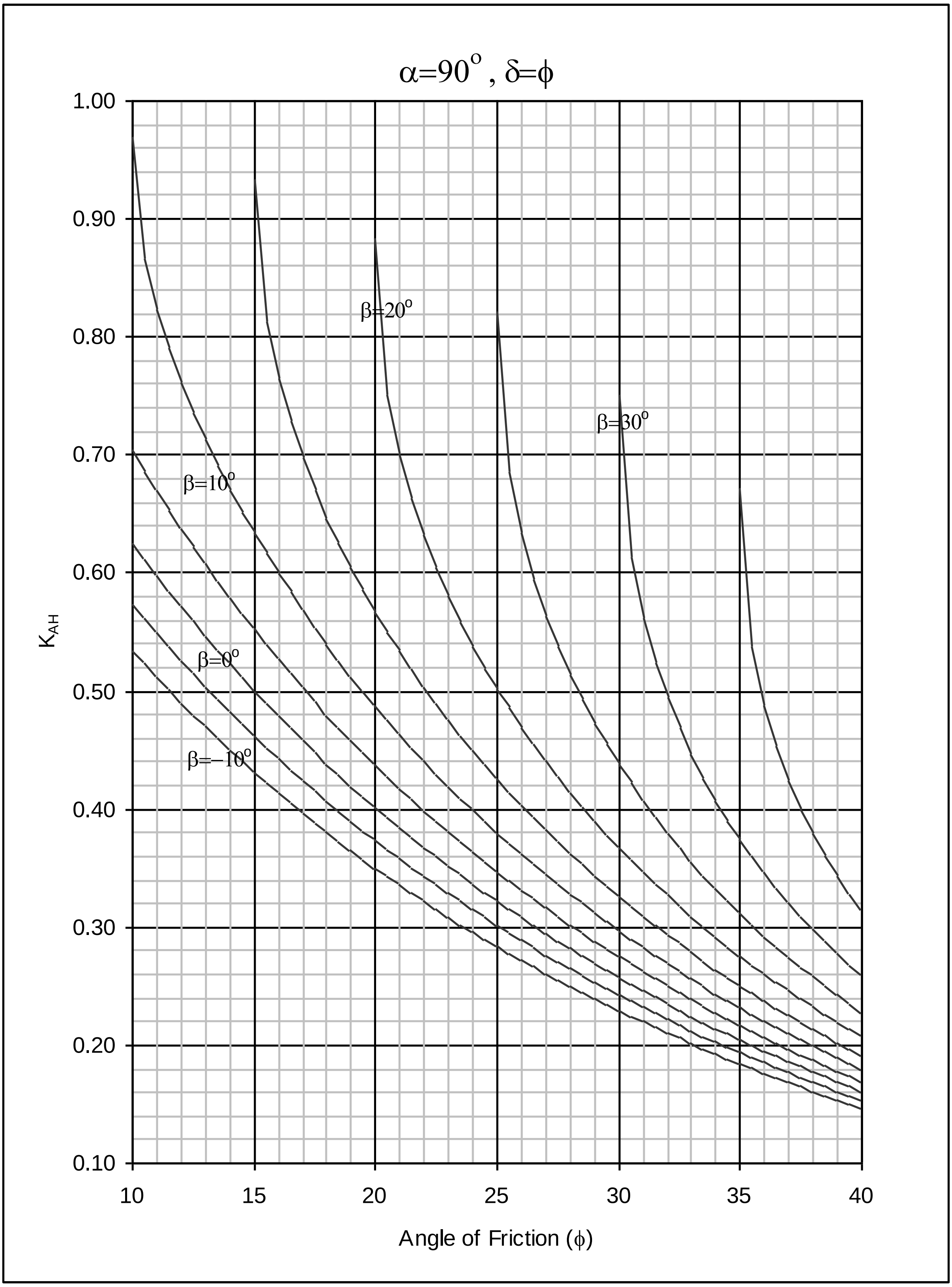
α=90°, δ=φ
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
K_AH
10
15
20
25
30
35
40
Angle of Friction (φ)
β=20°
β=30°
β=10°
β=0°
β=−10°

Figure 3.5c

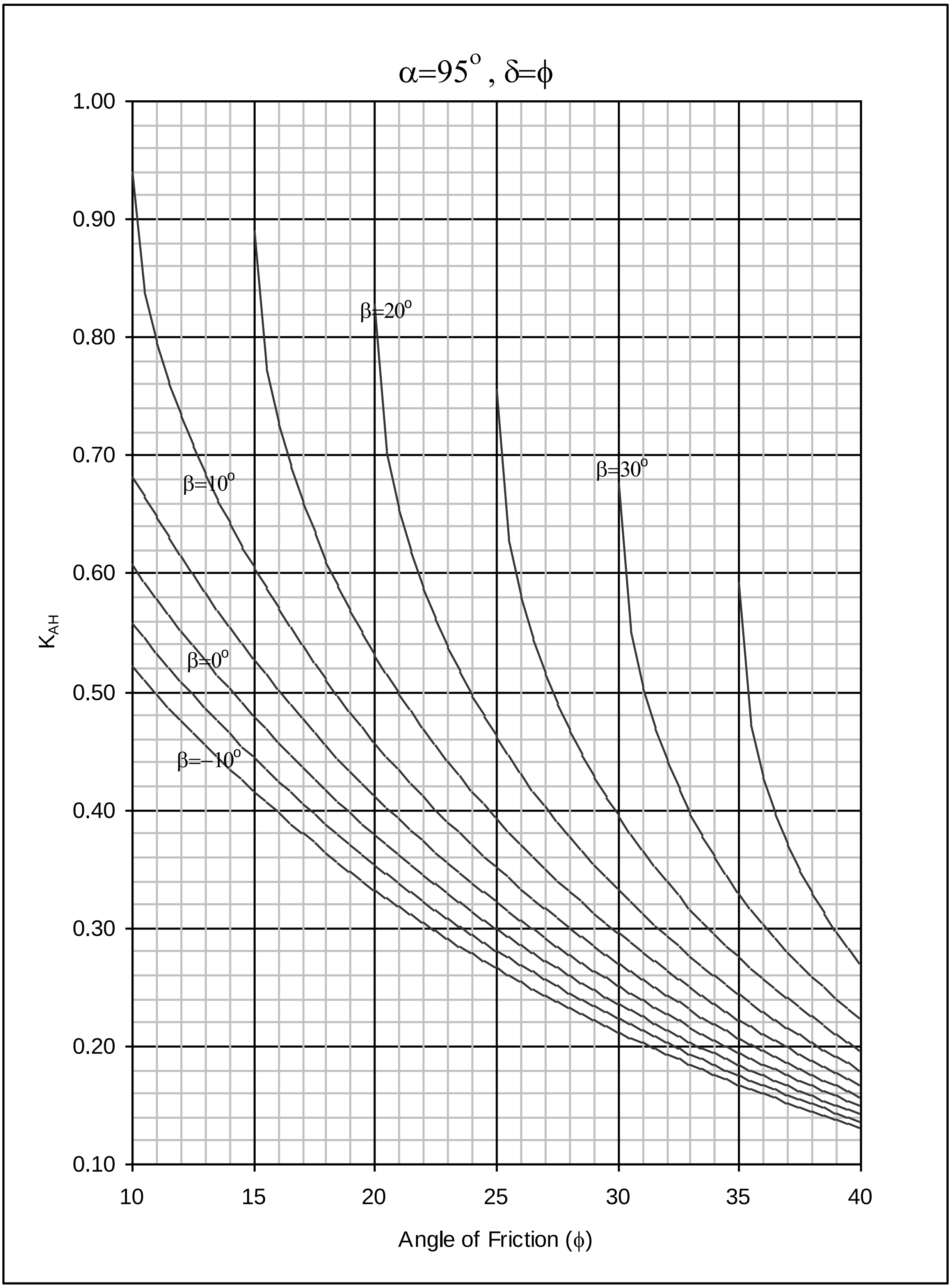
α=95°, δ=φ
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
K_AH
10
15
20
25
30
35
40
Angle of Friction (φ)
β=20°
β=10°
β=30°
β=0°
β=−10°

Figure 3.5d

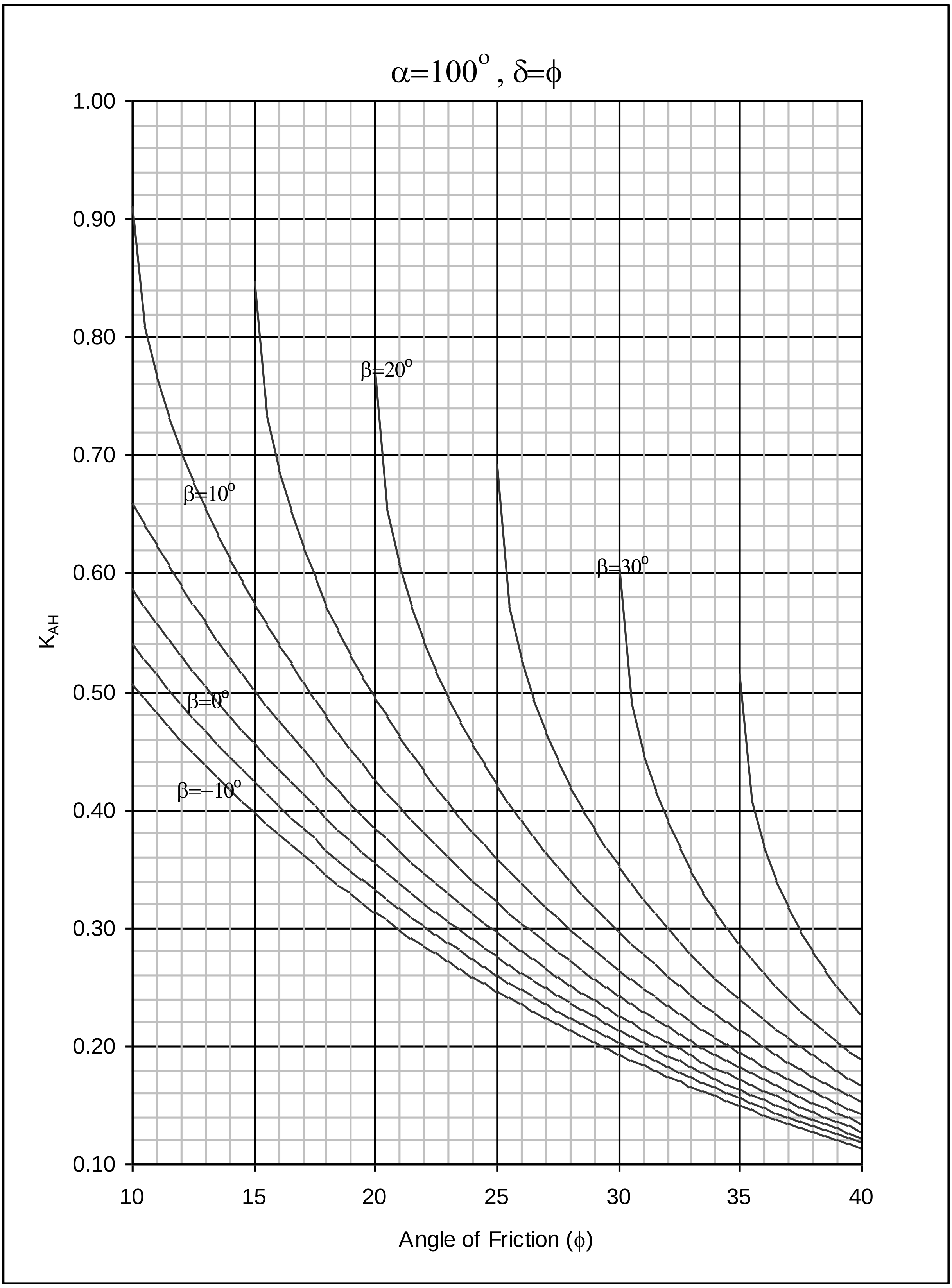
α=100°, δ=φ
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
K_AH
β=20°
β=10°
β=30°
β=0°
β=–10°
10
15
20
25
30
35
40
Angle of Friction (φ)

Figure 3.5e

Stability Checks - General

Gravity retaining walls are designed using limit states, failure in sliding, failure in overturning, bearing capacity failure and overall failure of the wall and ground.

In the UK the design of gravity retaining walls are covered by BS 8002:1994 Design of Earth-retaining structures or the Eurocode 7 Geotechnical Design.

BS 8002 allows both methods of limit state design; partial factors on the material, forces/actions and resistances or overall factors of safety against sliding and overturning. The overall safety factors are normally set at 1.3 for sliding and 1.5 for overturning. The only stipulations given in the BS 8004 are a factor should be applied to the 'reasonable' soil parameters equal to 1/1.2 and a porosity of 0.4 is used for the design of gabion type walls.

The Eurocode stipulates design methods for the stability of the wall, bearing capacity and overall slope stability using partial factors on the materials, actions and resistances. For retaining walls three design approaches have to be checked with each approach having different combinations of partial factors on the three variables, Material (X_k), Forces/Actions (F_{rep}) and Resistances (R). For stability (equilibrium) the effect of the actions, E_d should be less than or equal to the design resistances R_d.

Both approaches require checks on the stresses within the wall are within allowable limits.

The checks on internal stresses in the wall are covered in Section 3.3 above.

Worked examples of both design methods are given in Section 4.

Check for Sliding ULS: In the horizontal plane, the destabilising force from the active earth pressure has to be opposed by the stabilising forces - frictional resistance and cohesion along the base of the RAMWALL.

Stabilising Force	$F_s := N \cdot f$	for a c' = 0 soil
or	$F_s := N \cdot f + c \cdot B$	for a c' > 0 soil

The Normal Force, N, is the sum of all the vertical forces perpendicular to the sliding plane, including the weight of the wall, the vertical component of the active thrust and surcharge on top of the wall if present. The density, γ_r, and the porosity, η_r, of the backfilled units are required to calculate the density of the RAMWALL. Subject to tests a porosity value $\eta_r := 0.35$ can be used.

The coefficient of friction is equal to $f := \tan(\phi)$

Destabilising Force $F_{ds} := P_{HA}$

The factor safety against sliding is;

$$SF_s := \frac{F_s}{F_{ds}} \geq 1.3$$

The vertical component of active thrust may be ignored in favour of safety.

Check for Overturning ULS: Using basic statics and taking moments about the front toe of the RAMWALL, the overturning moment caused by the active soil pressure acting on the back of the wall is resisted by the restoring moment caused by the weight of the retaining wall.

The check may be expressed as:

$$M_r := 5 \cdot kN \cdot m \cdot m^{-1}$$

$$M_o := 5 \cdot kN \cdot m \cdot m^{-1}$$

$$Sf_o := \frac{M_r}{M_o} \geq 1.5$$

where M_r is the restoring moment, M_o is the overturning moment and SF_o is the factor of safety against overturning. The moments can be obtained by summing the products of the forces by their respective lever arms from the front toe of the RAMWALL.

Generally, the active soil pressure normally acts at through the third point of the wall height; any uniform surcharge will act through the mid point of the wall height. The restoring moment comprising the RAMWALL weight and the vertical component of active soil thrust multiplied by the respective lever arms. The level arms for the restoring moments are dependent on the particular geometry of the wall analysed.

Again the vertical component of the active thrust may be ignored in favour of safety.

Check on Foundation Bearing Capacity ULS: Foundation bearing pressures beneath the RAMWALL can be computed using the relevant values of M and N and the eccentricity e of the vertical force from the mid point of the base thus:

$$e_{bc} := \frac{B}{2} - \frac{(M_r - M_o)}{N}$$

where N is the overall vertical force component, M_r is the overturning moment component, and M_o is the overturning moment component.

The maximum bearing pressure on the foundation can be obtained using:

$$P_f := \frac{N}{B} \cdot \left(1 + \frac{6 \cdot e_{bc}}{B}\right)$$

if -B/6 <= e_{bc} <= B/6

where e_{bc} does not comply with this rule, part of the section will be in tension and the maximum bearing pressure can be obtained using:

$$P_f := \frac{2 \cdot N}{\frac{3 \cdot B}{2} \cdot - e_{bc}}$$

The maximum pressure must not exceed the allowable soil bearing capacity as with the other stability checks the calculation of the allowable bearing capacity is subject to the relevant code of practice or recognised procedure, which is beyond the scope of these calculations.

Serviceability Limit State: RAMWALLs are a flexible structure capable of sustaining large settlements without damage to the structure. Therefore, only the durability and the suitability of the backfill material needs to be considered for the serviceability limit state design.

3.4 Other Design Applications

The anticipated excellent interlocking and pullout characteristics of the RAMWALL grid should make it suitable for use as soil reinforcement in reinforced earth structures with the standard RAMWALL acting as a fascia wall, 1m thick, with extended strips of RAMWALL grid placed at suitable intervals extending into the backfill.

The design of this type of wall is covered by the appropriate codes of practice - BS8006 and Eurcode 7. Testing of the pullout characteristics of the RAMWALL grid is required before the system can be adapted for reinforced earth so the design of this type of RAMWALL will be covered by a subsequent report.

4. WORKED EXAMPLE

4.1 General

Figure 4.1 shows two configurations of an example RAMWALL, stepped rear face and stepped front face. Assuming the backfill slope material properties are $\gamma := 19.0\,kN \cdot m^{-3}$ and $\phi := 32 \cdot deg$ the stability of the RAMWALL can be checked as follows:

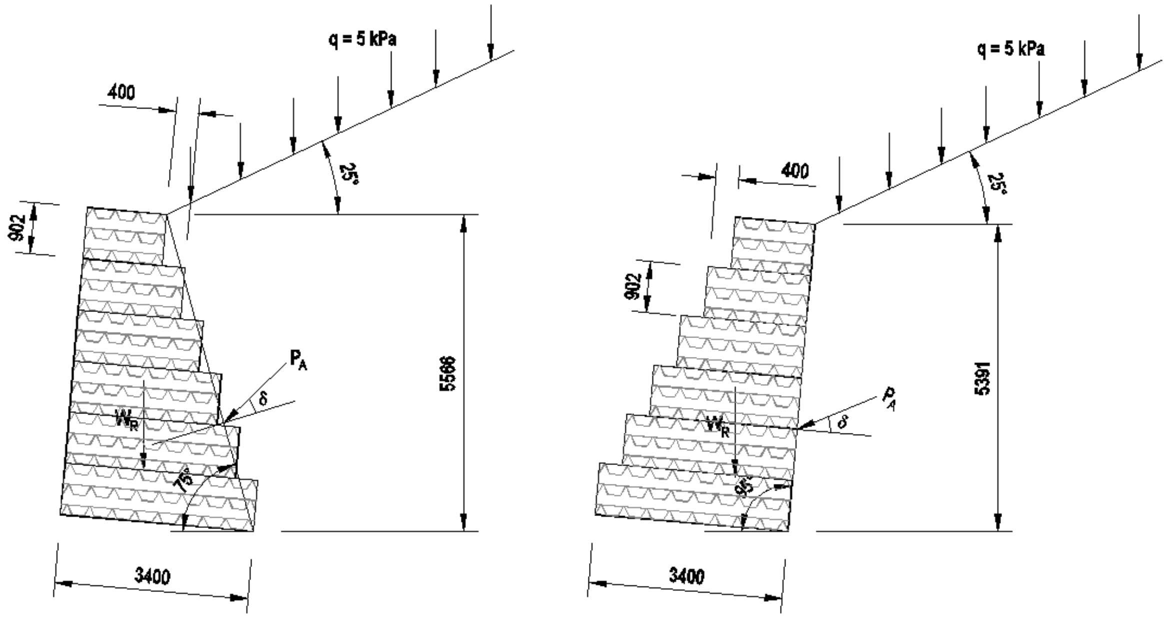

Figure 4.1

Check against sliding: (Conventional Analysis SF_S >= 1.3)

Stabilising Force:

$$F_S := (N_W + P_{VA}) \cdot f$$

for a c'=0 soil

Where N is the weight of the Ramwall, from Figure 4.1:

Wall dimensions:

$$H := 5.566m$$

$$B_b := 3.4m$$

$$B_t := (3.4 - 2.0) \cdot m$$

Wall properties:

$$\eta_r = 0.35$$

$$\gamma_r := 22.5\,kN \cdot m^{-3}$$

$$N_w := \left(\frac{B_b + B_t}{2}\right) \cdot H \cdot \gamma_r \cdot (1 - \eta_r)$$

$$N_w = 195.367\,kN \cdot m^{-1}$$

From Figure 4.1:

$$\alpha := 75 \cdot deg$$

$$\beta := 25 \cdot deg$$

$$\delta := \phi$$

$$q := 5 \cdot kPa$$

$$K_{HA} := \left[\frac{\csc(\alpha) \cdot \sin(\alpha + \phi)}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{(\sin(\phi + \delta) \cdot \sin(\phi - \beta))}{\sin(\alpha + \beta)}}}\right]^2 \cdot \sin(\alpha - \delta)$$

$$K_{HA} = 0.497$$

$$K_{VA} := K_{HA} \cdot \cot(\alpha - \delta)$$

$$K_{VA} = 0.533$$

$$P_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA}$$

$$P_{VA} = 171.531\,kN \cdot m^{-1}$$

$$F_s := (N_w + P_{VA}) \cdot \tan(\phi)$$

$$F_s = 229.263\,kN \cdot m^{-1}$$

Destabilising Force:

$$F_{ds} := P_{HA}$$

where :

$$P_{HA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{HA}$$

$$P_{HA} = 159.955\,kN \cdot m^{-1}$$

$$F_{ds} := P_{HA}$$

The factor safety against sliding is:

$$SF_s := \frac{F_s}{F_{ds}}$$

$$SF_s = 1.43$$

The stepped rear face wall passes in sliding with the configuration shown in Figure 4.1:

Check against Overturning: (Conventional Analysis SF_o >= 1.5)

Restoring Moment:

$$M_r := M_{rm} + M_{VA}$$

where:

$$M_{rm} := N_w \cdot d_w$$

and:

$$M_{VA} := P_{VA} \cdot d_{VA}$$

d_w is the distance from the front toe of the Ramwall to the centre of gravity,

from Figure 4.1:

Element Height:

$$R_{eh} := 0.902m$$

Element Widths:

$$B_1 := B_b$$

$$B_2 := B_b - 0.4m$$

$$B_3 := B_2 - 0.4m$$

$$B_4 := B_3 - 0.4m$$

$$B_5 := B_4 - 0.4m$$

$$B_6 := B_5 - 0.4m$$

Taking moments about the toe:

$$d_w := \frac{\left(\frac{B_1^2}{2} \cdot R_{eh}\right) + \left(\frac{B_2^2}{2} \cdot R_{eh}\right) + \left(\frac{B_3^2}{2} \cdot R_{eh}\right) + \left(\frac{B_4^2}{2} \cdot R_{eh}\right) + \left(\frac{B_5^2}{2} \cdot R_{eh}\right) + \left(\frac{B_6^2}{2} \cdot R_{eh}\right)}{\left(B_1 \cdot R_{eh}\right) + \left(B_2 \cdot R_{eh}\right) + \left(B_3 \cdot R_{eh}\right) + \left(B_4 \cdot R_{eh}\right) + \left(B_5 \cdot R_{eh}\right) + \left(B_6 \cdot R_{eh}\right)}$$

$$d_w = 1.297m$$

$$M_{rm} := N_w \cdot d_w$$

Therefore;

$$M_{rm} = 253.434 kN \cdot m \cdot m^{-1}$$

P_{VA} can be split into the surcharge component which acts at the mid point along the rear face and the active earth pressure component which acts at the lower third point along the rear face. Therefore the distances can be calculated knowing the width of the base and the angle of the rear face of the Ramwall.

$$M_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} \cdot \left(B_b - \frac{H}{3 \cdot \tan(\alpha)} \right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA} \cdot \left(B_b - \frac{H}{2 \cdot \tan(\alpha)} \right)$$

$$M_{VA} = 494.313 kN \cdot m \cdot m^{-1}$$

$$M_r := M_{rm} + M_{VA}$$

Giving a total Restoring Moment of:

$$M_r = 747.747 kN \cdot m \cdot m^{-1}$$

Overturning Moment comprises the horizontal component of the surcharge acting through the mid point of the rear face and the horizontal component of the active earth pressure acting through the lower third of the rear face as follows:

$$M_o := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} \cdot \left(\frac{H}{3} \right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{HA} \cdot \left(\frac{H}{2} \right)$$

$$M_o = 309.365 kN \cdot m \cdot m^{-1}$$

The factor of safety against overturning is:

$$SF_o := \frac{M_r}{M_o}$$

$$SF_o = 2.42$$

The stepped rear face wall passes in overturning with the configuration shown in Fig. 4.1. The maximum bearing pressures exerted by the Ramwall on the foundation can be calculated as follows:

$$e_{bc} := \frac{B_b}{2} - \frac{(M_r - M_o)}{(N_w + P_{VA})}$$

$$e_{bc} = 0.505 m$$

As e_{bc} is greater than $B_b/6$ then part of the base is in tension and the maximum bearing capacity is obtained by:

$$P_f := 2 \cdot \frac{(N_w + P_{VA})}{\left(\frac{3 \cdot B_b}{2} - e_{bc} \right)}$$

$$P_f = 159.7 kN \cdot m^{-2}$$

For stability the maximum bearing pressure given above must not exceed the allowable bearing capacity of the foundation. Standard bearing capacity analyses can be used to obtain the allowable bearing capacity.

Check on Internal Stresses - Stepped Rear Face

As discussed in Section 3.2 the stresses acting in the reinforcement must not exceed the allowable stress of the steel. The stresses in the reinforcement can be calculated using the Normal loads and Bending Moments acting within the Ramwall. Assuming a standard 0.9m high Ramwall unit constructed using 6mm diameter welded wire fabric, the area of reinforcement:

$$a_r := 0.0014 m^2$$

$$H_u := 0.9 m$$

The maximum stress developed in the wall taking into consideration the forces acting on the Ramwall can be obtained assumming a Meyerhof distribution:

$$\sigma_{max} := \frac{(N_w + P_{VA})}{(B_b - 2 \cdot e)}$$

$$\sigma_{max} = 153.535 kN \cdot m^{-2}$$

$$k_o := 0.426$$

The stress in the reinforcement can be calculated from (assumming k_o=0.426 for the backfill):

$$\sigma_r := k_o \cdot \frac{\sigma_{max} \cdot H_u}{a_r}$$

$$\sigma_r = 42047 kN \cdot m^{-2} \cdot m^{-1}$$

For high tensile welded wire fabric:

$$\sigma_t := 420000 kN \cdot m^{-2} \cdot m^{-1}$$

Therefore, the stresses in the Ramwall are well below the allowable stress in the steel.

4.3 Stepped Front Face

Check against Sliding: (Conventional Analysis SF_S >= 1.3)

Stabilising Force:

$$N_w = 195.367 kN \cdot m^{-1}$$

same as stepped rear faced wall.

From Figure 4.1:

$$\alpha := 95 \cdot deg$$

$$\beta := 25 \cdot deg$$

$$\delta := \phi$$

$$q := 5 \cdot kPa$$

$$H := 5.391 m$$

$$K_{HA} := \left[\frac{csc(\alpha) \cdot sin(\alpha + \phi)}{\sqrt{sin(\alpha - \delta)} + \sqrt{\frac{(sin(\phi + \delta) \cdot sin(\phi - \beta))}{sin(\alpha + \beta)}}} \right]^2 \cdot sin(\alpha - \delta)$$

$$K_{HA} = 0.339$$

$$K_{VA} := K_{HA} \cdot cot(\alpha - \delta)$$

$$K_{VA} = 0.173$$

$$P_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} + q \cdot H \cdot \frac{sin(\alpha)}{sin(\alpha + \beta)} \cdot K_{VA}$$

$$P_{VA} = 53.057 kN \cdot m^{-1}$$

$$F_s := (N_w + P_{VA}) \cdot tan(\phi)$$

$$F_s = 155.232 kN \cdot m^{-1}$$

Destabilising Force:

$$F_{ds} := P_{HA}$$

where:

$$P_{HA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} + q \cdot H \cdot \frac{sin(\alpha)}{sin(\alpha + \beta)} \cdot K_{HA}$$

$$P_{HA} = 104.13 kN \cdot m^{-1}$$

$$F_{ds} := P_{HA}$$

The factor safety against sliding is:

$$SF_s := \frac{F_s}{F_{ds}}$$

$$SF_s = 1.49$$

Therefore the stepped front face wall passes in sliding with the configuration shown in Figure 4.1. The calculation above indicates that the stepped rear faced wall is more reliant on the vertical component of the active earth pressure acting on the rear of the Ramwall.

Check against Overturning: (Conventional Analysis SF_o >= 1.5)

Restoring Moment:

$$M_r := M_{rm} + M_{VA}$$

where

$$M_{rm} := N_w \cdot d_w$$

and

$$M_{VA} := P_{VA} \cdot d_{VA}$$

d_w is the distance from the front toe of the Ramwall to the centre of gravity, from Figure 4.1:

Element Height:

$$R_{eh} := 0.902m$$

Element Widths:

$$B_1 := B_b$$

$$B_2 := B_b - 0.4m$$

$$B_3 := B_2 - 0.4m$$

$$B_4 := B_3 - 0.4m$$

$$B_5 := B_4 - 0.4m$$

$$B_6 := B_5 - 0.4m$$

Taking moments about the toe:

$$d_w := \frac{\left(\frac{B_1^{\,2}}{2} \cdot R_{eh}\right) + \left(\frac{B_2^{\,2}}{2} \cdot R_{eh}\right) + \left(\frac{B_3^{\,2}}{2} \cdot R_{eh}\right) + \left(\frac{B_4^{\,2}}{2} \cdot R_{eh}\right) + \left(\frac{B_5^{\,2}}{2} \cdot R_{eh}\right) + \left(\frac{B_6^{\,2}}{2} \cdot R_{eh}\right)}{\left(B_1 \cdot R_{eh}\right) + \left(B_2 \cdot R_{eh}\right) + \left(B_3 \cdot R_{eh}\right) + \left(B_4 \cdot R_{eh}\right) + \left(B_5 \cdot R_{eh}\right) + \left(B_6 \cdot R_{eh}\right)}$$

$$d_w := B - d_w$$

$$d_w = 2.203m$$

$$M_{rm} := N_w \cdot d_w$$

Therefore

$$M_{rm} = 430.349\,kN \cdot m \cdot m^{-1}$$

P_{VA} can be split into the surcharge component which acts at the mid point along the rear face and the active earth pressure component which acts at the lower third point along the rear face. Therefore the distances can be calculated knowing the width of the base and the angle of the rear face of the Ramwall.

$$M_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} \cdot \left(B_b - \frac{H}{3 \cdot \tan(\alpha)} \right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA} \cdot \left(B_b - \frac{H}{2 \cdot \tan(\alpha)} \right)$$

$$M_{VA} = 189.155\,kN \cdot m \cdot m^{-1}$$

$$M_r := M_{rm} + M_{VA}$$

Giving a total Restoring Moment of:

$$M_r = 619.504\,kN \cdot m \cdot m^{-1}$$

Overturning Moment comprises the horizontal component of the surcharge acting through the mid point of the rear face and the horizontal component of the active earth pressure acting through the lower third of the rear face as follows:

$$M_o := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} \cdot \left(\frac{H}{3} \right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{HA} \cdot \left(\frac{H}{2} \right)$$

$$M_o = 196.567\,kN \cdot m \cdot m^{-1}$$

The factor of safety against overturning is

$$SF_o := \frac{M_r}{M_o}$$

$$SF_o = 3.15$$

The stepped front face wall passes in overturning with the configuration shown in Figure 4.1.

The maximum bearing pressures exerted by the Ramwall on the foundation can be calculated as follows:

$$e_{bc} := \frac{B_b}{2} - \frac{(M_r - M_o)}{(N_w + P_{VA})}$$

$$e_{bc} = -2.487 \times 10^{-3}\,m$$

As e_{bc} is less than $B_b/6$ the base is in compression and then the maximum bearing capacity is obtained by

$$P_f := \frac{(N_w + P_{VA})}{B_b} \cdot \left(1 + \frac{6 \cdot e_{bc}}{B_b}\right)$$

$$P_f = 72.745 \text{kN} \cdot \text{m}^{-2}$$

For stability the maximum bearing pressure given above must not exceed the allowable bearing capacity of the foundation. Standard bearing capacity analyses can be used to obtain the allowable bearing capacity.

This calculation also shows that the stepped front face configuration is a more stable and exerts less pressure on the foundation.

Check on Internal Stresses - Stepped Front Face

As discussed in Section 3.2 the stresses acting in the reinforcement must not exceed the allowable stress of the steel. The stresses in the reinforcement can be calculated using the Normal loads and Bending Moments acting within the Ramwall. Assuming a standard 0.9m high Ramwall unit constructed using 6mm diameter welded wire fabric, the area of reinforcement:

$$a_r := 0.0014 \text{m}^2$$

$$H_u := 0.9 \text{m}$$

The maximum stress developed in the wall taking into consideration the forces acting on the Ramwall can be obtained assumming a Meyerhof distribution:

$$\sigma_{max} := \frac{(N_w + P_{VA})}{(B_b - 2 \cdot e)}$$

$$\sigma_{max} = 72.959 \text{kN} \cdot \text{m}^{-2}$$

The stress in the reinforcement can be calculated from (assumming k_o=0.426 for the backfill):

$$k_o := 0.426$$

$$\sigma_r := k_o \cdot \frac{\sigma_{max} \cdot H_u}{a_r}$$

$$\sigma_r = 19980 \text{kN} \cdot \text{m}^{-2} \cdot \text{m}^{-1}$$

For high tensile welded wire fabic:

$$\sigma_t := 420000 kN \cdot m^{-2} \cdot m^{-1}$$

Therefore the stresses in the Ramwall are well below the allowable stress in the steel.

4.4 Stepped Rear Face (to BS8004:1994)

Check against sliding: (Limit State Analysis SF_s >= 1.0)

BS8004 requires a reduction to the angle of friction equal to $\tan(\phi_d)=\tan(\phi)/1.2$

$$\phi := \operatorname{atan}\left(\frac{\tan(\phi)}{1.2}\right)$$

$$\phi = 27.507 deg$$

Stabilising Force

$$F_s := (N_w + P_{VA}) \cdot f$$

for a c'=0 soil

Where N is the weight of the Ramwall, from Figure 4.1:

Wall dimensions:

$$H := 5.566m$$

$$B_b := 3.4m$$

$$B_t := (3.4 - 2.0) \cdot m$$

Wall properties:

$$\eta_r := 0.4$$

$$\gamma_r := 22.5 kN \cdot m^{-3}$$

$$N_w := \left(\frac{B_b + B_t}{2}\right) \cdot H \cdot \gamma_r \cdot (1 - \eta_r)$$

$$N_w = 180.338 kN \cdot m^{-1}$$

From Figure 4.1:

$$\alpha := 75 \cdot deg$$

$$\beta := 25 \cdot deg$$

$$\delta := \phi$$

$$q := 5 \cdot kPa$$

$$K_{HA} := \left[\frac{\csc(\alpha) \cdot \sin(\alpha + \phi)}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{(\sin(\phi + \delta) \cdot \sin(\phi - \beta))}{\sin(\alpha + \beta)}}}\right]^2 \cdot \sin(\alpha - \delta)$$

$K_{HA} = 0.684$

$K_{VA} := K_{HA} \cdot \cot(\alpha - \delta)$

$K_{VA} = 0.627$

$$P_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA}$$

$P_{VA} = 201.59 kN \cdot m^{-1}$

$F_s := (N_w + P_{VA}) \cdot \tan(\phi)$

$F_s = 198.88 kN \cdot m^{-1}$

Destabilising Force:

$F_{ds} := P_{HA}$

where

$$P_{HA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{HA}$$

$P_{HA} = 219.943 kN \cdot m^{-1}$

$F_{ds} := P_{HA}$

The factor safety against sliding is

$$SF_s := \frac{F_s}{F_{ds}}$$

$SF_s = 0.90$

The stepped rear face wall fails in sliding with the configuration shown in Figure 4.1 using the design methods given by BS8004:1994. Try increasing the width of the wall:

Wall dimensions:

$H := 5.566 m$

$B_b := 4.0 m$

$B_t := (4.0 - 2.0) \cdot m$

Wall properties:

$\eta_r := 0.4$

$\gamma_r := 22.5 kN \cdot m^{-3}$

$$N_w := \left(\frac{B_b + B_t}{2}\right) \cdot H \cdot \gamma_r \cdot (1 - \eta_r)$$

$N_w = 225.423 kN \cdot m^{-1}$

From Figure 4.1:

$$\alpha := 75 \cdot deg$$

$$\beta := 25 \cdot deg$$

$$\delta := \phi$$

$$q := 5 \cdot kPa$$

$$K_{HA} := \left[\frac{csc(\alpha) \cdot sin(\alpha + \phi)}{\sqrt{sin(\alpha - \delta)} + \sqrt{\frac{(sin(\phi + \delta) \cdot sin(\phi - \beta))}{sin(\alpha + \beta)}}} \right]^2 \cdot sin(\alpha - \delta)$$

$$K_{HA} = 0.684$$

$$K_{VA} := K_{HA} \cdot cot(\alpha - \delta)$$

$$K_{VA} = 0.627$$

$$P_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} + q \cdot H \cdot \frac{sin(\alpha)}{sin(\alpha + \beta)} \cdot K_{VA}$$

$$P_{VA} = 201.59 \, kN \cdot m^{-1}$$

$$F_s := (N_w + P_{VA}) \cdot tan(\phi)$$

$$F_s = 222.356 \, kN \cdot m^{-1}$$

Destabilising Force:

$$F_{ds} := P_{HA}$$

where :

$$P_{HA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} + q \cdot H \cdot \frac{sin(\alpha)}{sin(\alpha + \beta)} \cdot K_{HA}$$

$$P_{HA} = 219.943 \, kN \cdot m^{-1}$$

$$F_{ds} := P_{HA}$$

The factor safety against sliding is:

$$SF_s := \frac{F_s}{F_{ds}}$$

$$SF_s = 1.01$$

The stepped rear face wall passes in sliding with an increased base width of 4m using the design methods given by BS8004:1994.

Check against Overturning: (Limit State Analysis SF_o >= 1.0)

Restoring Moment:

$$M_r := M_{rm} + M_{VA}$$

where :

$M_{rm} := N_w \cdot d_w$

and

$M_{VA} := P_{VA} \cdot d_{VA}$

d_w is the distance from the front toe of the Ramwall to the centre of gravity,

from Figure 4.1:

Element Height:

$R_{eh} := 0.902m$

Element Widths:

$B_1 := B_b$

$B_2 := B_b - 0.4m$

$B_3 := B_2 - 0.4m$

$B_4 := B_3 - 0.4m$

$B_5 := B_4 - 0.4m$

$B_6 := B_5 - 0.4m$

Taking moments about the toe:

$$d_w := \frac{\left(\frac{B_1^2}{2} \cdot R_{eh}\right) + \left(\frac{B_2^2}{2} \cdot R_{eh}\right) + \left(\frac{B_3^2}{2} \cdot R_{eh}\right) + \left(\frac{B_4^2}{2} \cdot R_{eh}\right) + \left(\frac{B_5^2}{2} \cdot R_{eh}\right) + \left(\frac{B_6^2}{2} \cdot R_{eh}\right)}{\left(B_1 \cdot R_{eh}\right) + \left(B_2 \cdot R_{eh}\right) + \left(B_3 \cdot R_{eh}\right) + \left(B_4 \cdot R_{eh}\right) + \left(B_5 \cdot R_{eh}\right) + \left(B_6 \cdot R_{eh}\right)}$$

$d_w = 1.578m$

$M_{rm} := N_w \cdot d_w$

Therefore

$M_{rm} = 355.667 kN \cdot m \cdot m^{-1}$

P_{VA} can be split into the surcharge component which acts at the mid point along the rear face and the active earth pressure component which acts at the lower third point along the rear face. Therefore the distances can be calculated knowing the width of the base and the angle of the rear face of the Ramwall.

$$M_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} \cdot \left(B_b - \frac{H}{3 \cdot \tan(\alpha)}\right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA} \cdot \left(B_b - \frac{H}{2 \cdot \tan(\alpha)}\right)$$

$M_{VA} = 701.891 kN \cdot m \cdot m^{-1}$

$M_r := M_{rm} + M_{VA}$

Giving a total Restoring Moment of:

$$M_r = 1.058 \times 10^3 \, kN \cdot m \cdot m^{-1}$$

Overturning Moment comprises the horizontal component of the surcharge acting through the mid point of the rear face and the horizontal component of the active earth pressure acting through the lower third of the rear face as follows:

$$M_o := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{HA} \cdot \left(\frac{H}{3}\right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{HA} \cdot \left(\frac{H}{2}\right)$$

$$M_o = 425.384 \, kN \cdot m \cdot m^{-1}$$

The factor of safety against overturning is:

$$SF_o := \frac{M_r}{M_o}$$

$$SF_o = 2.49$$

The stepped rear face wall passes in overturning with the configuration shown in Figure 4.1, but with an increased width of 4m to pass the check on sliding.

The maximum bearing pressures exerted by the Ramwall on the foundation can be calculated as follows:

$$e_{bc} := \frac{B_b}{2} - \frac{(M_r - M_o)}{(N_w + P_{VA})}$$

$$e_{bc} = 0.52m$$

As e_{bc} is greater than $B_b/6$ then part of the base is in tension and the maximum bearing capacity is obtained by

$$P_f := 2 \cdot \frac{(N_w + P_{VA})}{\left(\frac{3 \cdot B_b}{2} - e_{bc}\right)}$$

$$P_f = 155.831 \, kN \cdot m^{-2}$$

For stability the maximum bearing pressure given above must not exceed the allowable bearing capacity of the foundation. Standard bearing capacity analyses can be used to obtain the allowable bearing capacity.

Check on Internal Stresses - Stepped Rear Face

As discussed in Section 3.2 the stresses acting in the reinforcement must not exceed the allowable stress of the steel. The stresses in the reinforcement can be calculated using the Normal loads and Bending Moments acting within the Ramwall. Assuming a standard

0.9m high Ramwall unit constructed using 6mm diameter welded wire fabric, the area of reinforcement:

$a_r := 0.0014m^2$

$H_u := 0.9m$

The maximum stress developed in the wall taking into consideration the forces acting on the Ramwall can be obtained assumming a Meyerhof distribution:

$$\sigma_{max} := \frac{(N_w + P_{VA})}{(B_b - 2 \cdot e)}$$

$\sigma_{max} = 144kN \cdot m^{-2}$

The stress in the reinforcement can be calculated from (assumming k_o=0.426 for the backfill):

$k_o := 0.426$

$$\sigma_r := k_o \cdot \frac{\sigma_{max} \cdot H_u}{a_r}$$

$\sigma_r = 39495kN \cdot m^{-2} \cdot m^{-1}$

For high tensile welded wire fabic:

$\sigma_t := 420000kN \cdot m^{-2} \cdot m^{-1}$

Therefore the stresses in the Ramwall are well below the allowable stress in the steel.

4.5 Stepped Front Face - to BS8004:1994

Check against Sliding: (Limit State Analysis SF_s >= 1.0)

Stabilising Force:

$N_w = 225.423kN \cdot m^{-1}$

same as stepped rear faced wall.

From Figure 4.1:

$\alpha := 95 \cdot deg$

$\beta := 25 \cdot deg$

$\delta := \phi$

$q := 5 \cdot kPa$

$H := 5.391m$

$$K_{HA} := \left[\frac{\csc(\alpha)\cdot\sin(\alpha + \phi)}{\sqrt{\sin(\alpha - \delta)} + \sqrt{\frac{(\sin(\phi + \delta)\cdot\sin(\phi - \beta))}{\sin(\alpha + \beta)}}} \right]^2 \cdot\sin(\alpha - \delta)$$

$K_{HA} = 0.488$

$K_{VA} := K_{HA}\cdot\cot(\alpha - \delta)$

$K_{VA} = 0.202$

$$P_{VA} := \frac{1}{2}\cdot\gamma\cdot H^2\cdot K_{VA} + q\cdot H\cdot\frac{\sin(\alpha)}{\sin(\alpha + \beta)}\cdot K_{VA}$$

$P_{VA} = 62.117\,kN\cdot m^{-1}$

$F_s := (N_w + P_{VA})\cdot\tan(\phi)$

$F_s = 149.729\,kN\cdot m^{-1}$

Destabilising Force

$F_{ds} := P_{HA}$

where :

$$P_{HA} := \frac{1}{2}\cdot\gamma\cdot H^2\cdot K_{HA} + q\cdot H\cdot\frac{\sin(\alpha)}{\sin(\alpha + \beta)}\cdot K_{HA}$$

$P_{HA} = 149.911\,kN\cdot m^{-1}$

$F_{ds} := P_{HA}$

The factor safety against sliding is:

$$SF_s := \frac{F_s}{F_{ds}}$$

$SF_s = 1.00$

Therefore the stepped front face wall fails in sliding with the configuration shown in Figure 4.1.

Check against Overturning: (Limit State Analysis SF_o >= 1.0)

Restoring Moment:

$M_r := M_{rm} + M_{VA}$

where:

$M_{rm} := N_w\cdot d_w$

and

$M_{VA} := P_{VA}\cdot d_{VA}$

d_w is the distance from the front toe of the Ramwall to the centre of gravity, from Figure

4.1:

Element Height:

$R_{eh} := 0.902m$

Element Widths:

$B_1 := B_b$

$B_2 := B_b - 0.4m$

$B_3 := B_2 - 0.4m$

$B_4 := B_3 - 0.4m$

$B_5 := B_4 - 0.4m$

$B_6 := B_5 - 0.4m$

Taking moments about the toe:

$$d_w := \frac{\left(\frac{B_1^2}{2} \cdot R_{eh}\right) + \left(\frac{B_2^2}{2} \cdot R_{eh}\right) + \left(\frac{B_3^2}{2} \cdot R_{eh}\right) + \left(\frac{B_4^2}{2} \cdot R_{eh}\right) + \left(\frac{B_5^2}{2} \cdot R_{eh}\right) + \left(\frac{B_6^2}{2} \cdot R_{eh}\right)}{\left(B_1 \cdot R_{eh}\right) + \left(B_2 \cdot R_{eh}\right) + \left(B_3 \cdot R_{eh}\right) + \left(B_4 \cdot R_{eh}\right) + \left(B_5 \cdot R_{eh}\right) + \left(B_6 \cdot R_{eh}\right)}$$

$d_w := B - d_w$

$d_w = 1.922m$

$M_{rm} := N_w \cdot d_w$

Therefore

$M_{rm} = 433.313 kN \cdot m \cdot m^{-1}$

P_{VA} can be split into the surcharge component which acts at the mid point along the rear face and the active earth pressure component which acts at the lower third point along the rear face. Therefore the distances can be calculated knowing the width of the base and the angle of the rear face of the Ramwall.

$$M_{VA} := \frac{1}{2} \cdot \gamma \cdot H^2 \cdot K_{VA} \cdot \left(B_b - \frac{H}{3 \cdot \tan(\alpha)}\right) + q \cdot H \cdot \frac{\sin(\alpha)}{\sin(\alpha + \beta)} \cdot K_{VA} \cdot \left(B_b - \frac{H}{2 \cdot \tan(\alpha)}\right)$$

$M_{VA} = 258.727 kN \cdot m \cdot m^{-1}$

$M_r := M_{rm} + M_{VA}$

Giving a total Restoring Moment of:

$M_r = 692.04 kN \cdot m \cdot m^{-1}$

Overturning Moment comprises the horizontal component of the surcharge acting through the mid point of the rear face and the horizontal component of the active earth pressure acting through the lower third of the rear face as follows:

$$M_o := \frac{1}{2}\cdot\gamma\cdot H^2\cdot K_{HA}\cdot\left(\frac{H}{3}\right) + q\cdot H\cdot\frac{\sin(\alpha)}{\sin(\alpha+\beta)}\cdot K_{HA}\cdot\left(\frac{H}{2}\right)$$

$$M_o = 282.99\,kN\cdot m\cdot m^{-1}$$

The factor of safety against overturning is

$$SF_o := \frac{M_r}{M_o}$$

$$SF_o = 2.445$$

The stepped front face wall passes in overturning with the configuration shown in Figure 4.1 and the increased base width of 4m.

The maximum bearing pressures exerted by the Ramwall on the foundation can be calculated as follows:

$$e_{bc} := \frac{B_b}{2} - \frac{(M_r - M_o)}{(N_w + P_{VA})}$$

$$e_{bc} = 0.577\,m$$

As e_{bc} is less than $B_b/6$ the base is in compression and then the maximum bearing capacity is obtained by

$$P_f := 2\cdot\frac{(N_w + P_{VA})}{\left(\frac{3\cdot B_b}{2} - e_{bc}\right)}$$

$$P_f = 106.053\,kN\cdot m^{-2}$$

For stability the maximum bearing pressure given above must not exceed the allowable bearing capacity of the foundation. Standard bearing capacity analyses can be used to obtain the allowable bearing capacity.

This calculation shows that the stepped front face configuration is a more stable and exerts less pressure on the foundation.

Check on Internal Stresses - Stepped Front Face

As discussed in Section 3.2 the stresses acting in the reinforcement must not exceed the allowable stress of the steel. The stresses in the reinforcement can be calculated using the Normal loads and Bending Moments acting within the Ramwall. Assuming a standard 0.9m high Ramwall unit constructed using 6mm diameter welded wire fabric, the area of reinforcement:

$$a_r := 0.0014m^2$$

$$H_u := 0.9m$$

The maximum stress developed in the wall taking into consideration the forces acting on the Ramwall can be obtained assumming a Meyerhof distribution:

$$\sigma_{max} := \frac{(N_w + P_{VA})}{(B_b - 2 \cdot e)}$$

$$\sigma_{max} = 101.063 kN \cdot m^{-2}$$

The stress in the reinforcement can be calculated from (assumming k_o=0.426 for the backfill):

$$k_o := 0.426$$

$$\sigma_r := k_o \cdot \frac{\sigma_{max} \cdot H_u}{a_r}$$

$$\sigma_r = 27677 kN \cdot m^{-2} \cdot m^{-1}$$

For high tensile welded wire fabric:

$$\sigma_t := 420000 kN \cdot m^{-2} \cdot m^{-1}$$

Therefore, the stresses in the Ramwall are well below the allowable stress in the steel.

5. DURABILITY CONSIDERATIONS

5.1 General

The consideration of corrosion in the RAMWALL reinforcement panels and the durability of the backfill material is dependent on the design life of the proposed structure. For a short term design life, say 1 to 20 years the corrosion is only a minor consideration and generally can be ignored provided the backfill and the surrounding soil is reasonably inert. However, for a long term design life, say 50 to 120 years the corrosion of the RAMWALL panels and the durability of the backfill material is a major concern. Testing the soils' aggressiveness and design issues of the reinforcement panels need to be taken into consideration.

5.2 Metal Corrosion

The RAMWALL reinforcement panels and fascia panels are made of metal and are, therefore, subject to electrochemical corrosion. Different types of metal corrode in different ways:-

Steel, galvanised or not, exhibit general corrosion,
Aluminum and stainless steel exhibit pitted corrosion.

Of the two types general corrosion is often preferred as it is predictable and strength decreases can be quantified.

The factors that affect the rate of corrosion are the soil aggressiveness, water content, metal type, protective coatings and installation damage.

The soil in contact with the RAMWALL and the backfill material can be classified and scored against a series of criteria to classify its aggressiveness; non aggressive, weakly aggressive, aggressive and strongly aggressive.

Assessment of soil aggressiveness towards buried metals can be assessed using four criteria; Resistivity, Redox Potential, Normal Hydrogen electrode and Moisture Content. We would also, recommend that soil pH and soluble salts are tested as well.

As well as internal factors in the soil, external factors such as runoff of salts from roads or buildings need to be considered.

Galvanising the steel slows the rate of corrosion as it is a poor cathode and if damaged these sections corrode and seal the gaps between the galvanising so preventing further corrosion.

Rates of corrosion can be estimated for steel, galvanising the steel slows the initial rate until the zinc coating is used up and then the steel will corrode at the same rate as ordinary steel. Of the normally used rebar steels, low tensile steel grades are less susceptible to pitting and hydrogen embrittlement.

Cinders, carbon particles, coke and coal should be avoided in the backfill material as these materials have deleterious effect and can cause serious corrosion.

Physical damage during the installation can be assessed using a site damage test, see BS8006:1995.

5.3 Design for Durability

Long-term durability of buried or partially buried metal structures can be provided by designing for a sacrificial thickness, values are given in the UK and France for all but highly aggressive ground conditions. Reference to the relevant code of practice can be made to obtain the allowable sacrificial depths for the various degrees of soil aggressiveness.

Testing of the RAMWALL may be able to prove that the structure has sufficient redundancy in the internal reinforcement so the only durability questions would relate to the facure panels and the backfill material.

Other ways of providing durability is to physically protect the reinforcement by various methods, for example galvanising and/or PVC coating, nominally 0.25mm thick coating to BS4102.

Also, all metallic components should be electrolytically compatible or otherwise effective electrical insulation must be provided.

The design needs to consider the durability of the backfill material in relation to the design life of the structure, its location in terms of weather and groundwater chemistry and the internal forces acting within the wall.

Any backfill material used must be resistant to the weather, groundwater and not susceptible to crushing under the anticipated loads within the RAMWALL. The hardness, crushing strength and resistance to weathering of the backfill material can be tested to BS5390.

The RAMWALL structure is free draining and provided migration of fines from the adjacent soil mass in to the infill is prevented, seepage or pore pressure will not develop within the RAMWALL. Fines migration from susceptible soils can be prevented using a suitable graded filter behind the wall (see Section 6.4.4.5, BS 8004:1986) or a geotextile separator. The latter option provides a fast and economic solution to fines migration in most situations and geotextile manufacturers can provide specific guidance on selection and installation of suitable material. Soils are unlikely to require protection against fines-migration provided;

$$D_{15}\ \text{RAMWALL}/D_{85}\ \text{Soil} > 4.$$

6. CONCLUSIONS

RAMWALL can be designed as a standard gravity retaining wall using the conventional coulomb active wedge method of analysis. The choice of Safety Factors; whether global factors on the external forces or partial factors on the parameters are dependent on the design method or code of practice adopted. A worked example using both approaches is given in Section 4.0 above. These worked examples show that using partial factors is the more onerous method of analysis.

Calculations have also shown that the stepped rear face configuration of wall exerts significantly more pressure on the foundation than the stepped front face configuration.

Internal stresses on the RAMWALL units can be obtained assuming a Meyerhof distribution and the internal forces N and M. Assuming the effective stiffness of the reinforcement is high the tensile stress in the reinforcement can be calculated and checked against the allowable tensile strength. The allowable tensile strength is equal to the maximum tensile strength of the reinforcement divided by a partial material factor. This factor can consider the quality of steel manufacture, the reliability of the test results and the durability required for the design life. Values of between 1.15 and 2.0 can be considered for short and long-term designs.